

NIST Grant Contractor Report NIST GCR 26-071

Forward-Looking Codes and Standards: Future Hazards

*Workshop Report
June 4–5, 2025, Reston, VA*

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Abstract

Forward Looking Codes and Standards: Future Hazards workshop report includes recommended research needs on the following themes: confidence and uncertainty in hazard projections, local downscaling of global models, and conversion of hazard projections to engineering design criteria.

Keywords

Codes and standards; Building codes; Future hazards; Hazard models; Load effect: Design guidelines; Design criteria; Structural capacity; Adaptation; Resilience.

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Preface

In October 2024, the Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE) commenced a project under National Institute of Standards and Technology (NIST) Contract No.1333ND24PNB730652 to develop workshops on *Forward-Looking Codes and Standards*. This report documents the results of the first of four workshops on *Forward-Looking Codes and Standards: Future Hazards* based on contributions to the workshops from scientists, natural hazard experts, structural engineers and other design professionals, and standard and code development experts.

The following are the themes of the four workshops:

1. **Future hazards for design:** Confidence/uncertainty in hazard projections, local downscaling of global models, and conversion of hazard projections to engineering design criteria;
2. **Future load effects on the built environment:** Changes in hazard demand relative to historical basis, changes in structural capacity due to changes in material properties, and geotechnical conditions;
3. **Engineering design guidelines and criteria:** Nonstationary reliability, service life, design loads, resistance, and structural capacity degradation; and
4. **Adaptation and resilience:** Adaptive design for buildings and infrastructure systems, considering future hazards, material durability, and structural capacity degradation, and strategic planning methods for future conditions.

The impetus for the project was the observed increases in land and ocean temperature extremes; sea-level change; frequency and length of heat waves; and changes in the frequency and intensity of heavy precipitation, flash floods, severe storms, and cyclones. Because of potential changes in environmental hazards and structural capacity over time, the need to advance design practices to incorporate future hazard predictions and their uncertainties into codes and standards for buildings and infrastructure is urgent. NIST continues to conduct research and provide leadership in the advancement and knowledge of these hazards and to provide the science and engineering that supports the development of standards and guidelines that will lead to more resilient communities and economic continuity across the nation.

The workshop development process started with a review of ongoing research, guideline development efforts, and relevant case studies. An extensive workshop preparation process followed this review that convened four one-and-a-half-day workshops to obtain input from experts in these areas and resulted in report preparation and review by the Workshop Steering Committee (Obeysekera et al. 2026a, b, c, d).

The workshops identified a broad range of research and development activities required to advance codes, standards, and engineering design practice that capture the effects of future

conditions and have the goal of reducing impacts from severe environmental hazards. This report includes the discussion of current needs in design practice and specific recommendations on research needs to advance next generation building standards and codes and to achieve specific goals of adaptation and resilience.

SEI is indebted to the leadership of Jayantha “Obey” Obeysekera, Ph.D., P.E., M.ASCE, who served as the Workshop Director and the Workshop Steering Committee members Meg Ackerson, P.E.; Joe Ackroyd, P.E., M.ASCE; Joseph Barsugli, Ph.D.; Kevin Borth, P.E., S.E., M.ASCE; Michel Ghosn, Ph.D., F.SEI, M.ASCE; Matt Gilbertson, P.E., S.E., M.ASCE; Elisabeth Gilmore, Ph.D.; Jack Hogan, P.E.; Sihan Li, Ph.D., P.Eng., M.ASCE; Mari Tye, Ph.D., C.Eng., M.ASCE for their contributions to putting the workshop together and developing this report.

SEI gratefully acknowledges NIST for its leadership and vision for this project. Appreciation is also extended to the many individuals who participated in the workshop. Appendix D lists the names and affiliations of all who participated in the workshop and, therefore, contributed to this report. Thank you to the ASCE staff— especially Katie Stueckle, who served as Workshop Coordinator; Jessica Jun, who served as a Workshop Conference Manager; James Pullis, who served as the Conference Center Manager; and Addie Gordon, who served as a Workshop Coordinator and drafted and edited the final report.

Jennifer Goupil, P.E., F.SEI, F.ASCE
Managing Director Structural Engineering Institute and American Society of Engineers Chief
Resilience Officer

1. Section 1: Workshop Overview

1.1. Introduction

The National Institute of Standards and Technology (NIST) has a long history of conducting research and development to identify methods and practices; to advance codes and standards; and to support the resilience of buildings, physical infrastructure, and communities.

NIST's commitment to the effects of hazards on codes and standards for the built environment, and on engineering more broadly, is reflected in its being the lead agency for the National Earthquake Hazard Reduction Program, the National Windstorm Impact Reduction Program, and its Disaster and Failure Studies Program and Community Resilience Program. Similarly, ASCE/SEI is actively committed to integrating future hazard data and future conditions into technical standards, especially within the national model design standard for structural loads in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE/SEI 7-22, ASCE 2022). The next edition, ASCE 7-28, is currently developing a new section for future hazard design loads. To continue with these efforts, one of NIST's strategies is to further develop codes and standards to better prepare for future hazards and conditions.

The first workshop, *Forward-Looking Codes and Standards: Future Hazards*, held on June 4–5, 2025, and this resulting report, focused on the research and development efforts needed to implement future hazards and associated design criteria in codes and standards, to inform strategic planning for future requirements in the built environment, and to understand potential changes to design requirements.

1.2. Workshop Scope and Purpose

The purpose of the workshops was to provide a science-based assessment of next-generation data and development needs to advance design practice and building standards for future natural hazards and conditions across U.S. communities.

The workshop scope covered the broad subject area of future hazards for codes and standards development, specifically the needed input from scientists, practitioners, and researchers on how to do the following:

- Prioritize research and development needs to advance design practice for future hazards and conditions (beyond the ongoing efforts of ASCE/SEI 7-28);
- Use the best available science to characterize future hazards and conditions for design practice;
- Identify a path toward improving building standards and design practice; and
- Consider resilience, adaptation, and social and economic impacts to businesses and communities.

1.3. Workshop Development Process

The development of these workshops began with the selection of the Workshop Steering Committee (WSC) for all four workshops, which includes climate scientists, structural engineers, and social scientists. They are qualified academics and practicing experts who have worked in the fields of future hazard projections, engineering design, social impacts, resilience, and adaptation. The WSC included the following experts:

- Meg Ackerson, P.E., Arup;
- Joe Ackroyd, P.E., M.ASCE, Assistant Commissioner; Technical Affairs & Code Development; New York City Department of Buildings, NYC;
- Joseph Barsugli, Ph.D., Research Scientist III, CIRES, University of Colorado Boulder, NOAA Physical Sciences Laboratory Affiliate;
- Kevin Borth, P.E., S.E., M.ASCE, Sr. Structural Project Engineer | Associate Vice President, HGA;
- Michel Ghosn, Ph.D., F.SEI, M.ASCE, Professor, the City College of New York/CUNY;
- Matt Gilbertson, P.E., S.E., M.ASCE, Sr. Technical Manager, Simpson Gumpertz Heger;
- Elisabeth Gilmore, Ph.D., Professor, Carleton University;
- Jack Hogan, P.E., Associate Climate Risk and Resilience Engineer, Arup;
- Sihan Li, Ph.D., P.Eng., M.ASCE, Senior Specialist, Associate, RWDI; and
- Mari Tye, Ph.D., C.Eng, M.ASCE, NIST PREP Fellow, Whiting School of Engineering, Johns Hopkins University.

The WSC started meeting in February 2025 to develop the content of the workshop. The WSC selected the following topics as critical issues, and the participants were selected based upon their expertise in these areas:

- Confidence and uncertainty in hazard projections,
- Downscaling of global climate models, and
- Conversion of hazard projections to design loads and associated criteria.

To help understand the current state of hazard development in codes and standards, the WSC identified resources to share with workshop participants in advance: see Appendix C. These documents were used to formulate the workshop sessions.

The one-and-a-half-day workshop was convened on June 4–5, 2025, to identify the priority research needs that form the basis of this report. The WSC invited industry-leading experts, academics, and representatives from key government agencies to attend the workshop. Members of the public were also able to view speaker presentations on the first morning of the workshop via Zoom webinar. The workshop was held at ASCE headquarters in Reston, Virginia (Figure 1-1) and was simultaneously streamed for virtual participants (Figure 1-2). Thirty-eight in-person and 17 virtual participants attended the workshop.



Figure 1-1. In-person participants at the NIST/SEI *Forward-Looking Codes and Standards: Future Hazards* workshop on June 4, 2025.



Figure 1-2. Online participants at the NIST/SEI *Forward-Looking Codes and Standards: Future Hazards* workshop on June 4, 2025.

The design of the NIST/SEI *Forward-Looking Codes and Standards* workshop enabled all in-person and online participants to contribute in multiple ways. The workshop began with subject matter expert presentations of ongoing, synergistic efforts and several state-of-the-practice presentations that were also viewed by registered public attendees.

Following the presentations, the public session concluded, and a plenary session engaged the participants in a discussion to define the state of the art and the future ideal state needed to incorporate future hazards into design standards and codes.

The participants were then divided into breakout groups based upon the number of workshop attendees and asked to consider topics selected by the WSC. In the breakout groups, the participants were given three topics to identify and prioritize research needs: (1) project data needs for future hazards, (2) hazard design needs by design phases, and (3) the science and analysis capabilities needed to address gaps in hazard data by design phase (e.g., conceptual, preliminary, detailed). The breakout groups prioritized the top three to five research needs to address the gaps in available hazard data for future design standards and codes.

Each breakout group then reported back to all the workshop participants in a general session and described its prioritized research needs. Following these presentations and subsequent discussions, the workshop participants prioritized the research needs from all of the breakout groups.

1.4. Workshop Framework

The framework for Workshop 1 was developed around key questions and intended outcomes from the WSC and was organized into three main prompts:

The first topic asked the question: what are the project data needs for design for environmental hazards (such as, but not limited to, level of detail (spatial, temporal), time frame/horizon, etc.).

The second topic asked participants to consider the hazard design needs by phase for (1) planning (concept permits, feasibility) and (2) final design.

The third topic covered the science/analysis capabilities needed to address gaps in hazard data by phase.

1.5. Workshop Report Organization

This report is a record of the event and includes a synthesis of the discussions and distillation of the findings. Following Section 1, Introduction, the workshop report is organized as follows:

- Section 2 describes the current state of the art and summarizes presentations from the workshop.
- Section 3 describes the discussions on advancing the workshop goals that were held during breakout discussions.
- Section 4 describes the top recommended research needs that were identified during the breakout sessions.
- Section 5 describes the analysis of research needs that were identified during the breakout sessions.
- Section 6 lists acronyms and abbreviations.
- Section 7 provides the references cited.

The report also includes four appendices. Appendix A Priority Research Needs includes additional details about the priority research needs identified by each breakout session during the workshop. Appendix B Workshop Materials contains the workshop agenda, copies of the presentations. Appendix C Workshop Reading Materials contains the list of prereading materials sent to the participants. Appendix D Workshop Participants lists the workshop participants in alphabetical order.

2. Section 2: Current State of the Art

2.1. Workshop Presentations

The first set of speakers presented current and ongoing Synergistic Efforts to enable the workshop to then build on the current state of the art.

Abbie Liel (Appendix B.2.1.1) shared the rationale and framework for integrating future conditions into ASCE/SEI 7-28 Chapter 36. The chapter outlines nonmandatory but technically rigorous criteria for future environmental loads, including flood, snow, rain, ice, and wind. Liel highlighted the importance of translating these types of projections into actionable engineering loads and the collaborative efforts among ASCE, the National Oceanic and Atmospheric Administration (NOAA), and other entities to support this initiative.

Dan Walker (Appendix B.2.1.2) discussed the collaborative efforts between NOAA and ASCE to advance resilience in civil engineering practice. His presentation highlighted the outcomes of joint workshops, task forces, and technical notes aimed at bridging climate science with engineering applications. He emphasized the importance of co-producing knowledge, integrating projections into design workflows, and developing standards that reflect future hazard scenarios. Walker also highlighted the challenges of downscaling models and the need for credible, fit-for-purpose data to inform infrastructure design.

Sihan Li (Appendix B.2.1.3) introduced the work of the ASCE Committee on Adaptation to a Changing Climate. This committee focuses on promoting awareness in civil engineering, connecting practitioners with resources, and facilitating the integration of climate science into engineering standards. Li reviewed past research outputs, including manuals of practice and technical reports, and described ongoing efforts. The committee's work aims to support adaptive design and resilience across infrastructure sectors.

Michel Ghosn (Appendix B.2.1.4) presented findings from the ASCE/SEI Effects of Climate Change on Life-Cycle Performance of Structures and Infrastructure Systems project, which developed methodologies for assessing climate impacts on infrastructure safety, reliability, and risk. The presentation covered projection models, hazard attribution, and structural performance under nonstationary conditions. The project culminated in a multichapter report offering guidelines for future design practices. Ghosn stressed the need for risk-informed design, coordination among climate scientists and engineers, and the development of standards that reflect long-term risks.

The second set of presentations focused on Practice Perspectives for future hazard characterization.

Kevin Borth (Appendix B.2.1.5) presented a case study on the Derby Line Land Port of Entry in Vermont, where future risk analysis was integrated into the design process. The project involved assessing current and projected impacts, including snow, wind, and temperature

extremes, and incorporating resilience measures into mechanical and structural systems. Borth described the extensive documentation used to inform design decisions, including protection levels and adaptation strategies.

Badre Enam (Appendix B.2.1.6) represented the East Side Coastal Resiliency project in New York City, focusing on the importance of adaptability and resilience in urban flood protection systems and structural design challenges. The project aimed to provide integrated flood defenses while enhancing waterfront access and urban design. Enam discussed hydraulic design considerations, including sea-level-rise projections and Federal Emergency Management Agency (FEMA) standards, and structural challenges such as vessel and vehicle impact loads. He highlighted the need for standardized floodwall components and the complexities of interfacing with existing infrastructure.

Finally, Meg Ackerson (Appendix B.2.1.7) shared the California High-Speed Rail project, which integrated climate data into infrastructure planning. The project addressed hazards such as temperature extremes and riverine flooding, using projections to inform design decisions. Ackerson discussed the challenges of applying these data into large-scale transportation systems and the importance of interdisciplinary collaboration. Her presentation showed how future hazard characterization can guide resilient infrastructure development in complex environments.

2.1.1. Future Hazard Characterization

The plenary session engaged participants in a discussion to prepare them for the breakouts by collectively defining the current state of the art for hazard characterization and the future ideal state for hazard characterization 10 years in the future. The plenary discussion was intended to provide a common understanding of the current and future state for the breakout sessions to develop a list of the top three to five research needs to advance future hazard characterization and design. The current state of the art was established by overviewing the co-evolution of climate science and engineering standards/practice, based on a report from the 2024 ASCE–NOAA Summer Summit. A moderated discussion among the participants began to establish collective goals for the future state of characterizing hazards for engineering applications.

2.1.2. Current State of the Art

During the plenary session on the first day of the workshop, Joseph Barsugli, Ph.D., shared findings of the ASCE-NOAA partnership in his presentation, *The Co-Evolution of Engineering Practice and Climate Science*. The presentation summarized recent efforts by the ASCE–NOAA Task Force to understand the evolving needs of civil engineers for climate, weather, and other earth system data to support engineering standards and broader engineering practice. An overview of the presentation is provided here.

The Task Force held workshops in 2022 on data and science needs related to wind, temperature, coastal flooding, and heavy rainfall hazards in anticipation of the ASCE/SEI 7-28

standard update. The follow-on workshop in 2024, documented in the report *Climate Risk Reduction: Hazards and Processes for Operationalizing Climate Information into ASCE Standards and Manuals of Practice* (ASCE 2024), focused more broadly on hazards and on the process of connecting research to practice for additional ASCE standards, manuals of practice, and other engineering guideline documents. ASCE involvement was also expanded and included members from SEI, the Environmental and Water Resources Institute, the Coasts Oceans Ports and Rivers Institute, and the Geo-Institute.

The ASCE–NOAA Task Force workshop breakouts adopted a “practice-to-practice” approach, where the current engineering practice is used as the foundation for determining how to include future hazard conditions. The goal of the breakouts was to address future hazards, including data needs for engineering use cases related to six hazard types (Figure 2-1). The participants identified relevant hazard and other data; data characteristics such as requirements for statistical treatment; relevant ASCE standards and guideline documents; and contextual information including typical spatial scale, service life, or time frame for more than 60 engineering use cases. However, creating detailed specifications for data products was beyond the scope of the breakouts and requires further focused efforts.

The Task Force workshop report identifies cross-cutting data needs that would serve multiple use cases as higher priorities for further development, including the following: Completion of NOAA Atlas 15 for short-duration rainfall extremes, Volume 1 (nonstationary extreme value analysis of historical period) and Volume 2 (projections); projections of air freezing index (currently funded) and other temperature indicators used by cold regions engineers; provision of input variables for use in watershed-scale hydraulic modeling of flooding; development of projections of changes in groundwater/soil water (perhaps only directional risk may be possible); and continued development of data products to support compound flooding, particularly coastal flooding, including NOAA’s coastal reanalysis.

Breakout Sessions by Environmental Hazard	Highlighted Use Cases/topics
Temperature extremes (emphasis on Cold Regions)	Thermal management for permafrost Cold Regions Utilities Frost-Protected Foundations* Building envelope design*
Heavy Precipitation (beyond ASCE 7-28 needs)	Building External Loads* Stormwater control Hydrological and Hydraulic Modeling* Reservoir Operations
Compound Flooding	Inland* Lakes & Coastal* Groundwater flooding* Rain-on-snow flooding*
Impacts on earth materials	Groundwater loading, uplift* Soil Liquefaction Mass movement of Rock Frost Heave
Snow	Basic Roof Snow Loads* Drifting Snow* Rain on Snow Roof Loads*
Wind Extremes	Thunderstorm winds* Tropical Cyclone winds Tornado (future)

Figure 2-1. Selected use cases from the 2024 ASCE–NOAA Workshop report (ASCE 2024). Use cases that relate more closely to structural engineering standards are highlighted with an asterisk.

From the perspective of climate science and dataset development, several trends in engineering practice are driving the need for more complex earth system data. Perhaps the most pressing driver is the desire for reliable projections of future hazard values under climatic nonstationarity. As a result, many engineering analyses will shift from a stationary paradigm, which uses observational data, to the additional incorporation of projected data. The significance and difficulty of this shift should not be underestimated. The need is not only for climate model projections, but also for post-processing to translate climate model output to localized values of specific hazards that are of interest to engineers. This need goes beyond downscaling and bias-correction of climate model variables. Many hazards are not well represented in the global climate models, thus requiring a second modeling step to estimate these hazards (often called an “impacts” model in the climate science literature). For example, estimates of ice deposition hazard relies on identifying episodes of freezing rain. While an observing station can measure freezing rain, estimation from large model grids requires more effort. These estimates require model output from temperature, humidity and other model variables at multiple vertical levels in the atmosphere and at a time resolution of an hour or

less, potentially amounting to terabytes of model data to process for the development of future ice hazard maps.

The move toward reliability-targeted loads puts more demands on data providers to enable better characterization of the entire upper tail of the hazard probability distribution, both in the historical observations and in future projections. More broadly, performance-based design can require a more detailed characterization of hazards beyond the most extreme or nominal design value of a design parameter. For example, the prestandard for performance-based wind design (ASCE 2019) mentions wind direction and duration of wind events as relevant, in addition to mean wind speed and gust metrics. Adaptive design strategies intended for dealing with future uncertainties, such as dynamic adaptive pathways, track several future scenarios and indicators of change to inform when to trigger adaptation actions.

Compound events can refer to multiple hazards, or to multiple drivers of a single hazard, and require more holistic treatment of extreme events that cannot be obtained from single-hazard datasets. The treatment of combined (correlated) loads is one example where a shift from “principal” and “arbitrary point in time” loads to explicit treatment of correlations among hazards may be necessary. Compound flooding, where multiple flooding mechanisms determine the water depth, requires coordinated, consistent datasets across many processes. Obtaining observational data to support the analysis of these events is not simple, and the process becomes even more difficult for future conditions. The overall message is that evolving data needs are on a spectrum. Past history has demonstrated that focused and sustained collaborative efforts driven by engineering needs will likely have the greatest chance of success.

2.2. Goals for Future State

The plenary discussion centered on the challenges and opportunities for integrating future hazard data into engineering and design workflows. A key theme was the need to better utilize current hazard data, especially in the context of future time horizons and nonstationary climate conditions. Participants emphasized that many engineers are unaware of the future hazard datasets available or the scientific basis behind them, highlighting a gap in co-production between climate scientists and engineers. Participants also called for national-level agreement on which datasets are most appropriate for design purposes and how to apply them in projects and use them in standards, particularly when dealing with extreme events and multivariable stressors under future conditions.

Another major focus was the credibility and scalability of downscaled climate models. While local-scale projections are often desired for engineering applications, the group cautioned that higher-resolution models do not necessarily produce equivalent data quality and are likely to have increased uncertainty. Issues such as bias adjustment, representativeness, and the inclusion of critical processes (e.g., lake interactions in the Great Lakes region) were flagged as essential for ensuring local model outputs are fit for purpose. The discussion also touched on the limitations of current modeling approaches, the need for multiple future scenarios for addressing several engineering needs, and the importance of clear guidelines on how to

evaluate and apply future hazard data in project design. Overall, the consensus on the need for scientific assessment, transparency about uncertainty, future design considerations, and practical guidelines to support informed decision-making for buildings and infrastructure was strong.

