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WORLD FEDERATION OF
ENGINEERING ORGANIZATIONS

Global Engineering Leadership for a Sustainable Future

MODEL CODE OF PRACTICE

Climate Change Adaptation and Resilience for Engineers

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Model Code of Practice:

Climate Change Adaptation and Resilience for Engineers

Interpretive Guide

March 2026

WFEO President’s Foreword

In recent years, the global engineering community has witnessed a profound shift in how we understand and respond to climate change. In this context, adaptation and resilience are no longer optional considerations; they are essential responsibilities.

Engineers stand at the forefront of this challenge. Through the systems we design, the infrastructure we build, and the services we provide, our profession has a decisive influence on society’s ability to withstand and adapt to a changing climate. The World Federation of Engineering Organizations (WFEO) recognizes this responsibility and is committed to equipping engineers with the guidance and tools needed to act effectively and ethically.

The WFEO Model Code of Practice on Climate Change Adaptation and Resilience, represents a significant step forward in this effort. Building on earlier work, this updated document reflects the latest advancements in climate science, engineering practices, and resilience thinking. It offers both a principled framework and practical direction to support engineers in integrating climate considerations into all aspects of their work, whether in planning, design, construction, operation, or maintenance.

I commend the dedicated efforts of the Working Group on Climate Change (WGCC), its leadership, and all contributors who have brought this important document to fruition. Their work strengthens the capacity of our profession to respond to one of the defining challenges of our time.

I encourage all engineers, institutions, and stakeholders to embrace the principles outlined in this Model Code of Practice and to actively incorporate them into professional practice. By doing so, we not only safeguard the built and natural environments but also contribute meaningfully to global objectives such as the United Nations Sustainable Development Goals.

The path ahead will require innovation, collaboration, and resolve. With this guidance, the engineering community is better prepared to lead.

Er-Dr. Seng Chuan Tan
President, World Federation of Engineering Organizations (WFEO)

Message from WFEO WGCC Chair, Davide Stronati

Adaptation to our changing climate has been discussed in recent COP meetings, taking a central theme only last year at COP30 in Belem, Brazil, 2025. The same year, an increasing number of authoritative voices were announcing that we are on track to overshoot the 1.5°C Paris Agreement target, if we have not already done so.

Resilience and adaptation to climate change will take a leading role in the years to come. Discussions and decisions will be difficult because of the intrinsic uncertainties in climate projections and the financial investments required. Engineering and engineers have a central role in providing solutions and are ready to serve.

The *WFEO Model Code of Practice: Climate Change Adaptation and Resilience* for engineers with the associated *Interpretative Guide* are an essential set of documents that want to provide ethical principles as well as pragmatic guidance on equipping engineers to consider climate adaptation and resilience in their profession.

I am extremely grateful to David Lapp P.Eng. FCAE FEC IRP who led the project to update the existing Code of Practice of Climate Adaptation for Engineers, to WFEO leadership, the whole Working Group on Climate Change and Engineering and to all colleagues who provided input and feedback in their development.

I urge all engineers and engineering institutions to take an active role in advancing and considering climate adaptation and resilience as a fundamental aspect of our profession and to bring to life principles and guidelines of this WFEO Model Code of Practice on Climate Change Adaptation and Resilience.

Davide Stronati
Chair, WFEO Working Group on Climate Change (WGCC)

Message from co-author, David Lapp

It is my honor as a co-author to present this document for the use of all practicing engineers worldwide. The principles and suggested practices can be applied universally in any jurisdiction in the world. Not all will be applicable in every situation, task or project that an engineer undertakes in their everyday work. There will always be constraints imposed by project schedules, budgets or client decision-making. However, every engineer carries the responsibility to consider climate change in their work and to document the results of their considerations.

The principles and suggested actions to implement them are written to serve and protect engineers as they plan, design, construct, operate and maintain grey and green infrastructure to meet the needs of society and provide quality of life. Adopting and practicing these principles will enable engineers to contribute to the achievement of the UN Sustainable Development Goals in a meaningful and measurable way.

This document is an update to the WFEO Model Code of Practice – Principles of Climate Change Adaptation for Engineers, prepared by the WFEO Standing Committee on Engineering and the Environment and published in 2015. The updated document reflects advances in climate change adaptation practices and the incorporation of climate resilience as the key outcome of engineering adaptation practices.

Climate change can no longer be ignored by practicing engineers. It is a scientific fact and must be considered and documented. And we must take adaptation measures that substantially and materially improve the resilience of engineering works, particularly the built environment, to the impacts of extreme weather and systemic climate change. There is no excuse.

David Lapp P.Eng. FCAE FEC IRP
Member, WFEO Working Group on Climate Change (WGCC)
Former Secretary, WFEO Standing Committee on Engineering and the Environment (2007-2015)

Abstract

The WFEO Model Code of Practice – Interpretive Guide provides amplification and explanation to engineers and national engineering organizations to interpret and implement the 15 principles of climate change adaptation and resilience at a practical level. It is intended for all practicing engineers worldwide, including those who are registered with one or more of the national country-level engineering organizations that are members of the World Federation of Engineering Organizations (WFEO). The Model Code of Practice has been prepared to complement the WFEO Model Code of Ethics for Engineers and the WFEO Model Code of Practice for Sustainable Development and Environmental Stewardship. Both of these documents are available on the WFEO website (www.wfeo.org)

The Model Code of Practice - Climate Change Adaptation and Resilience for Engineers (Model Code) supports the WFEO vision of the global engineering profession supporting the achievement of the United Nations Sustainable Development Goals (SDGs). Climate resilient infrastructure supports and improves quality of life, economic activity as well as employment, social development and environmental sustainability. These are the positive outcomes of achieving the UN SDGs and our changing climate is a common and significant obstacle to achieving any of the SDGs. Therefore, engineers working to adapt infrastructure to withstand climate change impacts from extreme weather events and slower on-setting changes (e.g. sea level rise) to build and improve infrastructure climate resilience contributes significantly to the achievement of the SDGs.

The Model Code reflects the use of engineers' judgement using the 'Should, May, Shall' terminology.[1]

The word *should* is used 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 guide (*may* equals *is permitted*).

Governing bodies for engineers who wish to adopt a version of the Model Code 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*) to effectively implement in their jurisdiction.

Governing bodies for engineers who wish to reference or recommend, instead of adopting, the Model Code in whole or in part, are advised to communicate that the Model Code is voluntary i.e. it is not binding on their organization or its individual engineers unless they wish to make it so.

National bodies who register but do not necessarily govern engineers may wish to adopt or endorse this Model Code of Practice voluntarily as a best or preferred practice to assist their members.

This document provides amplification to the WFEO Model Code of Practice - Climate Adaptation and Resilience for Engineers - Summary, published at the same time as this Interpretive Guide.

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[1] The 'Should, May, Shall' terminology has been generalized from **National Guideline on Environment and Sustainability**, Engineers Canada (2006). http://www.engineerscanada.ca/e/pu_guidelines.cfm

Acknowledgments

The Model Code of Practice[2] – Summary and this accompanying Interpretive Guide were developed by the WFEO Working Group on Climate Change. The Summary was approved by the WFEO General Assembly in October 2025 and published in November 2025 for distribution to national and international members and placement on the WFEO website (www.wfeo.org). The Interpretive Guide was approved in March 2026, placed on the WFEO website and distributed to members of WFEO.

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[2] This document is a revision and update to the WFEO Model Code of Practice – Principles of Climate Adaptation for Engineers, published in December 2015.

Summary

The climate is changing. Historical climatic design data is becoming less representative of the future climate. Many future climate risks may be significantly underestimated. Engineers cannot assume that the future will be like the past. Historical climate trends cannot be simply projected into the future as a basis for engineering planning, design, operations and maintenance of infrastructure. The climate is already changing and will continue to change in significant ways over the full useful life of facilities designed today, threatening to undermine capital investments and impede critical services if they are not designed for future conditions.

Almost every action, be it turning on a tap or a light, buying food, driving down a road or crossing a bridge, relies on engineered systems, which is to say infrastructure, for its successful completion. Infrastructure that is in line with the decisions taken at the historic 2015 Paris Conference of Parties (COP) on climate change and is supportive of the UN's Sustainable Development Goals (SDGs) will play a vital role in supporting daily life and impacting people of all economic and social backgrounds.

The importance of building resilient infrastructure cannot be overstated, especially for developing countries that may lack adequate capacity, advanced technology, and financial resources to facilitate prompt response to, and recovery from, disasters.

The World Federation of Engineering Organizations (WFEO) and its national and international members are committed to raising awareness about the potential impacts of the changing climate as these relate to engineering of existing and future civil infrastructure and buildings. Engineers are encouraged to keep themselves informed about the changing climate and consider potential impacts on their professional activities.

Both climate change and the design challenge it poses to engineers are a moving target. New generally accepted engineering practices for responding to these challenges have not become established or incorporated into the standard of care. However, new practices—such as client risk communications, use of location-specific climate modelling or projection tools, and engaging consulting climate scientists to inform design conditions—are emerging to varying degrees and some may become "generally accepted" over time.

The Model Code of Practice is provided as guidance to engineers to consider the implications of climate change in their professional practice and that they create a clear record of the outcomes of those considerations. It consists of fifteen principles that constitute the scope of professional practice for engineers to initiate climate change adaptation and resilience actions, particularly for civil infrastructure and buildings. The principles are summarized into three categories:

A. Ethical and Professional Practice and Climate
B. Integrate Climate and Climate-Related Information
C. Engineering Practice Guidance

The 15 Principles are listed on the following page.

The 15 Principles for Climate Change Adaptation and Resilience

A. ETHICAL AND PROFESSIONAL PRACTICE AND CLIMATE

Principle 1: Adopt Climate Considerations into Practice

Principle 2: Exercise ethical leadership

Principle 3: Respect human rights and ensure solutions do not disproportionately affect marginalized or vulnerable groups

Principle 4: Exercise engineering judgment

Principle 5: Exercise precautionary measures considering climate uncertainty

Principle 6: Be aware of potential legal liability

B. INTEGRATE CLIMATE AND CLIMATE-RELATED INFORMATION

Principle 7: Interpret and specify climate information

Principle 8: Review the adequacy and application of locally applicable codes, standards and guidelines

C. ENGINEERING PRACTICE GUIDANCE

Principle 9: Work with multi-disciplinary and multi-stakeholder teams

Principle 10: Plan for the infrastructure service life (life cycle)

Principle 11: Use risk management to pro-actively address climate uncertainties

Principle 12: Enhance the climate resilience of infrastructures and engineered systems

Principle 13: Design and implement solutions, including nature-based, that consider long-term environmental, economic, and social impacts

Principle 14: Use effective language and communicate decisions clearly

Principle 15: Engage in lifelong learning and ongoing engagement to stay current with evolving climate science, and climate technologies, standards, tools and methods

The principles support sound professional judgment for this element of engineering practice. Adapting to climate change and achieving climate resiliency provides beneficial opportunities to save money, enhance operational reliability and recovery from extreme weather events as well as protecting public health, safety and welfare.

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1. Introduction

1.1. Background

The primary duty of engineers is 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. Engineering is on the front line in the provision of infrastructure to society. Infrastructure is greatly impacted by climate. For this reason, engineers have a significant role to play in addressing climate change issues and incorporating them into engineering practice.

Engineers have a wide diversity of occupations and responsibilities. Many are involved in different types of economic and product development, which occur in a cost effective, socially and environmentally responsible manner. Engineers develop new projects and public infrastructure and keep existing facilities operating effectively. 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 as a team where they are involved and must collaborate with other specialists in multi-disciplinary teams. An individual may or may not have control of, or be solely responsible for, a particular project. Regardless of the nature of their contributions, professional engineers should always pay heed to 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 practicing in accordance with the code of ethics of the association in which they are licensed or registered, provincial and national 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 should be encouraged and 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 climate change.

The current state of scientific knowledge indicates that the climate is changing and will continue to change. 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 (IPCC)). 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, in combination with social vulnerabilities and exposure to risks can produce climate-related disasters[3].

