

National Guideline: Principles of Climate Adaptation and Mitigation for Engineers

Notice

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Engineers Canada's national guidelines, model guides, and white papers were developed by engineers in collaboration with the provincial and territorial engineering regulators. They are intended to promote consistent practices across the country. They are not regulations or rules; they seek to define or explain discrete topics related to the practice and regulation of professional engineering in Canada.

The national guidelines, model guides, and white papers do not establish a legal standard of care or conduct, and they do not include or constitute legal or professional advice.

In Canada, engineering is regulated under provincial and territorial law by the engineering regulators. The recommendations contained in the national guidelines, model guides and white papers may be adopted by the engineering regulators in whole, in part, or not at all. The ultimate authority regarding the propriety of any specific practice or course of conduct lies with the engineering regulator in the province or territory where the engineer works, or intends to work.

About this Guideline

This national guideline was prepared by the Qualifications Board (QB) and provides guidance to regulators in consultation with them. Readers are encouraged to consult their regulators' related engineering acts, regulations and bylaws in conjunction with this guideline.

About Engineers Canada

Engineers Canada is the national organization of the provincial and territorial associations that regulate the practice of engineering in Canada and license the country's 290,000 members of the engineering profession.

About the Qualifications Board

QB is a committee of the Engineers Canada Board and is a volunteer-based organization that provides national leadership and recommendations to regulators on the practice of engineering in Canada by:

- » developing new national guidelines, model guides, and white papers on admission, training, practice and new areas of practice in Canada as well as maintaining the existing national guidelines and model guides;
- » developing and maintaining syllabi for the assessment of international engineering graduates;
- » organizing national events where professionals in similar areas of work can share information on similar issues as well as best practices; and
- » conducting research, monitoring and providing advice on key issues and trends for Engineers Canada and regulators.

Summary

The climate is changing. Historical climatic design data is becoming less representative of the future climate. Many future climate risks may be significantly under-estimated. Engineers cannot assume that the future will be like the past. Historical climate trends cannot be simply projected into the future for engineering planning, design, operations and maintenance of infrastructure.

The best available scientific evidence indicates that the global climate is changing at an unprecedented rate and that emissions of carbon dioxide and other greenhouse gases (GHGs) from human activities are contributors to this change. Recently recorded climate change is associated with more extreme weather events, and the frequency of these events is expected to increase over time. These events will intensify the damage and failure of infrastructure. Any mitigation of human-induced climate change is predicted to have multiple benefits, such as:

- » Reduction in air-pollution
- » Reduction in energy use which is anticipated to increase due to the changing climate
- » Reduction in disruption in the society through coastal hazards and extreme weather events, and consequently, reduction in the amount of adaptation required
- » Improvement of physical and mental well-being
- » Biodiversity sustenance

Engineers have important roles and responsibilities in helping guide society to adapt to these changes and to reduce GHG emissions to mitigate climate change. Accelerated climate change presents new and evolving challenges, opportunities and risks that will need to be considered by engineers in the fulfillment of their professional responsibilities.

Engineers Canada and its constituent associations (the engineering regulators) are committed to raising awareness about the continued releases of GHG emissions and the potential impacts of the changing climate as they relate to engineering practice. The commitment is to provide information and assistance to engineers in managing implications for their own professional practice. Engineers are encouraged to keep themselves informed about the changing climate and continued technological developments and consider potential impacts on their professional activities.

This national guideline is intended to set out general concepts and principles to inform engineering professionals on why adaptation to and mitigation of climate change is relevant in professional practice. The guideline helps inform engineers of the guiding principles, how to address the implications of climate change in their professional practice, and most importantly, how to create a clear record of the outcomes of those considerations.

The guideline consists of eleven principles that constitute the scope of professional practice for engineers to mitigate climate change and initiate climate actions that support the sustainability and resiliency of engineered systems, particularly for civil infrastructure and buildings. The principles are summarized into three categories:

Category #1 - Professional Judgment

Principle # 1: Integrate climate adaptation and resiliency into practice

Principle # 2: Integrate climate mitigation into practice

Principle # 3: Review adequacy of current standards

Principle # 4: Exercise professional judgement

Category #2 - Partnerships

Principle # 5: Interpret climate information

Principle # 6: Emphasize innovation in mitigation and adaptation

Principle # 7: Work with specialists and stakeholders

Principle # 8: Use effective language

Category #3 - Practice Guidance

Principle # 9: Plan for service life and resiliency

Principle # 10: Apply risk management principles for uncertainty

Principle # 11: Monitor legal liabilities

The principles support sound professional judgment for engineering practice. Mitigating and adapting to the changing climate presents beneficial opportunities to reduce costs, maintain levels of service, and protect public health and safety.

Use of language in this guideline

National guidelines use the word “should” to indicate that, among several possibilities, one is recommended as particularly suitable without necessarily mentioning or excluding others; or, that a certain course of action is preferred, but not necessarily required; or, that (in the negative form) a certain course of action is disapproved of, but not prohibited (“should” equals “is recommended that”). The word “may” is used to indicate a course of action permissible within the limits of the guideline (“may” equals “is permitted”).

Engineering regulators who wish to adopt a version of this guideline, in whole or in part, are advised to consider substituting the word “shall” for the word “should” to indicate requirements that must be followed (“shall” equals “is required to”). Regulators are encouraged to reference and provide links to applicable provincial or territorial legislation, policies, and regulations that mandate consideration of the changing climate.

Engineering regulators who wish to reference, instead of adopting, these guidelines in whole or in part are cautioned that national guidelines are voluntary and not binding on engineering regulators or individual engineers.

1. Introduction

1.1 Background

The primary duty of engineers is to hold paramount the safety, health and welfare of the public, the protection of the environment, and promote health and safety within the workplace.

The current state of scientific knowledge concludes that the climate is changing, and will continue to change, at a rate that is likely accelerated by anthropogenic releases of greenhouse gases. Furthermore, evidence suggests that climate change has led to changes in climate extremes such as heat waves, record high temperatures and, in many regions, heavy precipitation in the past half century (Intergovernmental Panel on Climate Change 2014). The IPCC, in its report *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (2012) notes that climate extremes, or even a series of non-extreme events, combined with social vulnerabilities and their exposure to risks can produce climate-related disasters [1].

Changing climate conditions, particularly weather patterns that deviate from historical climate ranges, may adversely affect the integrity of the design, operation, and management of engineered systems. In some cases, changing climate conditions can pose unaccounted for risks. It is the engineer's duty to take all reasonable measures to ensure that those systems appropriately anticipate the impact of changing climate conditions.

The engineer's job is to assess and minimize such risks within the scope of their work, which includes being a trusted advisor to the client while balancing client needs and the project budget. This understanding imposes a responsibility of due diligence on the engineering profession to address the issue of climate change within engineering works. This plays out in two ways. First, engineers, and those who retain them for design of public facilities and infrastructure, will have to accommodate climate change into their work to assure public health and safety. Second, given the level of awareness of this issue and high visibility of impacts arising from more intense and severe weather events, engineers that do not exercise due diligence regarding changing climate may ultimately be held personally or jointly liable for failures or damages arising from climate impacts on engineered systems. Scientific literature indicates significant departures from historical climate averages occurring globally and engineering designs must account for an expanded range of climate in their operating environments

Engineers have an important role to play in mitigating the rate and magnitude of climate change to the extent that is possible through reduction GHGs. In Canada, the federal and provincial regulatory environments mandate measures to decrease, monitor and report GHG emissions and reductions, in addition to the development of carbon pricing and market mechanisms. Engineers are central to the development and implementation of strategies and technologies that will lower carbon emissions.

Engineers have a wide diversity of occupations and responsibilities. Many are involved in different types of economic and product development in a cost effective, socially and environmentally responsible manner. Engineers develop new projects and public infrastructure and keep existing facilities operating effectively and efficiently. They explore resources and design economic and sustainable methods of developing these resources.

Engineers work as employees, employers, procurement and selection officers, researchers, academics, consultants, and in regulatory and managerial roles. They frequently work in environments where they must collaborate with other specialists as part of multi-disciplinary teams. An individual may or may not have control of, or be solely responsible for, a project. To the greatest extent possible, engineers should understand and manage the public health and safety aspects of the project.

Engineers are expected to exercise professional judgment and due diligence in the execution of their work. That expectation includes practising in accordance with the regulators' code of ethics for the jurisdiction in which they are licensed, complying with provincial and federal laws, restricting practice to areas of personal expertise, and practicing in accordance with established standards.

Engineers may or may not be directly managed by other engineers. Regardless, engineers will expect to be supported in making decisions that appropriately accommodate changing climate conditions even if data pertaining to these changes is sparse. Management and other team members also have a societal responsibility for the design, construction, operation and managing of safe engineered systems that may be impacted by changing climate.

Legislation and regulation in the field of climate change adaptation and mitigation is evolving rapidly. Concurrent with such regulation, engineers need guidance on how to address climate change in their professional work. This guideline is intended to fill this gap.

1.2 Limitations

While engineers have a duty to inform their clients or employers regarding matters related to climate change adaptation, mitigation and resiliency that may impact the professional activities for which they are responsible, they are generally not in a position of authority to ensure that the appropriate action is taken.

Engineers are not expected to assume responsibility for considering the implications of climate change adaptation in engineered systems or mitigation efforts beyond the scope of their authority. The engineer is not responsible for implementing solutions that address climate change adaptation if it is not within the engineer's scope of authority. The scope of authority is provided by the client or the employer.

While the engineer presents the alternatives and rationale for implementing solutions that address climate change adaptation or mitigation, the decision on the form of such solutions remains with the client or employer. Nevertheless, in keeping with professional obligations an engineer can and should appropriately communicate the risks associated with ignoring recommendations related to climate change adaptation or mitigation to their employer or client. Such communications should be clearly documented in the appropriate files.

If warranted, due to the long-term implications to public safety and/or the environment caused by the engineer's recommendations being ignored, the engineer may have to communicate the concerns more broadly if all other means, including internal communication with the client or employer, are exhausted.

1.3 Scope

This National Guideline is strictly advisory in nature and intended to assist engineers to balance competing interests as an essential element of practice.