The workshop participants envision a future design ecosystem where engineers and climate scientists work in close partnership to co-produce data, tools, and guidelines that are scientifically robust, useful, and usable. This vision includes the following:

- Climate data that will be seamlessly integrated into engineering workflows, with clear national consensus on which datasets are most appropriate for different design contexts and how to apply them.
- Downscaling techniques that will be applied with discernment, guided by rigorous scientific assessments that clarify when and how local-scale projections are credible and fit for purpose. The limitations of models—whether statistical or dynamic—will be acknowledged openly, without paralyzing progress.
- Engineers and design professionals who will have access to scalable, transparent, and well-documented resources that account for nonstationary conditions and multiple future scenarios and address the full range of uncertainty, empowering them to design resilient infrastructure that anticipates future hazards.
- Project teams who will be equipped with practical guidelines to evaluate future hazard datasets, understand their appropriate applications, and navigate associated uncertainty with confidence.

Ultimately, the goal is to foster a culture of informed decision-making, where future resilience to changing hazards and conditions is a shared responsibility across disciplines.

3. Section 3: Discussion of Advancing Future Hazard Characterization

This section includes summaries of the discussions that occurred in the breakout groups. The participants in the breakout groups discussed several prompts before agreeing on the research needs, which are summarized in Section 4.

3.1. Breakout 1

TOPIC 1: Project Data Needs for Hazards (Such as, but Not Limited to, Level of Detail [Spatial, Temporal], Planning Horizon, etc.)

In recently developed editions of Canadian building codes, the change factors for future climate conditions are produced at the city level and averaged over the provincial level, rather than being regionally downscaled. For hazards such as basic wind pressures and ground snow loads, the scaling factors are generally relatively small, typically ranging from approximately 5% to 10%, and these factors are revisited every five years to remain up-to-date with the latest available science.

The selection of an appropriate time horizon is essential in evaluating future hazards, particularly because the design life of different building elements can vary significantly. For example, the structure itself may be designed with a design life of 50 years (i.e., the reference period in Chapter 1 of ASCE/SEI 7-22), while HVAC, electrical, or plumbing equipment may have shorter lifespans. Therefore, understanding the appropriate time horizon is critical when selecting and utilizing data from climate models.

The level of detail in the future hazard data needed for building design varies by hazard types. For instance, assessing wind loads may require very localized analyses to capture short-term events like thunderstorms, which may not be represented in global, or even regional climate models. Similarly, flood hazards necessitate local modeling or analysis at the watershed level. However, future snow loads might be adequately represented at the regional level.

Future hazard projections inherently have a much greater degree of uncertainty than that associated with historical data. In addition, even past observations may not be stationary. Some factors, such as sea-level rise, are demonstrably nonstationary and have exhibited increasingly nonlinear trends in recent years.

In the context of flood risk, no uniform national approach currently exists for addressing future conditions; instead, individual jurisdictions at the municipal or state level often implement regulations to address worsening flood risk. Examples of cities that have adopted enhanced flood regulations include New York City; Boston; Houston; and Norfolk, Virginia.

Load combinations must consider multiple hazards occurring simultaneously or in tandem, such as the combined effects of wind and flood loads. In addition, the risk category or particular use

of a building may justify applying different climate scenarios depending on the criticality of the structure.

Notably, while climate models include extreme events to some extent, these models often overlook the role of the built environment itself. Factors such as impervious surfaces, drainage infrastructure, and urban development can significantly influence how hazards are experienced on the ground, for instance, by amplifying flood risk through increased runoff.

TOPIC 2: Hazard Design Needs by Phase: (1) Planning (Concept Permits, Feasibility) and (2) Final Design

In the initial stages of project planning and design, different aspects of environmental hazards are often more critical to define precisely than others. For flooding, early-phase decisions should prioritize future conditions that may influence project siting considerations—such as riverine erosion zones and projected future flood extents—over precise quantifications of floodwater elevation or flood velocity. In coastal flooding locations, a common approach at this stage might be the use of a simplified, linear sea-level-rise “bathtub” model to gain a general sense of vulnerability to flooding in the future. However, as the design progresses, a detailed coastal model that incorporates future water levels and storm events might be necessary to more accurately define the flood effects, such as loads on the structure. Future projections for wind tend to become more relevant during the design development phase because they can often be closely tied to the structural configuration of the building. The level of detail required for other types of natural hazards, such as rain or snow, is generally consistent throughout the design process.

Certain geographical regions, such as special regions for snow or wind, may require more advanced modeling and localized analysis earlier in the design process. High-level risk assessments conducted at the start of a project aim to answer key questions: Is the hazard expected to increase or decrease over time? Do any siting limitations influence the long-term performance of the project? Which screening tools or maps are available to help guide project decisions?

Artificial intelligence (AI) may help streamline the hazard assessment process. AI could be leveraged to automate data documentation, generate maps, and analyze various scenarios, allowing project teams to focus more on design development.

TOPIC 3: Science/Analysis Capabilities Needed to Address Gaps in Hazard Data by Phase

Evaluating future flood hazards is a significant challenge due to the highly site-specific nature of flooding. While projections such as sea-level rise and changes in future precipitation may be available, localized analyses must be performed to accurately define the flood characteristic to a level of precision suitable for design. This makes developing reliable flood hazard maps and design criteria a significant undertaking compared with other environmental hazards.

Currently, private companies, such as KatRisk, develop most hurricane models used to estimate storm-related hazards. A need exists for publicly available, peer-reviewed, and transparent hurricane models that incorporate future conditions, such as U.S. Army Corps of Engineers (USACE) U.S. Army Engineer Research and Development Center developing information for FEMA or ARA-developed hurricane maps in ASCE 7. These models could provide a standardized basis for developing hazard data for design applications.

Compound flooding, in which multiple sources of flooding, such as precipitation, riverine overflow, and coastal storm surge, occur simultaneously, is expected to worsen in the future. Models that aim to assess compound flooding need to account for future climate scenarios, such as sea-level rise.

Methodologies are needed to estimate the nonlinear relationship between sea-level rise and coastal flood impacts more rapidly. Simply adding projected sea-level rise to current flood conditions does not adequately capture the increasing severity of future flood risks; however, precise modeling is too costly and time-consuming for many projects.

Improvements to our existing rain and stream gauge infrastructure are critical. More frequent and extensive measurements are needed to capture hyper-localized weather events, such as microbursts or flash floods. This would support more accurate and responsive stormwater and riverine flood modeling.

Flood hazard modeling and mapping for future conditions should be decoupled from the National Flood Insurance Program (NFIP) and its Flood Insurance Rate Maps, which are intended for insurance purposes and do not reflect forward-looking design criteria.

Artificial intelligence may help users navigate building codes, interpret future hazard data, and assist with design tasks. These tools can streamline decision-making processes and improve the integration of future hazards into project planning and design.

3.2. Breakout 2

TOPIC 1: Project Data Needs for Hazards (Such as, but Not Limited to, Level of Detail [Spatial, Temporal], Planning Horizon, etc.)

The group identified that moving from climate models to specific projected loads requires an overlap among the spatial capabilities of the models with respect to the localized nature of structural loading. The ability of models to capture specific hazards, and their interaction with human elements such as land use, can vary considerably by hazard and location. While comparing local weather stations to the equivalent Earth system model grid cell is not possible (or advisable), deriving the needed information is often possible. This requires clear communication from engineers regarding the hazards, metrics, and statistics needed for design and from scientists with respect to different model capabilities and the methods used to derive decision metrics. Deep understanding of the bounds of uncertainty is not always necessary but

depends on the application. Improved communication could be achieved through bilateral communication of the large uncertainties that are also present in current-day design assumptions and those in climate models and attendant scenarios.

The group recommended the co-development of a consensus source for best practices in integrating future projections with engineering applications and determining the reliability of models, the scope of uncertainty, and guidelines on when specific and tailored information is necessary. Various entities have produced best-practice documents enabling engineers to ask the right questions for their installations, but these documents are not necessarily well-known or used by the majority of practice. A comprehensive document could also include how to leverage well-established engineering design techniques, such as station pooling, in the use of Earth system/future data. Furthermore, the handoff from model development to engineering communities has in the past taken place through boundary-spanning organizations and programs that have evolved over the last couple of decades. As those organizations disappear or disintegrate and expertise is absorbed into other roles and sectors, the need for well-documented guidelines is even greater.

Many data are known only to individual research communities but could be utilized by other projects. For instance, the Bureau of Reclamation and USACE have completed many basin-specific climate studies for hydrological and energy projects. While the output may not be viable for direct use, they could be used with advice, as noted previously, as input parameters or boundary conditions for more detailed flood models. However, the breakout group noted that the real limiting factor is the lack of a comprehensive, curated, and indexed repository of data sources and their derivatives that can be use in design; that are Findable, Accessible, Interoperable and Reusable (FAIR); and that will be maintained and archived indefinitely.

TOPIC 2: Hazard Design Needs by Phase: (1) Planning (Concept Permits, Feasibility) and (2) Final Design

The group agreed that the data to support the design planning phase are largely available although not readily accessible or well documented. Qualitative maps to help designers determine whether a project is within different hazard zones, the relative risk (high, medium, low), and likely severity would be beneficial. Specifically, burn probability maps were identified as a useful and needed high-level tool.

The qualitative maps identified for planning needs could in some cases be supplemented with quantitative information similar to the hazard maps used for design loading, including for wind speed and direction for wildfire assessment, flood depth and velocity, and source. As different organizations are already producing the data, the group recommended the establishment of standards to validate and ensure data quality, with a regular review cycle similar to other codes and standards. Embedding a comprehensive review cycle into infrastructure permitting to ensure that the asset still meets the hazard design requirements is also needed.

While large projects may have the resources to collaborate directly with Earth system scientists, or carry out site-specific data analysis, smaller projects are unlikely to have the same flexibility. However, engineers often follow similar workflows. Developing a framework to obtain and process the appropriate data—with decision criteria guidelines around data provenance and robustness—could enable engineers to calculate the local products that meet their needs. Caution was expressed that design engineers may be blind to future hazard risk in their region arising from their habituation to local constraints and norms. A solution may be the production of a checklist of (region-specific) hazards that may change in ways that are not obvious or might, for some other reason, not be considered.

Specific hazard requirements for design that the group considered poorly understood or documented at the moment include

- Load combinations and their evolving joint probabilities (e.g., rain on snow);
- Groundwater table responses to precipitation, intermittency, sea-level changes, and abstractions, and the subsequent influence on liquefaction effects;
- Snow, particularly urban snow and associated roof loading; energy exchange between snow and roofs; and intensity and frequency of heavy snow and associated freeze thaw; and
- The human influence on the built environment and responses to changes in hazards such as wildfire.

TOPIC 3: Science/Analysis Capabilities Needed to Address Gaps in Hazard Data by Phase

Explainable machine learning and AI methods could be leveraged to move directly from Earth system model outputs to nonstationary design loads. The emphasis has to be on explainable—whether the physical responses make sense—and ensuring that machine learning helps to constrain sources of uncertainty rather than adding another level. This will require best-practice guidelines for machine learning model architecture and data sharing, co-developed among computer scientists, engineers, and Earth system scientists to build the guard rails for trustworthy AI.

The uncertainty in the model and observational data and the safety factors employed by engineers in design and their associated tolerance for risk need to be reconciled. While improved communication of all assumptions and uncertainties in the existing science is imperative, so too is the acknowledgment that conservatism in design codes and standards masks empirical uncertainty in material and structural responses. Quantifying the margins of error in design may be sufficient to accommodate the projected hazard uncertainty over the design life of the structure.

Some advances in hazard assessments could be made by adopting the advances in statistical methods (e.g., spatial extreme analysis) made over the last two decades.

3.3. Breakout 3 and 6

Breakout groups 3 and 6 were originally two separate groups dedicated to virtual participants. Due to the small size of these groups, they were combined at the start of the breakout session into one larger breakout group.

TOPIC 1: Project Data Needs for Hazards (Such as, but Not Limited to, Level of Detail [Spatial, Temporal], Planning Horizon, etc.)

Reanalysis of land-based versus gridded snow products is an area that needs project data. Similarly, a need exists to understand variations in historical snow measurements. Data should also be able to bridge the gap between observations and second-order climate variables or modeled climate data. Better understanding of what most affects or produces the maximums is necessary because that understanding can enable us to identify where this is relevant to projects in specific regions rather than applying it universally.

Assigning levels of confidence to different variables is important. Wind presents a challenge because it is not very representative, so communicating confidence to engineers is key. Scenario likelihood and a clear definition of available data are also needed. In the context of risk-informed decision-making, we need context for uncertainties in design-level estimates in ASCE 7. Transparency in providing information for engineers is crucial, as we have shifted uncertainties to climate science and modeling by focusing on engineering. We must consider how specific the load needs to be to address design considerations and identify cut points for changes in design, as this may affect how climate science addresses uncertainties.

Identifying “actionable uncertainty” is necessary, and we must be thoughtful about what is actionable and for what purpose. This suggests that a range of plausible scenarios could be tied to types of project risks. Should we prescribe certain scenarios for certain types of structures? For example, precedent exists for earthquakes, where conditional probabilities are assigned to some structures.

TOPIC 2: Hazard Design Needs by Phase: (1) Planning (Concept Permits, Feasibility) and (2) Final Design

In the planning phase, understanding which hazard-specific risks are present for the project is needed. The communication issue for stakeholders is unique, differing from engineering design requirements, as opposed to specific technical requirements for the final design. Then, for the final design phase, detailed technical needs for design were discussed extensively. How local building officials work varies significantly; therefore, the standard for evidence-based approaches at the local level is low. Is there an educational component for building officials and owners or operators to consider when integrating new design standards? To address residential construction, we require an entirely different scope—not ASCE/SEI 7—focused and not ASCE/SEI 7 or the International Building Code (IBC)—that could pertain to International Residential Code (IRC), which follows a different approach and covers 90% of the economic activity in buildings.

TOPIC 3: Science/Analysis Capabilities Needed to Address Gaps in Hazard Data by Phase

Many ensemble members of multidecadal global climate model (GCM) simulations at convection-permitting model resolution are needed. Convection permitting means higher spatial resolution, and large ensembles involve many different models. Multidecadal simulations driven by different scenarios aim to achieve plausible outcomes, and ensembles allow multiple runs to address sources of uncertainty. What can be done for the engineering community? Efforts should improve to meet ASCE/SEI 7-28 data needs, such as the 15-minute rain load standard, which will be influenced by convection everywhere. This would be an appropriate model type for this application. Variables with high engineering value, such as 15-minute precipitation and 1-hour variables, should be selected. Future climate model development should consider specific engineering sectors and needs and incorporate them into new model development. Part of the success of the Canadian experience with the building code update was due to bespoke GCM output variables being archived by colleagues in Environment and Climate Change Canada (ECCC) specifically for codes and standards work. The idea is that this could be an experiment developed even earlier through the World Climate Research Program. Dynamic downscaling or regional climate models may potentially be sufficient to meet the modeling needs outlined in the prior request.

In the context of performance-based engineering and reliability analysis, a formal collection of software to facilitate rapid iteration with different climate product data (ideally through a cloud-based framework) is desirable and would help us understand which elements in design models are most sensitive to changes. Actionable uncertainties must be addressed by understanding and developing methods to propagate types of uncertainty into the most concerning design values. Additionally, reliability targets can now be tested for the most important factors. Looking forward, Coupled Model Intercomparison Project, Phase 7 (CMIP7) will be released in a couple of years, so a need exists to map out what can be done with the types of information expected in the next three to five years. Some information could help address uncertainties for practitioners involved in creating standards. Prior assessments evaluated climate based on sensitivity (such as “hot model” problem,) and should be considered and evaluated. (Cannon 2024; Hausfather 2022)

Engineers are grounded in the historical record and need to understand what has been seen historically and what is or is not consistent with climate model performance. A process for determining which types of models and data are fit for purpose is necessary, along with advice from climate scientists.

Communication and sustained co-production engagement are also critical; the way climate science is communicated to engineers is a pertinent question. Engineers expect data to equal observations and may be skeptical of model-source data for design parameters, presenting an education and communication challenge. Data and observations depend significantly on the type of project and its phase, so a menu of options is needed to meet engineers’ climate science requirements—some may not need much, while others require details. Currently no

climate boundary organization connects civil engineering applications, and conversations would be needed to determine if this is desirable and achievable. Finally, the economic argument must address more than just life safety; it also needs to focus on risk mitigation, which relates to life-cycle cost.

3.4. Breakout 4

TOPIC 1: Project Data Needs for Hazards (Such as, but Not Limited to, Level of Detail [Spatial, Temporal], Planning Horizon, etc.)

During construction, the unfinished structure could be subject to extreme weather events such as strong winds or heavy snow and prolonged rain that can affect soil conditions. Such events may introduce unexpected loads on the incomplete structure and its foundations, jeopardizing its structural stability. The design of temporary support systems to stabilize the incomplete structure requires the collection of short-term projections of hazard data to avoid construction failures. The load magnitudes to be considered in this phase are necessarily lower than the maximum magnitudes expected over the service life of a structure because their effects pose a lower risk to the wider community. As an example, for wind loads, *Design Loads on Structures During Construction* ASCE/SEI 37 (ASCE 2014) allows the application of reduction factors to design wind speeds for short-term exposures during construction. These factors range between 0.75 and 0.90 for construction periods lasting from six weeks to five years, respectively. These reduction factors are applicable for historic stationary conditions and may need to be updated to account for future conditions.

Structures should be designed to not only withstand the maximum expected loads but also to ensure their functionality and the comfort of their users and to avoid severe deterioration. Design codes and standards address these issues through “serviceability” criteria that can be classified into three categories: (1) deformations, (2) motion perception, and (3) deterioration.

Deformations, including lateral drift of buildings, bridges, and other structures, may cause local damage to nonstructural elements (e.g., ceilings, cladding, partitions) in buildings and issues for traffic safety and bridge users due to deflections under dead, live, wind, or snow load. Extreme temperature and humidity exacerbate large deformations, which may also lead to concrete creep and excessive stresses on connections and expansion joints. Motion perception, including vibrations and accelerations in tall buildings and long-span bridges under wind load, is a cause of discomfort to building occupants and traffic on bridges.

Deterioration includes items such as corrosion, weathering, efflorescence, discoloration, rotting, and fatigue. These are affected to various degrees by temperature variations and relative humidity, air salinity, carbon dioxide (CO₂), freeze-thaw cycling, and radiation exposure. Also, hail can cause major damage to building envelopes and is known to be the second most important driver of insurance claims. Repeated oscillations due to wind loads may lead to fatigue failure of structural components such as light-gauge roofs in buildings and hangers in cable-supported bridges, which could potentially lead to major disasters.

Fatigue and freeze-thaw cycling result from accumulated damage from a large number of cycling loads with relatively low amplitudes. Thus, collecting information on the rate of wind load occurrences and their intensities, freeze-thaw cycles and cyclical variations in temperature, and relative humidity is as important as collecting data on extreme loading events.

Basing maximum deformation criteria on the most severe expected loading that may occur only once during the service life of the structure is unrealistic and too stringent because the consequences of exceeding a serviceability limit state are usually not safety related. Various researchers have suggested different mean recurrence intervals for addressing serviceability issues. In particular, proposals have been made to develop criteria on an annual probability basis for issues related to deflections and motion perception.

Although serviceability checks are performed after the initial design of the structure for maximum loads, in many cases the serviceability criteria control the final design. Therefore, establishing adequate criteria associated with appropriate data on hazard intensities and frequencies over properly established planning horizons deserves more attention than they currently receive. (Griffis (2003), Galambos and Ellingwood (1986), and Irwin et al. (2021))

ASCE/SEI 7 was developed so that structural designs achieve uniform target reliability indexes for different building categories within a 50-year reference period. Although documents often refer to this reference period as “design life” or “service life,” the 50-year reference period is only intended to provide a basis for developing design criteria and as a means to compare the performance of new designs with those that have historically shown acceptable levels of safety over the years. The 50-year reference period does not imply that structures will collapse 50 years after their construction, and no evidence suggests that well-designed structures built with the loads determined based on the traditional 50-year reference period have incurred high failure rates.