The IPCC in its Sixth Assessment Report – Summary for Policymakers: Impacts, Adaptation and Vulnerability (2022) notes that climate change impacts and risks are becoming increasingly complex and more difficult to manage. Multiple climate hazards will occur simultaneously, and multiple climatic and

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[3] IPCC Press Release. http://ipcc-wg2.gov/SREX/images/uploads/IPCC_Press_Release_SREX.pdf

non-climatic risks will interact resulting in compounding overall risk and risks cascading across sectors and regions. Infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events, with resulting economic losses, disruptions of services and impacts to well-being (B1.5).

Changing climate conditions, particularly weather patterns that deviate from historical climate ranges, may adversely affect the integrity of the design, operation, maintenance and management of engineered systems, particularly civil infrastructure and buildings and the engineered systems that support their operation. It is vital, therefore, for engineers to consider how those systems might be adjusted to appropriately anticipate the impact of changing climate conditions, especially at the planning and design stages. In some cases, changing climate conditions result in impacts that pose un-accounted for risks.

Experience has shown that extreme weather events often lead to substantial damage and sometimes loss of infrastructure, requiring the expenditure of considerable financial and human resources for repair or replacement. The disruption of service from damaged or destroyed infrastructure negatively impacts the economic and social structures of societies that depend on infrastructure – hence the impact on public welfare. These impacts occur at local, regional, national and international levels.

Increasingly, governments worldwide, at national and local levels are creating climate change plans to respond to the climate threat by including provisions for adaptation and resiliency. Engineers and their employers and professional organizations need to work closely with governments and funding channels for engineering projects that enable climate resilience to support their work in areas like infrastructure resilience, flood control, and sustainable urban planning.

For these reasons engineers need to consider potential climate impacts on infrastructure not only to assure public health and safety, but also to minimize the economic and social impacts that adversely affect public welfare in the short term as well as in the long term. This requires that engineering practice encompasses not only safety considerations, but also better infrastructure durability, reliability and continued service over its long-life cycle (from multiple decades to hundreds of years) in a non-stationary and increasingly extreme climate.

Improving resilience to climate change is now a professional and ethical responsibility for engineers within their scope of practice and to the extent of authority delegated to them by infrastructure owners and operators. Further, engineers have a professional and ethical responsibility to advise decision-makers of the adverse impacts of climate change and build resilience through engineering solutions. Engineering design should account for an expanded range of climate in the operating environments intended for their designs.

It is incumbent upon the engineering profession to encourage and inform their engineers to advance means and practices to address the impacts of climate change on engineering works. Engineers in practice can contribute to this goal in two ways:

First, engineers who design public facilities and infrastructure, and those who retain them, should recognize the need to accommodate the changing climate at the local level to protect public health, safety and welfare.

Second, engineers should contribute their expertise in furthering the level of awareness of this issue and communicating the risks and impacts arising from more intense and severe weather events.

The Model Code of Practice Summary and this Interpretive Guide reflect advances in scientific understanding of climate and future projections, the availability of national and international standards, and the accepted notion of extending climate adaptation to climate resilience that contributes to advancing engineering practice. This includes the increased availability of, and experiences with, new and updated tools and processes for engineers and other infrastructure practitioners enabling support to the design, construction, operation, and maintenance and decommissioning of climate resilient infrastructure.

Of note is achieving the goal of climate resiliency to enable not only increased resistance to extreme weather events, but also the ability to repair and recover as quickly as possible for the engineered system to resume operational service.

This document is an update to the original document - Principles of Climate Change Adaptation for Engineers published in December 2015 by WFEO. The update includes additional principles that reflect evolving engineering practice and improved scientific understanding of future climate since that time as well as the responsibility to engage in lifelong learning and continuing engagement in this evolving area of practice.

The Model Code of Practice comprises two documents:

- The first is a three-page Summary, listing the principles and practices of climate adaptation and resilience with a brief explanation – suitable for quick reference as well as communication of the principles and practices at a high level to fellow engineers or outside stakeholders interested to know how engineers are addressing the climate change issue. The Model Code is advisory in nature and intent.

- The second document, Interpretive Guide, provides additional explanation and rationale for the 15 principles and practices and provides examples and ways of thinking to implement these in engineering practice.

The Interpretive Guide provides definitions for key terms and concepts applied in assessing and dealing with climate-induced risks to achieve climate resilient infrastructure. Climate risk and vulnerability consideration leads to informed engineering decisions that adapt the built environment (civil infrastructure and buildings) to our changing climate, achieving climate resilience over the service cycle. Furthermore, climate consideration requires full transparency and disclosure of evidence and rationale that supports engineering judgment.

The Interpretive Guide provides amplification and commentary on each of the fifteen principles. It summarizes how an engineer should practice engineering in a manner that anticipates the effects of a changing climate on engineered systems. The application of the Code will always be a matter of professional judgment. Application of its principles may require engineers to balance competing interests, an essential element of the practice of engineering. And not all the 15 principles can or should be applied to any given situation - it depends on project constraints and operational limitations which may limit or constrain climate consideration.

Legislation and regulation in the field of climate change adaptation is limited but evolving. Engineers are advised to determine local regulatory and legal requirements for the location of their project.

In the absence of regulation and guidance in local, regional or national jurisdictions, engineers need guidance on incorporating climate change considerations in their professional work. This Model Code of Practice - Climate Change Adaptation and Resiliency for Engineers fills this gap.

1.2. Limitations

While engineers should advise their clients or employers regarding matters related to climate change adaptation and resilience that may impact on the professional activities for which they are responsible, they are generally not able to guarantee that the appropriate action is taken.

Engineers are not expected to assume responsibility for considering the implications of climate change adaptation and resilience in engineered systems beyond their scope of authority. For example, an engineer is not responsible for implementing solutions that address climate change adaptation and improved resiliency if the engineer's scope of authority generally limits him or her from doing so. The scope of authority is provided by the client or the employer of the engineer.

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

This Model Code of Practice is the result of reviews of documents from various sources and reviews, and it represents the best scientific knowledge and engineering practice experience up to the time of publication using publicly available information. Any feedback, comments and suggestions are welcomed at any time that will be used to continually improve the documents and keep the Model Code up to date.

1.3. Scope and Purpose

The Model Code of Practice, through amplification and commentary of each of the fifteen principles, summarizes how an engineer can and should strive to influence decisions in a manner that anticipates the effects of a changing climate on engineered systems. The application of this guideline will always be a matter of professional judgment. Its application may require engineers to balance competing interests and project specific constraints, essential elements of the practice of engineering and the application of engineering judgment.

It is intended to inform, to provide guidance, and to encourage engineers acting as employees, clients or consultants as well as consulting engineering firms that participate in infrastructure planning, design, construction, operations and/or maintenance services. All engineers are encouraged to be proactive in anticipating and managing the impacts and consequences of a changing climate on engineered systems, particularly civil infrastructure and building works, through their entire life or service cycle.

In addition, the Model Code informs the general public, governments and international bodies like the UNFCCC and various UN bodies as well as International Financial Institutions such as the World Bank of the role and responsibilities engineers can and will assume to contribute to climate-resilient infrastructure. WFEO and its national and international engineering organization members are encouraged to disseminate and build awareness of the Model Code Summary and Interpretive Guide to these organizations.

The document provides an understanding and acceptance of definitions for key terms and concepts applied in assessing climate-induced risks.

1.4. 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 the practice of climate adaptation and climate resilience evolves, new definitions will be added as necessary and issued as addendums.

A fuller Glossary of Terms covering climate science, adaptation and mitigation and related topics is available through the International Panel on Climate Change (IPCC) website listed in the bibliography and references at the end of this document.

2. Engineering, Climate Change Adaptation and Climate Resilience

In 2001, the national members of WFEO agreed to an international code of ethics :

> *To hold paramount the safety, health and welfare of the public including people with activity limitations, and the protection of both the natural and the built environments in accordance with the Principles of Sustainable Development*

Furthermore:

> *Be aware of and make clients and employers 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 foundation for a method of addressing and 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. The changing climate and the increasing occurrence of weather events once considered extreme present many challenges. Primary among these is the reality of designing projects in the face of changing climate conditions which may bear directly on the function and endurance of built systems.

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, we define reasonable in terms of the standard of care. 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.

The standard of care is a reasonableness test. It asks whether the engineer acted with the care and skill ordinarily exercised by members of the engineering profession under similar circumstances, at the same time and place.

It is notable that this standard does not require that the engineer 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. 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.

This understanding is generally accepted within a broader societal context in the layperson's belief that the climate is changing. This guideline outlines principles for adjusting normal engineering practice to mitigate such risks.

The word reasonable is used throughout this document. This language is used in the context of the above commentary. The guidelines offer a series of objectives for professional engineers to incorporate in their practice to reflect the 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 document provides guidance on how to reasonably address the concern given the current level of understanding of the issue.

3. Interpretative Guidance on Model Code of Practice

The principles that comprise the Model Code of Practice are divided into three categories.

A. Ethical and Professional Practice and Climate
B. Integrate Climate and Climate-Related Information
C. Engineering Practice Guidance

Within each category are principles that engineers should apply within their professional practice.

The fifteen principles constitute the professional practice required to initiate climate change adaptation and resiliency actions.

Each principle is described in three parts:

1. A description of the principle.
2. An amplification of the principle; and
3. Suggested implementation actions that address the guideline principle.
4. Examples of actions for engineers to address these concerns.
5. Engineers may identify additional actions or may decide that only a subset of the suggested actions is necessary or appropriate.

Not all principles apply to a given situation or project. The engineer is advised to use discretion in applying the principles appropriately and reasonably in accordance with their engineering judgement and project constraints.

3.1. CATEGORY A: Ethical and Professional Practice and Climate

3.1.1. Principle # 1: Adopt Climate Considerations into Practice

Engineers should integrate an understanding of the impacts and risks of changing climate and extreme weather events on infrastructure resilience into the design, construction, operation, maintenance, decommissioning, planning and procurement activities for which they are professionally responsible. Refer to and consider recognized national and international existing guidelines on climate change and sustainable infrastructure.

Amplification

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

To this end, engineers engaged in each sector of the economy should integrate climate change 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 rest of the project team and project decision-makers, these practitioners may not be able to gain approval for adaptation and resiliency measures that 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. These individuals establish the environment within which other professionals, including engineers, must function. They should establish organizational objectives that incorporate the recognition that climate change may demand professional practice that may exceed codes, standards and professional guidelines. Accepting this, the policy environment would furthermore be amenable to reasonable increases in project costs that address climate adaptation objectives. By establishing this environment, the decision-maker enables their subordinates and contractors to take reasonable actions to address climate change in their professional work.

Similarly, those professionals that work in procurement positions, setting project specifications and reviewing competitive proposals should include requesting consideration of current and future climate impacts 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 will likely not lead to life cycle cost avoidance. The costs of future damage and disruption of service may far outweigh the incremental costs of anticipating climate change. Engineers engaged in, and advising others involved in 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 and support workers in operation and maintenance functions see the impact of extreme weather events as well as creeping climate change daily. They should not only operate systems for which they are responsible sustainably, but also, should clearly identify the impacts to which they are responding to other professionals and managers/owners. Professionals may have the capacity to incorporate appropriate changes in policies and procedures as well as their professional work, codes, standards and guidelines to reduce the impacts in the longer term.

Engineers rely on the work of other engineers, related professions and technical staff to support their work. It is critical that the profession creates an environment where climate change adaptation and resilience is not only an accepted part of daily practice, but also, a guiding principle of professional practice.

Given the scientific certainty of changing climate and the empirical evidence of increased frequency and severity of extreme weather events, consideration of climate change has become an imperative for engineers in their practice and the standard of care and due diligence.

Implementing Actions

The following actions can help engineers integrate the consideration of, and adaptation to climate into their scope of practice. This will vary widely across disciplines and the nature of the engineering works or task 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 physical infrastructure and supporting systems should be aware of the climate impacts and always consider if and how their work could be affected by current and future climate.

Climate consideration for infrastructure and buildings extends to the engineered systems that support their integrity and operation to provide the required services reliably over the service life. This includes, but is not limited to, mechanical and electrical support and supply systems, communication and IT, water quality and supply, road and transport systems that integrate with and support the infrastructure operation, its safety, reliability and durability as well as emergency response and recovery in the event of climate impact.