This document, through amplification and commentary of each principle, summarizes how an engineer should strive to adjust their practice to anticipate the effects of a changing climate on engineered systems and ensure resilience.

International scientific knowledge on climate change has also advanced to the point where anthropogenic GHG emissions are known to accelerate climate variability, thereby necessitating climate mitigation efforts. Energy efficiency measures, adoption of renewable energy, and innovative low carbon technology are three principles that can specifically address climate change mitigation.

1.4 Purpose

The purpose of the National Guideline is intended to inform, guide, and encourage engineers, Certificate of Authorization/Permit to Practice holders and consulting engineering firms to proactively manage the impacts of a changing climate on engineered systems. The document also provides a basis for understanding and accepting definitions for key terms and concepts applied in assessing climate-induced risks. It suggests adopting energy efficiency measures, renewable energy options, and innovative low carbon technologies and other strategies to reduce GHG emission and support efforts to reduce the rate of change and variability of our future climate.

This guideline offers a considered interpretation of the responsibilities of engineers to adapt to a changing climate and mitigate the change. The application of the principles described in this guideline will always be a matter of professional judgment.

1.5 Definitions

This guideline uses terms that may not be used in an engineer's day-to-day practice. These are defined in Appendix A. As this document evolves, new definitions will be added as necessary.

2. Climate change and engineers

Engineers are bound by their code of ethics [3] to:

Hold paramount the safety, health and welfare of the public and the protection of the environment and promote health and safety within the workplace

Furthermore, engineers are bound to:

Be aware of and ensure that clients and employers are made aware of societal and environmental consequences of actions or projects and endeavor to interpret engineering issues to the public in an objective and truthful manner

These expectations provide engineers with a duty of care and a foundation for addressing or discharging their professional responsibilities. That is, engineers must be mindful of the public health and safety aspects of their professional activities and are also bound to disclose issues that could compromise the integrity of their professional work.

Climate change imposes a new and evolving pressure on the practice of engineering. How does this play out in real professional practice?

Professionals can only be accountable for establishing that their work addresses concerns that could reasonably be identified given the state of knowledge at the time they executed the work. But what does reasonable mean in this context? In engineering practice, reasonable is defined by the standard of practice. In this context, the expectation is that engineers should behave in a way that draws on the composite of the entire professional community's opinion of how a typical member should behave in the same circumstances.

It is notable that this guideline does not require that the professional be an expert. Rather, it is based on how a typical engineer, with a normal level of professional experience and training, would discharge their responsibilities. However, this does not absolve the engineers from keeping themselves abreast of the climate science as it relates to their professional practice. In fact, it is incumbent on engineers to learn about future climate projections, adaptation and mitigation tools and resources relevant to their work to be able to:

- » hold paramount public health and safety;
- » protect the environment; and,
- » offer services in consideration of the changing climate to their clients where appropriate.

This learning can be through a combination of attending continuing professional development events, conferences, courses, workshops, seminars, webinars, technical talks and self-study. In engineering practice, when the engineer identifies areas of practice that are outside of the scope of their training and expertise, they are required to seek input and advice from other qualified professionals who do have that expertise.

It is important to recognize that engineers have a higher standard of practice than a layperson. They have more years of training and experience with engineering matters and are uniquely qualified to identify and respond to issues that may compromise the public health and safety implications of their work. In this way, the engineer will normally be held to a standard of practice that exceeds that of a layperson but is somewhat less than that of an expert. This is not always clearly defined and is a source of constant review by engineering regulators and the legal profession. As the body of knowledge increases, new understandings developed by experts become generally adopted within normal engineering practice. As a result, the measure of a reasonable standard of practice will continue to evolve over time. This is the fundamental reason why codes and standards undergo constant review and revision.

The word reasonable is used throughout this document. This language is used in the context of the above commentary. The guideline offers a series of principles for an engineer to incorporate into their practice to reflect an understanding that the climate is changing and that historical weather and climate information traditionally used by the professional may require adjustment. Such adjustments would account for the changing climate, based on scientifically defensible methods and projections that are documented as part of the engineering process. This guideline outlines principles for demonstrating due diligence by adjusting normal engineering practice to reasonably address climate risks given the current level of understanding of the issue.

3. National guideline principles

The principles that comprise the National Guideline are divided into three categories. Within each category there are several principles that engineers should apply within their professional practice.

The eleven principles constitute the professional practice required to initiate climate change adaptation actions that will improve resiliency and reduce the rate and magnitude of change. Each principle is described in the following format:

- » The principle defined;
- » Amplification and commentary on the principle; and
- » Suggested implementing actions with examples for reference and planning.

Engineers may identify additional actions or may decide that only a subset of the suggested actions is necessary or appropriate.

3.1 Principle # 1: Integrate Climate Adaptation and Resiliency into Practice

All engineers are responsible and need to be engaged

Engineers should integrate an understanding of the impacts of climate change, weather, and resiliency into the normal day-to-day design, operation, maintenance, planning and procurement activities for which they are professionally responsible. These activities constitute the scope of engineering work.

3.1.1 Amplification

Engineers participate in many facets of the Canadian economy. Instituting meaningful change into professional practice requires recognition of this reality. Simply changing professional expectations in one element of the design, supply, construction, or operation chain will be difficult and ineffective. Ultimately, professionals can only institute adaptation measures when there is a broader acceptance that these actions are required.

Improving the resiliency of engineered systems such as civil infrastructure to the impacts of extreme weather and changing climate serves as the basis for broader acceptance of adaptation measures. According to the Intergovernmental Panel on Climate Change (2014), resilience is:

“the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation”.

It is noted that the terms “climate resilience” and “green resilience” are also part of current discussions relating to public sector emergency preparedness and management.

Asset failures result in service risks (disruptions) which in turn affect community risks (health, safety, economic, social and environmental well-being). Community risks are reduced through redundancies and emergency preparedness. Infrastructure resiliency depends on the type of threat and the vulnerability of the asset to this threat, as well as recovery plans. Establishing resiliency objectives for infrastructure requires an assessment of:

- » **Robustness:** the inherent strength or resistance in a system to withstand external demands without degradation or loss of functionality.
- » **Redundancy:** system properties that allow for alternate options, choices, and substitutions under stress.
- » **Resourcefulness:** the capacity to mobilize needed resources and services in emergencies.
- » **Rapidity:** the speed with which disruption can be overcome and safety, services, and financial stability restored.

Engineers engaged in each sector of the Canadian economy should integrate climate adaptation and resiliency considerations into their professional works. It is unreasonable to place this entire obligation on the much smaller group of professionals that work specifically in design functions. Without support from the engineering profession, these practitioners may not be able to gain approval for adaptation measures that meet or exceed codes, standards or professional guidelines, especially if those changes result in higher overall project costs.

Understanding the potential of adverse impacts from climate change is especially relevant for those engineers that are in significant decision-making positions with respect to incorporating adaptation measures. These professionals establish the environment within which other professionals must function. They should establish organizational objectives that recognize how climate change may demand professional practice that exceeds codes, standards and professional guidelines. Proper recognition and support of such organizational objectives may increase acceptance for higher project costs to address climate

adaptation. By establishing this environment, the decision-maker enables their subordinates and contractors to take reasonable actions to address climate change in their professional works.

Similarly, those professionals that work in procurement positions, setting project specifications and reviewing competitive proposals should include consideration of current and future climate impacts as a requirement on their projects. Achieving sustainable infrastructure that will last its whole service life without major damage or disruption will lower life cycle costs.

Foregoing consideration of climate change impacts in project scope may not lead to life cycle cost avoidance. The costs of future damage and disruption of service may far outweigh the incremental costs of anticipating the changing climate. Engineers engaged in and advising on infrastructure specification and procurement should recommend including climate considerations. Engineers in management positions or advising management should recommend the provision of sufficient financial resources or proposal evaluation incentives to support the integration of climate considerations.

Finally, those engineers in maintenance and operation functions see the progressive impact of creeping climate change. They should work to ensure the sustained operation of the systems for which they are responsible. They should also clearly identify the impacts to which they are responding to other professionals and managers/owners. These professionals have the capacity and experience to incorporate appropriate changes in policies and procedures as well as their professional works, codes, standards and guidelines to reduce the impacts in the longer term.

Engineers rely on the work of other engineers and other professionals to support their work. It is critical that the entire profession creates an environment where adaptation to changing climate is not only an accepted part of daily practice, but also a guiding principle of professional practice. Individual engineers should make reasonable efforts to incorporate adaptation into their personal professional practice through continuing professional development and experience.

3.1.2 Implementing actions

The following actions can help engineers integrate the consideration of, and adaptation to, climate into their scope of practice to improve resiliency. These considerations will vary widely across disciplines and the nature of the engineering works or tasks being performed. Not all engineers will need the same level of integration into their practice; however, virtually all engineers engaged in direct and indirect work associated with all types of civil infrastructure and built environments should be aware of the climate change issue and always consider if and how their work could be affected by current and future climate.

For designers, the need to incorporate climate change through adaptation and resiliency considerations into engineering works can be realized through the following actions:

1. Listing the climate change predictions and potential impacts for the area where the project is located;
2. Discussing the aspects of the project the engineer believes could be impacted;
3. Detailing what has been done in the design to reduce those impacts;
4. Discussing the climate-relevant national, provincial, and municipal level codes, policies and bylaws establishing the level of acceptable risk, and identifying the client's level of risk tolerance;
5. Detailing what additional/revised operations and maintenance (O&M) and inspection procedures are recommended within the service life cycle of the project; and
6. Outlining policies and procedures to restore interruptions to service, loss of functionality or repair damages from extreme weather events.

All engineering disciplines should use professional judgment to modify the actions noted above to address the specific job or circumstance.

The following additional actions are suggested as good practices. Not all may be appropriate to every situation, nor is the list complete. The engineer is encouraged to give thought to these and other actions that may be appropriate to the situation. Any successful practices or improvements should be reported to the engineer's regulator and Engineers Canada. These can be incorporated into the next edition of this guideline.