Nevertheless, in many cases where the structure is expected to remain under the same ownership for very long periods of time, owners have requested that the reference period be extended to longer time frames. The standards were developed under the assumption of stationary conditions whereby the past may also represent the future, which may not be true for many types of hazards with statistical parameters that have shifted over the years. Most climate projection studies have concentrated on projecting future hazards up until the end of the century. Extending climate projections beyond the year 2100 is difficult and involves large levels of uncertainty. Yet, some clients such as hospital owners have asked their structural engineering teams to extend the design reference period from 50 years to 100 years. For the design of bridges, the American Association of State and Highway Officials developed its specifications on the basis of a 75-year reference period. For most hazards, the extension of the reference period may not lead to significant changes in the design loads and, depending on the region, may even indicate a decrease in some loads such as snow or ice. Under stationary conditions, increasing the reference period from 50 years to 100 years may increase the design

loads by about 5%, which is, generally speaking, within a range that would not lead to significant changes in required member resistance capacity and construction cost. This may vary by region or conditions: some initial calculations done by the ASCE/SEI 7-28 Future Conditions Subcommittee wind task committee suggest the increase of wind loads for longer service life can be larger than 5% depending on the variability of wind climates. Alternatively, accommodating the desire of long-term owners to increase the safety levels of their structures can be accomplished by choosing a higher building category than recommended in the standards for their intended function. For bridges, the same can be achieved by changing the classification of the bridge importance—say, from “essential” to “critical”—which increases the design loads by 5%. Finally, realizing that currently available data and climate models do not provide sufficient information and confidence levels in projected future conditions beyond the year 2100 is important. This obviously limits our ability to estimate future loads under nonstationary conditions while recognizing that the 5% increase associated with the 100-year reference period for stationary time-varying design loads may shift higher for nonstationary increases in climatic hazards.

The demand of long-term owners for higher safety levels contrasts with the aims of developers who seek to minimize their construction costs to the largest possible extent to realize the maximum possible short-term gain because construction developments typically undergo 5-year turnovers in ownership and the consideration of long planning horizons is not advantageous to them.

It should be emphasized that the determination of the primary loads to consider for design may differ from those observed from historic data. For example, a current site may not be classified as a risk in current flood maps. However, increased precipitation may make it more susceptible to future floods.

The design of structures not only requires the maximum effect of a hazard to be considered but also the combination of hazards. The current load combination factors in ASCE/SEI 7-22 and other standards assume that the combined hazards and their load effects are uncorrelated. The standards assume that the maximum combined loading will take place when the primary hazard is at its most extreme projected intensity and the second hazard is taking an average point-in-time value. While this approach has worked well in the past based on historic stationary hazard conditions, a review of the underlying assumptions is necessary to analyze future conditions and to study the effects of possible correlations among the hazards (e.g., wind and rain, rain on snow, wind and ice). The correlation among the influence variables that convert the hazards into load effects, the frequency or rate of occurrence of hazards, and hazard coincidences are also important factors. The duration of an extreme hazard is critical in many cases. For example, a slow-moving hurricane is more likely to combine with other extreme events than a fast-moving tornado.

Changes in future hazards can also change the effects of other hazards. For example, sea-level rise can amplify the effects of a tsunami. Similarly, sea-level rise may increase risk of structural collapses due to earthquake-related soil liquefaction, wildland fires may increase susceptibility

to landslides, repeated wind loads could reduce the stiffness of buildings affecting their vulnerability to seismic and other loads, and flood-related foundation scour increases the risk of structures to all other loads and hazards.

Life-cycle analysis (LCA) seeks to optimize the total cost of a structure over its entire lifespan. It considers all costs, including material selection; structural design; construction; operation; maintenance; inspection; repairs; rehabilitation; and ultimate disposal, recycling, or reuse. LCA helps optimize design choices by comparing alternatives and identifying cost-effective maintenance decisions that minimize long-term expenditures and extend the useful life of the structure.

Standards do not specify the planning horizon for an effective life-cycle analysis, which would depend on the priorities of project owners, their long-term plans, and risk tolerance. Life-cycle engineering can thus provide an approach for long-term owners to go beyond standard-defined reference periods and select a life-cycle range that matches their expectations. As such, the hazard data needs for effective life-cycle analyses are much more involved than those required for design. The approach requires the collection of site-specific hazard data for the select life-cycle period, which has ranged between 50 and 100 years in the existing literature, depending on the nature of the structure and its sector. After identifying all pertinent future hazards for the site, the approach requires the application of performance-based design principles to check the safety of the structure under the effects of extreme hazards and the possible simultaneous occurrence of hazards and the possible repeated occurrence of events on the original structure, a rehabilitated structure, or a structure partially damaged by previous events. A full-fledged life-cycle analysis requires the consideration of the safety of the structure and the costs associated with its construction and management, including its resilience in terms of estimating its reduced capacity after a damaging event and the speed of recovery. Risk assessment associated with LCA will allow for the determination of the optimum reliability target for design for a preselected service life. If properly implemented, a life-cycle-based risk analysis will provide an approach that long-term structure owners can use to decide on the design criteria that best serve their needs in accordance with their priorities and risk tolerance.

Life-cycle engineering also provides the opportunity to implement methods for adaptive design. Predicting future changes in hazards involves large levels of uncertainties. Therefore, monitoring these changes and the response of the structure over the life cycle of a project would be essential to observe how consistent the actual changes in the hazards are with prior estimates. In adaptive design, adjustments and modifications to existing designs are made if the observed trends indicate that previous assumptions would negatively affect structural safety. For example, the initial design of a flood wall can be configured to allow the height of the wall to be increased if, years after construction, flood levels were observed to be moving higher than initially assumed. Adaptive design requires sufficient foresight to ensure that the structural system can accommodate potential revisions without major deconstruction and rebuilding effort.

The level of spatial and temporal detail varies among models. Future hazard data are obtained from regional climate models (RCMs) that build on those obtained from GCMs. They provide hazard data on a spatial scale of 10–35 km, which is generally considered sufficient for structural design and assessment purposes as this is consistent with the scale used in developing historic load maps in structural design standards, although narrower 1 km scale local data have also been modeled by introducing refined site information in RCMs.

Although most research has focused on the horizontal spatial scale, modeling temperature and pressure on the vertical scale is critical for projecting future intensities of snow, freezing rain, and hail.

RCM algorithms can provide hourly and daily resolutions, which are typically sufficient for most hazards. Although the 3 s gust and the 15 min pour are required for wind and rain loads, these can be obtained by adjusting the hourly data.

TOPIC 2: Hazard Design Needs by Phase: (1) Planning (Concept Permits, Feasibility) and (2) Final Design

The structural design process involves distinct phases that require different levels of hazard assessment. Specifically, four design phases and an implementation phase are generally identified: (1) conceptual design, (2) schematic design, (3) design development, (4) construction document, followed by (5) construction.

In the conceptual or preliminary design phase, the architects work with the owners to develop the form and layout of the building or structure depending on its intended function. The identification of the pertinent loads and hazards is required at this stage based on functional needs and code requirements. If the site is within a flood zone, then site-specific flood hazard data are needed at the beginning of the design process as flood would help specify the location of a structure on the site, floor level elevation in buildings, and location of piers for bridges.

The schematic design adjusts and refines the conceptual design to give a general idea of the project shape, including structural layout, building floor plans, exterior elevations, and space relationships. A more complete list of relevant hazards is established based on structural type, building category, structural shape and elevation, project location, and site conditions and constraints. The process involves an understanding of the various structural load paths to identify how different loads will be transferred through the building's structure.

The design development phase involves a complete set of thorough calculations to determine the details of the structural system, including the type of materials and dimensions for each component, the arrangement of structural elements, and the connections among them. In addition to dead and live loads—and seismic loads, if relevant—pertinent climatic hazards, such as wind intensities of precipitation including rain, snow, and ice, and floods, are quantified and used as input to a detailed analysis of the load effects of all these hazards and their load combinations.

The construction document phase focuses on finalizing and refining structural plans and specifications to ensure they are ready for construction and to obtain the necessary permits. The detailed designs are presented in a complete and precise set of documents that will be used to build the project. The process involves completing outstanding details, integrating structural systems, ensuring compliance with regulations, and establishing construction sequences and stages. Because hazards such as wind and precipitation, including associated increases in water pressure and groundwater elevations, can significantly impact an incomplete structure during construction, information on these potential hazards and their load effects is essential for designing appropriate temporary supports and construction methods.

The construction phase is where detailed plans and specifications are translated into physical reality. It involves site preparation; foundation work; structural framing; and the installation of building systems like electrical, plumbing, and HVAC. Although the design process should consider the loads expected during the construction phase, unforeseen conditions during construction can still arise. For example, unforeseen weather events, such as strong winds, heavy snow, or prolonged rain that can affect soil conditions, can introduce unexpected loads on the incomplete structure, jeopardizing its structural stability. Reducing the associated risks may require revisions to construction methods and temporary support systems.

TOPIC 3: Science/Analysis Capabilities Needed to Address Gaps in Hazard Data by Phase

In initial stages of design, the estimation of some future hazards, such as flood elevations, require narrower horizontal ground-level resolutions than are currently available. This issue is particularly significant for estimating future riverine floods and flash floods, which are difficult to project with current modeling techniques.

Information on how groundwater tables could change over time is essential for the design of structure foundations. This issue has not yet attracted sufficient attention, and no models are currently available to estimate future groundwater-table levels.

Some hazards such as freezing rain require higher vertical resolution than is currently available. Modeling future conditions for ice accretion uses as input postprocessed model outputs at multiple elevations to account for vertical differences in ambient pressure, temperature, wind speed, and other parameters. Current models produce results that are inconsistent with measured ice thicknesses, raising questions about the accuracy of existing models and the appropriateness of existing spatial and vertical scales of input data.

The design of long-span bridges requires wind tunnel testing, although such tests are not mandatory for tall buildings according to ASCE/SEI 7 (although many tall buildings have tested in wind tunnels to ensure design safety, and other codes and standards could require wind tunnel testing under certain conditions for tall buildings). What changes in future conditions may necessitate a review of current test requirements for buildings?

While the selection of structural materials for the design of bridges takes place in the initial design phase, the selection of materials for building envelopes is considered at the final stage. The development of advanced models to describe how future weather conditions affect the material properties of structural steel, reinforced concrete, wood, masonry, aluminum, fiber-reinforced plastic, etc. and their aging processes and deterioration is ongoing. This requires information on long- and short-term variations in temperature, relative humidity, air salinity, CO₂, freeze-thaw cycling, radiation exposure, etc. Work is still needed to refine existing models, verify their validity, and standardize their application.

Hail is known to be the cause of the second-largest value of insured losses. Increases in the size, frequency, and spatial shift of future hailstorms require the consideration of the effect of hail on building envelopes and other components. Modeling future precipitation of hail and developing design criteria require data on covariates from larger-scale weather and climate models such as convective available potential energy, convective inhibition, and storm relative helicity. Other parameters such as temperature, wind speed and direction, and atmospheric humidity are usually available as output from existing models but may need additional refinement to improve their accuracy.

In addition to wind and hail, water is an important cause of damage to buildings. The anticipated increases in rainfall rates and hurricane wind speeds and slower translational speed of tropical storms highlight the importance of developing a better understanding of weather events that combine the effects of wind and rain. Structures damaged by wind pressures are more exposed to the accompanying rain, vastly amplifying the damage. Research and data are needed to improve existing climatology models to project future wind downbursts and thunderstorms and wind-driven rain.

Improved measurement science for uniform determination of historical data is a major research need. Verifying the accuracy of climate models and understanding the correlation among various parameters requires measuring, tabulating, and statistically analyzing historic hazard data and continually updating existing datasets. A sample, but not exhaustive, list of data that can benefit from improved measurement science and technology includes (1) intensity, frequency, and duration of all types of precipitation including rain, freezing rain, hail, and snow; (2) sea-level rise, coastal flooding, and wave intensities and frequencies; and (3) differences in the speeds of different types of wind. Accurate measurements will help improve the reliability of hazard data, improve our ability to develop accurate projection models, and reduce existing levels of the epistemic uncertainty associated with using these models to predict the effects of future hazards on structures and infrastructure systems.

Another research need is better understanding of the effects of extreme hazard events on other hazards. Changes in the frequency and intensity of future hazards can also increase the risks associated with other nonclimatic events that have traditionally been considered uncorrelated. For example, the melting of sea ice and permafrost thaw change ocean levels and the properties of the Earth's crust that may trigger increases and changes in the nature of seismic activities. Changes in the frequency and intensity of rainfall events can saturate the soil,

making slopes more prone to sliding. Research to improve our understanding of and quantify the correlation between climate and other environmental hazards should be encouraged to enhance the ability to model and mitigate the risk to structures and infrastructure systems.

3.5. Breakout 5

TOPIC 1: Project Data Needs for Hazards (Such as, but Not Limited to, Level of Detail [Spatial, Temporal], Planning Horizon, etc.)

The discussion around data needs for environmental hazards emphasizes the complexity and nuance required when considering emission scenarios. Selection of future scenarios can depend on applications and consensus among stakeholders. For example, the 3°C global warming level relative to the preindustrial period, rather than specific emission scenarios, was proposed for ASCE/SEI 7-28, whereas the latest updated Building and Bridge Codes in Canada relies on different representative concentration pathway (RCP) scenarios. RCP8.5 was adopted for buildings, with limited differences observed in structural design loads when considering regional impacts caused by RCP4.5 or RCP8.5, given the 50 years of design working life up to 2075. However, achieving consensus was more challenging for bridges, given a longer design life of 75 years pushing the application to the end of or beyond 2100. The engineering community ultimately settled on RCP6.0. This underscores how the choice of emissions scenario remains a significant and often debated issue—whether to use RCPs or fixed warming levels like 3°C. A few studies seem to indicate that extreme tropical cyclone events do not linearly correlate with global warming level; for instance, numerical simulations could result in higher tropical cyclone-induced wind speeds for a 2°C global warming level scenario than a 3°C one, adding further complexity. This may indicate that tropical cyclones are influenced by more than just average global warming level and need more studies. Past studies used many ensembles of projections that do not indicate such trends for other hazards, but more future studies are needed to confirm.

This complexity highlights the value of incorporating probability, uncertainty, and sensitivity when selecting different emission scenarios and incorporating climate models into decision-making frameworks. An essential question arises: who is best positioned to select the emission scenario—practitioners, climate scientists, or policymakers? Scientists must provide the foundational data for engineers and code developers to work with. Canada’s multidisciplinary approach, combining climate scientists, engineers, and code developers, offers a valuable model. Still, a common sentiment emerges: “we never built climate models for you to use in design,” which suggests a need to shift the question entirely, framing it instead around risk mitigation by engineering design and practice.

Scenario selection could also be, to an extent, project-specific, recognizing differences among buildings, bridges, retrofits, or models.

How to weigh different climate models and combine models (e.g., simple average, global warming limits weighted, or weighted based on accuracy) needs to be explored.

The data needs themselves will vary depending on whether the design approach is prescriptive or performance-based. Design parameters like wind loads may differ depending on the specific use case and the underlying data models. While current building codes provide a baseline, they must also incorporate methods for future adjustments. One area of concern is short-term storm events in nontropical regions, where a lack of consistency between climate model output and observation data creates a significant research gap. For example, climate models are currently incapable of providing 3 s gusts, which are used for ASCE/SEI 7-22 basic wind speed maps. The impact of future climate on extreme hourly mean wind speeds is assumed to be equivalent to its impact on 3 s gusts. Similarly, convective storms require much finer spatial resolution—on the order of 100 m—than current models can provide. For hurricanes, synthetic numerical modeling mechanisms offer a snapshot of global impacts but rely heavily on historical data, effectively functioning as a black box and assuming the mechanism derived in historical environments applies in the same way. The changes in response to future climate take place through the change of future environmental inputs, for example, sea surface temperature, but not necessarily feedback from the changes in the mechanisms, for example, locations of occurrence, detouring of storm tracks, and interaction of storms with large environmental flow at a basin level. In other words, different environmental inputs are used through the same functional mechanism to obtain different outputs. Tornadoes present an even greater challenge due to the complexity of wind shear and temperature interactions and the difficulty in confidently quantifying the frequency changes in climate projections.

Climate models were not used for design before. Simulation under past climates is needed for model validation. Criteria need to be developed to decide which models are good models and understand the model biases for individual hazards, considering also the correlation of the hazards (for multihazard design and risk analysis).

A pressing need exists to address nonstationarity considering future climate and to move away from metrics like the mean recurrence interval, especially for floods, which also require better spatial discretization and an understanding of data uncertainty over time.

Establishing timelines for when higher-resolution data will be required—and when it will be available—is crucial, as is defining the data needs over both short- and long-term periods. A key question remains: what is the minimum level of data we can tolerate while maintaining safety and performance?

Besides resolution, long time horizon modeling to generate enough extremes is needed to deal with design level exceedance probability.

Consideration should also be given to adjusting the ASCE/SEI 7 basis for design values and to better incorporate extreme event data. With large uncertainties present in climate models, evaluating how many models to use and which ones are most suitable for specific hazard types is important. Risk category-based scenarios might offer a structured path forward and provide the minimum design requirement, though multiple options in the mandatory code provisions

could introduce liability challenges. Performance-based design or an adaptation and resilience design standard may offer a viable alternative framework. Ultimately, incorporating time-dependent means, coefficients of variation, and distributions for key variables—along with simulation verification and guidelines on minimum spatial and temporal resolution—will support better design practices. Continuous time series data covering a sufficiently long historical period and future service life should be utilized wherever possible to ensure a robust, forward-looking approach.

TOPIC 2: Hazard Design Needs by Phase: (1) Planning (Concept Permits, Feasibility) and (2) Final Design

Nonstationarity needs to be incorporated into hazard design. The concept of cumulative lifetime exceedance probability during service life or maximum annual exceedance probability during service life could be proposed as a possible solution, although the former has the shortcoming that the annual exceedance probability can be above criteria for some years. Design life needs to be part of the hazard design explicitly.

Most projects' design phases are short relative to the time required to implement updated design information. Design phases for buildings can last 6 to 12 months for typical buildings. Larger, more complex buildings can take longer, while large infrastructure projects' feasibility and design phases can last for several years.

Acknowledging that nonstationarity needs to be incorporated, understanding when the project will be constructed and the desired design life for the project is important. Keeping consistent between the annual exceedance probability and lifetime exceedance probability is needed as in the current stationary climate assumption. The National Building Code of Canada 2025 (NBC 2025) uses a method known as the minimax approach and annual exceedance probability to ensure the probability of failure meets target values within design life.

Data needs for projects will vary due to the wide range of project sizes, scopes, and locations. For example, building projects will have a different set of data needs than a large infrastructure project. Considerations for different "risk appetites" may affect what data are needed. Code cycles effectively set a time frame for incorporating new data, but it is not necessarily aligned with climate science updates. Perhaps ways exist to capture continually changing climate data between code cycles.

TOPIC 3: Science/Analysis Capabilities Needed to Address Gaps in Hazard Data by Phase

Development of climate science capabilities to project extreme hazard events is essential because structural design loads for code-based performance objectives are centered around these. Other gaps in current climate science include small-scale hazards such as wind downbursts and thunderstorms.

A critical need is the ability to account for nonstationarity, which is the recognition that historical hazard data may no longer represent future conditions due to future climate. This will

require a shift in how environmental risks are discussed and communicated because the concept of a mean recurrence interval is no longer appropriate.

Given the inherent uncertainties in climate projections and hazard characterization, advanced methods for dealing with uncertainty are needed. Recognizing that current practice includes uncertainty, determining the current acceptable levels of uncertainty will prove helpful when incorporating future projections.

Designs implementing adaptive strategies (e.g., adaptation pathway) can be effective to allow for phased, flexible responses that can evolve as conditions change or as more information becomes available. Developing design guidelines could help design professionals incorporate these strategies on new projects.

Science and engineering approaches must increasingly support multihazard implementation, recognizing that cascading and compounding events may interact in complex ways. To ensure effective design, systems that have traditionally been developed under separate criteria for different hazards need to be unified. This integration supports a more holistic approach to risk management and improves system-wide resilience.

Clearly defined resilience design objectives and the development of analysis requirements that connect performance goals to hazard levels paired with instrumentation and monitoring can tie actual response to assumed behavior during design. These capabilities could allow for real-time assessments, post-event analysis, and feedback loops to validate resilient design decisions.

4. Section 4: Recommendation of Research Needs

During their discussions, the breakout groups identified the top five priority items and/or research needs to best develop the next-generation goals for future hazard characterization.

4.1. Breakout 1

This breakout group discussed research priorities in topic areas including improving data accuracy, standardizing modeling approaches, integrating observations with models, addressing evolving hazard conditions, and understanding the impact of built environment changes.

Specific research areas include

- Developing more efficient ways to identify site-specific hazard data and design criteria (e.g., riverine and urban flood hazards, microbursts);
- Standardizing methodologies for national, transparent, open-source models to develop hazard data and maps for present-day and future conditions (e.g., hurricane models, flood maps independent from NFIP);
- Developing methods to combine observational data and models (i.e., model verification);
- Determining how to transition between stationary and nonstationary hazards for reliability analysis; and
- Quantifying how future changes to the built environment affect hazards.

4.2. Breakout 2

During the breakout sessions, breakout group 2 discussed topics such as improvements to communication, frameworks, machine learning, and data. They emerged with four top-priority areas for research needs:

- Better communication to engineers of what the hazard is and the metrics and statistics used to quantify it and how they are computed. The group noted that uncertainty is wide, so choosing how to characterize or reconcile it is an additional factor.
- Development of a framework for processing data (less emphasis on the data itself) and a centralized repository or compendium for data.
- Need for machine learning to fill gaps in uncertainty, to downscale, to treat observable data, and perhaps to implement a process. The breakout group noted that trustworthy AI models will require input from computer science and from climate science, statisticians, and engineers.
- Low-hanging fruit is that planning-level data are so close but could be improved with novel statistics (e.g., flood maps).