In short, virtually all disciplines and functions of engineering need to consider current and future climate, and further, to document these considerations and resulting decisions and actions.

As a first step, engineers should consult potentially applicable national and international standards as well as practice guidelines on climate change and sustainable infrastructure. The bibliography at the end of this document provides a partial but not exhaustive listing of such resources. These will provide additional references on specific topics, types of infrastructure and climate impacts to provide more detail.

To date, there is no set of climate-focused design practices that can reasonably be termed “standard” or “generally accepted” among engineers. But these are expected to emerge in the coming years so engineers should keep a watching brief for such documents

For designers, the need to incorporate climate change considerations into the work can be realized through the following actions:

1. Listing the climate change predictions and potential impacts for the area where your project is located;
2. Discussing and documenting the aspects of the project the engineer believes could be impacted;
3. Detailing and documenting what has been done in the design to mitigate those impacts; and
4. Detailing and documenting what additional/revised O&M and inspection procedures are recommended over the design-life of your project.

All engineering disciplines should use professional judgment to modify the above noted actions to address the specific job or circumstance, particularly in the context of project constraints such as budget and schedule.

It is suggested that explicit professional accountability for climate risk disclosure and public reporting be implemented in jurisdictions where engineering is regulated or as a requirement in specification. Engineers should be aware of and be prepared to provide such documentation during a project or practice declaration. Going further, lack of climate consideration by an engineer may be considered professional misconduct and may result in sanctions.

Consideration of our changing climate for infrastructure climate resilience extends to engineers involved in specification and procurement. Procurement decisions strongly influence long-term resilience outcomes. A key strategy is embedding climate-resilient procurement standards emphasizing lifecycle performance and co-benefits beyond lowest upfront cost. This assures climate consideration and informed decision-making.

The following additional actions are suggested as good practices. Not all of these 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 their national body and the WFEO. These will be incorporated into addendums to this model code of practice.

1. Maintain a record of actions undertaken within daily practice that facilitate addressing climate change issues
2. As appropriate, pursue education and training on climate change and meteorology to provide a scientific grounding on the subject matter that forms a basis for climate change adaptation actions
3. If an engineer is responsible for specifying engineering work, the specification should explicitly include consideration of climate
    a. Consider the long-term sustainability of the infrastructure
    b. In procurement, allow margins (cost and schedule) to accommodate climate adaptation measures
    c. In management, be receptive to recommendations that address climate risk
4. Review operations, maintenance and management procedures and practices and specify additions or modifications that specifically address future climate risks
5. Consider using approaches that balance economic, environment and social considerations in recommending and implementing adaptation and resilience measures.
6. Explicitly identify the requirements for identifying climate adaptation and resiliency measures in contracted engineering work and reward proposals that include such recommendations.
7. In defining environmental impact assessment terms and conditions, include climate change implications of the proposed project.

3.1.2. Principle # 2: Exercise ethical leadership

Engineers should act as ethical leaders to minimize harm caused by climate change, acting with diligence to address climate impacts and ensuring their actions promote sustainability, respect environmental limits and the needs of future generations.

Amplification

Climate change clearly endangers public health and environmental integrity. Engineers have an ethical duty and affirmative obligation to anticipate, prevent and mitigate those harms. Public safety, health and welfare necessarily include future generations not just current clients or stakeholders. This future facing lens aligns closely with all the UN Sustainable Development Goals.

Simply meeting current legal requirements while contributing to future climate risk violates the engineer's duty to protect public welfare and the environment. The business-as-usual pathway is hard to justify against the engineer code of ethics.

Engineers are known to have and adhere to a high level of ethical practice that is free from corruption or undue influence. Engineers should remain steadfast in their pursuit of climate adaptation and nature-based solutions to achieve improved climate resilience for the civil infrastructure and buildings and support systems in which they are involved.

Furthermore, engineers must prevent personal bias from distorting their statements or actions around climate change. They must temper their advocacy with respect to, and deference to specialized knowledge and avoid misplacing their authority.

Implementing Actions

Engineers should periodically review the WFEO Code of Ethics as well as the Code of Ethics published by their national engineering body to remind themselves of the high principles of ethical behavior and thinking that are the foundation and basis for incorporating climate adaptation and resilience into their professional practice.

This review could include finding examples of such behavior in projects through engineering reports or conversations with the engineers involved.

An important element of practice is the proper and appropriate specification of design and operational requirements, proper maintenance as well as anticipating future uses over the life cycle that may require rehabilitation or renovation. This extends into procurement and construction phases as well as the on-going operation and maintenance.

As part of an engineer's ethical leadership, integrate measurable climate-resilient infrastructure service levels for vulnerable populations to ensure equity and accessibility. Ethical leadership in climate change adaptation and resilience can be demonstrated through measurable service continuity outcomes for vulnerable groups.

It is incumbent on engineers responding to or working on project specification and procurement phases to evaluate the extent to which climate change is considered, and where there are gaps, document these with recommendations on changes in writing to the appropriate authorities. This upholds the ethical principle of an engineer's duty to report.

Engineers involved in any phase of a project should always anticipate current and future climate impacts from extreme weather events by planning and instituting climate-resilient designs, policies and procedures. Choosing the status quo in the face of clear climate risk conflicts with the Code of Ethics highest principles.

Furthermore, national engineering organizations and engineering regulators should introduce explicit accountability on their engineers for climate risk disclosure and public reporting within professional ethics. Such transparency reinforces trust and informed decision-making

3.1.3. Principle #3: Respect human rights and ensure solutions do not disproportionately affect marginalized or vulnerable groups

Consider how climate adaptation and resilience projects affect different social groups and ensure that solutions are equitable and just, with a focus on inclusivity. Ensure inclusive decision-making by actively involving women and minorities in the design and implementation of climate change adaptation and resilience strategies.

Amplification

Climate change is a human rights issue, threatening rights to life, health, food and housing and disproportionately affecting lower income countries and marginalized communities globally. It threatens the effective enjoyment and extent of human rights including those to life, water and sanitation, food, health, education and housing – key components addressed in the UN SDGs. The impacts are disproportionate across countries and regions of the world (e.g. low-lying countries, arid regions) and are more severe for vulnerable populations who have limited means to adapt to climate change impacts.

It is important for engineers to engage with the local population, indigenous groups and other stakeholders in assessing and defining climate risks and consulting on equitable and viable solutions. This enhances legitimacy of the process, adds contextual relevance, and contributes to long-term climate resilience of the infrastructure and the community it serves.

Successfully addressing human rights requires suitable, reliable and sustainable civil infrastructure and buildings and their associated engineering support systems. Engineers have a vital role in designing, constructing and sustainably operating and maintaining infrastructures to withstand climate impacts with minimized disruption and ability to repair (or if necessary, replace) to enable these systems to continue their service to society.

Engineers can contribute solutions to mitigate negative and accentuate positive climate impacts through their work on civil infrastructure and buildings. Engineers have an ethical and professional responsibility to consider climate impacts and develop equitable solutions to address inequities, needs and concerns within the limits of their authority.

Implementing Actions

Engineers should work to include the voices of marginalized or vulnerable groups to completely understand the infrastructure needs of the local population and take these views into account in their work.

Some actions and considerations include:

1. Develop and use an equitable and rights-based approach to design projects to protect vulnerable communities from disproportionate impacts of climate change
2. Promote inclusive co-production with communities, incorporating indigenous and local knowledge through participatory design processes.
3. Focus on equity, free, prior and informed consent and use risk-based approaches that include potentially affected groups to define and rate climate risks and societal impacts
4. Make sure adaptation and resilience measures do not exacerbate existing inequalities or leave vulnerable populations behind
5. Enhance the climate resilience of critical infrastructure systems such as water supply, sanitation and transportation in vulnerable or marginalized areas
6. Engage in emergency preparedness and planning by contributing expertise and local knowledge, working with local authorities to strengthen emergency services
7. Ensure no human rights are infringed upon in the pursuit of climate adaptation and resilience goals.

3.1.4. Principle #4: Exercise Engineering Judgment

Consider the implications of climate change for each project, including adjustments to codes, standards and regulations as needed to meet the needs for climate resilience and create a clear record of the outcomes of those considerations. Prioritize sustainable solutions that protect natural resources, minimize waste, and reduce the carbon footprint, while ensuring future generations can benefit from a healthy environment.

A reasonable standard of professional judgment should be applied in order that changing climate conditions are considered within their professional practice and these should be formally documented.

Amplification

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 ensure 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 and buildings, the factors of safety will be higher if the following are not present:

1. High quality and consistency of materials, construction, maintenance and inspection
2. Good control or knowledge of the actual loads and environment over the life cycle e.g. climate loads
3. 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 is 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 outweigh the “cost” of implementing either fail-safe or safe-life designs. “Cost” of failure may include:

1. Physical harm to people or the environment;
2. Loss of, or damage to property or equipment;
3. Loss of productivity, reduced level of service or use of the failed “system” or device;
4. Damaged reputation; or
5. 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:

1. Increased expense and time for design and testing;
2. Increased construction costs; or

3. Decreased infrastructure 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. By virtue of the professional's training and experience, they are expected to apply a high level of expertise to issues that affect their professional practice. Engineers 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 should also be sensitive to the potential for changing climate conditions and appropriately apply these sensitivities to their professional practice. 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.

This model code of practice should not be interpreted to mean that an engineer should become an expert on weather and climate issues. Rather, the expectation is that engineers should, as part of their normal practice, determine where climate information is embedded in codes, standards and assumptions and evaluate how the information is applied in their professional work.

Where climate information is embedded in their professional work, they should challenge the information to assess if changing climate conditions might affect the information leading to a wider spectrum of operating environments that could lead to unanticipated outcomes from their engineering work. As a best practice, the engineer should document that they have undertaken this analysis and the outcomes to document the basis for their engineering judgment. As part of this documentation, the engineer should outline their rationale for:

1. Not adjusting climate information embedded in their work;
2. Changes that they may have made; and
3. Any other factor that may have been considered includes, but not limited to, the results of their consultations with outside experts on the climate change issues affecting their work.

The overall intent of this principle is that engineers should consider the implications of climate change on their professional practice and that they create a clear record of the outcomes of those considerations to document their engineering judgment. Documentation strengthens accountability and professional defensibility.

Implementing Actions

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

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 lifetime. 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:

1. Develop a checklist of climate parameters with potential to impact performance of design
2. Develop a checklist of climate parameters and operations/maintenance processes that may affect resiliency to climate events
3. Apply ethical decision frameworks under uncertainty and transparently document assumptions, decision triggers, and precautionary measures and document results.
4. 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.
5. 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.
6. If any changes to climate information embedded in the work were identified and the rationale for making or not making the changes;
7. Assumptions and methods used in the design of the engineering work to account for changes in the climate and potential mode(s) of failure;
8. Changes made or recommended to assure a level of resiliency of the design, operations and maintenance;
9. Any other factor that may have been considered including but not limited to the results of consultations with outside experts on climate change issues affecting the work; and
10. The date of the review.
11. The engineer responsible for engineering activity should sign the accompanying memo

As knowledge of the nature, extent, and range of reasonably foreseeable climate conditions evolves, it is anticipated that more formalized design practices, processes, and technology will develop over time in response to this emerging information and experience.

The nature and extent of their deployment for any given project will depend on factors such as project location, anticipated service life, and criticality of function, along with the client's desire to explore, fund, and implement climate-related design investigations and solutions.

3.1.5. Principle #5: Exercise precautionary measures considering climate uncertainty

In the face of uncertainty about climate change impacts, take a precautionary approach, prioritizing prevention and minimizing potential harm. Implement proactive risk mitigation and climate resilience measures where there are threats of serious climate related damage or destruction even in cases where there are unavailable, scientifically inadequate or highly uncertain climate data or projections.

Amplification

Our future climate is uncertain. The intensity, duration and frequency of extreme weather events is expected to increase on all counts and in most geographic locations in our world. The challenge for engineers in design, operations and maintenance functions is when and to what extent extreme weather events will impact the infrastructures for which they have responsibility. Knowing that such events are likely over the long service life of civil infrastructure and buildings drives the need for engineers involved to take precautionary measures in their work.