- » Maintain a record of actions undertaken within daily practice that facilitate addressing climate change issues.
- » As appropriate, pursue education and training on climate and meteorology to provide a scientific grounding on the subject matter that forms a basis for climate change adaptation actions.
- » If an engineer is responsible for specifying engineering work, the specification should explicitly include:
 - » Considering the long-term sustainability and resiliency of the infrastructure over its anticipated service life
 - » In procurement, allowing margins to accommodate climate adaptation measures
 - » In management, being receptive to recommendations that address climate risk and improve resiliency
- » Review operations, maintenance and management procedures and practices and adjust as necessary to accommodate future climate risks and ensure any reduction measures continue to function as originally designed.
- » Consider using approaches that balance economic, environment and social (sustainability) considerations in recommending and implementing adaptation measures.

- » Explain to the client the solution in economic terms, i.e., through the use of net present value, incremental capital costs and avoided costs to aid decision making.
- » Explicitly identify the requirement for climate adaptation measures in contracted engineering work and reward proposals to include such recommendations.
- » In defining environmental impact assessment terms and conditions, include the requirement to explicitly identify and explain the climate change implications to the proposed project.

3.2 Principle # 2: Integrate Climate Mitigation into Practice

All engineers have a responsibility to reduce GHG emissions

Engineers should investigate and evaluate options for minimizing GHG releases into the atmosphere whenever there is potential for such releases from current operations and installations. For new installations, the availability and potential for enhancing energy efficiencies, adopting renewable energy options and/or substitution of low carbon technologies, and carbon sinks should be explored.

3.2.1 Amplification

There is mounting consensus that human behaviour is changing the global climate. Globally, reducing the annual 30 billion metric tons of carbon dioxide emissions [2] from stationary and mobile sources is a gigantic task involving both technological challenges and monumental financial and societal costs.

Mitigation, as defined by the United Nations Framework Convention on Climate Change (UNFCCC), is any intervention that seeks to either reduce the sources of, or enhance the sinks for GHGs. Sources can be reduced in diverse ways, including using fossil fuels more efficiently, switching to renewable energy sources, and reducing the carbon footprint of buildings. Similarly, a sink refers to forests, vegetation, or soils that can absorb carbon dioxide.

Engineers identify, develop and use the best technological solutions that affect the daily life of every citizen of the world. The present mitigation activities range from energy conservation, carbon-neutral energy conversions, advanced carbon combustion processes that produce no GHGs and/or enable carbon capture and sequestration, to other advanced technologies in renewable energies. The issues surrounding climate change mitigation involve multidisciplinary science and technology.

Engineers can and must provide leadership in mitigating climate change and moving society towards renewable energies. Energy will progressively cost more since the costs for carbon capture and storage or the detrimental effects of climate change are not currently factored into the cost of energy. All branches of engineering will need to work cooperatively to ensure progress will be realized more quickly. [4]

Controlling GHG emissions is the essential component of climate change mitigation. This may entail measures such as material substitution, process modification, process controls, alternative technologies and innovation. Subsequently, mitigation is largely specific to the sector of interest.

Engineers need to consider the following for mitigating climate change [4]:

- » Does the project generate GHG emissions or affect the removal of carbon dioxide from the atmosphere?
- » To what extent have GHG emissions been accounted for in project planning?
- » Can the project be adjusted to reduce adverse contributions to a changing climate?
- » What measures could be taken to assess and improve climate performance during operation?

An engineering input to carbon mitigation would include a comprehensive approach to the identification and advancement of technologies under the following themes [5]:

- » Energy saving or efficiency measures;
- » Standards to encourage the use of sustainable materials and renewable energies;
- » Alternative propulsion technologies and fuels;
- » Electric propulsion especially for vehicles;
- » Electric transmission, distribution and storage using smart grids;
- » Environmentally sound carbon and capture technologies; and
- » Nuclear waste management and next-generation nuclear power plants.

By adopting and implementing technologies that are currently available, the expected increases in carbon emissions due to population and economic growth could largely be offset. Best of all, many measures would help to offset increased energy costs [6].

Many technologies not only reduce carbon releases, but also other pollutants that contribute to atmospheric and water pollution. With an added emphasis on reducing carbon emissions, engineers can greatly contribute to the broader and more comprehensive objective of sustainability.

3.2.2 Implementing Actions

Opportunities to reduce GHG emissions from all aspects of the project should be sought during the procurement phase of a project. While incorporating mitigation measures, such as increased energy efficiency or enhanced sinks for GHG emissions, may add to the initial project costs, the resulting energy savings over the lifecycle of the project could compensate for the higher initial cost.

The following actions would help engineers integrate mitigation into their scope of practice and contribute to the goals of sustainability. All engineering disciplines that perform design work need to take the potential for carbon releases into consideration, while civil, chemical, electrical, and mechanical engineers should consider climate mitigation in essentially all of their projects. The following actions are suggested for consideration in each project:

- » Identify all potential sources of GHGs related to the scope of the project;
- » Given the materials and processes on-site, quantify the potential releases of GHGs;
- » Seek opportunities to improve energy efficiency or reduced energy consumption as well as evaluate renewable energy options;
- » Compare the level of potential GHG emissions with alternative technologies and approaches;
- » Suggest the use of technologies that minimize the release of GHGs;
- » Examine options for controlling the GHGs if appropriate;

Ensure recommended technologies will be aligned with other management requirements;

Consider mitigation opportunities through material substitution, process modification, process controls or other innovations.

All engineering disciplines should use professional judgment to modify the above actions to address the specific project. Not all actions are necessary or cost-effective in all cases.

The following additional actions are suggested as good practices. Not all may be appropriate to the situation at hand nor is the list complete. The engineer is encouraged to give thought to and implement other actions in addition to those listed here. Any successful practices or improvements should be reported to the engineer's regulator and Engineers Canada. These will be incorporated into the next edition of this guideline.

- » Establish baseline or status quo GHG emissions prior to the start of any project.
- » Estimate potential GHG emissions at the planning phase for projects.
- » Build, install and operate systems to monitor and measure GHG emissions from the project start-up and on-going operations.
- » Investigate available cost-effective alternative clean technologies for given project requirements.
- » As appropriate, pursue education and/or training on climate change mitigation developments and on the status of alternative technologies to form an informed recommendation on climate change mitigation measures.
- » If an engineer is responsible for specifying engineering work, the specification should explicitly include:
 - » Consideration of the long term GHG implications of the cost-effective approach versus cost implications of any alternative technologies that may ensure greater sustainability;
 - » In procurement, allowing for margins to enable the selection of more sustainable solutions, such as enhanced energy efficiency;
 - » In management, recommendations that minimize and eliminate GHG emissions and contribute to sustainable development.
- » Review operations, maintenance and management procedures and practices and adjust as necessary to minimize GHG emissions.
- » Consider using approaches that balance economic, environment and social (sustainability) considerations in recommending and implementing mitigation measures.

- » Explicitly identify the requirement for climate mitigation measures in contracted engineering work and select proposals that enhance sustainable development.

In defining environmental impact assessment terms and conditions, include the requirement to explicitly identify and explain the climate change and sustainability implications of a project.

3.3 Principle # 3: Review Adequacy of Current Standards

Review applicable codes and standards and advise stakeholders on potential revisions or updates

Engineers should review the local design standards used within their professional practice from both an adaptation and a mitigation perspective. These standards should reasonably represent the current and anticipated climate that the engineered system will experience over its useful operating life. Standards – for example, those dealing with energy efficiency – should be assessed to determine if they are reflective of current technological capabilities or are based on less efficient technology.

3.3.1 Amplification

Given the potential impact of changing climate on engineering works, it may no longer be appropriate for professionals to simply rely on the veracity of codes, standards and professional guidelines that include embedded assumptions about climate or available technology. The professional should actively work towards the adoption of any changes in codes, standards and professional guidelines, as appropriate.

Engineers must adhere, as a minimum, to published codes and standards, even when evidence may suggest that designing below a code or standard is possible. Codes and standards serve as a minimum requirement and should be viewed as the starting point for application to the engineering work. Often these must be exceeded to assure safety or to accommodate a local condition of future climate considerations.

Engineers should routinely review and challenge the tools used in professional practice. This is an outcome of Principle # 1, but the focus here is broader than the assessment of an individual project or work conducted by the professional. It is to ensure that knowledge gained through ongoing review of the tools and processes is shared and ultimately universally represented in the tools of the professional discipline. Once an engineer has identified a deficiency in a code, standard or professional guideline, he or she has an obligation to share their findings within the professional community. This will reduce the risk that the deficiency will creep into other professionals' work and create threats to public health and safety.

The obligation to review tools and processes also covers those used by engineers in their daily practice, including procedures, codes of practice, rules of thumb, etc. These should be evaluated within the context of each situation to which the engineer applies the tool on a routine basis. Small modifications should be documented and shared within the group of professionals who normally use them. For example, do historical return periods in available flood statistics accurately reflect recent trends in flooding? In many cases, a 1 percent (1:100 year) rain event from an older historical record may not reflect conditions where flooding has become more frequent in recent years.

3.3.2 Implementing actions

The following are some suggested actions engineers should undertake in their use of current codes and standards. Engineers should advise other engineers, as well as the governing bodies responsible for the specific codes and standards, when a code or standard warrants review based on evidence from ongoing practice.

Not all actions may be appropriate to the situation nor is the list complete. Engineers are encouraged to develop their own successful strategies and experiences. Notifying their regulator as well Engineers Canada will enable practice guidelines to be updated to reflect most current and best/better practices.

- » Apply the most up-to-date revisions of relevant practice guidelines, codes and standards, as a baseline from which climate change adaptation or mitigation measures are applied.
- » Create a file of adjustments made to codes, standards and assumptions to accommodate changing climate or reflect improvements in technology. As appropriate, communicate adjustments:
 - » Within the department, division or organization;
 - » To employers and clients;
 - » To professional societies, associations or groups; and
 - » To standards organizations and regulators who developed the codes and standards.

3.4 Principle # 4: Exercise Professional Judgment

Evaluate and document the impact of climate and achieving resiliency for engineering works, and consider opportunities for advancing climate change mitigation

Engineers should apply a reasonable standard of professional judgment to consider changing climate conditions, resiliency, and mitigation opportunities within their professional practice.