4.3. Breakout 3 and 6

Combined breakout group 3 and 6 identified five top-priority items during its discussion of the breakout prompts. The selected top research needs center on software, data methodologies and modeling, and communication:

- Engineering software that could quickly assess impacts on the reliability of the design. This priority would enable us to interrogate climate model impacts at scale quickly and to evaluate implications such as costs.
- Good or better use of the data sources and methodologies currently used within actionable timescales to understand model outputs so engineers can easily consume them (e.g., U.S. Geological Survey (USGS) into NEHRP Provisions Update Committee (PUC) process), including boundary organizations for infrastructure decisions.
- Need for improved communication of hazards and climate model results so design teams can evaluate or interpret the results across all stakeholders and evaluate impacts, especially costs.
- Many ensemble members of multidecadal global climate model simulations at convection-permitting model resolution. This made the list of priority needs because engineers want higher spatial resolution (more detail) and large ensembles/multidecadal simulations to sample plausible model outcomes and sample the three traditional sources of uncertainty well.
- Need for the engineering community to align future conditions thinking with the historical records of environmental hazards to establish how to feel more comfortable with models of the future and how to determine when data are fit for the design purpose.

4.4. Breakout 4

After discussions of project data needs, hazard design needs, and current gaps in hazard data, breakout group 4 identified top research priorities that focus on advancing hazard data and measurement science to improve life-cycle cost evaluations, design methods, and service life determinations:

- Hazard data to support a life-cycle cost evaluation. The breakout group specifically noted the need for future hazard data to determine the material used for the exterior envelope, bridge construction material, and so on.
- Data for concurrent/compounding hazards. The breakout group referenced several specific areas of data in this category: hazard data needed to develop load combinations for concurrent hazards; duration of event, frequency of event, and intensity of event (not only extremes); and data for more frequent and less extreme hazards versus single extreme hazards for design.
- Improved measurement science for uniform determination of historical data. For clarification, the group noted that this could include better data collection or estimation of freezing rain, rain fall rate, snow, wind speed, and so on.
- Determination of service life—window of future hazard data to deal with the extension of service life beyond 50 years. Additional context clarifies that this needs to include understanding the priorities of the project owner, because data needs depend on those priorities. Understanding the risk associated with the project is also a factor.

- Data and design methods for hazards not fully considered now but projected to increase, including wind-driven rain and hail. This is particularly needed for selection and design of envelope systems and materials.

4.5. Breakout 5

The final breakout group selected its top-priority items after discussing project data needs for design environmental hazards, design needs by phase, and gaps in hazard data by phase. They identified five research needs to enhance future capabilities for addressing data needs:

- Investigating uncertainties associated with chosen climate conditions (e.g., 3 °C warming);
- Evaluating climate models in terms of their hazard estimation relative to historical observations;
- Better understanding and projecting “extremes” (e.g., wind speeds with 1/1,000 annual exceedance probability) from climate science perspectives;
- Understanding ideal and minimum requirements for spatial and temporal resolution and projection time periods by hazard types; and
- Collecting temporally continuous data to support nonstationarity design criteria, such as replacing return period with lifetime exceedance probability and annual exceedance probability and including design life (start-end period and length) as a design parameter.

5. Section 5: Analysis of Research Needs

Following the breakout sessions, the workshop participants reconvened and reviewed the recommended research needs from each breakout session. Along with the review, the participants engaged in robust discussions about the identified research needs, noting some duplication. As the workshops progressed, the WSC noticed the emergence of several themes that were aligned with, but not quite identical to, the focus of the specific workshop. Consequently, the WSC reviewed the prioritized research needs and indexed each according to the themes identified below.

5.1. Prioritized Research Needs Indexed to Themes

A summary discussion of results is useful for understanding the scope and complexity of the workshop topic. In general, the workshops were designed to build upon each other and progress the participants' thinking and understanding of the research needs. While each workshop focused on a specific aspect of overall need, each workshop yielded meaningful discussions in several areas. In review of the results, six themes emerged and the research priorities identified were aligned with the themes to consistently organize all topics across all of the workshops. The following briefly describes these themes.

1. *Future Hazard Data and Information.* Development of **up-to-date, scientifically credible and fit-for-purpose, future-ready hazard data frameworks** that are scientifically robust, transparent, and directly usable in engineering and planning decisions. Identifies future hazard datasets and associated information, including projections and their uncertainties, that are needed for future engineering design criteria.
2. *Future Load Effects and Infrastructure Conditions.* Advancement of **load characterization under future conditions, infrastructure performance modeling, and structural capacity assessments** that explicitly account for future climate, nonstationarity, and evolving built-environment conditions. The aim is to enable reliable, transparent, and forward-looking load and infrastructure condition assessments that support resilience modeling, code development, and risk-informed engineering decisions under future conditions.
3. *Design Guidelines, Criteria, and Tools.* Modernization of **design guidelines, criteria, and engineering tools** to explicitly address nonstationary hazards, future climate conditions, and time-dependent infrastructure performance. Translates evolving climate science and infrastructure performance knowledge into practical, transparent, and flexible design guidelines that support resilient infrastructure under future conditions.
4. *Resilience and Adaptation.* Advancing **resilience- and adaptation-focused engineering frameworks** that move beyond prescriptive design toward performance-based, risk-informed, and decision science-based approaches suited for future conditions. The aim is to enable transparent, scalable, and socially informed adaptation strategies that support long-

term infrastructure performance and community resilience under evolving climate and risk conditions.

5. *Planning and Design Frameworks*. Evolution of engineering practice toward **risk-informed, adaptive, and life-cycle-based decision frameworks** capable of addressing nonstationary hazards and long-term climate uncertainty. Includes research needs to align engineering design, planning, and code development with long-lived infrastructure performance, community resilience outcomes, and evolving societal risk preferences under future conditions.
6. *Codes and Standards*. **Modernization of codes, standards, and design philosophies** to reflect system-level risk, nonstationary hazards, and long-term infrastructure performance under future climate conditions. Enables adaptive, evidence-based codes and standards that support resilient infrastructure, informed decision-making, and timely adoption of best available knowledge.

The final outcome is the list of research needs indexed according to the six themes identified by the WSC (Table 5-1). Note that the list of research needs are those prioritized by the workshop participants, but the list is not in priority order. Additional details from each breakout group, along with preliminary indexing, are provided in Appendix A.

Table 5-1. Priority Research Needs Identified by the Workshop Participants Indexed across Six Themes *

Research Need	Future Hazard Data and Information	Future Load Effects and Infrastructure Conditions	Design Guidelines, Criteria, and Tools	Resilience and Adaptation	Planning and Design Frameworks	Codes and Standards
Develop more efficient ways to identify fit-for-purpose, site-specific hazard data, models, and design criteria	1		2			
Standardize methodologies for national, transparent, open-source models to develop and archive hazard data and maps for present-day and future conditions; develop framework(s) for processing data and a centralized repository for data	1	2				3

Develop methods to combine observational data and models and improve measurement science and processing approaches for uniform determination of historical hazard data	2		1			
Determine how to detect nonstationarity and transition between stationary and nonstationary hazards for reliability analysis; adapt the design criteria to nonstationarity		2	1		3	
Quantify how future changes to the built environment affect hazards	2	1				
Improve communication to engineers and design teams of what the hazard is, climate model results, metrics, and statistics used to quantify it and how they are computed	2	1	2			
Develop machine learning/engineering software to fill gaps in uncertainty, downscaling, treatment of observable data, impacts on design reliability, and perhaps in implementing a process	1	2	2			
Improve planning-level data with novel statistics	1		2			
Use hazard data to support a life-cycle cost evaluation	2				1	
Make good/better use of the data sources and methodologies currently used within actionable timescales	1	2				

Develop a suite of multidecadal regional and/or global climate model simulations that are run at convection-permitting spatial resolution (4 km or finer) with variables relevant to engineering standards stored at temporal and spatial resolutions appropriate for the design of projects	1		2			
Clarify how uncertainty could be considered in future conditions decisions for engineering approaches	1	2			1	
Improve understanding about “extremes” from the climate science perspective	1		2			
Understand the minimum requirements for spatial/temporal resolution, length (past and future), and continuousness of the projections by hazard types	2		1			
Develop a database of concurrent/compounding hazards to create of improved load combinations and for site-specific hazard analysis	1	2				
Determine the service life–window of future hazard data to extend service life beyond 50 years			1	2		

Develop data and design methods for hazards not fully addressed now that are projected to increase, including wind-driven rain and hail, and for future conditions needed for foundation design, including frost depth and permafrost, groundwater elevations, and saltwater intrusion into groundwater		2	1			
Align understanding of the way global warming level is calculated by climate science community and how engineering handles GWL as the target future condition	1		2			

*Table Key:

- 1 = Primary research need
- 2 = Secondary research need
- 3 = Related research need

5.2. Discussion of Results

The outcomes of Workshop 1 on future hazards provided a solid technical foundation for advancing hazard characterization to develop necessary components for estimating loads, including data on structural degradation under future conditions. These components will provide essential information for design practice, planning frameworks, and codes and standards that will be required for design practice under future conditions. The high-priority research topics reflect standardized, transparent methods; better use of observations and models; and clearer treatment of uncertainty and nonstationarity.

5.2.1. Future Hazard Data and Information

Workshop 1 identified research topics that reflect a shared push to make future hazard information more practical, trustworthy, and usable for engineering applications and decisions. At the core is the need to more efficiently identify **fit-for-purpose, site-specific hazard data, models, and design criteria**. This requires nationally consistent, transparent, and open-source

methodologies for developing, processing, and archiving hazard data and maps for both present and future conditions, supported by centralized repositories. Participants also emphasized the promise of machine learning and advanced engineering software, not as black boxes but as tools, to help address gaps in uncertainty, downscaling, treatment of observations, and impacts on design reliability. At the planning level, a clear need exists for improved data at multiple scales and novel statistical methods, alongside better and timelier use of the data and methods already available.

Looking ahead, the participants called for sustained investment in multidecadal and more accurate climate simulations for hazard events with variables and resolutions tailored to engineering design requirements and standards. Underpinning this is the need to clarify how uncertainty should be treated in future-conditions decision-making, to improve understanding of climate “extremes,” to systematically address concurrent and compounding hazards in load combinations, and to better align how global warming levels are defined in climate science with how engineers use them for future-conditions targets (e.g., 3 °C rise in global temperatures over the next 50 years).

Research priorities also include developing reliability-based methods to combine observational records with future hazard models and improving measurement science for historical hazard data so that they are determined consistently and transparently. A strong need also exists to better quantify how changes in the built environment, such as urbanization and infrastructure modifications, alter hazard behavior (e.g., rainfall drainage or floods). This includes more clearly communicating how hazard events are defined, modeled, and quantified, including metrics and statistics. In addition, a need exists to define minimum spatial and temporal resolution levels, record length, and continuity requirements for hazard event projections, recognizing that these needs vary by hazard type and design application.

5.2.2. Future Load Effects and Infrastructure Conditions

Priority research gaps relate to limited understanding of how **future hazard events translate into load effects on infrastructure systems**. This includes insufficient methods to quantify how evolving climate conditions interact with the **built environment itself** (e.g., urbanization, drainage, materials degradation) and how these interactions modify loads over time. The research topics also highlighted a need for improved treatment of **compounding and concurrent hazards**, especially where multiple drivers affect structural demand simultaneously.

5.2.3. Design Guidelines, Criteria, and Tools

A major research gap is the absence of **standardized, transparent methodologies** to convert future hazard information into **design loads and criteria**. This includes guidelines on

incorporating uncertainty, scenario selection, and nonstationarity into reliability-based design. High-priority needs also include development of **engineering-oriented tools and workflows**, potentially leveraging machine learning, that remain explainable, auditable, and consistent with design requirements.

5.2.4. Resilience and Adaptation

The workshop also identified gaps in applying hazard data to support **life-cycle, adaptive, and resilience-based decision-making**. While concepts such as adaptive design and life-cycle cost analysis are recognized, guidelines on how to operationalize them using future hazard information is limited. Priority research is needed to link hazard projections with **performance objectives, recovery, and long-term risk mitigation**, rather than focusing solely on life-safety thresholds.

5.2.5. Planning and Design Frameworks

At the planning level, priority gaps reflect the need for **screening-level, decision-support information** that is consistent with later design phases. This includes improved planning-scale hazard characterization; clearer alignment between planning assumptions and final design requirements; and better frameworks to ensure future hazards are considered early, before siting and layout decisions are locked in.

5.2.6. Codes and Standards

Finally, the workshop highlighted a critical gap between **available science and codified practice**. Priority needs include clarifying how future hazards and uncertainty can be incorporated into **codes and standards without undermining consistency or enforceability**, addressing limitations of current stationary assumptions, and identifying pathways for updating provisions between code cycles as science evolves.

5.3. Summary

The workshop attendees identified several higher-priority research topics, including (1) improved communication to engineers regarding the hazard, future climatic conditions, and how the design parameters are computed; (2) efficient development of site-specific hazard data and design criteria; (3) uncertainty quantification of future conditions; (4) development of minimum requirements for spatiotemporal data for each hazard; and (5) standard methods for developing a national, transparent, and open source database of hazards.

6. Section 6: Acronyms and Abbreviations

AI	Artificial Engineering
ASCE	American Society of Civil Engineers
CO ₂	Carbon Dioxide
FEMA	Federal Emergency Management Agency
GCM	Global Climate Model
GWL	Global Warming Level
LCA	Life-Cycle Analysis
NFIP	National Flood Insurance Program
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SEI	Structural Engineering Institute
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WSC	Workshop Steering Committee

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Appendix A. Discussion of Priority Research Needs

Each breakout group identified and prioritized its top research needs. The lists of needs from all the breakout sessions were combined into an overall list that was examined for themes. The following provides the original breakout session prioritized lists.

A.1 Breakout 1

1. Develop more efficient ways to identify site-specific hazard data and design criteria (e.g., riverine and urban flood hazards, microbursts);
2. Standardize methodologies for national, transparent, open-source models to develop hazard data and maps for present-day and future conditions (e.g., hurricane models, flood maps independent from NFIP);
3. Develop methods to combine observational data and models (i.e., model verification);
4. Determine how to transition between stationary and nonstationary hazards for reliability analysis; and
5. Quantify how future changes to the built environment affect hazards.

A.2 Breakout 2

1. Improve communication to engineers what the hazard is, metrics and statistics used to quantify it, and how they are computed. Because uncertainty is wide, choosing how to characterize or reconcile is an additional factor.
2. Develop a framework on processing data (less emphasis on the data itself) and a centralized repository or compendium for data.
3. Develop machine learning to fill gaps in uncertainty, downscaling, treatment of observable data, and perhaps in implementing a process. The breakout group noted that trustworthy AI models will require input from computer science and climate science, statisticians, and engineers.
4. Low-hanging fruit: planning-level data are so close but could be improved with novel statistics (e.g., flood maps).

A.3 Breakout 3 and 6

1. Develop engineering software that could quickly assess the impacts on the reliability of the design:
 - a. Why: so we can interrogate the climate model impacts at scale, quickly;
 - b. We need to understand the tolerance for new uncertainties; and
 - c. Evaluate implications, such as costs.
2. Make good/better use of the data sources and methodologies currently used within actionable timescales. Understand needs from model outputs so we can easily consume the outputs (e.g., USGS into PUC process), including boundary organizations for infrastructure decisions potentially set up as experiments through the WCRP (as one of various work streams) to identify what is achievable in 10 years. Develop robust connections between

engineering needs and science capability such as discussion and consensus on specific design needs (select key engineering needs—not *all* outputs, but what is relevant and needed for engineering design—at the particular phases needed. For example, climate boundary organizations: What is this entity? What do we need it to do? Is this sector specific or encompassing? This will need resources: money, experts, and leadership.

3. Improve communication of hazards and climate model results so design teams can evaluate/ and interpret the results across all stakeholders and evaluate impacts, especially costs. This includes
 - a. Climate literacy and how we think about managing the risk: how to communicate to engineers and then to clients/owners/community;
 - b. Part of the education is to understand the costs, risks, return on investments, and life-cycle costs;
 - c. Many ensemble members of multidecadal global climate model simulations at convection-permitting model resolution;
 - d. Why: we want higher special resolution (more detail), we want large ensembles/multidecadal simulations to sample plausible model outcomes and sample the three traditional sources of uncertainty well;
 - e. This has an immediate direct application as this output is needed to provide appropriate data for engineering purposes; and
 - f. We want global to have it all but if just CONUS is wanted just then we could do dynamic downscaling.
4. Stress the need for the engineering community to align thinking with the historical records of environmental hazards to feel more comfortable with models of the future and determine when data are fit for the design purpose.

A.4 Breakout 4

1. **Hazard data to support a life-cycle cost evaluation.** Future hazard data to help engineers determine the optimum choice of material to be used for the exterior envelope, bridge construction material, and so on, based on their exposure to different extreme hazards, frequent hazards, and deterioration processes.
2. **Data for concurrent/compounding hazards.** Hazard data are needed to develop load combinations for concurrent hazards. These include the duration of events and their frequencies and intensities (not only extremes).
3. **Improved measurement science for accurate determination of historical data.** Better data collection and estimation of climate hazards, including freezing rain, rain fall rate, snow, wind speed, and so on.
4. **Determination of service life.** Develop methods and future hazard data to address issues related to ensuring the reliability of the structure over its expected service life beyond the standard 50-year reference period. This involves optimizing the safety of the structure over the service life based on an understanding of the priorities of the long-term project owner and an understanding of the risks associated with the project.
5. **Data and design methods for hazards not currently fully considered.** Climate projections indicate that the future may exhibit increases in some hazards that are not currently fully

considered in current design. Such hazards include wind-driven rain that may exacerbate damage to buildings damaged by wind pressures and hail, which is information needed for selecting and designing envelope systems and materials.

A.5 Breakout 5

1. Investigate uncertainties associated with chosen climate conditions (e.g., 3 °C warming);
2. Evaluate climate models in terms of their hazard estimation relative to historical observations;
3. Improve understanding and projecting of “extremes” (e.g., wind speeds with 1/1,000 annual exceedance probability) from climate science perspectives;
4. Understand the ideal and minimum requirements for spatial/temporal resolution and projection time periods by hazard types; and
5. Need temporary continuous data to support nonstationarity design criteria, such as replacing return period with lifetime exceedance probability and annual exceedance probability and including design life (start-end period and length) as a design parameter.

Table A-1 summarizes the breakout session research needs. After the breakout session reporters presented and described their sessions’ research needs, the full group of participants rated each research recommendation from all breakout sessions. Table A-2 summarizes the research needs receiving the highest priority ratings.