Acting in advance of potential and future climate impacts is rooted in the Precautionary Principle which dictates that action should be taken to prevent environmental harm even when scientific certainty about nature, occurrence and consequences of the harm is lacking.

The precautionary principle encourages a basic no-regret approach to help determine if an action should or should not be undertaken when the associated risks are not known with full certainty. This can be difficult to interpret however and can be used to suggest that the precautionary principle either does not apply but demands certainty that cannot be had, or that measures that do not benefit the client should not be taken.

Engineers are often employed for their ability to deal with uncertainty. Problem definition and constraint identification allow costs and benefits to be evaluated and projects to move forward. The use of the precautionary principle can help this process. Engineers should be wary, however, that the precautionary principle can be misused or even abused.

A more useful interpretation of the precautionary principle that goes beyond the no-regrets approach by including costs is that of Principle #15 of the United Nations 2012 Rio Declaration:

> "*In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*."

The Rio Declaration definition of the precautionary principle may be scaled to the ability of practitioners to apply it. Its application is recommended to avoid other self-serving definitions that might be used to circumvent accountability and responsibility.

The uncertainty of future climate and its impacts on civil infrastructure and buildings suggests a precautionary approach to reduce and at best prevent loss and damage, like the notion of preventing environmental degradation as referred to in the Rio Declaration. Some things can be done to adapt infrastructure to improve its resiliency to withstand future extreme weather impacts projected for our future climate.

Implementing Actions

Assessing risks due to uncertainties or incomplete scientific information informs decisions on actions is a precaution to potential impacts. Uncertainties in scientific data or incomplete evidence of adverse impacts can be addressed through the proven process of risk management. This includes assessing risks, developing mitigation strategies, communicating the risks and strategies to stakeholders and implementing accepted mitigative actions.

Initially, engineers can employ the precautionary principle to recommend actions that have little or no cost, and that can help protect, restore or even improve the environment and the climate resilience of civil infrastructure, buildings and their support systems. These are often referred to as low or no regrets actions.

A risk assessment/risk management methodology can be employed to identify potential concerns and appropriate measures to deal with them. Developing an inventory of infrastructure and its components that might be vulnerable to the impacts of climate change is the first step to identify potential risks and possible mitigation measures. The inventory could be developed for asset management purposes and thus add value whether climate change proves to have a significant negative effect on any infrastructure.

A risk assessment or asset management approach enables planning and implementation of precautionary measures. The following is a recommended series of steps engineers can undertake within project constraints (e.g. costs and scheduling):

1. Assess climate risks in advance to recommend actions that protect, restore or improve the environment and the sustainability of the infrastructure and its components over their service life.
2. Establish a level of climate risk tolerance the infrastructure owner or operator is willing to accept to set constraints for precautionary measures
3. Ensure “no” or “low regret” actions that are precautionary are not excessive and lead to unnecessary expense or schedule delay for limited benefit or risk reduction. Determine through risk assessment the potential impacts and liabilities of specific actions or not taking specific actions.
4. Provide the decision-maker with a clear statement of the potential actions required to reduce risks by improving climate resilience, facilitating quicker repair and rehabilitation should loss or damage occur and, if possible, improving the environment that may be impacted as well as respecting local needs and concerns.

3.1.6. Principle #6: Be aware of potential legal liability

Take reasonable steps so that potential legal liability from their practice in general and to particular engineering work as it relates to climate consideration is understood. Take actions that incorporate climate considerations in work for civil infrastructure and buildings and document such considerations to ensure there is a written record available in the event of litigation.

Amplification

Engineers operate under both a professional and social license. Social license is equally 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 work on public health and safety. With increasing understanding of the scope and impact of climate change, professionals may be held accountable for anticipating the social impacts of climate change on their professional work.

The standard of care is one legal standard in some jurisdictions such as the United States and Canada by which the performance of engineers and other professionals are judged. Any claim against an engineer for negligence requires proof of four things: (1) there must be a professional duty owed by the engineer to the party bringing the claim; (2) the engineer must have breached that duty; (3) that breach must be the legal cause of harm to the party bringing the claim; and (4) the party bringing the claim must have incurred damages. The standard of care determines whether an engineer satisfied or breached their professional duty.

The standard of care is inherently flexible and dynamic. It requires an engineer to exercise the care and skill ordinarily used by members of the same engineering discipline practicing under similar circumstances at the same time and in the same locality. In other words, an engineer should act in accordance with generally accepted practices existing at the time and place where the services are performed.

This standard is well suited to the issue of climate change because it considers both the time and place of the performance of the services. What constitutes "generally accepted practices" is not static; engineering practices adapt over time to changing factors, conditions and technology.

Foreseeability of harm is a key area of inquiry in determining whether an engineer may have breached their professional duty. As extreme weather events become more frequent and severe, questions of whether such events were reasonably foreseeable will become increasingly important in determining whether an engineer has met the duty owed under the standard of care. However, foreseeability must be evaluated considering how reasonable the engineer's knowledge is, and not that of a climate scientist.

Reliance on codes, standards and professional guidelines that fail to reflect an understanding of the impact of climate change may not be sufficient to mitigate potential liability on professional work. This is especially the case where there is an understanding that historic climate information is likely not reflective of future climatic conditions. With this understanding, it may be difficult for an engineer to argue that an average professional in their discipline would not have known that climate change might impact the work. The standard of reasonable care is evolving with society's increased awareness and understanding of potential climate change impacts, resulting in a corresponding evolution in the professional'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 engineer 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 professional engineer to professional sanctions and/or legal action.

If the applicable standard of care reflects an understanding that a technical standard may be deficient it follows that merely adhering to this outdated standard could be a breach of a professional 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 to remain apprised of decisions and case law in their country of work governing societal expectations of reasonable professional care and practice. As a matter of self-interest, if for no other reason, the engineer should periodically contact his/her national body or the appropriate government agency to determine if there have been any material changes in liability case law in this area, or if new or amended practice guidelines to mitigate this risk for engineers are under development. In doing so, 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.

Implementing Actions

Engineers should take reasonable steps to assure that potential legal liability from their practice in general and to particular engineering work as it relates to climate change is understood. Actions that consider and/or adjust the engineering work to accommodate current and future climate should be documented.

Not all the following 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.

1. Consult 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.
    a. Professional associations where they exist in countries routinely report on disciplinary actions and will report on such cases as they arise
    b. National members of WFEO or professional and technical associations may develop practice guidelines specific to the topic of climate or include reference to it in the context of more specific areas of practice.
2. 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
3. Pursue additional professional training on climate change and meteorology to increase knowledge of climate science, measurement, data and definitions to enable critical review of climate analysis and advice provided by climate scientists and specialists.

4. As appropriate, consult with climate and meteorological specialists to inform climate change adaptation and resiliency measures
5. In working papers and personal files, maintain written documentation of training and consultation on climate change and meteorology
6. In certain cases, professional liability insurance for the engineer may be required or prudent if their scope of practice requires climate consideration.

3.2. CATEGORY B: Integrate Climate and Climate-Related Information

3.2.1. Principle #7: Interpret and specify climate information

Engineers should work with climate and meteorological specialists/experts in order 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.

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.

1. 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 considering our changing climate.
2. 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.
3. 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.

Many engineers do not have extensive training or experience in managing and assessing climate and weather information necessary to be considered expert in the field. Engineers do not have to become a climate expert (but extremely helpful if the case) but know enough to ask the right questions, interpret the climate data and projections for engineering (and not scientific) decisions as well as interpret or challenge the answers provided by the climate specialist that would normally be part of the adaptation team.

Historically, the professions have been consumers of such information, relying on government agencies and other authorities to package information into the formats useful for their professional 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 must 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.

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. Armed with this understanding, engineers will be better 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 localized 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 local weather information to develop a baseline. Engaging a specialist is even more important with respect to climate change information. Climate change projections are based on very sophisticated modeling and analysis derived from socioeconomic and greenhouse gas emission forecasts. Many models are used in developing climate projections and the models all have different strengths and weaknesses. Due to the inherent uncertainty associated with modeling, 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 professional engineer. It is therefore important that engineers consult with climate experts to understand the overall integrity and limitations of the information they are planning to use and can incorporate appropriate measures from their own professional discipline to accommodate these factors within their professional work.

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[4]. Published in September 2014 and updated 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 modeling concepts that support a good understanding of climate information in general.

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[4] Charron, I. (2016). A Guidebook on Climate Scenarios: Using Climate Information to Guide Adaptation Research and Decisions. 2016. Edition Ouranos, 94p. ISBN (Print) : 978-2-923292-19-8. ISBN (PDF) : 978-2-923292-21-2. Copies of this guidebook can be downloaded from http://www.ouranos.ca/

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; a single best climate scenario does not exist

It is important to understand the limitations of the climate information used. 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.

Implementing Actions

The following are suggested actions for engineers to specify, interpret and assess climate information. Not all of these may be appropriate to the situation at hand nor is the list complete.

1. 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.
    a. Develop the current climate profile based on analysis of historical weather data;
    b. Estimate the changes in frequency and value of extreme values of relevant climate parameters based on scientifically defensible methods of future climate projections over the service life of the engineered system;
    c. 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 advice from climate scientists and climate experts to define the:
    a. Associated uncertainties with the information;
    b. Assumptions made;
    c. Data sources;
    d. Relative differences between current climate data derived from measured metrological data and projected climate information based on modeling;
    e. Scientific validity of the methods and data used to derive current and future climate parameter values and frequencies

1. Assess the criticality of the impact of the climate assumptions on the overall engineering design and function of the system.
2. Determine if the assumptions and factors have undergone recent review/update considering climate change.
3. Review the assumptions and factors with climate experts to assess the applicability of the assumptions and factors over the anticipated service life of the design.
4. Based on professional judgment, add appropriate safety factors or margins 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.

Engineers should work with climate scientists to establish a Unified Climate Information Framework for use at local, regional and national levels defining data typologies, time horizons, uncertainty treatment, and quality assurance for engineering use. This would improve the consistency and scientific defensibility of climate information used in engineering design.

3.2.2. Principle #8: Review the adequacy and application of locally applicable codes, standards and guidelines

Engineers should review the local design codes, standards and regulations and determine whether these reasonably represent the current and anticipated climate in the location that an infrastructure will operate over its life cycle. Specify, review and or adjust operation and maintenance procedures and standards to adjust as necessary to assure a climate resilient infrastructure over its complete life cycle. Consider exceeding design codes and standards where it is prudent to do so and document the rationale.

Amplification

Consistent standards for climate information are essential to ensure scientific defensibility, comparability across projects, and the reduction of maladaptation risks. Given the potential impact of changing climate on civil infrastructure, buildings and support systems as engineering works, it may (and in many cases is) no longer be appropriate for professionals to 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 **<u>minimum requirement</u>** and should be viewed as the starting point for application to the engineering work. Often these must be exceeded to assure safety first, then continued reliability and service as well as accommodate extreme weather events in the future climate.

Exceeding minimum codes and standards in design to anticipate future climate is a practical implementation of the Precautionary Principle. It is an additional tool to provide an increased factor of safety to accommodate the uncertainties of future climate.

For ongoing operations and maintenance, exceeding minimum thresholds, policies or procedures for such things as inspection and routine maintenance cycles is prudent and can be adjusted as scientific knowledge advances. It is important to undertake such activities shortly following exposure of the infrastructure to an extreme weather event. Increased inspection may be required to detect the effects of creeping climate change where the rate of deterioration decreases capacity over time from weathering and increased uses of the infrastructure.

Engineers should routinely review and challenge the tools used in professional practice. 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.

A dilemma for engineers in some jurisdictions is how to elevate an issue related to climate change, for example, if an engineer realizes the standards of a certain jurisdiction are not sufficient to support climate adaptation and resiliency, how should they first go about alerting appropriate bodies to make that change? And if the first body alerted does not accept the suggested change, what is the next step?

Implementing actions

The following are suggested actions engineers should undertake in their use of current codes and standards in the jurisdiction in which the project is located.