3.4.1 Amplification

The overall intent of this principle is that engineers should consider the implications of climate change, both from an adaptation and a mitigation perspective, and improving resiliency in their professional practice. They should create a clear record of the outcomes of those considerations to provide the rationale for their professional judgement.

Inherent in engineering practice and professional judgment is the concept of the “factor of safety”.

The factor of safety is usually expressed as a ratio of the “load carrying capability” of the structure to the expected loading, which in this case is the climate loading. Loading may be static, impact, fatigue, wear/damage from extreme climate events, or a combination of these factors. The purpose of the safety factor is to assure that the design does not fail in the event of unexpectedly high loads or the presence of material or design defects. Factors of safety are applied to decrease the probability of failure, or in more positive terms, they increase the probability of success. They are applied in part due to inherent “ignorance” present in all designs. Ignorance stems from natural variability in materials and manufacturing processes, maintenance, and the uncertainty of future climate, including extreme weather events over the life or service cycle of the infrastructure. For civil infrastructure including buildings, the factors of safety will be higher if the following are not present:

- » High quality and consistency of materials, manufacturing, maintenance and inspection
- » Good control or knowledge of the actual loads and environment over the life cycle e.g. climate loads
- » Highly reliable analysis and/or experimental data

The degree of “ignorance” is not the only element that the engineer should use to determine appropriate factors of safety. The potential harm that failure can produce is also important. If failure would result in a mere inconvenience, then a smaller factor of safety may be acceptable. If failure would be expensive or life threatening, a larger factor of safety is justified.

How does an engineer determine an appropriate factor of safety? In some instances, such as pressure vessels, minimum factors of safety are mandated by codes and standards. However, this is often not the case with our changing climate.

The benefit of safe-life designs includes reducing the likelihood of unplanned maintenance failures. Benefits of fail-safe designs include being able to manage the unexpected and reducing damage if failure occurs.

There is no method to help determine which of these philosophies should be employed. Engineers must use their judgment on a case-by-case basis. The decision to use either of these philosophies is justified whenever the “cost” and likelihood of failure outweighs the “cost” of implementing either fail-safe or safe-life designs. “Cost” of failure may include:

- » Physical harm to people or the environment;
- » Loss of, or damage to property or equipment;
- » Loss of productivity, reduced level of service or use of the failed “system” or device;
- » Damaged reputation; or
- » Likelihood of failure.

The engineer should always consider how likely a certain failure will be. In so doing, it is important to consider all potential loading conditions – even abusive loads. “Cost” of implementing can include:

- » Increased expense and time for design and testing;
- » Increased production costs; or
- » Decreased product performance;

There are no formulas to help determine when fail-safe or safe-life designs should be employed. Airplane designs employ both concepts, making air travel one of the safest modes of transportation. Yet, it is not possible to make aircraft completely safe. There are always conditions that are prohibitive to guard against.

Engineers are held to a higher standard of reasonable care than the average layperson. From their professional training and experience, they are expected to apply a high level of expertise to issues that affect their professional practice. Professionals are expected to be aware of the limitations of their professional scope and access other qualified professionals to augment those areas where they may not be fully qualified to express professional judgment.

Through extensive media coverage, the average layperson is cognizant of the climate change issue and its potential for

disruptive and serious impacts. Similarly, the average engineer must also be sensitive to the potential for changing climate conditions and appropriately apply these sensitivities to their professional practice, as well as considering the need for mitigative measures to reduce GHG emissions or enhance sinks for GHGs. Given the level of public awareness of the climate change issue, a professional cannot make the argument that they were unaware that climate change could potentially affect their professional work. Not considering these factors may lead to additional professional liability.

This should not be interpreted to mean that the engineer should become an expert on weather and climate issues. Rather, the expectation is that engineers will, as part of their normal practice, determine where climate information is embedded in codes, standards and assumptions; evaluate how the information is applied in their professional work; and identify and assess opportunities for advancing climate change mitigation.

Engineers should challenge the information to assess if and how changing climate conditions may lead to a wider spectrum of operating environments and unanticipated outcomes from their professional works. To exercise due diligence, the engineer should document this analysis and the outcomes. As part of this documentation, the professional should outline their rationale for:

- » Any decisions made regarding measures to reduce GHG emissions, such as consideration of energy efficiency, alternate fuels, or enhancing the potential for GHG removal from the atmosphere;
- » Any adjustments made or not made to climate information embedded in the work;
- » The rationale for changes that improve resiliency of the engineered work; and,
- » Any other factor that may have been considered including, but not limited to, the results of consultations with outside experts on the climate change issues affecting the work.

3.4.3 Implementing actions

The following actions are suggested to aid professional judgment. Not all may be appropriate to the situation at hand nor is the list complete. As engineering practice in climate change adaptation evolves, the nature and range of examples to help guide future practice will no doubt increase and will be reflected in future updates to this guideline.

Techniques will depend on the type of failure condition that the engineered work is to be designed for and may include safe-life design or fail-safe design within more complex systems.

In “Safe-Life Design”, it is imperative that the component or system not fail within the predicted life time. Safe-life designs involve extensive testing and analysis (typically fatigue analysis) to estimate how long the component can be in service before it will likely fail. Since no amount of analysis and testing can assure how long an individual component will perform without failure, a generous factor of safety should be included to prevent catastrophic failure. The engineering work should be designed so that it can be easily inspected in service.

Techniques for “Fail-Safe or Safe-Fail Design” include redundancies (avoiding single point failures), use of back-up systems (if failure of a critical subsystem will cause severe losses), multiple load paths (if a structural element fails, the load it was carrying will be transferred to other members) or an “Intentional Weak Link”. The latter can be an inexpensive and easy to replace component used to prevent damage to an expensive or difficult to repair component. Fuses in electrical circuits are an example of this for electrical systems. Shear pins used on boat propellers are a mechanical example. If the propeller strikes an object, the shear pin is designed to fail before the propeller or shaft is damaged.

For professional judgment related to the consideration of climate, several actions are suggested:

- » Develop a checklist of climate parameters with potential to impact performance of design
- » Develop a checklist of climate parameters and operations/maintenance processes that may affect resiliency to climate events
- » In the process of design, operation, procurement, management and maintenance activities, confirm applicability of climate information, policies/procedures, and assumptions about available technology that may be embedded in codes, standards, guidelines, etc.
- » In engineering working papers, spreadsheets and other documents, note that the review has been completed and prepare an accompanying memo to file that the review was completed. The engineer responsible for engineering activity should sign the accompanying memo. Outline:
 - » If any changes to climate information embedded in the work were identified and the rationale for making or not making the changes;
 - » Assumptions and methods used in the design of the engineering work to account for changes in the climate and potential mode(s) of failure;
 - » Changes made or recommended to assure a level of resiliency of the design, operations and maintenance;
 - » Changes made or recommended to incorporate GHG mitigation in the design and operation;

- » Any other factor that may have been considered including but not limited to the results of consultations with outside experts on the climate change issues affecting the work; and
- » The date of the review.

3.5 Principle # 5: Interpret Climate Information

Consult with climate scientists and specialists

Engineers should work with climate and meteorological specialists/experts to ensure that interpretations of climatic and weather considerations used in professional practice reasonably reflect the most current scientific consensus regarding the climate and/or weather information.

3.5.1 Amplification

Climate is the weather conditions prevailing in an area over a long period of time. Planning for long-lived assets requires defining the climatic information for a given location. Definitions and use of terms can vary but generally engineers need to consider historical climate, weather over the short term and climate projections over the long term.

- » Historical climatology is the study of historical weather and the seasonal variation considered over periods of 30 years or longer. Historical climate is generally not considered a reliable guide to future weather and climate in the face of our changing climate.
- » Weather is the day to day conditions with seasonal precessions through the year. It is generally a combination of current conditions and the forecast for the next few days.
- » Climate change projections are the long-term outlooks for future weather and associated seasonal variation that collectively determine the climate. They are based on potential socio-economic emissions scenarios and therefore include a range of potential conditions that should be considered for planning purposes.

Each of these areas is serviced by specialists who may not all be concerned with the data needs of engineers.

Most engineers do not have the extensive training or experience in managing and assessing climate and weather information that is necessary to be considered experts in the field. Historically, the professions have been consumers of such information, relying on government agencies and other authorities to package information into the formats used within their professional practice.

Assessing climate information can be a very subtle and technically demanding activity requiring a significant level of professional expertise. On the other hand, climate and weather specialists may not have a detailed understanding of the nature of the engineer's area of practice and may find it difficult, without guidance, to provide climate and weather information that is meaningful within the professional's area of practice.

These groups must work together to identify and develop the sorts of data that address the engineer's technical requirements. This may include the type, format, availability and scenario basis for the information. There may also be some sensitivity analysis available (e.g. perhaps ensemble modelling) that speaks to the robustness of the dataset. Engineers should secure the technical expertise and support provided by climate scientists and experts.

Climate and weather information often may contain embedded uncertainties or sensitivities. Climate experts are aware of these issues and can help the engineer come to understand the overall quality of the information they are being provided. Furthermore, an uninformed engineer could apply climate and weather information in ways that are completely inappropriate based on the methodological limitations of the processes used to develop that information. The engineer should work with climate and weather specialists to gain a fulsome understanding of the strengths and limitations of the information they are using. Likewise, the engineer will perform analysis where other sensitivities may emerge due to the interaction of the data and the system that they are designing. With this understanding, the engineer will be equipped to incorporate appropriate measures within their own work to accommodate the quality of the information they are using.

Key to understanding future climate conditions is a fundamental knowledge of historical and current climate conditions and how these have evolved.

While consulting with weather and climate specialists, it is important to develop a firm understanding of historic weather information to develop a baseline. Historic climatology is still an emerging field with revisions likely as climate data specialists trend for missing data and adjust for systemic data collection errors.

Engaging a specialist is even more important with respect to climate change information. Climate change projections are based on very sophisticated modelling and analysis derived from socioeconomic and GHG emission forecasts. These are not the same as weather forecasts. Climate change scenarios can have significantly different projections depending on the interaction of social, economic, and political choices.

A large number of models are available to use in developing climate projections and these have strengths and weaknesses.