Table A-1. Breakout Session Research Needs, as Rated by the Workshop Participants

Research need	Neutral	Lower priority	Priority	Highest priority
Develop more efficient ways to identify fit-for-purpose, site-specific hazard data and design criteria (e.g., riverine and urban flood hazards, microbursts)	6.7%	13.3%	53.3%	26.7%
Standardize methodologies for national, transparent, open-source models to develop and archive hazard data and maps for present-day and future conditions (e.g., hurricane models, flood maps independent from NFIP); develop framework(s) for processing data and a centralized repository for data	8.9%	15.6%	42.2%	33.3%
Develop methods to combine observational data and models (i.e., model verification); improve measurement science and processing approaches for uniform determination of historical hazard data	4.4%	22.2%	31.1%	42.2%
Determine how to detect nonstationarity and transition between stationary and nonstationary hazards for reliability analysis; adapt the design criteria to nonstationarity	6.7%	31.1%	31.1%	31.1%
Quantify how future changes to the built environment affect hazards (i.e., future land use development)	11.1%	35.6%	37.8%	15.6%
Improve communication to engineers and design teams on what the hazard is, climate model results, metrics, and statistics used to quantify it and how they are computed	2.2%	8.9%	35.6%	53.3%
Develop machine learning/engineering software to fill gaps in uncertainty, downscaling, treatment of observable	8.9%	42.2%	37.8%	11.1%

data, impacts on design reliability, and perhaps in implementing a process				
Improve planning-level data with novel statistics (e.g., flood maps)	24.4%	37.8%	33.3%	4.4%
Use hazard data to support a life-cycle cost evaluation	13.3%	24.4%	35.6%	26.7%
Make good/ better use of the data sources and methodologies currently used within actionable timescales (e.g., understanding of needs from model outputs, including boundary organizations for infrastructure decisions)	8.9%	22.2%	53.3%	15.6%
Develop a suite of multidecadal regional and/or global climate model simulations that are run at convection-permitting spatial resolution (4 km or finer) with variables relevant to engineering standards stored at temporal and spatial resolutions appropriate for the design of projects	17.8%	24.4%	35.6%	22.2%
Clarify how uncertainty could be considered in future-conditions decisions for engineering approaches	11.1%	11.1%	37.8%	40.0%
Better understanding about “extremes” from climate science perspective (e.g., 1/1,000 annual exceedance probability)	4.4%	24.4%	37.8%	33.3%
Understand the minimum requirements for spatial/temporal resolution , length (past and future), and continuousness of the projections by hazard types	4.4%	17.8%	48.9%	28.9%
Develop a database of concurrent/compounding hazards to create improved load combinations (e.g., moving from arbitrary point in time to copula treatment) and for site-specific hazard analysis	8.9%	22.2%	48.9%	20.0%
Determine the service life–window of future hazard data to extend service life beyond 50 years	15.6%	37.8%	31.1%	15.6%
Develop data and design methods for hazards not fully addressed now that are projected to increase , including wind-driven rain and hail, and for future conditions needed for foundation design , including frost depth and permafrost, groundwater elevations, and saltwater intrusion into groundwater	8.9%	28.9%	37.8%	24.4%
Align understanding of the way global warming level is calculated by climate science community (e.g., 31-year average) and how engineering handles GWL (i.e., period used to evaluate reliability/risk) as the target future condition	20.0%	26.7%	35.6%	17.8%

Table A-2. Top Five Breakout Session Research Needs, as Rated by the Workshop Participants

Rank	Priority research needs
1	Improve communication to engineers and design teams of what the hazard is, climate model results, metrics, and statistics used to quantify it and how they are computed
2	Develop more efficient ways to identify fit-for-purpose, site-specific hazard data and design criteria (e.g., riverine and urban flood hazards, microbursts)
3	Clarify how uncertainty could be considered in future-conditions decisions for engineering approaches
4	Understand the minimum requirements for spatial/temporal resolution , length (past and future), and continuousness of the projections by hazard types

5	Standardize methodologies for national, transparent, open-source models to develop and archive hazard data and maps for present-day and future conditions (e.g., hurricane models, flood maps independent from NFIP); develop framework(s) for processing data and a centralized repository for data
---	---

Appendix B. Workshop Materials

B.1. Workshop Agenda



SEI NIST Forward-Looking Codes and Standards: Future Hazards Workshop

DATE: June 4–5, 2025

LOCATION: ASCE Bechtel Conference Center,
1801 Alexander Bell Drive, Reston, VA 20191

VIRTUAL: Zoom and Teams links sent separately

Workshop Agenda_v3

Workshop Director: Jayantha “Obey” Obeysekera, Ph.D., P.E., Research Professor,
Director of Sea Level Solutions Center, Institute of Environment at FIU

WORKSHOP MATERIALS: [Link to Digital Materials Package](#) (password: futurehazards)

Day 1: June 4, 9:00am–5:00pm ET

8:00am–9:00am: NETWORKING CONTINENTAL BREAKFAST PROVIDED

GENERAL SESSION

9:00am–9:30am: Welcome

- Welcome, Purpose, and Workshop Agenda and Goals
 - Welcome and Opening Remarks—Jayantha “Obey” Obeysekera, Ph.D., P.E., Research Professor, Director of Sea Level Solutions Center, Institute of Environment at FIU
 - Purpose—Therese McAllister, Ph.D., P.E., F.SEI, Dist.M.ASCE, Deputy Chief, Materials and Structural Systems Division, NIST
 - Workshop Agenda and Goal—Jennifer Goupil, P.E., F.SEI, F.ASCE, Managing Director SEI, Chief Resilience Officer ASCE
- Introductions—All Participants

9:30am–10:30am: Synergistic Efforts

Presentations on current, ongoing synergistic work: this workshop will leverage and build on complementary efforts.

- **ASCE/SEI 7-28 Future Conditions including supported research** [15 min];
Abbie Liel, University of Colorado Boulder
- **NOAA-ASCE Partnership and Task Force Efforts** [15 min];
Dan Walker, University of Maryland
- **ASCE Committee on Adaptation to a Changing Climate** [15 min];
Sihan Li, RWDI
- **ASCE/SEI Effects of Climate Change on Life-Cycle Performance of Structures and Infrastructure Systems** [15 min]; Michel Ghosn, City College of NY

10:30pm–10:50am: PICTURE + COFFEE BREAK

10:50am–12:00pm: Practice Perspectives for Future Hazard Characterization

Presentations of projects that characterized future hazard for design and panel discussion of “What do you wish you had?” to prime thinking for breakout sessions.

- **Case Study: Vermont Port of Entry** (snow/wind/temperature) [15 min];
Kevin Borth, HGA
- **Case Study: NYC Eastside Coastal Resilience** (coastal inundation/flood/SLR) [15 min];
Badre Enam, ARCADIS
- **Case Study: West Coast High Speed Rail** (temperature, riverine flooding) [15 min];
Meg Ackerson, ARUP
- **Case Study Moderated Panel Discussion with Case Study Speakers and Q&A** [25 min];
Moderator: Jayantha “Obey” Obeysekera

12:00pm–12:30pm: WORKING LUNCH PROVIDED

12:30pm–1:30pm: Plenary Discussion

Session to define the state of the art and the ideal state, followed by instructions for the breakout sessions.

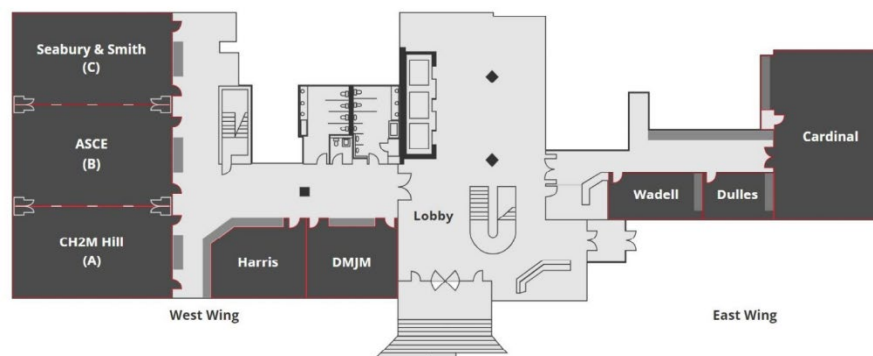
Moderators: Jayantha “Obey” Obeysekera, Therese McAllister, Jennifer Goupil

- **Current State of the Art:** ASCE-NOAA Summer Workshop 2024 [15 min]; Joe Barsugli
Overview of co-evolution of climate science and engineering standards/practice
- **Goals for Future State** [30 min]; all participants
Discussion of goals for characterizing future hazards for engineering applications
- **Research Agenda for Advancing Future Hazard Characterization and Design** [15 min]
Discussion of process to identify and prioritize research needs:
 1. Project data needs for hazards (such as, but not limited to, level of detail (spatial, temporal), planning horizon, etc.)
 2. Hazard design needs by phase: (1) Planning (concept permits, feasibility) and (2) final design
 3. Science/analysis capabilities needed to address gaps in hazard data by phase

GOAL: Identify and prioritize the top three to five needs to address the gaps in hazard data by phase.

1:30pm–1:45pm: MOVE TO ASSIGNED BREAKOUT ROOMS (see following plan)

ASCE Conference Center



1:45pm–3:30pm: Concurrent Breakout Sessions

3:30pm–3:45pm: COFFEE BREAK

3:45pm–4:45pm: Concurrent Breakout Sessions (cont.)

4:45pm–5:00pm: Reconvene

- Summary and Adjourn Day 1

Day 2: June 5, 8:00am–12:00pm ET

7:30am–8:00am: NETWORKING CONTINENTAL BREAKFAST PROVIDED

8:00am–8:15am: Welcome

- Purpose and Goals of Day 2

8:15am–11:45am: Report Out and Prioritization

- Breakout Session Report Out [25 min EACH = 15 min + 10 min Q&A]
- Prioritization of Research Needs [20 min]

10-minute COFFEE BREAK

- Moderated Panel Discussion of WSC [30 min]
Moderator: Jayantha “Obey” Obeysekera
Panelists: Workshop Steering Committee

11:45am–12:00pm: Conclusion

- Summary and Adjourn Day 2

12:30–3:30pm: Workshop Steering Committee Meeting

B.2. Workshop Presentations

B.2.1. Day 1: Overview Presentation

FUTURE HAZARDS IN DESIGN

*The workshop presentations and discussion do not necessarily reflect
the views or policies of NIST or the United States Government.*

June 4-5, 2025

SEI/NIST Forward Looking Codes and Standards Workshop #1



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FORWARD-LOOKING CODES AND STANDARDS: WELCOME

Jayantha 'Obey' Obeysekera, Ph.D., P.E.

Research Professor & Director, Sea Level Solutions Center,
Institute of Environment at Florida International University
Project Director, SEI/NIST Workshops



WELCOME & OVERVIEW

- Already observing increasing land and ocean temperature, more frequent and prolonged heat waves, increased frequency and intensity of heavy precipitation, severe storms and cyclones, and increased droughts in some areas.
- There is an urgent need to advance design practices to incorporate future hazard projections into codes and standards of buildings and infrastructure.
- The Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE) has contracted with the National Institute of Standards and Technology (NIST) to develop and execute a series of **four workshops** on Forward-Looking Codes and Standards.



OVERARCHING GOAL: RESEARCH ROADMAP INFORMED BY WORKSHOPS

- Address future hazards, conditions, impacts for design:
 - Temperatures (atmospheric, sea surface)
 - Precipitation (rain, snow, ice, hail)
 - Flood (sea level; coastal/inland flooding)
 - Wind (convective storms, hurricanes)
 - Earthquake (landslides, liquefaction, drought)
 - Wildland-urban interface (WUI) fires
 - Material/Structural degradation (e.g., concrete, steel corrosion)
- Identify and prioritize gaps and research needs for implementing future hazards and associated design criteria in codes and standards.
- Inform strategic planning for future requirements in the built environment, and potential changes to design parameters (e.g., nonstationary reliability, service life, design loads).



WORKSHOP STEERING COMMITTEE

- **PROJECT DIRECTOR: Obey Jayantha**, Ph.D., Research Professor, Director of Sea Level Solutions Center, FIU
- **Meg Ackerson**, P.E., Arup (Co-participant with Jack Hogan)
- **Joe Ackroyd**, Assistant Commissioner; Technical Affairs & Code Development; New York City Department of Buildings, NYC
- **Joseph Barsugli**, Ph.D., Research Scientist III, CIRES, University of Colorado Boulder, NOAA Physical Sciences Laboratory Affiliate
- **Kevin Borth**, P.E., S.E., Sr. Structural Project Engineer | Associate Vice President, HGA
- **Keith Dixon**, Ph.D., Deputy Division Head of the GFDL Marine Ecosystems & Downscaling Division, NOAA Geophysical Fluid Dynamics Laboratory
- **Michel Ghosn**, Ph.D., Professor, The City College of New York / CUNY
- **Matt Gilbertson**, Sr. Technical Manager, Simpson Gumpertz Heger
- **Elisabeth Gilmore**, Professor, Carleton University
- **Jack Hogan**, P.E., Associate Climate Risk and Resilience Engineer, Arup
- **Sihan Li**, Ph.D., P.Eng., Senior Specialist, Associate, RWDI
- **Amanda McCarty**, Director, NOAA Climate Ready Nation
- **Mari Tye**, Ph.D., Project Scientist II, Climate and Global Dynamics Laboratory (CGD), National Center for Atmospheric Research (NCAR)



WORKSHOP STEERING COMMITTEE (CONT.)

NIST

Materials and Structural Systems Division, Engineering Laboratory

- **Terri McAllister**, Ph.D., P.E., MSSD Deputy Chief, Research Structural Engineer for Community Resilience Group
- **Marc Levitan**, Ph.D., Research Structural Engineer, Structures Group
- **Siamak Sattar**, Ph.D., Earthquake Engineering Group Leader, Research Structural Engineer
- **Jennifer Helgeson**, Ph.D., Acting Group Leader and Program Manager, Community Resilience Program
- **Scott Jones**, Ph.D., Research Material Scientist, Infrastructure Materials Group

ASCE/SEI

- **Jennifer Goupil**, P.E., ASCE Chief Resilience Officer and Managing Director, Structural Engineering Institute of ASCE
- **Katie Stueckle**, Structural Engineering Institute of ASCE



WORKSHOPS THEMES

ASCE/NIST will host 4 workshops in 2025 for advancing building and infrastructure codes and standards. Cross-cutting topics will include future hazards, design impacts, and social and economic consequences:

1. **Future hazards for design** - confidence/uncertainty in hazard projections, downscaling of global models, converting hazard projections to design criteria
2. **Future load effects on the built environment** - (a) load effects for future hazards, (b) changes in load effects relative to historical basis, (c) changes in structural performance, material properties, soils, ...
3. **Engineering design guidance and criteria** - non-stationary reliability, service life, design loads, resistance, deterioration
4. **Adaptation and resilience** - buildings and infrastructure system assessment, material durability, mitigation, retrofit,...



FORWARD-LOOKING CODES AND STANDARDS: PURPOSE AND SCOPE

Terri McAllister, Ph.D., P.E., F.SEI., Dist.M.ASCE, NIST



PURPOSE AND SCOPE

- **Purpose:** to provide a *science-based assessment of data and development needs* to advance *design practice and building standards* for future natural hazards and conditions across US communities.
- **Scope:** Input from scientists, practitioners, and researchers is needed on how to:
 - Prioritize what is needed to achieve *the next generation of determining hazard and conditions for design* (beyond ASCE 7-28)
 - Use the best available science to characterize future hazards and conditions for design practice.
 - Identify a path forward to improve building standards and design practice.
 - Consider resilience, adaptation, and social and economic impacts to businesses and communities.



STANDARD DEVELOPMENT ORGANIZATIONS

- **ASCE 7-28: Standard for Minimum Design Loads for Buildings and Other Structures**

Published every 6 years

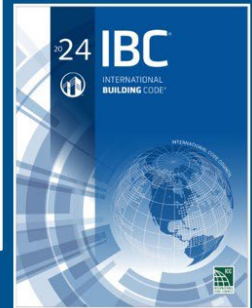
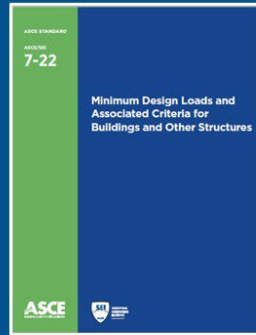
The 2028 version will have a new section on Future Conditions

- **Other SDOs**

ASTM, American Concrete Institute, American Institute of Steel Construction, NDS for Wood Construction, etc.

- **NIST Grants to support ASCE 7-28**

- Nonstationary reliability methods
- Wind maps
- Atmospheric icing criteria
- Consequences of climate change in structural loads
- Corrosion in reinforced concrete
- Ground failure and impacts on structures
- Adaptive design and assessment of reinforced concrete structures



COMMUNITY AND BUSINESS RESILIENCE

- Develop performance goals that include functional recovery
- Assess current and future exposure and interdependencies
- Identify primary risks and hazards
- Evaluate potential solutions for new and existing infrastructure
- Prioritize investments
 - Infrastructure vulnerabilities
 - Social and community consequences



Shopping Center
Marianna, FL

Tyndall AFB, FL

Alicia Devine/Tallahassee Democrat

Hurricane
Michael
2018



<https://www.airandspaceforces.com/daily-report/>

SYNERGISTIC EFFORTS

NIST Climate Science and Building Codes Workshop--Jan 2021

- *Future hazard needs of building regulatory community*

SEI Climate impacts workshops--March, May, Oct 2022

NIST-ASCE-NOAA Community Resilience Workshops--Nov 2023 to Jan 2024

- *Leading practices for future hazards in community resilience planning*

ASCE-NOAA Task Force Summit--Feb 2023

- *Temperature, Rainfall Workshop---Sep 2022*
- *Extreme Wind, Coastal Hazards Workshop---Oct 2022*

ASCE 7-28 Future Conditions Subcommittee--2022 to 2027

ASCE Committee on Adaptation to a Changing Climate

ASCE/SEI Special Report--2024

- *Effects of Climate Change on Life-Cycle Performance of Structures and Infrastructure Systems*



PRIORITIZING NEEDS FOR PRACTICE RAIN-FLOOD EXAMPLE

Current State of the Art

Topic 1: Data sources for hazards

- SLR, flood zones, ATLAS 14, 1-hr regional rain gage data

Topic 2: Hazard design – planning vs final design

- Flood elevation, velocity, waves

Topic 3: Science/analysis capabilities

- Hydrostatic, hydrodynamic analyses, **offshore** wave and storm surge analyses

Future Ideal State (Goal)

Topic 1: Data needs for hazards

- Flood zone elevation/extent/duration, local extreme rain intensity

Topic 2: Hazard design needs – planning vs final design

- Flood elevation, velocity, waves

Topic 3: Science/analysis capabilities to address gaps

- **Onshore** hydrodynamic (wave, storm surge) analyses

FORWARD-LOOKING CODES AND STANDARDS: AGENDA AND GOAL

Jennifer Goupil, P.E., F.SEI., ASCE/SEI

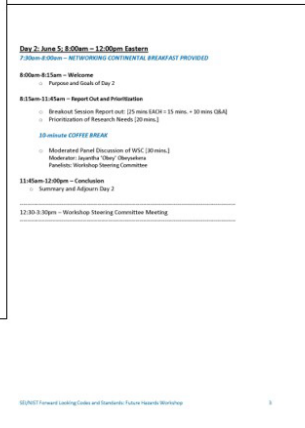
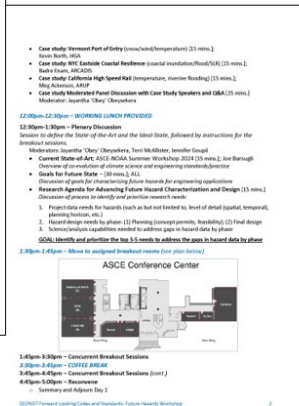
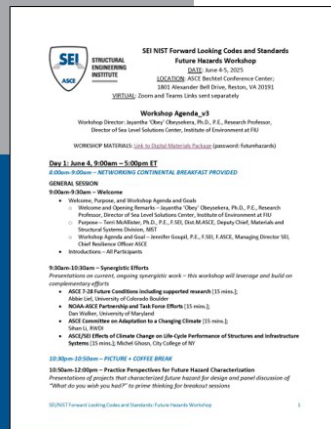


AGENDA

Digital Package

(password: futurehazards)

- AGENDA
- Participant List
- Slide Decks



SELF INTRODUCTION

Name, Organization



ON SITE PARTICIPANTS

Ahmed Abdelaal	SUNY Polytechnic Institute	Katherine Johnson (Jo)	NIST
Ahmed Attar	National Research Council Canada	Katie Stueckle	SEI
Andrew Newman	NSF NCAR	Kevin Borth	HGA
Aron Newman	NIST	Marc Levitan	NIST
Ayse Hortacsu	Applied Technology Council	Mari Tye	NSF NCAR/Johns Hopkins University
Christopher Clavin	NIST	Matt Gilbertson	Simpson Gumpertz & Heger
D.J. Rasmussen	Degree Day LLC	Meg Ackerson	Arup
Daniel Cox	Oregon State University	Michel Ghosn	The City University of New York (CUNY)
Don Scott	Don Scott Consulting	Ning Lin	Princeton University
Eun Cha	University of Illinois at Urbana-Champaign	Peter Vickery	Consultant
Eyitayo Opabola	University of California, Berkeley	Ruohua Guo	Reliability Equity LLC
Hanping Hong	University of Western Ontario	Scott Jones	NIST
Irem Efe	NIST	Siamak Sattar	NIST
J. G. (Greg) Soules	CB&I	Sihan Li	RWDI
Jayantha Obeysekera	Florida International University	Sissy Nikolaou	NIST
Christopher Clavin	ASCE/SEI	Subhadarsini Das	Central Michigan University
Jennifer Helgeson	NIST	Terri McAllister	NIST
Joe Ackroyd	Department of Buildings	Yating Zhang	NIST
		Zoubir Lounis	National Research Council Canada

VIRTUAL PARTICIPANTS

Abbie Liel	University of Colorado
Alex Cannon	Climate Research Division, Environment and Climate Change Canada
Amanda McCarty	NOAA
Ariane Laxo	HGA
Brennan Bean	Utah State University
Bruce R. Ellingwood	Colorado State University
Elisabeth Gilmore	Carleton University
Erik Zuker	HNTB
Francis Zwiers	Pacific Climate Impacts Consortium, University of Victoria
Keith Dixon	NOAA Geophysical Fluid Dynamics Laboratory
Kenneth Kunkel	North Carolina State University
Kevin Reed	Stony Brook University
Lauren Mudd	Applied Research Associates
Lucas Harris	NOAA/Geophysical Fluid Dynamics Laboratory
Michele Barbato	University of California, Davis CITRIS and the Banatao Institute
Robert (Jeff) Trapp	University of Illinois
Seth Thomas	KPFF
Shideh Dashti	University of Colorado Boulder
Xuebin Zhang	Pacific Climate Impacts Consortium, University of Victoria,

SYNERGISTIC EFFORTS

9:30 am – 10:30 am



PRESENTATIONS

9:30am-10:30am – Synergistic Efforts

Presentations on current, ongoing synergistic work – this workshop will leverage and build on complementary efforts

- **ASCE 7-28 Future Conditions including supported research** [15 mins.];
Abbie Liel, University of Colorado Boulder
- **NOAA-ASCE Partnership and Task Force Efforts** [15 mins.];
Dan Walker, University of Maryland
- **ASCE Committee on Adaptation to a Changing Climate** [15 mins.];
Sihan Li, RWDI
- **ASCE/SEI Effects of Climate Change on Life-Cycle Performance of Structures and Infrastructure Systems** [15 mins.]; Michel Ghosn, City College of NY



B.2.1.1. Synergistic Efforts: Loads Considering Future Conditions; Abbie Liel

ASCE 7-28 FUTURE CONDITIONS

Abbie Liel, University of Colorado Boulder



ASCE 7 28 LOADS CONSIDERING FUTURE CONDITIONS

ABBIE LIEL, PHD, PE
UNIVERSITY OF COLORADO BOULDER
CHAIR OF FUTURE CONDITIONS SUBCOMMITTEE

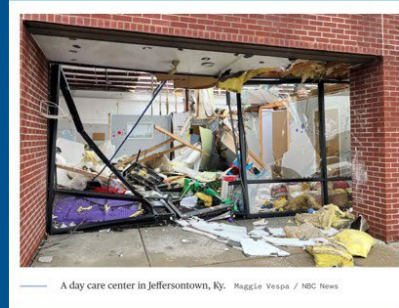
June 4-5, 2025

SEI/NIST Forward Looking Codes and Standards Workshop #1



RATIONALE

- Current loads are based on historical data, but climate change is already affecting loads on structures and community resilience
- These effects are likely to increase over the lifetime of structures we build now
- Standards are needed to provide guidance to designers and jurisdictions seeking to design for these effects now
- Structural engineers need to provide leadership to protect and support prosperous communities



Damage from storms in Kentucky (Feb. 2025)



LOADS CONSIDERING FUTURE CONDITIONS

- ASCE 7-28 Chapter 36 will present criteria for design of structures, accounting for future conditions of environmental loads associated primarily with the impacts of climate change.
- We are addressing
 - Flood loads – sea level rise; erosion
 - Snow loads – ground snow load
 - Rain loads – rainfall intensity
 - Atmospheric icing loads – ice thickness
 - Wind loads – basic wind speeds, tornado wind speeds
- The Chapter is non-mandatory; written in mandatory language but deferring decisions about its adoption to the Authority Having Jurisdiction and/or owner.