- Apply the most up-to-date revisions of relevant practice guidelines, codes and standards, as a baseline from which climate change adaptation and resilience measures are applied.
- Consider the risk profile of the infrastructure to future climate impacts considering if exceeding code or standards improves climate resiliency cost-effectively

Engineers should advise other engineers, as well as the governing bodies responsible for the specific codes and standards, and their engineering association, registering or regulatory body when a code or standard warrants review based on evidence from ongoing practice. Steps that may be undertaken in making a representation include:

As part of the design process, create a file of adjustments made to codes, standards and assumptions to accommodate changing climate and improve resiliency. Similarly for operations and maintenance, periodically review policies, procedures and methods to recognize potential for future climate impacts and revise existing documents or create new ones where needed.

As appropriate, communicate adjustments:

- Within the department, division or organization;
- To employers and clients;
- To government regulators;
- To professional societies, associations or groups; and
- To standards organizations and regulators who developed the codes and standards.

Robust operations and maintenance policies, procedures and guidance are a key contributor to climate resilient infrastructure. It is not economically or technically feasible to design and construct climate proof infrastructure that resists all extremes of future weather. Robust operations and maintenance practices will complement design efforts and are vital to anticipate and respond to future events. Suggested actions to improve operations and maintenance policies and procedures to anticipate future extreme weather and effects of creeping climate change over time include:

- Increasing the frequency of inspection of potentially vulnerable infrastructure components, particularly as the infrastructures ages or the climate changes at a faster rate than originally projected
- Revisiting the results of climate risk and vulnerability assessments that may have been performed to inform the design process to determine any substantive changes based on operational performance or changes in climate projection to inform adjustments to operations and maintenance or to justify rehabilitation or upgrades to the infrastructure. Such assessments should be undertaken every 5 to 10 years.
- Review and potentially adjust policies and procedures after assessing impacts from an extreme climate event on the infrastructure during its operational life cycle
- Consider adding (or specifying) a recommended operations and maintenance schedule to anticipate the changing climate as a deliverable to a design and construction contract
- Specify a requirement for as built drawings of the infrastructure to inform operations and maintenance practices as well as repair and rehabilitation in the event of extreme weather impacts
- Promote performance-based resilience codes with measurable KPIs (e.g., recovery time, service loss, avoided losses) to enable outcome-focused resilience design

Not all actions described above may be appropriate to the situation nor is the list complete. Engineers are encouraged to develop their own successful strategies and experiences. Notifying their engineering body, local or national government regulator will enable practice guidelines to be developed and updated to reflect most current and best/better practices.

3.3. CATEGORY C – Engineering practice guidance

3.3.1. Principle # 9: Work with multi-disciplinary and multi-stakeholder teams

Work with other engineers, other infrastructure practitioners, climate specialists and natural scientists to form multi-disciplinary project teams to engage with stakeholders (infrastructure owners, the public), gaining a common understanding of the risks, vulnerabilities and impacts (physical, social and environmental) of current and future climate on the infrastructure and its service to the society it serves. Engage these teams to develop feasible adaptation and resiliency measures within project constraints to ensure a comprehensive approach to climate adaptation and resilience.

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 change, 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 # 7***. 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 in order that, as a minimum, the team possesses:

- Fundamental understanding of risk and risk assessment processes;
- Direct 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 as needed;
- 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, arising; 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:
- Natural sciences (geologists, hydrologists, agronomists, etc.) as appropriate to the geographic location and climatic region in which the engineering work is located;
- Social impact analysis (social scientists and policy specialists);
- Environmental impact analysis;
- Economic impact analysis;
- Political decision makers;
- Insurance specialists;
- Environmental practitioners;
- Asset managers;
- Legal and accounting expertise;
- 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 councilor.

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 have the right balance of skill and experience 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.

Additional skills recommended for engineers to acquire and gain experience in working in multi-disciplinary teams include Negotiation and Facilitation. These soft skills are not normally part of engineering curriculum or continuing professional development of engineers but are becoming increasingly critical as engineers engage with other professionals and practitioners and other stakeholders in public consultation and design teams.

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 develop acceptable adaptation solutions. Not all of these 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 national body and the WFEO. These will be incorporated into addendums to this model code of practice.

- During the formation of multi-disciplinary teams, review the overall service life and operability requirements of the engineered system to have 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 and skill sets and training of each member of the multi-disciplinary team relative to the project/assignment.
- Pursue continuing professional development in the form of courses and on-the-job experiences to acquire negotiating and facilitation skills that enhance ability to engage with other practitioners and professionals

3.3.2. Principle #10: Plan for the infrastructure service life (life cycle)

Consider the impact of current and projected climate (long term changes and climate extremes) over the entire service life of an infrastructure. Make appropriate and feasible decisions within the context of current scientific, economic, project and social constraints through enhancements in design, construction, operations, maintenance, decommissioning and management policies, procedures and practices.

Amplification

Climate change is a long-term issue. Climate models project changes in climate parameters twenty, forty, 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 will not be sustained throughout the entire service life.

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.

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. It is a question of allocating more resources now along with good operations and maintenance practices to reduce or avoid substantially higher costs of repair and replacement at some unexpected time later in the service life.

There are two facets to this issue. First, while it is difficult to anticipate climate change impacts forty or one hundred years hence, professionals should 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 engineer opportunities to incorporate appropriate adaptive measures at several points over the life of the project.

It is sometimes possible in the design process to make provision for future adaptation of the infrastructure to anticipate future climate changes, but which do not require implantation at the time of construction. These considerations can lower initial capital costs and offer flexibility to implement later when the need arises. The same holds true for operations and maintenance policies and procedures that can be adjusted as the climate changes or its future projection becomes more certain.

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, rehabilitation or expansion 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.

Implementing Actions

Engineers can anticipate the impacts of changing climate by considering actions that address the service life of the infrastructure asset. Not all of these 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 over the service life. Any new practices or improvements should be reported to their national body and WFEO. These will be incorporated into addendums to this model code of practice.

1. 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.
    a. Identify any adjustments made to the design based on climate considerations

    a. Identify the basis for any adjustments made to the design based on climate considerations
    b. Identify the economic impact of changes made to design based on climate considerations
    c. Identify how the adjustments address the full-service life cycle of the engineered system
    d. Provide instructions on when and how the infrastructure should be maintained over its service life cycle (similar in format to instructions for car maintenance)

2. 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.
    a. Identify any adjustments made to the refurbishment design/plan based on climate considerations
    b. Identify the basis for any adjustments made to the refurbishment design/plan based on climate considerations
    c. Identify the economic impact of changes made to the refurbishment design/plan based on climate considerations
    d. Identify how the adjustments address the full-service life cycle of the refurbishment design/plan
3. Ask the climate specialist to recommend a range of alternative methodologies for projecting climate information over the shorter timeframes used for refurbishment service cycles.
4. Develop, institute, review and/or revise operations and maintenance policies, standards, and procedures to permit the infrastructure asset to function at the capacity it was designed to perform, including ability to respond to loadings imposed by future changes in climate.
5. 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.
6. Review and modify training and competency policies and standards to enable operations and maintenance personnel to enhance operations and maintenance practices as well as emergency preparedness and response. In some ways, anticipating climate change in a refurbishment plan is simpler than it would be for the entire life of a project. The climate change projections are on 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.
7. 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 that is somewhat less detailed than a full climate projection. This can save costs and time.

Similarly, engineers in operations, maintenance and planning functions should seek to 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 sufficient authority to do so.

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 capital dollars on new infrastructure to a later date. It also defers decisions on building new structures into a timeframe where data may be more certain. Engineers can support this strategy by instituting monitoring and measurement programs to secure climate data and projections to define evolving climate conditions. Such climate information is less uncertain.

Engineers can implement adaptive-pathway designs with predefined decision triggers linked to climate thresholds. Flexible adaptation strategies can be retrofitted into existing facilities in stages, as climate change impacts become clear in different locations. Examples include:

1. Modular seawalls that can be raised as needed;
2. Prefabricated highway bridges that can be elevated as peak flows beneath them rise;
3. Floating intake systems at water treatment plants, designed to rise and fall as reservoir levels change; and,
4. Install larger air conditioning ducts at construction to accommodate higher flows that may be required as temperature extremes increase in frequency and severity. This minimizes disruption and incurred costs to adapt to a higher temperature regime in the future.

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 timelines for each project.

3.3.3. Principle #11: Use risk management to proactively address climate uncertainties

Engineers should employ the principles of risk assessment and management to manage the uncertainty of future climate on civil infrastructure, buildings and support systems. They should develop and maintain a reasonable level of competence and experience in infrastructure climate risk and vulnerability assessment as well as risk management. Be aware of and utilize recognized procedures, processes and tools based on ISO internationally recognized climate risk and adaptation standards.

Amplification

The focus of this principle is the application of standard risk assessment techniques to the question of climate change. 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 a publication from Engineers Canada[5].

International standards on risk management are published by the International Standards Organization (ISO) in its 31000 and 14090 series[6] as follows:

1. ISO 31000:2018, Risk management – Guidelines provide principles, framework and a process for managing risk. It can be used by any organization regardless of its size, activity or sector. ISO 31000 has three main components – Principles, Framework and Process.

2. ISO/IEC 31010:2019, Risk assessment techniques - Focuses on risk assessment concepts, processes and the selection of risk assessment techniques.

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[5] Engineers Canada **National Guideline – Risk Management** (2013), https://www.engineerscanada.ca/sites/default/files/Risk-Management.pdf

[6] http://www.iso.org/iso/home/standards/iso31000.ht

3. ISO Guide 73:2009, Risk management - Vocabulary complements ISO 31000 by providing definition of terms related to risk management to mutual and consistent understanding.

4. ISO 14090:2019, Adaptation to climate change – Principles, requirements and guidelines -A voluntary international standard that provides a high-level framework to assess climate change impacts, develop adaptation plans and manage related risks and opportunities.

5. ISO 14091:2021, Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment – Provides guidelines for understanding vulnerability and developing and implementing a sound climate change risk assessment.

6. ISO 14092:2020, Adaptation to climate change – Requirements and guidance on adaptation planning for local government and communities -Provides specifications and guidelines in adapting to climate change based on vulnerability, impacts and risk assessments

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

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

Implementing Actions

Engineers should 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 these 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 national body and WFEO. These will be incorporated into the next edition of this model code of practice.

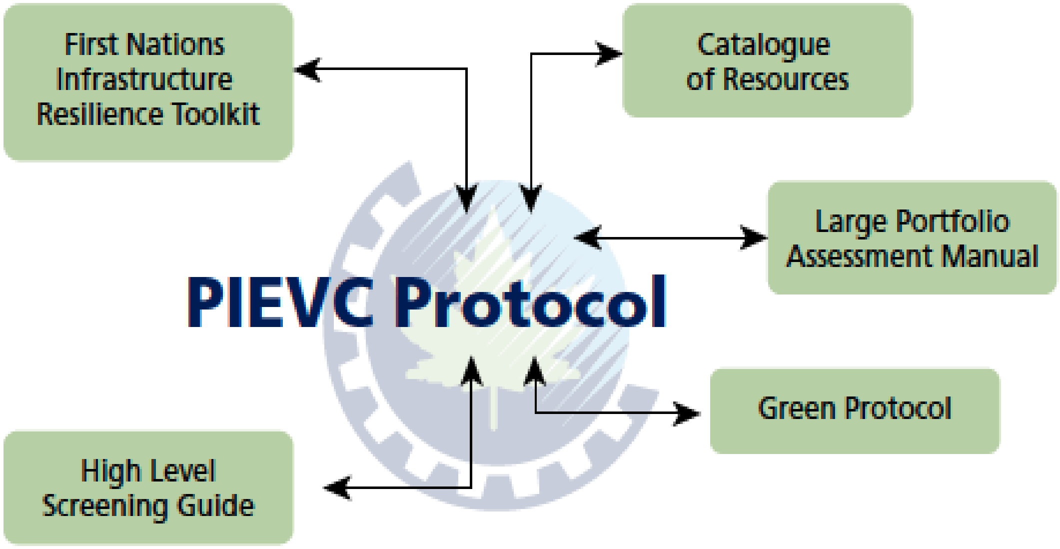
1. First, develop competence in risk assessment.
    a. Establish awareness and knowledge of the range and applicability of risk assessment tools, including international standards such as ISO 31000.
    b. Where appropriate, pursue professional development and training in risk assessment tools and approaches relevant to professional practice.
2. Where the engineer does not have sufficient expertise in risk assessment, seek guidance from qualified professional practitioners that have such expertise.
3. As appropriate, retain the services of professional practitioners with risk assessment expertise to advise and/or assist in the review of climate risks.
4. Consider building risk assessment into all stages of the process – design, operation, maintenance, planning, procurement, management, etc.
    a. 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.
5. Consult with the broad range of stakeholders/users of the engineered system to assess their overall risk tolerance levels for the system.
6. Conduct climate risk and vulnerability assessment. This should be undertaken for existing infrastructures that are to be rehabilitated or added to as well as for designing new infrastructure employing this approach as an input to the detailed design process.