Due to the inherent uncertainty associated with modelling, current practice is to apply an ensemble approach where more than one model is used to establish the boundaries of projected climate change.

Furthermore, the underlying emission forecasts and socioeconomic assumptions are often not stated when presenting climate change projection information.

While these factors introduce some uncertainty into climate projections, the uncertainty can be managed through appropriate data treatment and climate scenario development. These practices are typically outside of the experience of the engineer. It is therefore important that engineers consult with climate experts to ensure that they understand the overall integrity and limitations of the information they are planning to use and incorporate appropriate measures from their own professional discipline to accommodate these factors within their professional work.

Engineers can also conduct sensitivity analyses to account for the potential consequences of different climate change scenarios.

The OURANOS Consortium on Regional Climatology and Adaptation located in Montréal, Quebec, Canada has published a guidebook on climate scenarios and the use of climate information to guide adaptation research and decisions <https://www.ouranos.ca/publication-scientifique/Guidebook-2016.pdf>. Published in its second edition in 2016, the guide is a resource for climate change adaptation decision-making and research. The following is an excerpt from the Executive Summary (reproduced with permission):

“This guide is a tool for decision-makers to familiarize themselves with future climate information. It is aimed at all actors involved in climate change adaptation, from those in the early stages of climate change awareness to those involved in implementing adaptation measures.

The guide consists of three main sections. The first categorizes climate information based on its use and on its level of complexity. The second section presents a catalogue of different ways in which climate information can be presented to decision-makers, such as planners, engineers, resource managers, and government. Finally, a third section outlines key climate modelling concepts that support a good understanding of climate information in general.

This document is not detailed enough to inform users on how to prepare different types of climate information, nor is it intended as a critical analysis of how the information is produced. Rather, it highlights the importance of working in collaboration with climate service providers to obtain climate information. The guide allows users to engage more easily with climate service providers and to become more critical of the information that is provided to them. It should be recognized that, at this point in time, the number of climate service providers is low relative to the demand for climate information.

Using this guide will allow engineers to become more familiar with climate information products and hence better evaluate what climate information best suits their needs.”

Key important messages emerging from the guide include:

- » Climate information at different levels of complexity can be valuable, depending on the type of decision being made;
- » More detailed information is not always necessary to inform better decisions;
- » Climate information can be tailored into formats that best match the level of expertise of the decision-makers;
- » Decisions should be based on a range of plausible futures, and a single best climate scenario does not exist.

It is important to understand the limitations of the climate information. Engineers are cautioned that whatever climate information or methodologies used in their professional work should be considered scientifically defensible by the climate specialists they consult. More broadly this extends to defensible sources of data, uses of data, and the decisions arrived at and designs produced.

3.5.2 Implementing actions

The following are some suggested actions to aid engineers in interpreting and assessing climate information. Not all may be appropriate to the situation at hand nor is the list complete.

- » List climate information needs in terms of parameters that are listed in codes, standards, guidelines and “rules of thumb” as well as other information that is not formally codified within codes, standards, etc. but are nonetheless relevant to the professional work.
- » Develop the current climate profile based on analysis of historical weather data. Engineers should make sure that they are using data from the most current treatment of the subject.
- » Estimate the changes in frequency and extreme values of relevant climate parameters based on scientifically defensible methods of future climate projections over the service life of the engineered system.
- » Engage climate scientists and climate experts as appropriate to derive current and future extreme values and

frequencies of relevant climate parameters.

For this climate information, seek the advice from climate scientists and climate experts to define the:

- » Associated uncertainties with the information
- » Assumptions made
- » Data sources
- » Relative differences between current climate data derived from measured metrological data and projected climate information based on modelling
- » Scientific validity of the methods and data used to derive current and future climate parameter values and frequencies
- » The criticality of the impact of the climate assumptions on the overall engineering design and function of the system
- » Assumptions and factors that have undergone recent review/update due to climate change
- » Assumptions and factors with climate experts to assess the applicability of the assumptions and factors over the anticipated service life of the design
- » Appropriate safety factors or margins based on professional judgment to plans and designs to accommodate anticipated future climate conditions in relation to the current climate conditions and where applicable and available, the climate design parameters used in the original design
- » Data requirements for resiliency planning to deal with both extremes (e.g. temperature and wind) and cumulative impacts (e.g. water tables and permafrost).

3.6 Principle # 6: Emphasize Innovation in Mitigation and Adaptation

Seek collaborative, innovative strategies, technologies and/or new approaches

Engineers should stay abreast of state-of-the-art developments in their respective fields that reduce or eliminate GHG emissions. They should understand emerging policy frameworks at all levels of government as well as implementing innovative strategies and methods that adapt engineered systems to extreme weather and the future climate. This includes encouraging research and demonstration that support:

- » climate resilient systems that are energy efficient, and
- » energy efficient systems that are climate resilient.

3.6.1 Amplification

Reducing GHGs emissions to the levels required to slow the magnitude and rate of global temperature rise is a long-term challenge that requires the implementation of strategies, innovative technologies in several fields and recognition of the importance of sustained long-term commitments [7].

Turn-key engineering projects generally address a project from start to finish. In such cases, engineers can select the technology and materials that minimize the release of GHGs within stated financial considerations. For projects that seek changes or minor improvements to an existing process, the engineering contribution to climate change mitigation may be limited but still possible if the current GHG emissions are identified and means of controlling these releases are investigated.

Engineers can have the greatest impact in the design of new facilities. Such projects allow engineers to investigate possible methods for delivering the anticipated product using a combination of technologies that limit GHG emissions or use an innovative approach that may avoid any releases of GHGs and may in fact lead to sustainable development. In such instances, engineers need to be very familiar with state-of-the-art technological options and should further investigate current research findings in the given field.

In large-scale operations, where significant GHGs are emitted, engineers should also seek an excellent understanding of all the point and fugitive releases of GHGs within a facility. This would then permit the identification of key emission areas that would allow the investigation of GHG control options or alternatively the identification of a technology that would not produce GHGs in the first place. It should be noted that solutions may not be readily apparent to engineers responsible for the operation of a facility nor would the required resources be available to develop alternative technologies. In such cases, the engineers should raise the issue with management and cooperate with researchers in the field or within academia to explore options for minimizing GHG releases.

A good example might be the current effort in finding appropriate solutions for sequestering carbon emissions in oil sands operations [8]. Resources from such facility operators have been pooled, together with public funding for supporting research organizations that explore various options. These could entail preventing GHG releases from certain operations to capturing

such GHG releases for subsequent sequestration underground or in materials for possible re-use or stockpiling. Another approach may consist of extracting the oil in a way that does not release any GHGs or even substituting the hydrocarbons for some other more sustainable or even renewable energy source. In any case, the solutions provided must address the resiliency of the project for its entire design life.

Naturally such research takes years and possible solutions may not become economical until several other factors evolve over time. Market mechanisms and incentives within policy frameworks are likely necessary to sustain solutions long enough for them to have an impact. Engineers are encouraged to contribute to such policy discussions to assure that technically feasible and cost-effective solutions are available.

Innovation for successful climate change adaptation requires the development and application of good practices within an encouraging policy and fiscal framework that recognizes the service life and resiliency of engineered systems. Typically, climate change adaptation and mitigation have been considered as separate endeavours, but there are potential strategies that increase resilience to climate impacts while reducing GHGs. These strategies may be considered in areas including energy efficiency, green infrastructure, public transit and transportation, water use, buildings, and agriculture. Good practices extend from project definition, through planning and procurement, design, construction, operations and maintenance. It is the innovative combination of these processes that will enhance adaptation to our changing climate to achieve the intended service life and resiliency of the engineered system.

3.6.2 Implementing Actions

As noted above, innovation can be supported in several ways. In Canada, innovative concepts and technologies for mitigating GHGs within municipalities for buildings and infrastructure are largely inspired by the Federation of Canadian Municipalities (FCM) using Green Municipal Funds provided by the federal government. Sustainable Development Technology Canada (SDTC) largely assists industrial research which is also funded by the federal government. Cutting-edge innovation is largely done in partnership with provincial funds and industrial research organisations. A good example of such pooling of resources is the effort on vehicle electrification at the Institut de Véhicule Innovant (IVI) in St-Jerome, Quebec.

This reflects a systems approach. It supports innovation by recognizing and strengthening the various stages of the innovation process to overcome existing barriers to the development and deployment of commercially viable technologies [8]. Within a systems approach, the linkages between technology areas and long-term goals and objectives are recognized. Science and technology objectives should then be aligned with the needs and opportunities for innovation.

A comprehensive analysis would follow for each initiative to identify technological innovation and engineering solutions required for GHG mitigation [9]. Areas of importance to Canada and globally are known from the numerous and detailed GHG emission inventories that have been prepared under IPCC. For each technological domain, the engineer should be aware of the best available information by undertaking the following actions:

- » Identify known technologies and their status of development and implementation
- » Investigate areas of current research and their potential to deliver GHG reductions
- » Determine Canadian research expertise capabilities and its role in international endeavours
- » Research enabling and breakthrough or transformative technologies for the longer-term
- » Implement mechanisms for enhancing research and development of promising climate mitigation technologies that may have resilient co-benefits.

Similarly, innovation for climate adaptation is supported by policies, programs, and funding offered by all levels of government in Canada and Non-Government Organizations such as the Federation of Canadian Municipalities.

Examples include incorporating the requirement for climate change considerations in infrastructure procurement, and defining climate risk and impacts as part of environmental impact assessment. Incorporating changes in climate to infrastructure codes and standards is well underway and requires innovative thinking for practical definition and implementation. Engineers should contribute to these policy and related discussions to the extent that their time, interest and support allows.

Innovative approaches for financing adaptive measures requires not only engineering solutions and alternative options, but new ways to raise capital that require the expertise of sister professions such as law and finance. Engineers should engage with these professions to develop fully integrated solutions that extend beyond the current focus of adaptation and into mitigation.

3.7 Principle # 7: Work with Specialists and Stakeholders

Work with multi-disciplinary and multi-stakeholder teams

Engineers should work with others, including those that are not engineers, to ensure that they have a full understanding of the implications of changing climate and weather on the engineered systems for which they are responsible. This includes the development of integrated solutions with others that are technically feasible and cost-effective.