CHAPTER 36. LOADS CONSIDERING FUTURE CONDITIONS

36.1 General

36.1.1 Basis for future conditions associated with climate effects

36.1.2 Scope

36.1.3 Definitions

36.1.4 Symbols

36.2 Flood loads

36.3 Snow loads

-Balloted in subcommittee

36.4 Rain loads

36.5 Ice loads

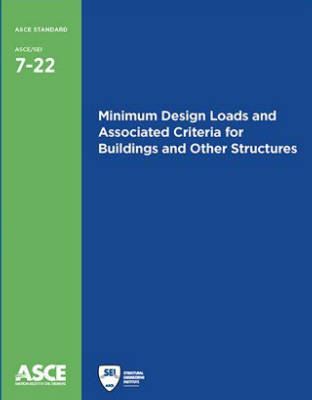
36.6 Wind loads

36.7 Tornado loads

36.7 Site-specific studies

36.8 Consensus standards and other reference documents

Plans for data also to be incorporated into ASCE Hazard Tool



HOW?

- Use best available climate science models to estimate future changes in load
- Translate climate science outputs to meaningful engineering loads that are consistent with ASCE 7 reliability targets
- Leverage ASCE-NOAA agreement, complementary work and guidance by other entities, including ASCE Board of Direction, NIST, FEMA, related SEI Technical Activities

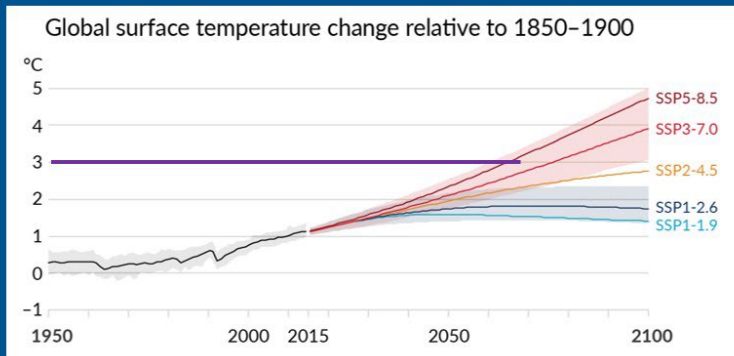


Recent subcommittee meeting



GUIDING PRINCIPLES

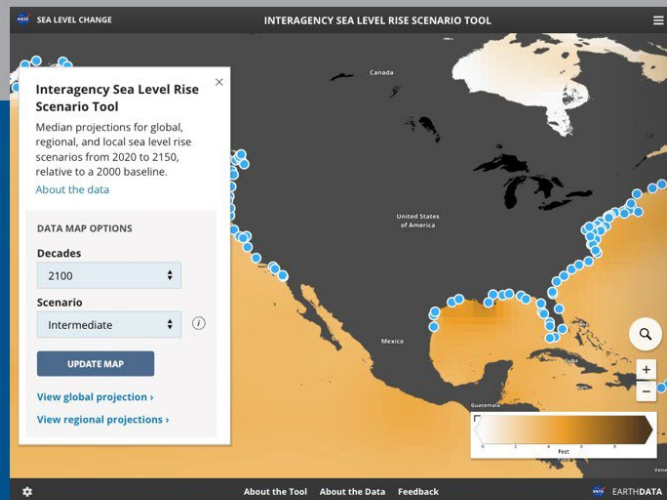
All loads are based on a 3 degree C global warming level and ASCE 7 reliability targets



FLOOD LOADS

Task Committee lead: Matt Gilbertson

- Technical work to date focusing on sea level rise and shoreline erosion
- Sea level rise will be used to modify stillwater elevation
 - Sea level rise will use projections from Interagency report



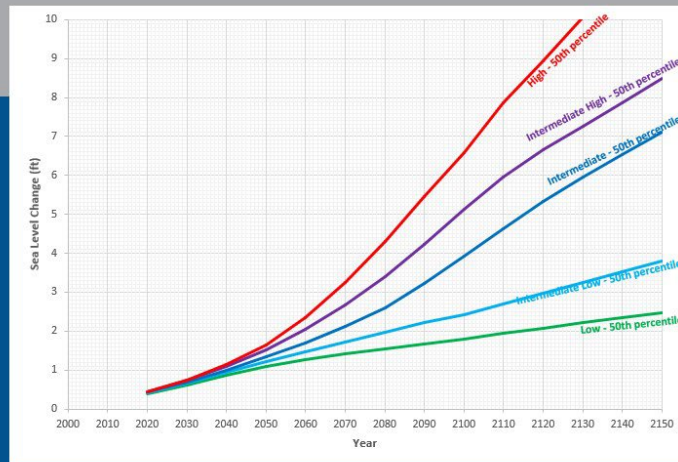
<https://sealevel.nasa.gov/task-force-scenario-tool>



FLOOD LOADS

Task Committee lead: Matt Gilbertson

- Technical work to date focusing on sea level rise and shoreline erosion
- Sea level rise
 - Sea level rise will use projections from Interagency report/tool
 - Curves selected based on non-stationary reliability analysis consistent with ASCE 7 Chapter 1



Family of sea level rise curves from Interagency effort for Manhattan

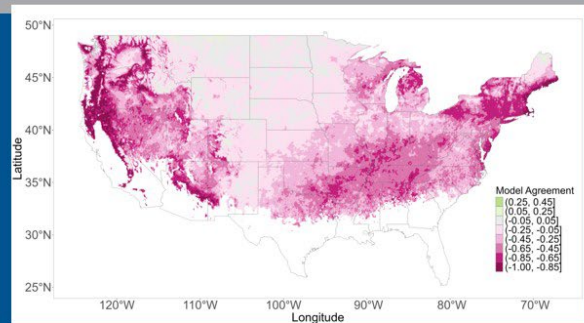


SNOW LOADS

Task Committee lead: Brennan Bean

Source: Bean

- Snow load trends are changing, with some increase in extreme loads, despite warming
- Proposed loads are based on compilation of multiple climate models



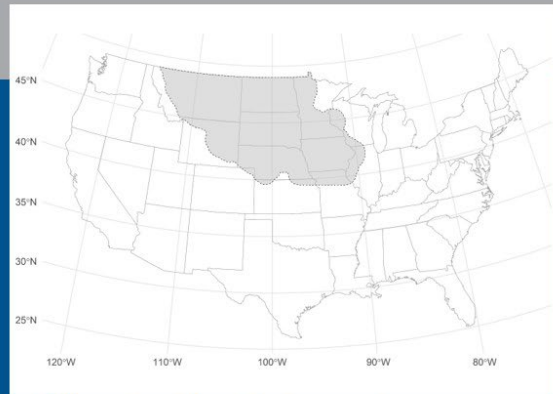
Change in reliability-targeted snow loads, based on one climate model



SNOW LOADS

Task Committee lead: Brennan Bean

- Snow load trends are changing, with some increase in extreme loads, despite warming
- Proposed loads are based on compilation of multiple climate models
- Preliminary results suggest most locations will not see an increase in snow loads, with the exception of the upper Midwest



Likely region with modest increases in snow loads (DRAFT)

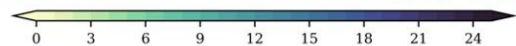
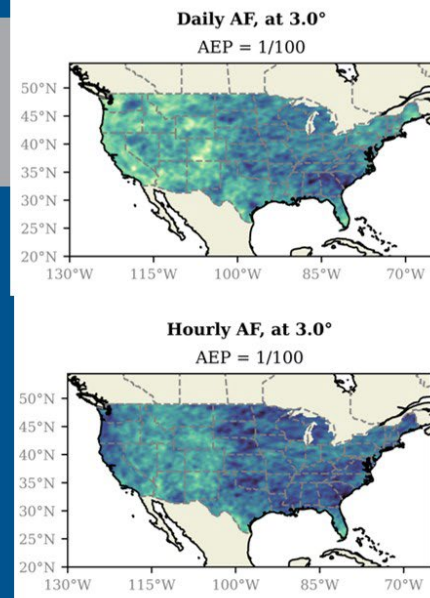


RAIN LOADS

Task Committee lead: Sean Homem

- Technical work intended to align with NOAA Atlas 15 and will develop 15 min rainfall intensities
 - Using cloud resolving climate models to investigate Clausius-Clapeyron scaling
 - Addressing changing distribution and quantity of precipitation
 - Many locations will see increase in rainfall intensity

Preliminary analysis of rain intensities



RAIN LOADS

Task Committee lead: Sean Homem

- Technical work aligns with Atlas 15 and will develop factors to adjust 15 min rainfall intensities
- Many locations will see increase in rainfall intensity
- Impacts on design loads depend on hydraulic head and drainage design (not proportional)

Table C5.2-1. Flow Rate (Q) in Gallons per Minute for Secondary (Overflow) Roof Drains at Various Hydraulic Heads (d_w) above the Dam or Standpipe, in Inches.

Flow Rate (gal./min)	Hydraulic Head (in.) above Dam or Standpipe						
	Overflow Dam 8 in. Diameter		Overflow Dam 12.75 in. Diameter		Overflow Dam 17 in. Diameter	Overflow Standpipe 6 in. Diameter	
	Drain Outlet Size (in.)						
	3	4	6	8	10	4	
	Drain Bowl Depth (in.)						
	2	2	2	2	3.25	4.25	2
50	0.5	0.5	0.5	0.5	0.5	—	1.0
75	1.0	—	—	—	—	—	—
100	1.5	1.0	1.0	1.0	0.5	1.0	1.5
125	2.0	—	—	—	—	—	—
150	2.0	1.5	1.5	1.0	—	—	2.5
175	3.0	—	—	—	—	—	—
200	—	2.0	2.0	1.5	1.5	1.5	2.5
225	—	—	—	—	—	—	—
250	—	2.5	2.5	1.5	—	—	2.5
300	—	3.0	3.0	2.0	1.5	—	3.0
350	—	3.5	3.5	2.5	—	—	3.5
400	—	3.5	3.5	2.5	2.5	2.0	—
450	—	—	4.0	3.0	—	—	—
500	—	—	5.0	3.5	3.0	2.5	—
550	—	—	5.5	4.0	—	—	—
600	—	—	6.0	5.5	3.5	2.5	—
650	—	—	—	—	—	—	—
700	—	—	—	—	3.5	3.0	—
800	—	—	—	—	4.5	3.0	—
900	—	—	—	—	5.0	3.5	—
1,000	—	—	—	—	5.5	3.5	—
1,100	—	—	—	—	—	4.0	—
1,200	—	—	—	—	—	4.5	—

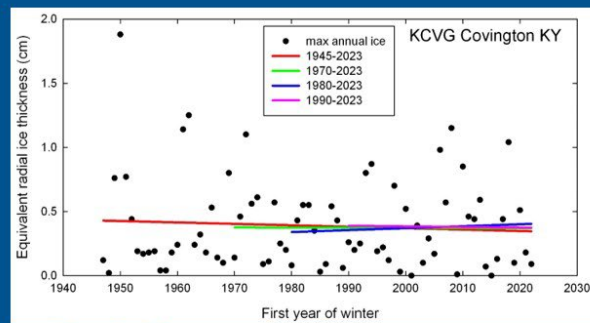
Source: Adapted from FM Global (2016).



ICE LOADS

Task Committee lead: Ahmed Abdelaal

- Began with historical trends in annual maximum ice thickness from freezing rain
 - 74% of trends are negative
 - 12% of trends are significantly different from zero
- Results suggest that there will be some regions where ice loads will increase

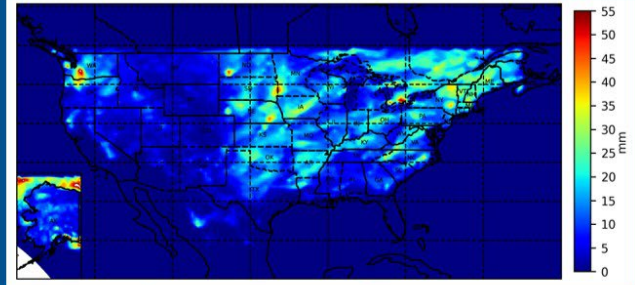


ICE LOADS

Task Committee lead: Ahmed Abdelaal

Source: Abdelaal

- Ongoing work to incorporate climate model data, considering combinations of precipitation and wind that generate ice loads



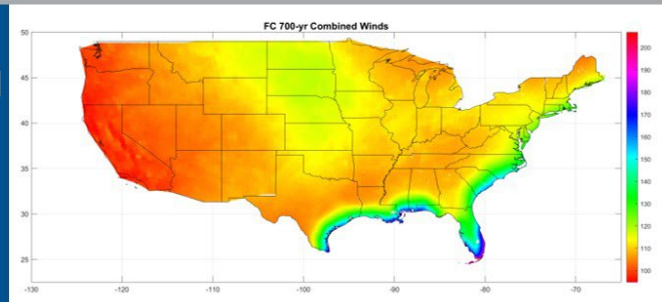
Ice thicknesses from Canadian regional climate model



WIND LOADS

Task committee leads: Marc Levitan and Sihan Li

- Ongoing technical work addressing the basic wind speed for hurricane and synoptic in future climate
 - Considers non-hurricane and hurricane winds separately, and then recombines
- Tornado wind speed increases are small, but change in location and frequency not yet considered



Early (DRAFT) change factors for wind loads



STANDARDS ARE KEY
TO PROVIDING
ENGINEERS WITH THE
INFORMATION
NEEDED TO SERVE
CLIENTS AND
COMMUNITIES

The Preparedness Payoff: The Economic Benefits of Investing in Climate Resilience

2024 Climate Resiliency Report
Produced in partnership by the U.S. Chamber of Commerce,
Allstate, and the U.S. Chamber of Commerce Foundation



U.S. Chamber of Commerce



Allstate.



U.S. Chamber of Commerce
Foundation



STRUCTURAL
ENGINEERING
INSTITUTE

WE LOOK
FORWARD TO
YOUR
CONTINUED
PARTNERSHIP
IN MEETING
THE EVOLVING
NEEDS OF OUR
PROFESSION



Image from [Cloudy with a Chance of Meatballs](#)



STRUCTURAL
ENGINEERING
INSTITUTE

B.2.1.2. Synergistic Efforts: NOAA-ASCE Partnership and Task Force Efforts; Dan Walker

NOAA-ASCE PARTNERSHIP AND TASK FORCE EFFORTS

Dan Walker, University of Maryland



ASCE NOAA TASK FORCE

Climate Resilience in Civil Engineering Practice

Dan Walker, Ph.D., P.G., M. ASCE
University of Maryland, Center for Technology and Systems Management
And
EA Engineering, Science, and Technology, Inc. (PBC)



ASCE and NOAA Partnership

- Shared strategic goals by ASCE and NOAA
 - Climate adaptation
 - Impactful outcomes for communities
- Strengthening connections between NOAA/science community and ASCE/civil engineering community
- Expanding mutual understanding of shared goals and objectives
- Identifying priority climate and weather data sets and data products (e.g., projections) for ASCE needs
- Exploring ways of operationalizing development, release, and periodic update of climate/weather products for civil engineering needs



4



Global Risks Report 2024

Top 10 risks



Please estimate the likely impact (severity) of the following risks over a 2-year and 10-year period.



Source: World Economic Forum Global Risks Perception Survey 2023-2024.



5

NOAA's Data and Services



- Observations
- Data and information stewardship
- Research and development
- Modeling, prediction, and projection
- Co-development and engagement
- Service delivery and decision-support tools
- Evaluation



ASCE

6

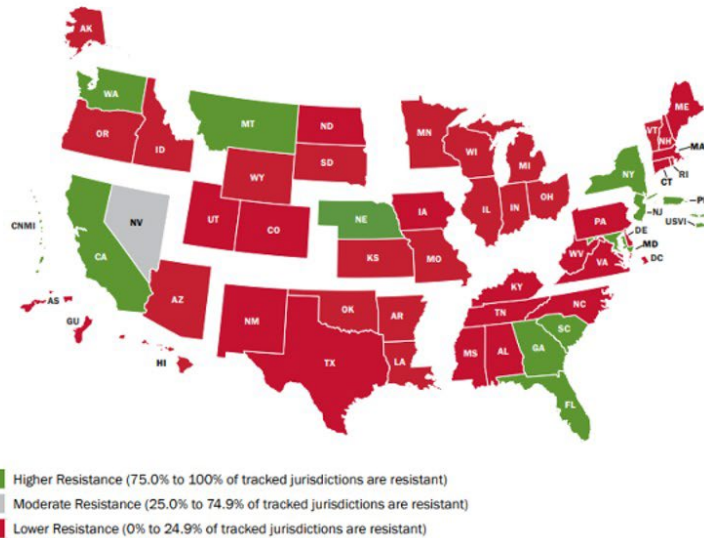
ASCE Standards and Manuals of Practice



ASCE

7

- Only 32% adopted current hazard resistant building codes
- Utilizing and enforcing current hazard-based building codes incorporate better science and new technologies



Source: <https://www.fema.gov/emergency-managers/risk-management/building-science/bcat>



ASCE

8

Improved Delivery of Climate Data and Information

- 15 - 60-minute rainfall ([HPD](#))
- NClimgrid - [Monthly](#), [Daily](#)
- [Atlas 14, Forward looking IDF curves](#)
- [Atlas 15 Pilot](#)
- [Climate projections](#), scenarios
- [Sea Level Change](#)
- [Atmospheric Humidity](#)
- [Climate Normals](#)
- [Billion Dollar Disasters](#) (County-level with risk data)
- [Air Freezing Index](#)
- [Storm Events Database](#)
- [Engineering Weather Data Update](#)

Architecture and Engineering



From residential buildings to critical infrastructure like bridges, dams, and roads; the Nation's existing structures are impacted by weather and climate. Changes in extreme heat, heavy rainfall, and sea level all affect how we need to design and build in the future throughout every region.



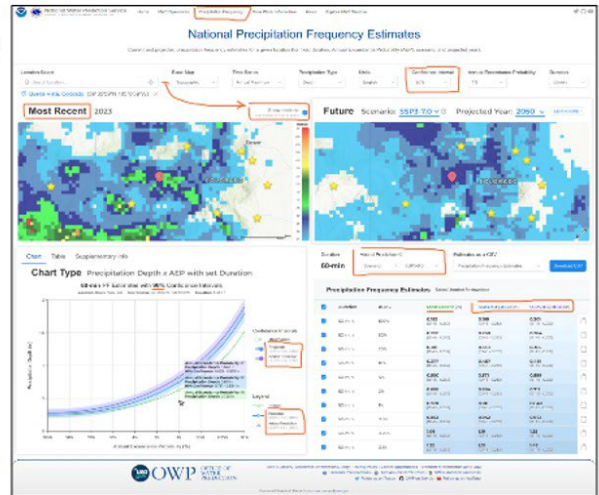
ASCE

9

ATLAS 15 - Designing for the Future

This pilot includes developing estimates of future extreme rainfall to assist infrastructure design and land use

The NOAA Atlas 15 Pilot over Montana is now available for early feedback using the QR code shown here or go to water.noaa.gov/about/atlas15



10

Natural Hazard Risk Reduction: Building the Resiliency Business Case ASCE-NOAA Workshop

June 24-25, 2025 | ASCE Headquarters



UNIVERSITY OF
MARYLAND



Email Erika Haldi (ehaldi@asce.org) if you are interested in participating.