7. Encourage the use and integration of risk-based financial and insurance instruments aligned with resilience outcomes (e.g., parametric insurance, resilience bonds) to reinforce proactive resilience investment.

Engineers Canada developed a tool that engineers may use to aid in these assessments[7]. 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 several tools and methodologies that have been developed to help professionals assess the impact of climate change through risk assessment. Several versions of the Protocol are now available to undertake assessments depending on the depth of analysis required as well as the nature of analysis.

The PIEVC Protocol forms the foundation for other climate risk assessment tools called the PIEVC Family of Resources. Each resource draws from the Protocol to address distinctly different applications but remains true to core PIEVC principles. The PIEVC user community continues to identify applications that focus on unique needs that expand the Protocol's reach to other areas of climate risk assessment. The diagram below summarizes the various tools available based on the PIEVC Protocol core methodology.

Further information on each of these tools and their application are provided on the PIEVC website www.pievc.ca.



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[7] https://engineerscanada.ca/guidelines-and-papers/public-guideline-principles-of-climate-adaptation-and-mitigation-for-engineers#4

Source: www.pievc.ca

3.3.4. Principle # 12: Enhance the climate resilience of infrastructures and engineered systems

Engineers should develop robust designs and enhance operations and maintenance policies and procedures to increase the capacity of infrastructures and engineered systems to withstand a greater range of current and future anticipated extreme weather events. Engage with other responsible parties in the planning and design of emergency response measures to deal with immediate impacts. Additionally, develop and implement strategies and methods to accelerate rehabilitation and reconstruction of infrastructures and engineered systems from damage or loss to restore service as soon as practical. All these measures will increase the climate resiliency of the infrastructure.

Amplification

The impacts of climate change go way beyond direct physical risks as damage to and possible loss of infrastructure and property impacts economically and socially. It affects a broad spectrum of functions, infrastructure, and services and compounds and aggravates existing non-climatic stresses, such as urbanisation, migration, water demand, sanitation, etc. Considering the heavy cost implications associated with the damage of infrastructural services, there is an urgent need to make climate resilience a standard for infrastructure. Choices made today about infrastructure will have impacts for decades to come; it is vital to build resilience rather than lock in vulnerability.

In recent years the concept of climate resiliency has been introduced as a desired outcome of climate adaptation for all types of civil infrastructure and buildings and their support systems. Resiliency measures enable infrastructure to continue operation during and after an extreme weather event or, if there is loss or damage, then restoring partial or full operational capacity through expedited recovery or repair to minimize service disruption to a period that is “tolerable” to the local community.

Climate resilient infrastructure has the following attributes:

1. **Protection against climate risks:**
    - Designed to withstand climate change effects such as increased temperatures, shifting rainfall, and extreme weather events.
    - Minimizes the risk of infrastructure failure due to flooding, wildfires, and other climate-related disasters.
2. **Ensuring continuity of services:**
    - Guarantees that essential services like transportation, energy, and water supply remain operational during and after climate-related disruptions.
    - Helps communities and economies continue to function even in the face of extreme climate events.
3. **Long-term cost savings:**
    - Reduces the financial burden of frequent repairs and retrofits associated with climate-related damage.
    - Avoids long-term costs by incorporating resilience from the outset, rather than reacting to damage after it occurs.
4. **Public safety and economic stability:**

  - Protects lives and livelihoods by preventing catastrophic infrastructure failures.
  - Supports economic stability by reducing disaster-related losses and maintaining access to markets.
5. **Environmental and social benefits:**
   - Contributes to sustainability goals, such as reducing carbon footprints, and can incorporate nature-based solutions like wetlands.
   - Promotes social equity by ensuring vulnerable communities have access to reliable infrastructure.
6. **Adaptability for the future**
   - Builds in the capacity to adapt to future changes and accommodates growth and transformation.
   - Supports the development of climate-smart infrastructure that can be upgraded or modified as climate conditions evolve.

Climate resilient infrastructure is planned, designed, constructed and operated to withstand climate impacts with ability to recover and restore service quickly after disruptions. Climate resiliency is the goal, and adaptation is the key strategy to achieve it. Therefore, all adaptation actions should contribute to an outcome of improved resiliency of the infrastructure for all communities – urban, rural, from small towns to large cities.

This means decision makers, with the engagement and input of engineers, regularly devising strategies to optimise the ability of infrastructure to cope with future impacts from extreme weather events. It extends to developing national (and local) emergency and disaster response policies, plans and programs to which engineers should be engaged to provide input.

Implementing Actions

Recommended actions depend on the criticality and/or the size of a capital project. Some facilities or components are classified as critical either because of the services they provide (e.g., hospitals and key transportation assets) or their importance during an emergency (e.g., designated shelters and back-up energy generators). In complex projects with multiple components, whether the full facility is considered critical, designers should identify critical components. This identification should occur as early in the scoping process as possible.

Critical components essential to the facility's functionality should be protected to the higher standard provided even if the facility itself is non-critical. For example, at a non-critical vehicle maintenance yard, some components are critical to the functioning of the site, such as an emergency generator. Critical component protection should also be evaluated if a facility is expected to be fully and continuously operational. Performance of an asset should be monitored in real time and regular stress testing should be common practice.

New York City has developed Climate Resiliency Guidelines Version 4.1 ("the Guidelines")[2] to provide step-by-step instructions to go beyond building code and standards, which are informed with historic climate data, by also looking to specific, forward-looking climate data for use in the design of City facilities. Introductory remarks to the guidelines provide the rationale for resiliency in the design process.

Resilient design should not exist in a silo but rather be a well-integrated part of existing processes and address other goals of the City. For example, resilient design choices should be made as an integral part of the City's project planning, risk management, and financial planning. Similarly, resilient design choices should be selected to maximize the efficacy and efficiency of investments. Some ways this can be done include: 1) integrating "soft" resiliency strategies (such as green infrastructure), "hard" resiliency strategies (built or intensive investments), and operational resiliency strategies; 2) addressing multiple climate hazards with single interventions; and 3) reducing climate change risk in concert with other goals (e.g., energy efficiency or reduction in greenhouse gas emissions)[8].

The Guidelines are to be used throughout the design process—during project scoping and planning initiation, as a reference to requests for proposals (RFPs), during the preliminary design or study phase, through to final design—for all new construction and substantial improvements of City facilities.

A successful resilient design is one that meets these Guidelines, provides co-beneficial outcomes, reduces costs over the life of the asset wherever possible, and avoids negative indirect impacts to other systems. Resilient design does not always add cost and can be incorporated into standard project delivery frameworks.

The United Nations Disaster Risk Response (UNDRR)[9] defines several principles of infrastructure resiliency to all forms of hazards, including those from climate.

Resilient infrastructure must be able to adaptively transform

The first principle of a climate resilient asset is that it's adaptively transforming, essentially meaning it must be able to overcome unexpected climate events and grow into unforeseen roles.

Implementing actions include designing infrastructure that can:

- Fail safely,
- Adapt beyond its primary or original purpose,
- Operate according to unforeseen human intervention, and
- Handle the variability of a changing environment, including climate consideration.

Resilient infrastructure must be environmentally integrated

The second principle dictates infrastructure must be environmentally integrated to qualify as resilient.
This recognises the importance of the natural environment and cautions against any move towards mitigating climate change that itself causes further damage.

Actions here include:

1. the use of nature-based solutions;
2. integration of ecosystem data into decision making; and
3. actively maintaining the immediate environment around a project.

Climate resilient infrastructure must be protected by design

The third principle is protection by design, which requires active up-front consideration of the climate risks that could face an infrastructure once it is operating.

1. Critical components should exceed basic requirements, and the inter-connectivity of different infrastructure channels should be carefully considered to slash the risk of cascading failure.

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[8] NYC Mayors Office of Climate and Environmental Justice – Climate Resiliency Design Guidelines Version 4.1 May 2022

[9] UNDRR - Principles for Resilient Infrastructure – May 2023

2. Emergency response and management plans should be drawn up in advance.

In addition, engineers should plan for resilient operations, maintenance, and emergency logistics to ensure redundancy, modularity, and accessible communication. Operational resilience is critical for service continuity during extremes.

Resilient infrastructure must be conducive to social engagement

The fourth principle is social engagement. Resilient infrastructure must boost people's awareness of how best to use it considering present and future challenges. This relies on clear communication between infrastructure asset managers and users about an upcoming disruption.

Resilient infrastructure must be a shared responsibility

The fifth principle outlines the concept of collaborative data and knowledge sharing regarding an infrastructure asset.

This enables the development of the best possible hazard-response. Following common standards is a key action here, along with cultivating collaborative management.

Generating a shared understanding of resilience goals among different stakeholders is also important, as is assuring data safety, and sharing information relating to risk and return.

Resilient infrastructure will require continuous learning

The sixth and final principle is continuous learning. Learn from the interactions and response of the infrastructure to extreme climate events to guide repair and reconstruction efforts.

Resiliency to the impacts of the full range of extreme events cannot be achieved through robust design and construction alone. Impacts can be minimized up to a certain level or frequency of such events through design and construction. Coping beyond such levels will require on-site collaboration and coordination with emergency response and recovery measures normally provided by local or national government bodies.

Engineers are encouraged to consult with, and provide input to, the design and execution of such measures as they design and get involved with the operation and maintenance of the infrastructures for which they are involved.

Where infrastructure is placed is as important as how it is built. Strategic location and siting are critical for climate resilience. For example, locating infrastructure in areas that can benefit from natural buffers, such as wetlands or forests, can enhance resilience to floods and storms. Avoid constructing in high-risk zones, such as floodplains, coastal erosion areas, or wildfire-prone region adds complexity and cost to design and implement resilience measures. For existing infrastructure in vulnerable locations, relocation or protective measures might be necessary.

The principle of redundancy is to prevent single points of failure from causing widespread infrastructure collapse. Redundancy and backup systems are vital for ensuring continued service delivery during disruptions. This can involve creating alternative routes for transportation networks, establishing backup power sources for critical facilities, or developing redundant communication systems. Backup systems should be regularly tested and maintained to ensure their readiness when needed.

Given the uncertainty of climate, adaptable design is a specific kind of resilient design that provides a useful, iterative approach for managing uncertainty and designing resilient facilities. An adaptable facility is one that can be engineered with a flexible protection level which reduces risk to acceptable levels for part of its useful life and can be re-evaluated as risk levels change. Adaptable design may not apply equally to all types of projects or climate change projections. Flood defenses, for example, may more easily incorporate an adaptable design than the selection of heat-vulnerable materials or below-grade drainage systems.

Adaptable design is particularly useful for facilities with a useful life that extends past 2050 - beyond which the uncertainty of projections increases - and for expensive, long-lived, and highly complex facilities. It provides a way to balance uncertainty with cost, as well as manage operational and maintenance constraints.

Evaluating the impact of design decisions on site-specific operations and maintenance is critical to the performance of a resilient facility. Considerations for operations and maintenance, and creative solutions, should be explored during the design phase.

Develop (or build on) emergency response measures at the community level to respond to low likelihood, extreme weather events that would cause serious infrastructure damage or loss of assets. The most cost-effective strategies for severe but rare events such as tornadoes are emergency response plans. These plans are vital for the purpose of reducing the vulnerabilities of critical infrastructure in the face of extreme events and focus on decreasing the duration and scope of disruptions as well as facilitate response and recovery.

Emergency response plans should include measures that provide sufficient resilience to ensure the health and safety of workers that operate and maintain the infrastructure, as well as the public. Engineers should be engaged and provide input in the plan development.