3.7.1 Amplification

Engineers normally work in multi-disciplinary teams. However, it is quite common for engineers to define those teams with respect to disciplines within engineering. To address climate adaptation, the definition of multi-disciplinary teams should be expanded to include a much broader spectrum of players. The need for climate specialists is outlined in Principle # 4. However, the impacts of climate change can be far reaching and outside of the scope of an engineer's normal practice. To accommodate this reality, the professional should structure project teams to ensure that, as a minimum, the team possesses:

- » Fundamental understanding of risk and risk assessment processes;
- » Directly relevant engineering knowledge of the system;
- » Climatic and meteorological expertise/knowledge relevant to the region;
- » Expertise in natural sciences such as hydrology, geology, forestry, biology and other specialized sciences;
- » Hands-on operation and maintenance experience with the system or similar systems;
- » Hands-on management knowledge with the system or similar systems;
- » Local knowledge and history, especially regarding the nature of previous climatic events, their overall impact in the region and approaches used to address concerns; and
- » High awareness of levels of process or design “minimum acceptable performance” for the community and stakeholders reliant on the design.

Additionally, the professional should also consider adding skills for the team in:

- » Social impact analysis (social scientists and policy specialists);
- » Environmental impact analysis;
- » Economic impact analysis;
- » Political decision makers;
- » Insurance specialists;
- » Environmental practitioners;
- » Community stakeholders;
- » Emergency planning and response specialists; and
- » Other stakeholders as appropriate. This may include members of the public or at the political level e.g. city councillor.

Skill sets may include those supporting climate change mitigation – to achieve energy efficiency, use of renewable energy, carbon reduction or reducing resource consumption to minimize GHG emissions. For mitigation opportunities the GHG emissions can be modelled and various alternative reduction options can be evaluated. Mitigation modelling should consider potential operational changes that would accrue with climate change and therefore affect future emissions.

For most infrastructure projects the opportunities for mitigation, adaptation and resilience are likely to be interrelated. It is important therefore that the team include these objectives as part of their project constraint management.

Practitioners may possess more than one of the requisite skill sets. Thus, teams may comprise a smaller number of individuals than the skills list may suggest. Engineers should evaluate the skills represented on their teams to ensure that the right balance of skill and experience is represented to reasonably anticipate climate change and incorporate reasonable adaptive measures into the project.

Where professionals do not have the skills outlined above, they should consult with other qualified professionals to augment the team's expertise, as they would normally do when they encounter issues outside of their professional scope of practice.

3.7.2 Implementing actions

The following actions can help engineers secure the requisite range of skills and expertise that are needed to identify potential climate risks and impacts as well as to develop acceptable adaptation solutions. Not all may be needed or appropriate as skill set needs depend on the situation at hand and the stakeholders that need to be involved.

The engineer is encouraged to give thought to and implement other actions or engage other stakeholders and expertise not listed in this guideline. These should be reported to their regulator and Engineers Canada. These will be incorporated into the next edition of this guideline.

- » During the formation of multi-disciplinary teams, review the overall service life and operability requirements of the engineered system and ensure that the entire range of skills necessary to assess climate implications of the work are covered.
- » In working papers and files maintain a written record of the team membership, skill sets, and training of each member of the multi-disciplinary team relative to the project/assignment.

3.8 Principle # 8: Use Effective Language

Communicate effectively

Engineers should communicate about climate change adaptation and mitigation issues and recommendations using simple, unambiguous language.

3.8.1 Amplification

Engineers possess unique technical knowledge and skills necessary to plan and implement effective adaptation to changing climate conditions or to mitigate GHG emissions. However, engineers can only implement such measures when decision-makers approve these actions. Sometimes, decisions are politically motivated and arguments based on pure logic and cost analysis may not be persuasive.

In most circumstances, the engineer cannot implement adaptive or mitigation measures independently. This places a demand on the engineer to communicate effectively with the decision-maker about climate change adaptation issues and the associated risks or benefits of reducing carbon emissions. As part of this communication, the engineer should clearly communicate the costs and benefits of recommended actions and how those actions reduce the identified risks. It is important that the engineer clearly articulate the economic benefits of the adaptation measure and the potential costs of not adapting to the identified risks.

Engineers should ensure that the complexities and uncertainties inherent in this work do not cloud the necessity for action. Assessing climate change impacts demands a significant level of professional judgment that can be perceived to be subjective. However, professional judgment reflects a level of competence and knowledge of technical standards obtained through many years of training and professional practice in a specific area. Thus, the judgment applied by professionals on climate change should be based on a solid foundation of technical expertise and experience.

It is not unusual for expert practitioners to communicate using language embedded with technical terms. Even more perplexing, professionals may use common language with nuanced or very different meanings than understood by a layperson. The layperson may not know the meaning of the language being used by the professional and may not fully understand the professional's message. In addition, they may not know that they do not fully understand and may interpret the professional's language incorrectly, resulting in inappropriate responses.

This is a very subtle problem. For their part, engineers may not realize that they have been misunderstood until the decision-maker takes decisions that do not seem to address the concerns the professional was attempting to convey.

Given the critical importance of these issues, it is the engineer's duty to ensure that they have been correctly understood. They should alter their language so that an average layperson can understand the magnitude of the risks. In addition, the professional should understand how they may be using common language in different ways than the average layperson. This is a situation where the professional cannot afford to simply sound knowledgeable, but rather should focus on effectively communicating their knowledge and ensuring that they are appropriately understood.

When decision-makers have a fulsome understanding of the issues they are facing, they are much better equipped to place the climate change adaptation concerns and mitigation actions in the broader context of the entire range of issues that the decision-maker is managing. With this context, they are better placed to advance appropriate, well rounded decisions on climate change adaptation matters.

The professional's obligation to communicate in clear and effective language also includes their interactions with the public. The professional may sometimes be required to communicate to the public during consultations on behalf of a client or in representing their client or employer with media. In these circumstances, the professional should strive to clearly communicate the issue using language easily understood by the layperson. The public can influence decision makers to take either appropriate or inappropriate actions in response to climate change adaptation or mitigation recommendations. The professional should strive to ensure that the public has a correct, if not comprehensive, understanding of the issues and recommended adaptive measures.

Finally, the professional may find that they have identified and communicated climate risks and adaptive measures, including potential mitigation measures, to non-receptive decision makers. The decision maker may opt to reject or ignore the professional's recommendations. In this situation the professional must assess the potential long-term implications of the decision maker's actions and decide if they are obliged, in the interest of public health and safety, to communicate their concerns more broadly. This situation is not unique to climate change, and the profession has a long history in managing such issues. The Code of Ethics holds the duty to the public welfare paramount in these situations, and the professional may be

required to first advance the issue within their own organizations, and then finally externally with regulators and other responsible agencies.

The provincial regulators may provide guidance and advice to engineers who suspect that they are in such a situation. For climate change adaptation the question is a bit less certain as the case law on these matters is evolving. However, the professional should be aware that simply proposing actions to decision makers may not sufficiently protect them from disciplinary action or litigation if a case can be made that they did not sufficiently communicate a climate change risk to appropriate authorities. Their professional obligations regarding climate change risks may not be satisfied simply by proposing actions to decision makers. Increasingly, federal, provincial and territorial governments are recognizing climate mitigation through mechanisms such as carbon pricing or cap and trade. Implementing such measures requires reporting on emissions and reductions, which are roles where engineers can and should be involved.

With respect to resilience and climate change mitigation, these concepts are subtle, can be confusing to decision makers, and may be easily ignored or assumed to be dealt with. The engineer should ensure that they are brought forward and presented clearly to enable informed decision making.

3.8.2 Implementing actions

The following actions can help engineers review communication of climate risks, costs and adaptation or mitigation actions to decision-makers and the public as necessary. Not all may be needed or appropriate for the situation.

The engineer is encouraged to give thought to and implement other actions that result in improved and effective communication or climate risk, impacts and adaptation actions. These should be reported to their home regulator and Engineers Canada. These will be incorporated into the next edition of this guideline.

- » Review each piece of professional writing with an eye to the intended audience for the piece
- » In aid of clearly communicating the primary message of the piece, apply common language and expressions more likely to be understood by the audience
- » As necessary, discuss suitable language with the intended audience and come to an agreement regarding the definition of terms used in the writing
- » In situations where common language may not suffice, ensure that the piece contains sufficient background information and definitions to promote the audience's understanding
- » Where the professional does not have the skills or expertise to simplify the writing, consult with or engage suitably qualified communications professionals to revise the piece for more general, broader understanding
- » Consider hiring a communications consultant to redraft the language to convince the necessary decision-making audience(s)
- » Assume that each piece of writing may be misunderstood and challenge the writing from different perspectives to identify areas where simplification or clarity may be necessary
- » Work with other members of the multi-disciplinary team and stakeholders engaged in the work for appropriate communication to different target audiences and stakeholders that will inform or trigger evidence-based decision-making with regards to climate change adaptation
- » It may be advisable to periodically remind the reader of the definition of terms that are not in common use and have the potential to be misunderstood.

3.9 Principle # 9: Plan for service life and resilience

Consider the level of service and resilience over the entire operating life of the engineering work

Engineers should give reasonable consideration of the required length of service and resiliency of an engineered system from the impact of changing weather and climate conditions over its entire operating life. This requires incorporating life cycle costing and resiliency principles.

3.9.1 Amplification

Climate change is a long-term issue. Climate models project changes in climate parameters for twenty, forty, and even one hundred years into the future. The uncertainty in climate projections increases as the time horizon for those projections is extended farther into the future. Engineers develop and operate works that must be resilient to changing climate conditions over similar periods. Stable climate conditions observed in the past or even today may not be sustained throughout the entire operating life of a project.

Engineers may find this a daunting task. Many large infrastructure systems are designed for an extended service life. If climate conditions change over that service life, it can be difficult to adapt the engineered system to the new environment without wholesale changes to the system. However, the engineer is not being asked to make perfect decisions that correctly anticipate all future events. They are being asked, based on professional judgment, to make appropriate decisions within the context of current scientific, economic and social constraints.