11

B.2.1.3. Synergistic Efforts: ASCE Committee on Adaptation to a Changing Climate; Sihan Li

ASCE COMMITTEE ON ADAPTATION TO A CHANGING CLIMATE

Sihan Li, RWDI



RESEARCH ADVANCEMENT ON CLIMATE ADAPTATION BY ASCE COMMITTEE ON ADAPTATION TO A CHANGING CLIMATE (CACC)

SIHAN LI, PH.D., P.ENG., CRM, ENV SP, M.ASCE
RWDI
CACC - CHAIR

June 4-5, 2025

SEI/NIST Forward Looking Codes and Standards Workshop #1



ASCE COMMITTEE ON ADAPTATION TO A CHANGING CLIMATE (CACC)

- Introduction of CACC
- Past Research, Publications, and Webinars
- Research and Task Groups



INTRODUCTION OF CACC





Changing Climate Committees

<https://www.asce.org/communities/institutes-and-technical-groups/changing-climate/committees>

Activities of the committee include research and development related to a changing climate and its effects on the safety, health and welfare of the public as it interfaces with civil engineering infrastructure. This research may lead to the establishment of appropriate standards, loading criteria and evaluation and design procedures for:

- Building and other structures
- Coastal, river and port facilities
- Communications
- Dams
- Earthworks and foundations
- Energy generation and transmission
- Stormwater
- Transportation
- Water Supply
- Wastewater Treatment

The Committee on Adaptation to a Changing Climate was formed in 2011 to evaluate the technical requirements and civil engineering challenges for adapting to a changing climate.



Vision

Civil engineers design and adapt infrastructure to address climate change and its potential current and future consequences using appropriate high-confidence climate science infused across all of ASCE's activities and all aspects of civil engineering.

Mission

The Committee on Adaptation to a Changing Climate evaluates and communicates the technical requirements and civil engineering challenges for adapting to a changing climate to support future thinking and civil engineering practice.

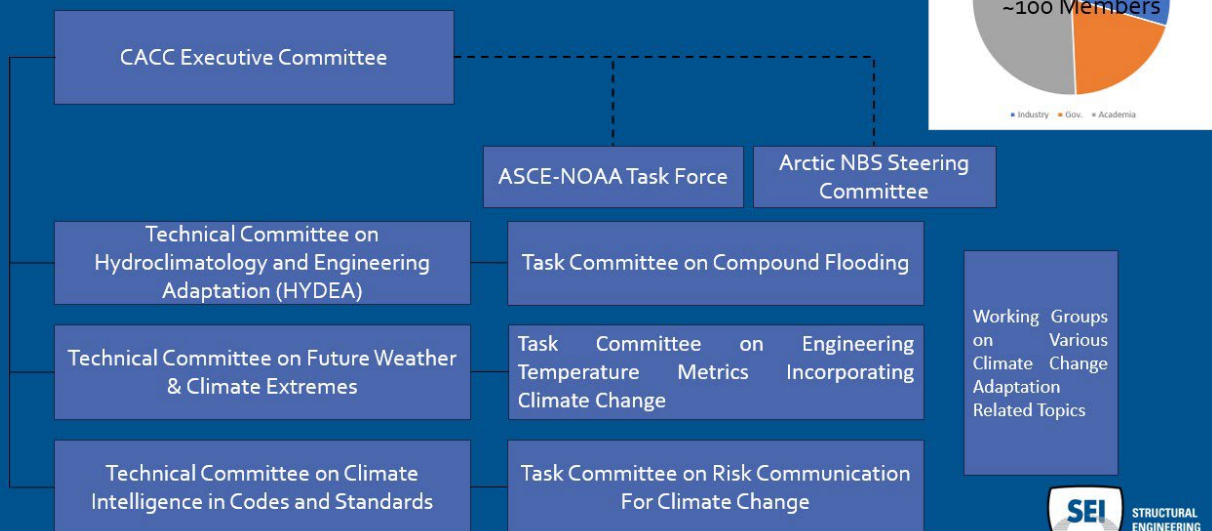


Objectives

1. Promulgate climate change information in civil engineering practice.
2. Connect with ASCE Institutes and other technical committees within CTA at the leadership level to amplify impact and to understand the needs of practicing engineers.
3. Connect practicing engineers to resources and information regarding appropriate current steps for adaptation of infrastructure to a changing climate.
4. Perform continuous awareness-level review of state-of-the-art applied meteorology, climate research, and climate science development related to civil engineering practice.
5. Facilitate climate science practicable for civil engineers by identifying barriers and potential solutions for climate science application to civil engineering practice.



Structure and Membership



Leadership Team

Sihan Li – Chair
Dan Walker – Immediate Past Chair
Craig Musselman – Vice Chair
Eun Cha – Secretary
Jayantha Obeysekera – ExCom member
Kelcy Adamec - ExCom member and Chair of HYDEA
Teng Wu – Chair of FWCX
Grace Yan – Vice Chair of FWCX
Carol Considine – Chair of CICS
John Dai – ExCom member/Young Member

Rolf Olsen – Chair of Task Committee on Compound Flooding
Chris Anderson - Chair of Task Committee on Engineering Temperature Metrics
Sihan Li – Chair of Task Committee on Risk Communication for Climate Change

Editors for Technical Note : Dan Walker and Craig Musselman

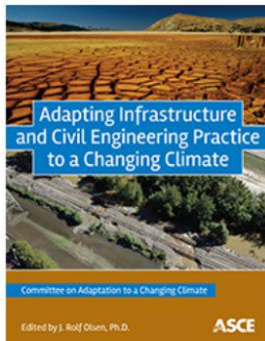
Past Chairs:

Bilal Ayyub
Ana Barros
Rolf Olsen
Constanti Samaras
Mari Tye
Dan Walker



PAST RESEARCH, PUBLICATIONS, AND WEBINARS





2015

Edited by Rolf Olsen,

This book explores how climate change impacts civil engineering and the challenges of integrating climate science into long-term infrastructure planning. It highlights the need to bridge the gap between climate science and engineering practice and addresses key topics such as:

- How to incorporate climate data into engineering
- Sectors of civil engineering vulnerable to climate change
- Research and development needs
- Case studies showing different adaptation strategies



Engineering Methods for
Precipitation under a
Changing Climate



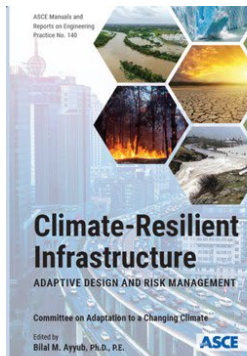
2017

Edited by Rolf Olsen, and Kelcy Adamec

This collection presents selected peer-reviewed papers from the ASCE Workshop on Engineering Methods for Precipitation under a Changing Climate, held in May 2017, sponsored by ASCE's Subcommittee on Hydroclimatology and Engineering Adaptation of CACC. These papers focus on:

- Engineering methods for designing and managing infrastructure in response to extreme precipitation and flooding.
- Approaches to handling uncertainty and defining acceptable risk.
- Collaboration between engineers and climate scientists to meet engineering information needs.

This report also included a summary of workshop discussions and recommendations.



2018

Manual of Practice 140

Climate-Resilient Infrastructure: Adaptive Design and Risk Management

Edited by Bilal Ayyub, prepared by ASCE's Committee on Adaptation to a Changing Climate, it addresses how to design civil infrastructure in response to shifting and uncertain climate conditions. This MOP introduces a new, adaptive design philosophy centered on probabilistic risk analysis and low-regret strategies that enhance infrastructure resilience. Key topics:

- Climate hazards and their implications for infrastructure.
- Estimation and monitoring of extreme events, especially precipitation.
- Flood design criteria and computational flood load methods.
- Life-cycle engineering, economics, and adaptive risk management.
- Emerging climate resilience technologies.





2021

Edited by Mari Tye, and Jason P. Giovannetone

This book is prepared by ASCE's Task Committee on Future Weather and Climate Extremes, examines how changing extreme weather and climate events may affect U.S. infrastructure. It identifies vulnerabilities across five key infrastructure sectors: energy; transportation; drinking water and wastewater; water storage and flood protection; navigation. This book assesses each sector's exposure to climate risks, current resilience, and interdependencies with other sectors. It also provides frameworks for decision-makers to prioritize adaptation actions under limited budgets, including a step-by-step prioritization process and case studies.



RESEARCH AND TASK GROUPS



Approved Ongoing Research Group

- Review on Climate Change Impact on Extreme Wind Hazards
- Review on Adaptation Practice
- Risk Communication for Climate Change
- Deep Uncertainties in Climate Change Adaptation Implementation
- MOP for Compound Flooding
- Emerging Arctic Community of Practice
- Task Committee on Engineering Temperature Metrics Incorporating Climate Change

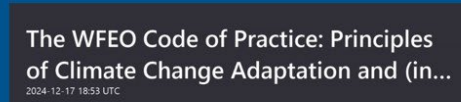
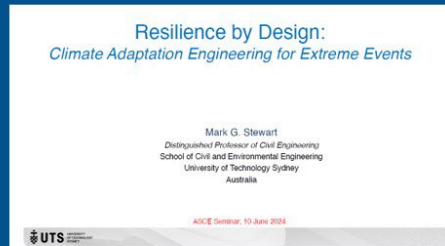
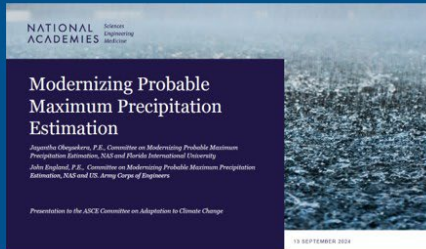


Webinars

American Meteorological Society (AMS)/American Society of Civil Engineers (ASCE) Joint Webinar Series



Invited Presentations



Sponsor, Collaboration, and Engagement

- ASCE NOAA Task Force for Climate Resilience in Civil Engineering Practice
 - ASCE-NOAA Workshop
 - News-Letter
- Climate Technical Note
- Arctic NbS workshop
- MOU between ASCE and AMS for Climate Adaptation and Resilience Collaboration
- Workshop on Resilience of Navy Waterfront Facilities in a Changing Climate
- ASCE 7-28 Chapter 36



B.2.1.4. Synergistic Efforts: ASCE/SEI Effects of Climate Change on Life-Cycle Performance of Structures and Infrastructure Systems; Michel Ghosn

ASCE/SEI EFFECTS OF CLIMATE CHANGE ON LIFE-CYCLE PERFORMANCE OF STRUCTURES AND INFRASTRUCTURE SYSTEMS

Michel Ghosn, City College of NY



EFFECTS OF CLIMATE CHANGE ON LIFE-CYCLE PERFORMANCE OF STRUCTURES AND INFRASTRUCTURE SYSTEMS:

SAFETY, RELIABILITY, AND RISK

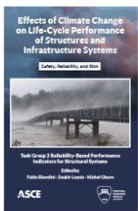
June 4-5, 2025

SEI/NIST Forward Looking Codes and Standards Workshop #1



Effects of Climate Change on Life-Cycle Performance of Structures and Infrastructure Systems: *Safety, Reliability, and Risk*

Editors: Fabio Biondini
Zoubir Lounis
Michel Ghosn



SEI Task Group 2 on Reliability-Based Performance Indicators for Structural Systems
Former Technical Council on Life-Cycle Performance, Safety, Reliability, and Risk of Structural Systems



BOOK OBJECTIVES

SEI Special Project

Literature Review, Survey of Experts, and Workshop to develop a multidisciplinary state-of-the-art report that outlines methodologies for:

- Projecting the impacts of future climatic hazards
- Analyzing the effect of future climate on structures and infrastructure systems
- Outlining approaches for the design and safety assessment of buildings, bridges and other structures.
- Assessing the impact on the life-cycle performance and risk of structures and infrastructure systems.

Team Expertise

Climate Science; Structural Reliability; Code Development; Life Cycle Analysis



BOOK CONTENT

Five Chapters:

- Introduction (Biondini, Lounis, Ghosn)
- Climate Projection Models and Data (Giovannettone, Tye, AghaKouchak)
- Impact of Climate on Infrastructure Performance (Ellingwood, Bocchini)
- Life-Cycle Risk-Based Decision Making for Future Climate (Frangopol, Liu, Yang)
- Conclusions (Lounis, Ghosn, Biondini)

Two Annexes:

- Survey Overview and Results (Biondini, Lounis, Ghosn)
- International Workshop Overview and Outcomes (Biondini, Lounis, Ghosn)



CHAPTER TWO

Climate Projection Models and Data

Lead authors: Jason P. Giovannettone, Mari R. Tye, Amir AghaKouchak

Content:

- Future global climate and the portfolio of responses
- Climate projection scenarios, sensitivity, and downscaling
- Attribution of extreme events
- Projection of future climate variables relevant to structure and infrastructure engineering



COUPLED MODEL INTERCOMPARISON PROJECTS (CMIP)

Climate models describe the dynamics of climate system governed by *basic physics principles*:

- conservation of air mass
- conservation of water mass
- conservation of energy
- conservation of momentum of air in three directions
- ideal gas law applied to air

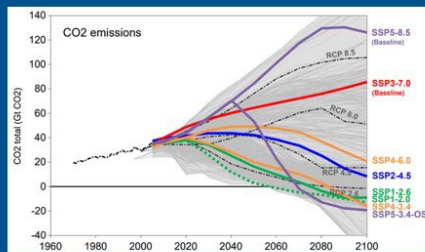
Constrained by basic *climate parameters*:

- air temperature
- pressure
- density
- water vapor content
- wind intensities in three directions

Use “parameterizations” to model other variables such as rain, snow, and ice

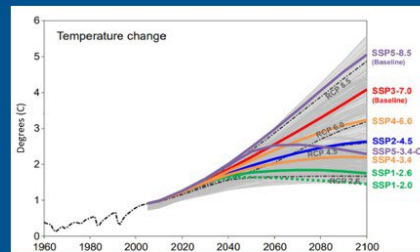


GLOBAL CHANGE AND RESPONSES



IPCC AR6 accounts for short-lived (methane, ozone) and long-term (CO₂) climate forcers

TCR simulates CO₂ increases by 1% per year until doubled: IPCC AR5 → 1.0 to 2.5 °C
IPCC AR6 → 1.4°C to 2.2°C



- | | |
|---------------|---------------------|
| • Temperature | • Surface winds |
| • Humidity | • Tropical cyclones |
| • Rainfall | • Sea level rise |
| • Snow | • Flooding |
| • Icing | • Wave climate |
| | • Wildland fires |



GLOBAL vs. REGIONAL CLIMATE MODELS

General circulation models (GCMs) simulate the global climate with grid spacing typically between 250 and 600 km for various Shared Socio-Economic Pathway (SSP) Scenarios

Regional climate models (RCMs) are downscaling tools for finer spatial (10 to 50 km) and temporal (daily and seasonal) projections by incorporating more complex land surface models and atmospheric processes.

Local-scale climate that are needed to correct for biases even in RCM's



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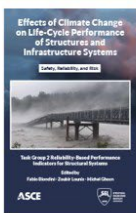
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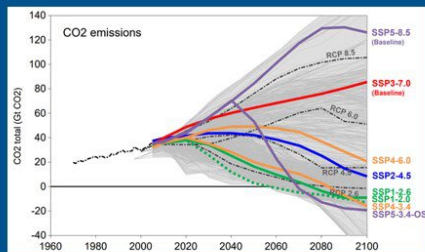
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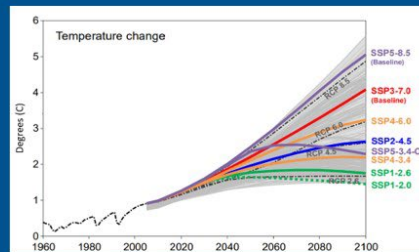


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PROJECTIONS OF RELEVANT CLIMATE HAZARDS

Database	Source	Variables available	Model(s) / Scenario(s)
Climate Data Store	ECMWF (2022)	temperature, precipitation, wind	CMIP6; all SSP scenarios
Climate Explorer	U.S. Federal Government (2022)	temperature, precipitation	CMIP5; RCP4.5; RCP8.5
NOAA Sea Level Rise Viewer	NOAA (2022a)	sea level rise	CMIP5 RCP2.6, RCP3.4, RCP4.5, and RCP8.5
Coordinated Ocean Wave Climate Project (COWCLIP)	COWCLIP (2022)	significant wave height, mean wave period, mean wave direction	CMIP5; RCP4.5; RCP8.5
North American component of the Coordinated Regional Downscaling Experiment (NA-CORDEX)	Mearns et al. (2017)	temperature, precipitation, wind, humidity, surface air pressure, radiation To come: snow, freezing rain	CMIP5; RCP4.5; RCP8.5
NCAR Community Climate System Model (CCSM) projections in GIS formats	NCAR	Temperature, precipitation	CMIP5; all RCP scenarios
Localized Constructed Analogs (LOCA)	Pierce et al. (2014)	Temperature, precipitation, humidity	CMIP5 RCP4.5; RCP8.5
Multivariate Adaptive Constructed Analogs (MACA)	Abatzoglou and Brown (2012)	Temperature, precipitation, humidity, relative humidity, shortwave radiation, Surface wind	CMIP5 RCP4.5; RCP8.5
Design Value Explorer	PCIC (2020)	temperature, precipitation, relative humidity, snow	RCP2.6, RCP4.5, RCP6.0, RCP8.5
Environment and Climate Change Canada	Cannon et al. (2020)	temperature, precipitation and moisture, wind, and snow and ice	RCP2.6, RCP4.5, RCP6.0, RCP8.5

CHAPTER THREE

Impact of Extreme Climate on Infrastructure Performance

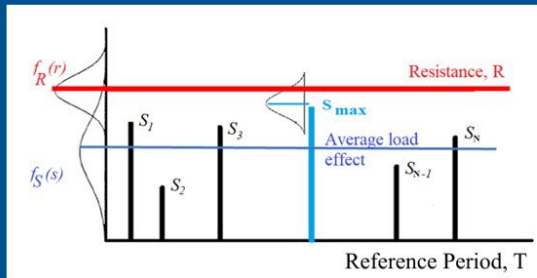
Lead authors: Bruce Ellingwood, Paolo Bochini

Objectives:

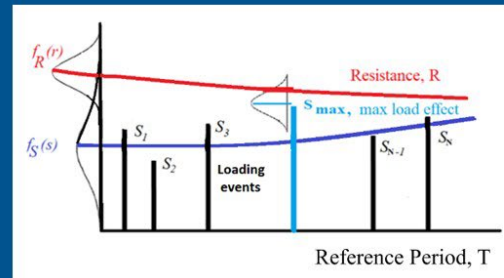
- Identify and characterize hazards that are significant for design of buildings and other structures
- Summarize principles of reliability-based structural design and risk-informed decision-making, as applicable to nonstationary climate;
- Investigate the issue of non-stationarity of climate and its implications on climatic loads, load combinations and structural reliability levels
- Identify and assess the impact of changes in climatic hazards and climate related loads on the performance of structures and resilience of communities.