3.3.5. Principle #13: Design and implement solutions, including nature-based, that consider long-term environmental, economic, and social impacts

Engineers should consider both immediate and future risks (e.g., climate creep, sea-level rise, extreme weather), as well as any probable combination of each when designing resilient systems for the defined service life of an infrastructure. Investigate and consider nature-based solutions (NbS) i.e. green infrastructure to complement or replace grey or engineered infrastructure.

Amplification

Building infrastructure that can withstand climate change is no longer optional; it’s a fundamental requirement for sustainable and equitable development. Infrastructure serves communities, and therefore, community engagement and social equity are integral to climate resilience. Involving local communities in the planning and design process ensures that infrastructure projects are tailored to their specific needs and vulnerabilities. It also fosters a sense of ownership and responsibility, which is crucial for long-term sustainability.

Planning and engineering practice for adaptation and resilience is shifting to foster more social, equitable and inclusive approaches. Financial models go beyond job creation and may include water related sustainable industries such as fisheries, shrimp/oyster farms, eco-tourism, access to waterfronts, integrated public transportation over water etc., a shift in the business case towards indirect benefits. Multi-functionality is key, and provides the business case for sustainable solutions

It moves beyond traditional infrastructure design, which often assumes a stable climate, to proactively account for the impacts of climate change. This paradigm shift is not merely about fortifying structures; it's about rethinking the approach to building and maintaining the essential systems that underpin modern society. The urgency is clear - infrastructure designed without climate resilience in mind is not just inefficient; it is a liability, potentially exacerbating vulnerabilities and hindering sustainable development.

Implementing Actions

The following lists and discusses several approaches and actions that provide or support engineering solutions to improve climate resiliency considering economic, social and environmental factors. Engineers should evaluate their benefits and costs and that their use is appropriate for the type and age of the infrastructure, its geographic location and its functions that serve the public.

Robust Design and Material Selection

The physical integrity of infrastructure is paramount. This starts with robust design that considers projected climate change risks and impacts. For example, bridges and roads in coastal areas need to be designed to withstand higher sea levels and storm surges. Buildings in regions prone to heatwaves require designs that minimize heat absorption and maximize natural ventilation.

Material selection is equally important. Using materials that are durable under extreme weather conditions, such as corrosion-resistant steel in coastal environments or heat-resistant concrete in urban heat islands, is essential. Innovation in material science is continually yielding new options that offer enhanced resilience.

Adaptive and Flexible Systems

Climate change is characterized by uncertainty. Therefore, climate resilient infrastructure must be adaptive and flexible. This means designing systems that can adjust to changing conditions over time. For instance, water management systems can be designed to handle both droughts and floods by incorporating flexible storage capacities and diverse water sources.

Energy grids can be made more resilient by decentralization and incorporating distributed generation, such as solar and wind power, which are less vulnerable to large-scale disruptions. Flexibility also implies modularity, allowing for easier expansion or modification as climate change impacts evolve.

Community Engagement and Social Equity

Addressing social equity is paramount. Climate change disproportionately affects vulnerable populations, and climate-resilient infrastructure should prioritize their needs, ensuring equitable access to essential services and protection from climate hazards. This includes considering affordability, accessibility, and cultural sensitivity in infrastructure development.

Monitoring, Evaluation, and Learning

Climate change is a dynamic and evolving challenge. Therefore, monitoring, evaluation, and learning are continuous components of climate-resilient infrastructure. This involves establishing systems to monitor the performance of infrastructure under changing climate conditions, evaluating the effectiveness of resilience measures, and learning from both successes and failures.

Financial Analyses

The adaptation space is evolving to include more refined social cost benefit evaluation and comprehensive solution decision models. Customized approaches result in cost-effective appropriate solution scales and levels of protection given local circumstances (physical, social). Additional adaptation measures not always considered (but should be) include retreating existing infrastructure from coastal zones and floodplains as well as repurposing.

Nature-based Solutions (NbS)

Nature-based solutions, also known as NbS, play an important role in meeting sustainable development goals (SDGs) and the transition to net zero. They are increasingly recognized as a cost-effective way to replace, augment, or complement traditional grey infrastructure, and for their ability to support climate resilient infrastructure.

The Global Infrastructure Hub (www.gihub.org) summarizes well the purpose and scope of NbS in the following paragraphs.

There are many types of nature-based solutions, spanning urban, rural, national, district, and community levels. As per their definition, nature-based solutions encompass both non-infrastructure and infrastructure solutions. Due to the connectedness of the natural and built environment, even nature-based solutions which are considered non-infrastructure typically also provide downstream benefits to infrastructure. For example, forest restoration and management projects – while having direct benefits to native fauna and biodiversity – have downstream benefits for infrastructure such as reduced flooding severity and increased water quality for downstream water and energy infrastructure.

Significant examples of nature-based solutions that have a direct or downstream impact on infrastructure include:

- Green roofs, urban gardens, green spaces, and bioswales: These incorporate nature into an urban environment to provide benefits such as mitigating urban heat, improving community wellbeing, and supporting better urban stormwater and flood management.
- Construction or restoration of wetlands: These offer nature-based alternatives to traditional wastewater treatment by increasing the quality of treated water and alleviating flooding.
- Implementing native mangroves to coastal environments: These use mangroves to replace or augment traditional grey infrastructure solutions such as sea walls for benefits including

decreasing coastal erosion, increasing flood protection, and acting as a carbon sink to capture emissions.

The development and application of NbS towards supporting and providing resilient infrastructure is a rapidly growing field of engineering practice. It offers a viable and cost-effective option to replace or augment grey infrastructure and contributes to social well being and preservation of the local environment. The body of knowledge and experience in using NbS for climate adaption and resiliency of

Engineers are encouraged to consider NbS to replace or support hard infrastructure to deal with climate impacts such as sea level rise and storm surge, management of estuarine river levels and flooding and the reduction of urban heat using tree canopies as examples. Solutions include replacing hard ((grey) infrastructure with green (nature-based) infrastructure; another solution requires a combination of green and grey infrastructure. There are numerous sources of information and case studies on the Internet that report on the methods, results and impact of NbS.

Furthermore, engineers should work towards incorporating regenerative and nature-positive solutions as part of implementing NbS for climate resiliency, to enable net biodiversity gains where possible. Nature-positive approaches enhance ecosystem services in addition to improving climate resiliency.

Engineers are encouraged to acquire working knowledge of NbS through their own research, formal education and training as well as through professional practice. Further guidance and case studies are available through organizations such as the UN Environment Program and government organizations worldwide. A modest listing of these references is provided in Appendix B, but this is by no means complete and will continue to expand.

Adaptive Management of Infrastructure

Adaptive Management, at its most fundamental level, is about embracing uncertainty, learning from experience, and continuously improving management strategies to achieve desired outcomes in complex systems. Its substance lies in its ability to adapt and evolve in response to new information, making it a powerful tool for tackling environmental and sustainability challenges.

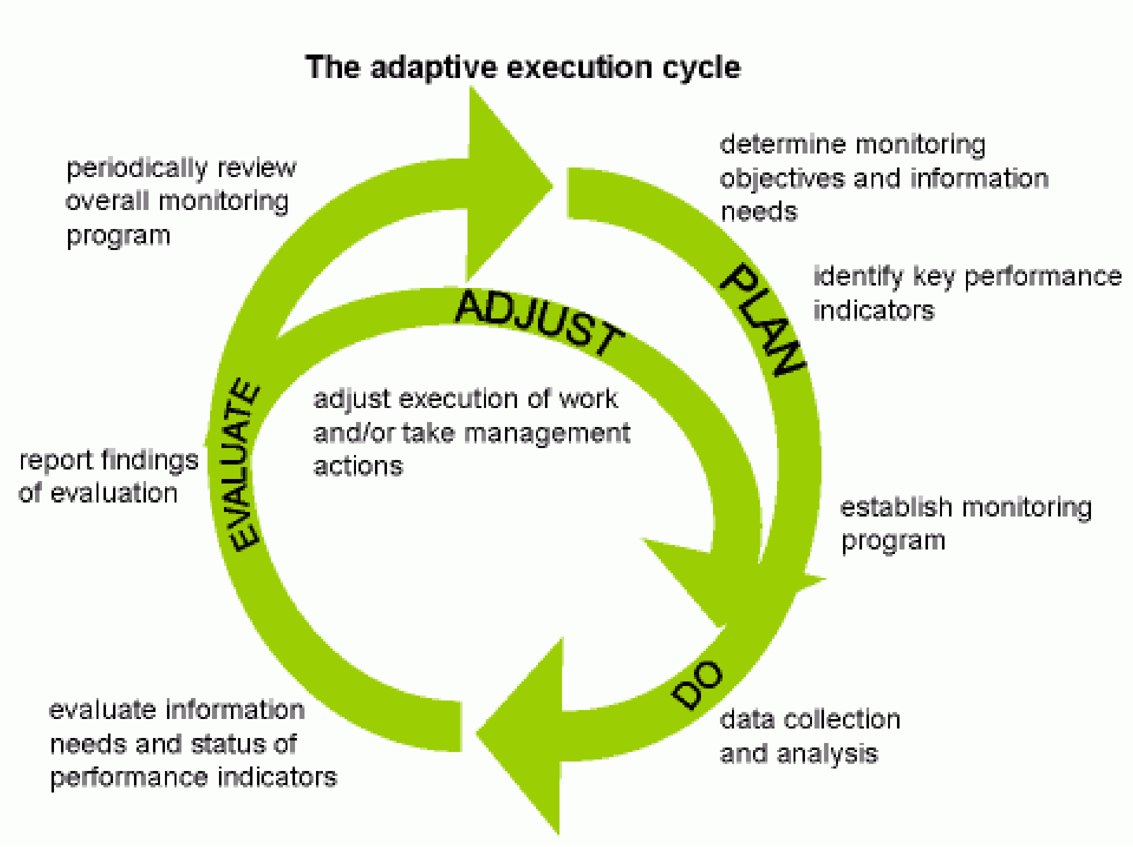
It is a structured, iterative approach to decision-making in the face of uncertainty. It is particularly relevant in fields like sustainability and environmental management where outcomes are often complex and hard to predict. It is ‘learning by doing’ in a systematic way, allowing for adjustments as new information becomes available. It is based on ongoing monitoring and evaluation, essential for ensuring that infrastructure remains resilient in the face of evolving climate risks. This iterative, cyclical process allows for adjustments and improvements over time, ensuring long-term effectiveness**.** It is not a one-off plan, but a continuous loop. This loop typically involves several key stages:

1. Designate or review clear objectives → what are you trying to achieve or adjust?
2. Develop a management plan based on the best available knowledge, acknowledging that this knowledge is likely incomplete.
3. Implementation, putting the plan into action.

4. Monitor the outcomes. Are the results what were expected? If not, why not?
5. Evaluation and adjustment. Based on what is learned, review and refine the management plan and possibly the objectives, and the cycle begins again.

The monitoring phase is critical because it provides the data for the next stage. This cyclical description is key to grasping its dynamic, on-going nature.

Adaptive Management can be integrated into on-going operations and maintenance reviews of an infrastructure system to anticipate future climate impacts. For example, updating climate risk and vulnerability assessments can follow this process and are recommended every 5 to 10 years or following an extreme weather event.



Source: www.ecoshape.org

3.3.6. Principle #14: Use effective language and communicate decisions clearly

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

Communicate to clients, employers and the public as appropriate, providing transparent information about risks, benefits, and potential impacts, climate-related and resiliency recommendations using simple, unambiguous, language. Include the costs and benefits of recommended actions, how those actions mitigate the identified risks as well as the economic benefits of the adaptation and resilience measures and the potential costs of not adapting to the identified risks.

Amplification

Engineers possess unique technical knowledge and skills necessary to plan and implement effective adaptation to changing climate conditions. However, engineers can only implement those adaptive 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 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. As part of this communication, the engineer should clearly communicate the costs and benefits of recommended actions and how those actions mitigate the identified risks. It is important that the engineer clearly articulates the economic benefits of the adaptation measure and the potential costs of not adapting to the identified risks.