There are two facets to this issue. First, while it is difficult to anticipate climate change impacts forty or one hundred years hence, professionals must nonetheless contemplate the possible impacts of such change. Second, while projects may last for extended periods, they are normally subject to periodic refurbishment and upgrading that will afford the professional opportunities to incorporate appropriate adaptive measures at various times over the life of the project. The benefits of adaptation measures are increased resilience at different scales that include individual, community, organisation, country and global. For example, road improvements to help withstand severe flooding increase the resiliency of the community as a whole.

The refurbishment of infrastructure allows for checkpoints throughout the service life of a system. If there are no refurbishment opportunities then the evaluation of climate change in the initial design becomes more critical, as the system will have to stand for a very long time without any routine opportunities to adjust. Even in these cases, many climate risks can be addressed through enhancements in operations, maintenance and management procedures and practices.

Engineers should capitalize on refurbishment opportunities to review, revise and adapt during the life of a project. Replacement in kind may not be the appropriate professional response for refurbishing a system. The engineer should evaluate the possibility that climate change may have contributed to the observed wear and tear on the project and upgrade the system appropriately. Furthermore, the professional should consider not only the useful life of the project, but also the useful life of the refurbishment activities with respect to climate change impacts. Even if the system elements being refurbished are not presently seeing the impact of climate change, it is possible that they will experience those impacts before the next refurbishment is planned. The engineer should contemplate those impacts in refurbishment planning in the same way that professionals would consider these factors for a new project.

In some ways, anticipating climate change on a refurbishment plan is simpler than it would be for the entire life of a project. The climate change projections are for a shorter time horizon and therefore have much less uncertainty associated with them. This provides the engineer with much greater confidence to recommend appropriate adaptive responses.

Extending the service life of an infrastructure system may sometimes be viewed as an adaptation strategy. It deals with infrastructure deficit issues by deferring the need to spend on new infrastructure to a later date. It also defers decisions on building new structure into a timeframe where data may be more certain. Engineers can support this strategy by instituting monitoring and measurement programs to secure climate data that will help define evolving climate conditions. This climate information is less uncertain.

Refurbishment timeframes are typically shorter than the service life of the entire engineered system. Under these conditions, the engineer may be able to access sufficient climate data that can address the issue in less detail than a full climate projection. This can reduce costs and time.

Similarly, professionals in operations, maintenance and planning functions should ensure that they allocate (or are allocated) appropriate resources to allow other professionals the scope to incorporate appropriate adaptive measures into their engineered works. Where the engineer does not have direct authority to allocate resources, they should advocate decision-makers to delegate them sufficient authority to do so.

Projects that do not include consideration of climate in their scope may seem to be less costly for initial procurement. However, projects with no scope for incorporating climate risk are likely to incur much higher costs associated with renewing non-resilient designs over the life of the system. Allocating more resources at the beginning, along with good operations and maintenance practices, can reduce or avoid substantially higher costs of repair and replacement at some unexpected time later in the service life.

Civil engineers have always built 'demand flexibility' into systems – for example, designing a bridge so that a span can be added as traffic flow increases. Now there is a need to add climate flexibility.

3.9.2 Implementing actions

The following actions can help engineers anticipate the impacts of changing climate by considering actions that address the service life of the infrastructure asset. Not all may be appropriate to the situation at hand nor is the list complete. The engineer is encouraged to give thought to and implement other actions that better manage identified risks of the service life. Any new practices or improvements should be reported to their regulator and Engineers Canada. These will be incorporated into the next edition of this model guideline.

- » During the design phase of a project, maintain a record of any reviews of climate and/or meteorological assessment conducted during the design of the engineered system
- » Identify any adjustments made to the design based on climate considerations
- » Identify the basis for any adjustments made to the design based on climate considerations

- » Identify the economic impact of changes made to design based on climate considerations
- » Identify how the adjustments address the full-service life cycle of the engineered system
- » During and after the construction phase provide as-built drawings to verify that the project was executed as designed to support ongoing operations and maintenance as well as for assessing the need for and planning of refurbishments later in the service cycle
- » During the operations and maintenance period of the project, maintain operating records of climate events that caused damage or interruption of service. Ideally this would include the routine collection of site specific climate data (e.g. through an on-site meteorological station) that will inform the design of future refurbishment or replacements
- » During refurbishment planning and design, maintain a record of any reviews of climate and/or meteorological assessment conducted during the design/plan of the refurbishment
- » Identify any adjustments made to the refurbishment design/plan based on climate considerations
- » Identify the basis for any adjustments made to the refurbishment design/plan based on climate considerations
- » Identify the economic impact of changes made to the refurbishment design/plan based on climate considerations
- » Identify how the adjustments address the full-service life cycle of the refurbishment design/plan
- » Ask the climate specialist to recommend a range of alternative methodologies for projecting climate information over the shorter timeframes used for refurbishment service cycles.
- » Develop, institute, review and/or revise operations and maintenance policies, standards, and procedures to better ensure the infrastructure asset functions at the capacity it was designed to perform, including ability to respond to loadings imposed by future changes in climate.
- » Good practices can extend service life beyond the design life, which means replacement or rehabilitation can be delayed, allowing re-allocation of human and financial resources to other priorities
- » Review and modify training and competency policies and standards on operations, maintenance, and emergency preparedness and response.

In some cases, engineers will have little choice but to armour structures against rare extreme events – for example, the 9.4-foot storm surge that Hurricane Sandy pushed into lower Manhattan in 2012. However, using a rare flood or storm as a design standard is expensive, since it may require building new structures or retrofitting existing ones with enough protective features to withstand stresses that may occur only once in a lifetime, if at all.

Designing projects so they are “safe to fail”, on the other hand, is an option that may be cheaper and more efficient. For example, a community might opt to build a dam with capacity to contain a 100-year flood, and then develop a comprehensive evacuation plan for the surrounding area in the event of a more severe flood. This strategy anticipates that the dam may not control extreme flooding, but adds other protective measures for higher levels of safety.

Flexible adaptation strategies can be retrofitted into existing facilities in stages, as climate change impacts become clear in different locations. Examples include modular seawalls that can be raised as needed; prefabricated highway bridges that can be elevated as peak flows beneath them rise; and floating intake systems at water treatment plants, designed to rise and fall as reservoir levels change. An incremental approach has fewer social and environmental impacts than building huge structures in one phase – if the operation can keep up with climate-induced changes. Flexible adaptation is a valuable alternative approach and will be appropriate in certain cases. When an engineer starts planning climate adaptation actions, the needs vary site by site according to vulnerability assessment results, analysis of alternatives and time lines for each project.

3.10 Principle # 10: Apply Risk Management Principles for Uncertainty

Use risk management to address uncertainties

Engineers should maintain a reasonable level of professional competence in risk management to assess the impact of changing climate on engineered systems where the engineer has professional responsibility. Where the engineer does not have a sufficient level of this expertise, they should ensure that their activities are reviewed with professionals that do have such expertise.

3.10.1 Amplification

Assessing the resiliency of the infrastructure starts with evaluating risks (“risk assessment”), which in a risk management context entails:

- » Identifying and defining the threat
- » Assessing the vulnerability

- » Establishing and prioritizing the risks
- » Selecting and implementing the risk treatments
- » Monitoring progress and reporting

Asset (infrastructure, buildings and facilities) risks/failures can be structural (failure of the asset or one of its components) or operational (capacity of the asset cannot accommodate the demand).

Assessing climate change impacts on professional work is, by its nature, a risk assessment process. In this work, professionals project the future climate and assign measures of the likelihood of those projected futures and the seriousness of the impacts of those changes on systems for which they are responsible. This is the very definition of risk assessment. The engineer will find further guidance on risk management approaches in the Engineers Canada Model Guide: Risk Management.

International standards on risk management are published by the International Standards Organization (ISO) in its 31000 series as follows:

1. *ISO 31000:2009, Risk management – Principles and Guidelines* provides principles, framework and a process for managing risk. It can be used by any organization regardless of its size, activity or sector.
2. *ISO/IEC 31010:2009, Risk management – Risk Assessment Techniques* focuses on risk assessment concepts, processes and the selection of risk assessment techniques.
3. *ISO Guide 73:2009, Risk management - Vocabulary* complements ISO 31000 by providing a collection of terms and definitions relating to the management of risk.

These standards are revised periodically, and engineers should ensure they are referring to the latest versions for practice guidance going forward.

With this understanding, and to address potential climate change impacts, the engineer should develop a comprehensive understanding of risk assessment techniques or consult, as appropriate, with professionals who have those skills.

Engineers Canada, recognizing this reality, developed a tool that engineers may use to aid in these assessments [4]. The Public Infrastructure Engineering Vulnerability Committee Engineering Protocol (the Protocol) guides professionals through the risk assessment process from project concept through to an evaluation of adaptation options in a manner that weighs social, environmental and economic factors. The Protocol is one of the tools and methodologies developed to help professionals assess the impact of climate change through risk assessment. Not every engineer may be conversant with risk methodologies. In such cases, the engineer is urged to consult with those that do have risk assessment expertise and be guided through a robust evaluation of their professional work.

When considering the application of risk assessment methodologies in managing the impacts of a changing climate on engineered systems, engineers must follow relevant federal and/or provincial/territorial legislation regulating how such assessments are carried out.

The focus of this guideline principle is the application of standard risk assessment techniques to the question of climate change. The engineering profession has developed a body of work that can support this activity (<https://www.pievc.ca>). It is up to the engineer to access and apply that knowledge.

3.10.2 Implementing actions

The following actions can help engineers apply climate risk management principles and practices to plan and implement adaptations to their work to accommodate the impacts of current and future climate.

Not all actions may be appropriate to the situation at hand nor is the list complete. The engineer is encouraged to give thought to and implement other actions that better manage identified risks. Any new practices or improvements should be reported to their regulator and Engineers Canada. These will be incorporated into the next edition of this national guideline.

- » First, develop competence in risk assessment
- » Establish awareness and knowledge of the range and applicability of risk assessment tools
- » Where appropriate, pursue professional development and training in risk assessment tools and approaches relevant to professional practice
- » Where the engineer does not have sufficient expertise in risk assessment, seek guidance from qualified professional practitioners that have such expertise
- » As appropriate, retain the services of professional practitioners with risk assessment expertise to advise and/or assist in the review of climate risks
- » Consider building risk assessment into all stages of the process – design, operation, maintenance, planning, procurement, management, etc.
- » Different tools will be applicable in different stages and the engineer should apprise themselves of the risk

assessment approaches that are appropriate at each stage of a project or engineering task.

- » Consult with the broad range of stakeholders/users of the engineered system to assess their overall risk tolerance levels for the system.

Risk tolerance establishes the stakeholder/owner's willingness to trade off between a certain level of risk and the costs and complexity to reduce those risks by designing to a higher safety factor.

In addition, assessing different options with stakeholders that address the economic, environmental and social trade-offs is recommended. This will achieve buy-in of all parties to the final engineering solution.

3.11 Principle # 11: Monitor legal liabilities

Be aware of potential legal liability

Engineers should be aware of any legal liability associated with reliance on historic climatic and weather information within their professional practice.

3.11.1 Amplification

Case law is presently evolving on this issue.

Engineers operate under both a professional and social license. The professional license is governed by other engineers and the regulators that license them. The social license is equally as important. The engineer should address the issues that concern the stakeholders under whose social license they are allowed to practice. In this case, if climate change is deemed to be a broad social concern, the profession neglects that issue at its peril. If engineers don't address this, they will be held accountable to a broader social group and ultimately may be sidelined as other professionals take up the task.

Engineers have always been held responsible for the effects of their works on public health and safety. With increasing understanding of the scope and impact of climate change, engineers may be held accountable for anticipating the impacts of climate change on their professional work.

Reliance on codes, standards and professional guidelines that fail to reflect an understanding of the impact of climate change may not be sufficient to reduce the liability related to managing these impacts on professional work. This is especially the case where there is an evolving understanding that historic climate information may not be reflective of future climatic conditions. With this understanding, it will be difficult for an engineer to argue that an average professional in their discipline would not have known that climate change may impact the work. The standard of reasonable practice is evolving with society's increased awareness and understanding of potential climate change impacts as well as recognition by engineering regulators to establish defensible standards of practice. This is resulting in a corresponding evolution in the engineer's obligation to evaluate those potential impacts and address them in their professional work.

Engineers have a much more detailed understanding of the codes, standards and guidelines that govern their professional practice than would a layperson. In this regard, the professional is much better placed to evaluate the implications of potential climate change impacts on climate, weather information and assumptions embedded in their professional tools. Failure to consider these implications may be construed as professional negligence and could expose the engineer to professional sanctions and/or legal action. Considering that a standard may be deficient, it follows that merely adhering to this outdated standard could be considered a breach of an engineer's standard of care. Under certain circumstances, merely designing to meet minimum code requirements may still be deemed negligent if the circumstances and the applicable standard of care dictate a design solution that clearly exceeds code.

As this is an evolving issue, it is important for the engineer and engineering regulators to remain apprised of decisions and case law governing societal expectations of reasonable professional practice. As a matter of self-interest, if for no other reason, the professional should periodically contact their regulator to determine if there have been any material changes in liability case law in this area, or if new or amended practice guidelines to reduce this risk for engineers are under development. In so doing, they will develop an appreciation of what their profession and society demands from them and take appropriate action to respond to those demands within their own professional practice.

3.11.2 Implementing actions

Engineers should take reasonable steps so that potential legal liability from their practice in general and to engineering work is understood. The following are actions engineers could undertake. Ensure that actions consider and/or adjust the engineering work to accommodate current and future climate are documented.

Not all actions may be appropriate to the situation at hand nor is the list complete. The engineer is encouraged to review these and give thought to other actions that address the need to demonstrate due diligence of the issues at hand. Such documentation will help discharge professional responsibility for dealing with this aspect of practice.

- » Consult with the regulator on any applicable case law that may apply to the general scope or responsibilities as an engineer, including projects, engineering work or tasks that may be affected by climate considerations.
 - » The regulators routinely report on disciplinary actions and will report on such cases as they arise
 - » Regulators may develop practice guidelines specific to the topic of climate or include reference to it in the context of more specific areas of practice.
- » Maintain a record of actions undertaken to address climate change issues within daily practice as appropriate or as part of the documentation of a completed task or project
- » Pursue enough additional professional training on climate change and meteorology to increase knowledge of climate science, measurement, data and definitions to enable review of climate analysis and advice provided by climate scientists and specialists.
- » As appropriate, consult with climate and meteorological specialists to inform climate change adaptation measures
- » In working papers and files, maintain written documentation of training and consultation on climate change and meteorology

4. Other Resources

In 2015, the American Society of Civil Engineers (ASCE) released a white paper providing considerable detail on adapting infrastructure and civil engineering practice to a changing climate <https://ascelibrary.org/doi/pdf/10.1061/9780784479193> . The executive summary describes the purpose and scope of this document as follows:

The purpose of the white paper is to:

- » foster understanding and transparency of analytical methods necessary to update and describe climate, including possible changes in the frequency and intensity of weather and extreme events and for planning and engineering design of the built and natural environments
- » identify (and evaluate) methods to assess impacts and vulnerabilities caused by changing climate conditions on the built and natural environments
- » promote communication of best practices in civil engineering practice for addressing uncertainties associated with changing development and conditions at the project scale, including climate, weather, extreme environments and the nature and extent of the built and natural environments”

It consists of the following sections:

- » Section 2: “Review of climate science for engineering practice,” provides an overview of the current knowledge of climate and weather science, as well as its limitations and relevance to engineering practice.
- » Section 3: “Incorporating climate science into engineering practice,” presents the challenges of incorporating climate change and weather science into engineering practice.
- » Section 4: “Civil engineering sectors,” reviews the impacts of climate change on specific sectors, including codes and standards that may be affected and recommendations for action.
- » Section 5: “Research, Development and Demonstration needs,” proposes research and other activities to advance civil engineering practices and standards to effectively address climate change impacts.
- » Section 6, “Summary, Conclusions and Recommendations,” concludes the white paper with a discussion on near-term decision making and recommendations for research, development and implementation of improved practices”.

Engineers active in planning and implementing adaptation actions are encouraged to consult this paper for the background science of climate and to gain further understanding of the issues facing engineers and what can be done to address them.

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Appendix A – Definitions

For the purposes of this guideline, the following terms and definitions apply.

Act: The applicable engineering act in the province or territory. Some acts include “geoscientists” or “geologists and geophysicists.”

Adaptation to climate change: An adjustment in natural or human systems in response to actual or expected climatic changes, which moderates harm or exploits beneficial opportunities.

Associations/ordre or constituent associations: The 12 provincial and territorial associations that regulate the practice of engineering (in Quebec, the practice of engineering) in their respective jurisdiction. Now referred to as the “Engineering Regulators”

Adverse effect: Impairment of, or damage to, the environment, human health or safety or property.

Climate: The statistics of weather events over a long period of time. The term weather is used to describe discrete events in place and time.

Climate change: The statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. [5]

Climate information: Data, projections, and any other form of climate factor/assumption/etc. In other literature this may sometimes be called climate factors or parameters.

Climate scientist: Individuals engaged in the development of, or execution of, scientific climate projections based on one or more climate models.

Climate specialist: Any individual compiling, analyzing and/or interpreting meteorological and/or climatological data, producing or interpreting weather forecasts, or any other individual that may interpret climate information. The expressions “meteorologist” or “weather forecaster” refer to those individuals that provide climate information based on measured data. In this document, use of the phrase climate specialist is inclusive of all those individuals.

Climate risk mitigation: Actions taken to reduce the level of risk associated with changing climatic conditions. These can include changes in system designs or other procedural, operational or management adaptations to reduce impacts from identified risks.

Cumulative effects: Individual effects that are incremental, additive or synergistic such that they must be considered collectively and over time, for a true measure of the total effect and associated environmental costs of an activity to be assessed.

Due diligence: The reasonable care that a person exercises under the circumstances to avoid harm to other persons, property and the environment. In professional practice, engineers must document the steps that they have undertaken to demonstrate due diligence.

Engineer: The protected title given to a person licensed to engage in the practice of engineering under the applicable engineering act in a Canadian province or territory. In Quebec, the title of such a person is “engineer” or “ingénieur”. Engineers use the designation “P.Eng.”, or in Quebec “Eng.” or “Ing.”

Engineered system: Any civil infrastructure including buildings or engineering work that interacts with or may be affected by climate.

Engineering vulnerability: The difference between an engineered system's capacity and the loads that the system is expected to have.

Green Resilience: Strategies that increase the resilience of projects to extreme weather events and climate change while decreasing the greenhouse gas emissions from the project.

Liability: Legal responsibility to another or to society, which is enforceable by civil remedy or criminal penalty.

Mitigation: Within the context of this model guideline, mitigation refers to technological change and changes in activities that reduce greenhouse gas emissions or enhance removal of greenhouse gases from the atmosphere, thereby reducing the anthropogenic emissions causing climate change.

Professional judgment: A level of competence and knowledge of technical standards obtained through many years of training and professional practice guided by practitioners with many more years of professional practice in a specific area of engineering practice. Typically, it takes four years of university, five years of practice under the guidance of licensed professionals and then many more years of professional practice as a licensed professional before the profession would deem an individual fully qualified to express independent professional judgment.

Resiliency: The ability of a system to withstand stress, adapt, recover from a crisis or disaster and move on. Resiliency is the societal benefit of collective efforts to build collective capacity and the ability to withstand stress including that caused by a changing climate.

Risk Tolerance: The amount of climate change related risk the client is willing to accept.

Stakeholder: A person or organization that is directly involved with, or affected by, a development, product, or activity or has an interest in it.

Sustainability: Ability to meet the needs of the present without compromising the ability of future generations to meet their own needs, through the balanced application of integrated planning and the combination of environmental, social, and economic decision-making processes.

Sustainable Development: Development that meets the social, economic, and environmental needs of the present without compromising the ability of future generations to meet their needs. [14]

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate, including climate variability and extremes or any other natural events or man-made activity.

Weather: Specific events that occur within a set of meteorological data. The term weather is used to describe discrete events in place and time. Unique pieces of data contribute to an overall statistical synopsis.

Endnotes

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