The complexities and uncertainties inherent in the engineer's work should 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 is 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 professional practice. 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 the average person. The layperson may not know the meaning of the language being used by the professional and may not fully appreciate the full message the professional is attempting to convey. 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 makes decisions that do not seem to address the concerns the professional was attempting to convey.

Given the critical importance of these issues, engineers should take all reasonable measures to be 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 focus on 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 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 need for communicating in clear and effective language also includes the professional's interactions with the public. The professional may sometimes be required to communicate with the public, such as during public consultation on behalf of a client or representing their client or employer with the 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 recommendations. The professional should strive for an accurate, if not comprehensive, understanding of the issues and recommend adaptive measures by the public.

Finally, the engineer may find that they have identified and communicated climate risks and adaptive measures to non-receptive decision makers. The decision maker may opt to reject or, even worse, simply 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 outside with regulators and other responsible external agencies.

Registering bodies 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, it is essential for professionals to recognize that their professional obligations regarding climate change risks may not be satisfied simply by proposing actions to decision makers.

Implementing Actions

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

Engineers are 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 registering body and WFEO. These will be incorporated into the next edition of this model code of practice.

1. Review each piece of professional writing with an eye to the intended audience for the piece.
    a. In aid of clearly communicating the primary message of the piece, revise, edit and adjust the language used in the piece applying common language and expressions more likely to be understood by the audience.
    b. As necessary, discuss suitable language with the intended audience and come to an agreement regarding the definition of terms used in the writing.
    c. In situations where common language may not suffice, including sufficient background information and definitional material to promote the audience's understanding.
2. Where the professional does not have the skills or expertise to simplify the writing, consult with or engage suitably qualified communications professionals in revising the piece for more general, broader, understanding.
3. Consider hiring a communications consultant to redraft the language to convince the necessary

decision-making audience(s).

4. Assume that each piece of writing may be misunderstood and challenge the writing from different perspectives to identify areas where simplification or greater amplification may be necessary.
5. 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

3.3.7. Principle #15: Engage in lifelong learning and ongoing engagement to stay current with evolving climate science, and climate technologies, standards, tools and methods

Pursue continuous learning to ensure work remains relevant, reflects best practices and innovations and is ethically sound. Stay informed about new technologies, methods, and strategies to improve climate resilience, and share these findings with the engineering community.

Amplification

Engineers work in a changing and dynamic environment They have a duty to maintain their competence in their area of practice for the duration of their career.

The climate crisis requires engineers to update their skills as well as acquire and assimilate knowledge to address climate adaptation and resilience challenges and opportunities. The knowledge gained should be focused on supporting current and future practice in planning, designing, and managing climate resilient infrastructure assets and their components.

To be effective, engineers need a diverse skill set that includes not only technical competencies required for their discipline of practice, but also additional climate related skills and knowledge in areas such as climate science, risk management (including risk and vulnerability assessment) data analysis, local codes and standards as well as project management.

Additional soft skills like creativity, adaptability, collaboration, negotiation and facilitation enable teamwork and collaboration with other professionals and public stakeholders. Equally important are effective communication skills to clearly articulate the societal and economic impacts of climate change to policymakers, decision-makers, industry leaders and the public. Effective communication, both oral and written within a climate context to infrastructure owners and clients about the benefits and costs of climate adaptation and resiliency measures is critically important to enable understanding and acceptance of proposed measures and their implementation

Implementing Actions

Engineers should regularly engage in continuing professional development (CPD) (also known as lifelong learning) to acquire and upgrade their skills and knowledge of climate change and its impacts not only on society, but also the practice of engineering.

Formulating a Continuing Professional Development plan helps an engineer identify gaps and chart a progressive path towards gaining knowledge and skills that enhance their current and anticipated practice as well as support the pursuit of new opportunities.

Courses, conferences, meetings, presentations that support peer interaction provide exposure to new ideas, practices and tools related to climate change, adaptation and resilience and technologies. This includes contributions to educate peers through presentations, papers and reports. These expand the technical

knowledge base and communicate practice experience among engineers in developing adaptation solutions to achieve enhanced climate resilience of civil infrastructure, buildings and their support systems

Sources for climate-related professional development for practicing engineers include:

1. Formal learning provided by educational institutions (universities, colleges, technical institutes, government ministries), Non-Government Organizations (NGOs), including engineering societies and regulators and private sector providers. Courses are provided as part of continuing education, for Master or PhD or a certification and offered as part of a program or as individual courses. Completion and recognition are in the form of credits, professional development hours, certificates, designations and so forth.
2. Informal learning that is less structured and often not formally recognized e.g. no issue of certificate. The same institutions that offer formal training may also offer informal training as described here. It can also occur within the workplace or maybe a seminar or a presentation at a meeting as examples.
3. On-the-job experience in climate related work with colleagues and stakeholders

Engineers should keep a record of their learning to enable review and planning of future activities that expand their competency as well as for professional recognition. Recording and reporting of CPD activities may be required as a condition of registration as an engineer. CPD activity reporting may be voluntarily or mandated as part of their registration with their national society or regulator.

The scope of topics and knowledge areas required to practice competently in climate adaptation and resiliency depend on the career pathway of the engineer and the areas of practice, function and responsibility that they may have or aspire to. Engineers can be involved in specification and procurement of climate resilient infrastructure i.e. on behalf of the client or infrastructure owner or provide the design, construction and project management for delivery of the infrastructure. Both roles are key to the delivery of climate resilient infrastructure. Each role has unique and common areas of specialized knowledge skills and experience that match the role the engineer plays in these processes.

The following is a list of the most common areas of technical knowledge and soft skills that support and enhance an engineer’s ability to engage in climate resilient infrastructure:

- Basic and applied climate science (climate science principles, climate change principles, climate data, climate modelling and projections);
- Climate change adaptation processes, tools and guidance ;
- Climate policy and climate law;
- Specifying and procuring infrastructure climate design and construction services;
- Climate risk assessment and risk management;
- Developing business case for climate adaptation and resilience;
- Facilitation principles and practices;
- Negotiation principles and practices;
- International codes and standards (e.g. ISO);
- Local codes and standards (location specific).

Engineers are encouraged to pursue other areas of knowledge and acquire skills that build upon and expand their capacity to advocate, manage and engage in climate resilient infrastructure design, construction, operation, maintenance, decommissioning and management functions.

Engineers and their registration bodies should advocate strengthening of their respective professional education systems to embed resilience ethics and adaptive management for future engineers. Long-term transformation of the engineering workforce to embrace the principles of this Model Code as well as the required technical and non-technical knowledge, competencies and skills depends on early and sustained education.

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[10]. The content in this document remains relevant to the discussion of the engineer's role in climate adaptation and resilience today. The executive summary describes the purpose and scope of this document as follows:

1. 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.

2. 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. This information is updated by more recent publications of the International Panel on Climate Change (IPCC) references which are provided in the bibliography attached at the end of this Interpretive Guide.

- 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 might be affected, and includes 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.

A more recent ASCE publication - *Climate-Resilient Infrastructure: Adaptive Design and Risk Management*, MOP 140, as quoted on their website - Provides guidance for and contributes to the developing or enhancing of methods for infrastructure analysis and design in a world in which risk profiles are changing and can be projected with varying degrees of uncertainty requiring a new design philosophy to meet this challenge.

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[10] "Adapting Infrastructure and Civil Engineering Practice to a Changing Climate Committee on Adaptation to a Changing Climate". Edited by J. Rolf Olsen, Ph.D., Published by American Society of Civil Engineers (2015) (with permission of ASCE), http://ascelibrary.org/doi/pdfplus/10.1061/9780784479193

It is available for purchase on the ASCE website https://ascelibrary.org/doi/book/10.1061/9780784415191

The underlying approaches in this manual of practice (MOP) are based on probabilistic methods for quantitative risk analysis, and the design framework provided focuses on identifying and analyzing low-regret, adaptive strategies to make a project more resilient.

Beginning with an overview of the driving forces and hazards associated with a changing climate, subsequent chapters in MOP 140 provide observational methods, illustrative examples, and case studies; estimation of extreme events particularly related to precipitation with guidance on monitoring and measuring methods; flood design criteria and the development of project design flood elevations; computational methods of determining flood loads; adaptive design and adaptive risk management in the context of life-cycle engineering and economics; and climate resilience technologies.

MOP 140 will be of interest to engineers, researchers, planners, and other stakeholders charged with adaptive design decisions to achieve infrastructure resilience targets while minimizing life-cycle costs in a changing climate.

There are several publications of the ASCE focused on engineering climate adaptation and resilience for specific types of infrastructures that are listed in the bibliography.

The International Federation of Consulting Engineers (FIDIC) State of the World Report 2025 – Infrastructure Adaptation for Emerging Economies – Scaling Sustainable Solutions, published in September 2025 offers insight into the role of engineers and the importance of infrastructure to all economies, especially the emerging ones in the world.

As the Executive Summary notes, the report explores the urgent need and transformative opportunities to build infrastructures that are not only climate resilient and technically sound, but also inclusive of society and its needs regionally and locally. The report is designed as both an informative and action-oriented resource for policymakers, infrastructure professionals, investors and development practitioners seeking to navigate the complexities in delivering climate resilient and inclusive infrastructure in emerging economies. It provides a strong rationale for climate resilient and inclusive infrastructure and its linkage to attaining the United Nations Sustainable Development Goals.

Appendix A – Definitions

The Model Code of Practice uses the following terms and definitions.

Act	The applicable engineering act that has legal standing in a jurisdiction. Some acts in Canada 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.
Acquiescence	To accept or comply passively, without question or objection.
Adverse effect	Impairment of, or damage to, the environment, human health or safety or property.
Climate	Climate is 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	Climate change refers to a 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.[9]
Climate information	In this document "climate information" means data and projections and any other form of climate factor/assumption/etc. In other literature this may sometimes be called climate factors or parameters.
Climate scientist	Those 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.

Cost-benefit analysis	An economic analysis method that seeks to express the costs of an activity, in comparison to the benefits, using common units, to aid decision-making. The analysis would normally include capital, operating, maintenance, and decommissioning, social and environmental costs.
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 people, property and the environment. In professional practice, engineers must document the steps that they have undertaken to demonstrate due diligence.
Engineered system	Any civil infrastructure including buildings or engineering work that interacts with or may be affected by climate.
Engineering adaptation	A process of engineering decision-making in response to any kind of vulnerability or socio-political consideration.
Engineering vulnerability	The difference between an engineered system’s capacity and the loads that the system is expected to see
Environmental effects	Outcomes arising from a technological activity that cause changes to the environment. Any change that project may cause in the environment, including but not limited to: ● Health and socioeconomic conditions ● Physical and cultural heritage ● Current use of land and resources ● Or any change to the project that may be caused by the environment.
Liability	Legal responsibility to another or to society, which is enforceable by civil remedy or criminal penalty.
Life-cycle assessment	Assessing the environmental, social or economic effects of a chemical, product, development or activity from its inception, implementation and operation through to termination or decommissioning. It is the assessment of a system throughout the term of its entire service life.
Mitigation	Within the context of this model guideline, mitigation refers to technological change and changes in activities that reduce greenhouse gas emissions, thereby reducing the anthropogenic emissions causing climate change.
Nature-based Solutions (NbS)	Actions to protect, sustainably manage, and restore natural and modified ecosystems to address societal challenges like climate change, disaster risk reduction, and water and food security. These solutions provide benefits for both human well-being and biodiversity.

Professional 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. Canadian professional engineers use the designation “P.Eng.”, or in Quebec “Eng.” or “Ing.” In the United States the designation is P.E. and in Europe through FEANI the designation is EurEng. Other countries may use other forms of designation to identify engineers.
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.
Quality of life	The factors related to the state of health and well-being of an individual or a community
Resiliency	The ability of a system to withstand stress, adapt and 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..
Societal values	The attitudes, beliefs, perceptions and expectations generally held in common in a society at a particular time.
Socio-economic effects	The effects of a development, product or activity, on the economy and social structure of affected communities. Socio-economic effects may include issues such as: employment, housing and social needs, medical services, recreational facilities, transportation and municipal infrastructure and financial benefits to residents and businesses.
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.
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 that contribute to an overall statistical synopsis.

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