STRUCTURAL SAFETY ASSESSMENT



Stationary Conditions



Nonstationary Conditions

$$\text{Max. Load} \rightarrow S_{\max, T} = C \max_{i=1}^N (H_i) = \text{influence coefficient} \times \text{Max. hazard}$$



HAZARD ANALYSIS

Given N extreme events in a structure's reference period, T , the maximum hazard event intensity is:

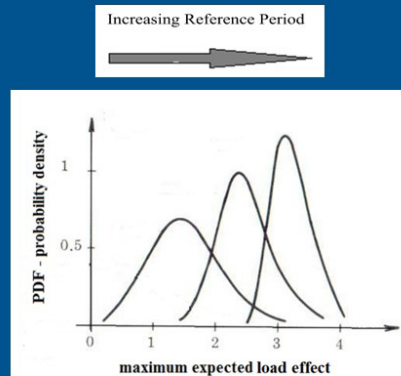
$$H_{max,T} = \max_{i=1}^N (H_i)$$

Assuming independence, the cumulative probability distribution of $H_{max,T}$

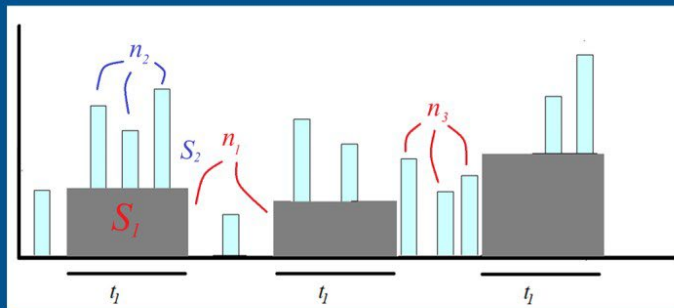
$$F_{H_T}(\dots) = Pr(H_T < h)$$

$$F_{H_T}(h) = F_{H_1}(h) \times F_{H_2}(h) \times \dots \times F_{H_N}(h)$$

Hazard Analysis evaluates extreme distribution of hazard alone



LOAD COMBINATION MODEL



$$S_{max,T} = \max \left\{ \max_{n_1} \left[S_1 + \max_{n_2} [S_2] \right], \max_{n_3} [S_3] \right\}$$

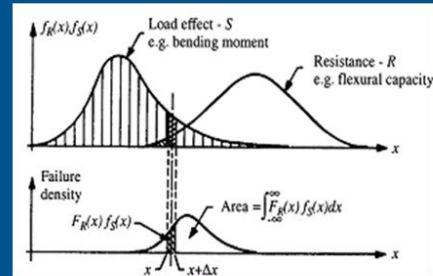
$$= \max \left\{ \max_{n_1} \left[C_1 H_1 + \max_{n_2} [C_2 H_2] \right], \max_{n_3} [C_2 H_2] \right\}$$



STRUCTURAL RELIABILITY

Probability of failure = Pr. of exceeding limit state calculated from the probability distribution of the extreme load event and that of the resistance (load carrying capacity).

$$\text{Reliability index, } \beta = \Phi^{-1}(1 - P_f)$$



Safety Margin = Limit State Function, $Z = R - S = 0$

Probability of Limit State Exceedance, $P_f = \Pr [Z < 0] = \Pr [R < S]$



EXAMPLE: LIMIT STATE EQUATION FOR WIND LOAD

Design Check Equation

$$0.9R_n = 1.2D_n + W_n = 1.2D_n + C_{w,n}V_n^2$$

Limit state equation:

$$Z = \lambda_R \left[\frac{1.2D_n + 1.0C_{w,n}V_n^2}{0.9} \right] - \lambda_D D_n - \lambda_W [C_{w,n}(\bar{V}_{max})^2]$$

$$Z' = \lambda_R \left[\frac{1.2D_n + 1.0C_{w,n}V_n^2}{0.9V_n^2} \right] - \lambda_D \frac{D_n}{C_{w,n}V_n^2} - \lambda_W \left[C_{w,n} \left(\frac{\bar{V}_{max}}{V_n} \right)^2 \right]$$

$$P_f = \Pr(Z < 0) = \Pr(Z' < 0)$$

If the bias and the COV of V_{max} and λ_W do not change with V_{max} , then the $\Pr (Z' < 0)$ remains unchanged if $\frac{\bar{V}_{max}}{V_n}$ is unchanged

Random Variables

Variable	Mean	COV	PDF
λ_R	1.08	9%	Lognormal
λ_D	1.05	10%	Normal
λ_W	0.68	From Eq.	Type I
V_{max}	From site	From site	Included in λ_W

$$\text{COV}[\lambda_W] \approx \sqrt{(27\%)^2 + 4[\text{COV}(V_{max})^2]}$$



RISK-INFORMED UNIFORM RELIABILITY VS. UNIFORM HAZARD

- Risk-informed codes adjust β_{target} to consider risk defined as $Risk = P_f \times Consequences$
- Reliability-calibrated design equations provide a reliability index β that closely matches β_{target} for the entire range of applications.
- Return period, T_R , gives the magnitude of the yearly hazard for design loads: $H_{ni}^* = F_{H_1}^{-1} \left(1 - \frac{1}{T_R} \right)$
- For nonstationary hazards define “Equivalent Yearly Distribution”: $F_{H_{eq, yearly}}(h) = [F_{H_{max, T}}(h)]^{1/N}$

Example: Return periods for wind design load in ASCE-7

Building Category	Reference period	Target reliability		Return period
structures presenting low hazard to humans	T=50 years	$\beta_{target}=2.50$	→	$T_R=300$ yrs
All other buildings	T=50 years	$\beta_{target}=3.00$	→	$T_R=700$ yrs
high occupancy and vulnerable users	T=50 years	$\beta_{target}=3.25$	→	$T_R=1700$ yrs
essential buildings needed for continuous use	T=50 years	$\beta_{target}=3.50$	→	$T_R=3000$ yrs

STRUCTURAL
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CHAPTER FOUR

Life-Cycle Risk-Based Decision Making in a Extreme Climate

Lead authors: Dan Frangopol, Ming Liu

Content:

- Impacts of extreme future climate on lifetime structural reliability, risk, redundancy, robustness, and resilience;
- Infrastructure interdependencies and multi-hazard effects under climate events;
- Optimization techniques for life-cycle management of new and existing structures in extreme climates; and
- Strategies for infrastructure management subject to extreme climate illustrated through the management of transportation systems as an example case.



RISK-INFORMED DECISION-MAKING



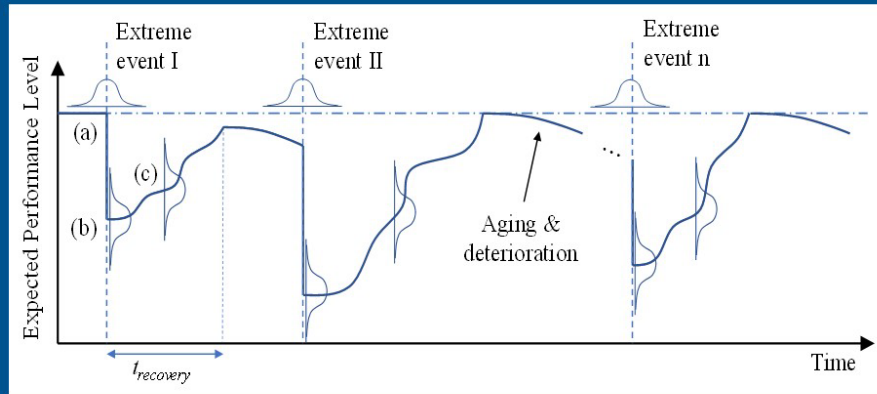
ACCELERATED DETERIORATION

Example: Accelerated deterioration in Reinforced Concrete due to climate effect

Scenario	Carbonation	Chloride Corrosion	Root Causes
SSP1-2.6	10% ↑ in rate by 2060 6% ↑ in rate by 2100	12% ↑ in rate by 2100	Temperature ↑ less than 2°C (Paris Agreement)
SSP2-4.5	20% ↑ in rate by 2100 10-15% ↑ in depth and 7 years ↓ to 20 mm by 2075	22% ↓ in initiation time (bridges)	CO ₂ concentration Compound effects of CO ₂ and temperature
SSP5-8.5	65% ↑ in rate by 2100		CO ₂ concentration
Changes in RH	25% ↓ in diffusion coefficient	15% ↓ in rate	RH ↓ from 80% to 75%
	11% ↑ in diffusion coefficient	15% ↓ in rate	RH ↓ from 65% to 60%
	negligible rate	negligible rate	RH less than 50%



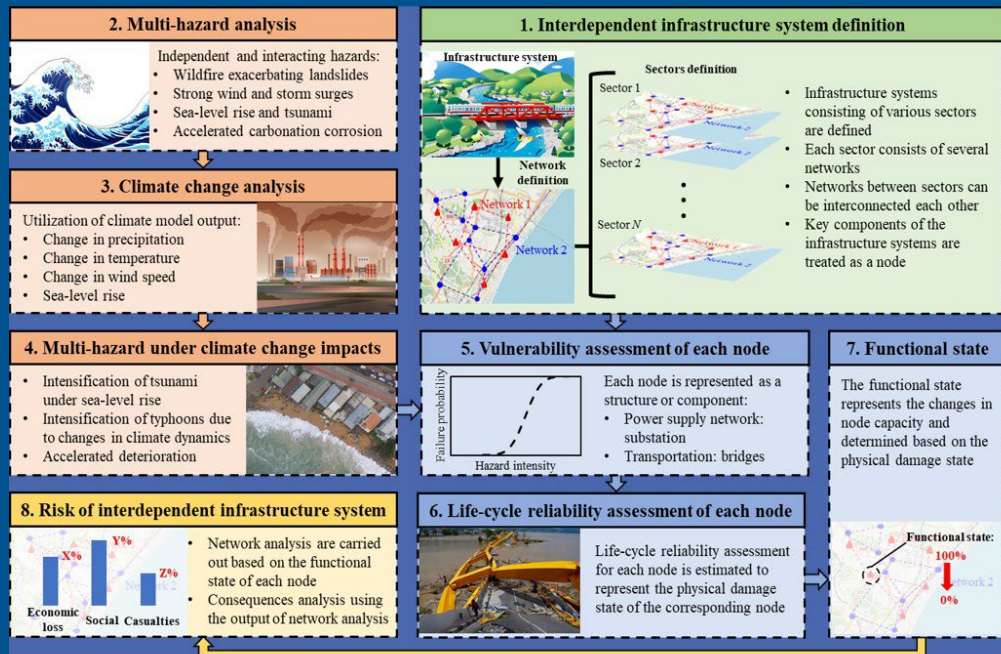
STRUCTURAL RESILIENCE



lifetime performance of a system



Framework for estimating reliability and risk of interdependent infrastructure systems under multi-hazard effects and extreme climate impacts



MAIN RECOMMENDATIONS

1. Closer coordination between climate scientists; experts in structural reliability methods, hazard and risk assessment; and code writers.
2. Climate projections should provide estimates of the maximum annual extreme events as well as general trends in hazard intensities, frequencies and durations.
3. Information on the correlations between different climate hazards are needed for analyzing the effects of load combinations.
4. Projections must be presented in formats that can be easily retrieved for direct implementation by structural design code developers and design engineers.
5. Choice of SSP scenario should be made by code writing units or project owners on a risk-informed basis.
6. Code writers should seek approaches other than return periods to express the magnitudes of design loads.



PHOTO & COFFEE BREAK

15 minutes

In person attendees – PLEASE head outside for photo
Virtual attendees – PLEASE TURN CAMERAS ON for photo

PUBLIC attendees – We will restart at 10:50 am



PRACTICE PERSPECTIVES FOR FUTURE HAZARD CHARACTERIZATION

10:50 am – 12:00 pm



PRESENTATIONS

10:50am-12:00pm – Practice Perspectives for Future Hazard Characterization

Presentations of projects that characterized future hazard for design and panel discussion of “What do you wish you had?” to prime thinking for breakout sessions

- **Case study: Vermont Port of Entry** (snow/wind/temperature) [15 mins.];
Kevin Borth, HGA
- **Case study: NYC Eastside Coastal Resilience** (coastal inundation/flood/SLR) [15 mins.];
Badre Enam, ARCADIS
- **Case study: California High Speed Rail** (temperature, riverine flooding) [15 mins.];
Meg Ackerson, ARUP
- **Case study Moderated Panel Discussion with Case Study Speakers and Q&A** [25 mins.]
Moderator: Obey Jayantha



B.2.1.5. Practice Perspectives: Vermont Port of Entry; Kevin Borth

VERMONT PORT OF ENTRY

Kevin Borth, HGA



DERBY LINE LAND PORT OF ENTRY

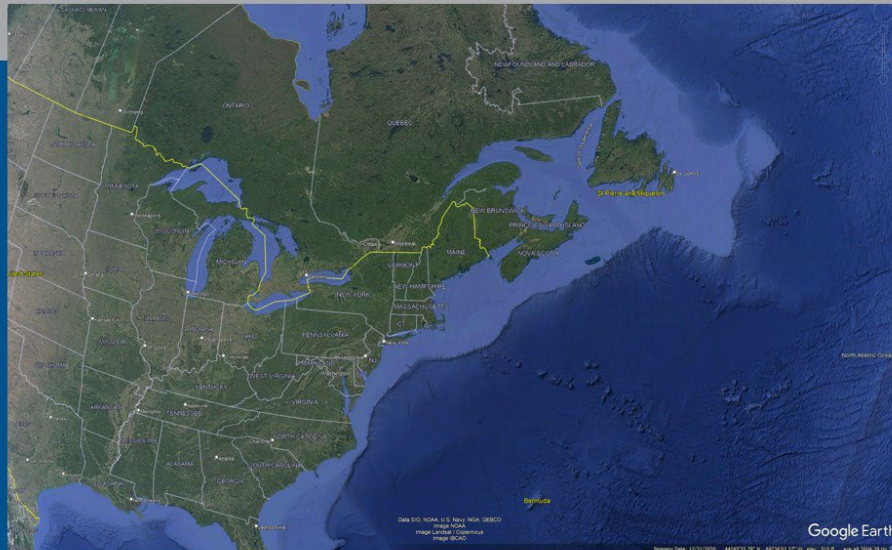
A case of future conditions





DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Building Information

Client: U.S. General Services Administration (GSA)
User: U.S. Customs and Border Protection (CBP)

Project start: June 2013
Construction completed: January 2018

21,500 sq ft single story steel-framed structure with architectural precast concrete walls.

Program included:

- Inspection Booths
- Commercial Inspection
- Offices
- Public Lobby
- Holding and Interview Rooms



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Statement of Work

Climate Risk Analysis:

Before concepts are developed during the design concept phase, analyze and document and submit the following for review and comment by GSA:

1. ***Investigate available data regarding current climate impacts to the project site*** including wind, extreme precipitation, and extremes of temperature in duration with a focus on reduction of green house gas emissions and resilient site hydrology able to handle extremes. Data shall be sourced from federal sources: USGCRP and contributing agencies.
2. Incorporate in this analysis and ***professional recommendations*** sufficient flexibility to ***address*** current climate conditions and ***likely changes to ensure that the project remains responsive and resilient across a range of future circumstances.***



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Statement of Work

Climate Risk Analysis (continued):

3. ***Provide a condition assessment of existing facilities*** that have critical functions supporting this project. ***Analyze existing climate conditions and address the ability of the project to meet mission requirements*** within the context of incremental climate changes over time. Interview GSA and customer representatives and other stakeholders.
4. Document the development process to ***demonstrate that resulting recommendations are responsible choices*** among alternatives.
5. ***Identify and evaluate a range of alternatives*** over a period of time ***and preferred recommendations*** including potential damages and gains, and thresholds beyond which impacts may pose a project challenge or opportunity.
6. ***Analyze and document each recommendation from technical, financial and functional points of view***, for determination and selection by GSA.
7. ***Document the reasoning that led to the recommendation***, including how it meets/exceeds GSA's and client agencies' requirements and objectives.



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Statement of Work

Study for Climate Adaptation:

Submit the following to GSA for review and comment during the Pre-Design stage:

1. ***Identification of climate factors projected to affect the project***; including flooding (rising or falling water) or extreme precipitation events, reduced water availability (summer) or drought caused by soil shrinkage, subsidence, gust patterns (length), wildfire, sustained extreme temperatures or humidity affecting the building enclosure or building system's capacity to maintain internal comfort, or disruption of site access by suppliers or federal employees based on latest assessment by the U.S. Global Change Research Program (USGCRP) <http://www.globalchange.gov/>
2. ***Identify the vulnerabilities and potential consequences*** if recommended actions are not taken.



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Statement of Work

Study for Climate Adaptation (continued):

3. *Summarize existing climate impacts and projected climate impacts* and identify climate protection levels (CPL) to secure the federal investment, support mission continuity and resiliency. *Determine the level that climate change adaptation is a driver for the project* to be fit for purpose over time (appropriate, and of a necessary standard, for its intended use). If it is a driver, identify project climate protection levels – outcome-focused, performance-based criteria to inform the POR and project specifications. If climate change adaptation is not a current driver, identify outcome-focused, performance-based thresholds to monitor the asset should climate conditions change affecting the customer mission at this project site.



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Statement of Work

Study for Climate Adaptation (continued):

Based on the professional recommendations, GSA and CBP decide on the climate protection level to be incorporated into the project POR and all further design phases of this project.

With each Design Stage phase submission and Value Engineering exercise, validate that the climate risk analysis recommendations executed in Pre-Design Stage, and included in POR are addressed.



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Information Provided

- IPCC Climate Change 2013: The Physical Science Basis – Summary for Policymakers (1,060 pages)
- US Department of State 2014 Climate Change Report – Draft. (258 pages)
- 2012 Guidance for Real Property Inventory Reporting. GSA Federal Real Property Council. (79 pages)
- Final Report of the National Drinking Water Advisory Council. EPA/Climate Ready Water Utilities. Dec 2010 (76 pages)
- Adaptive Response Framework for Drinking Water and Wastewater Utilities. EPA/Climate Ready Water Utilities. Nov 2012 (14 pages)
- Regional Highlights from Global Climate Change Impacts in the United States (2 pages)
- Regional Climate Trends and Scenarios: The Northeast U.S. (2 pages)
- Resilience: A Report on the Health of Vermont's Environment (2011). The Vermont Agency of Natural Resources. (28 pages)
- 2014 Climate Change Adaptation Roadmap. Department of Defense. (20 pages)
- Climate Adaptation and Resiliency – Fit for Purpose in a Changing Climate (2 pages)



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Information Provided (continued)

- U.S. General Services Administration FY 2013 Climate Change Adaptation Action Plan. (22 pages)
- Guidance for Federal Agencies on Sustainable Practices for Designed Landscapes. United States Botanic Garden. (32 pages)
- Global Climate Change Impacts in the United States – Highlights. U.S. Global Change Research Program. (20 pages)
- *Global Climate Change Impacts in the United States. U.S. Global Change Research Program. www.globalchange.gov/usimpacts (196 pages)*
- *Predicted Climate Change Impacts: Northeast Region. (3 pages)*
- *Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. NOAA Technical Report NESDIS 142-1. (87 pages)*



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Information Provided (continued)

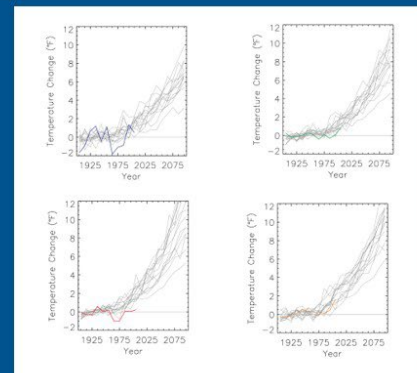
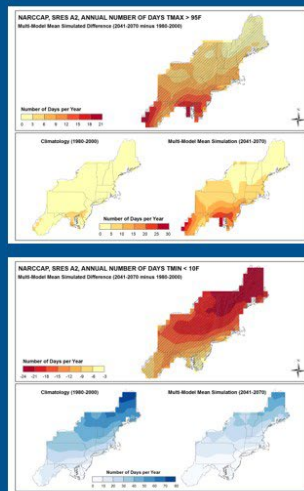
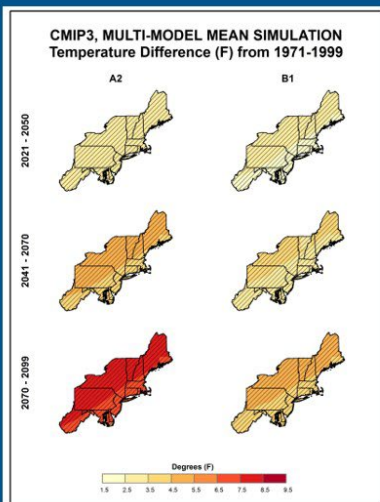
1,901 total pages!



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

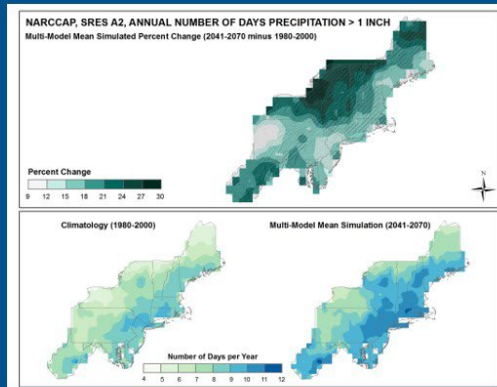
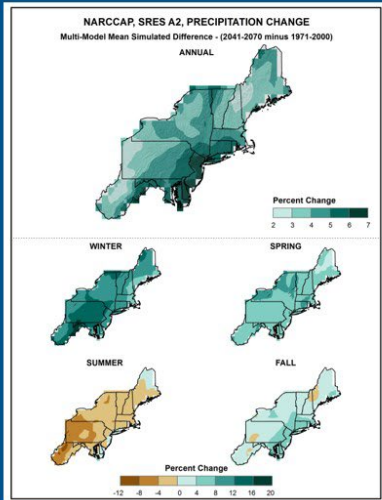
Information Provided (continued)



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Information Provided (continued)



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Information Provided (continued)

Outcome: To provide robust climate ready workplaces for our federal customer agencies and secure the federal real property investment .

Predicted Climate Change Impacts: Northeast Region- Real Property Supporting Occupants

EXPOSURE		TIME SCALE				SENSITIVITY		ADAPTIVE CAPACITY	
Climate Change Impacts	Relative To	Observed by 2010	Near-Term Projections (2010-2040)	Mid-Term Projections (2040-2070)	Long-Term Projections (2070-2100)	Projected Impacts on Occupants M- Mission H/S- Health/Safety C/P-Comfort/Productivity	Sensitivity of Occupants to Sensitivity of Real Property to Accommodate Projected Impacts With Min. Disruption or Costs	Adaptation Options for Existing Built Environment Adaptive Capacity dependant on Context of site/facility/region and occupant	
TEMPERATURE	Average annual air temperature	1961-1979	↑ Increase of 1.3 degrees F	↑ Increase of 1.3 to 3.8 degrees F	↑ Increase of 1.9 to 6.8 degrees F	↑ Increase of 3 to 12.5 degrees F	M- Demographics, Continuity of Operations, Site Access H/S- IEQ, site access C/P- Hazardous sites, IEQ, Temperature	MED	Determined by site/facility/region M- demand planning, alt. locations H/S- alt. locations C/P- alt. location, comfort range
	Average summer air temperature	1961-1979	n/a	↑ Increase of 1.3 to 3.7 degrees F	↑ Increase of 1.8 to 6.9 degrees F	↑ Increase of 2.7 to 14.1 degrees F	M- Demographics, Continuity of Operations, Site Access H/S- IEQ, site access C/P- Hazardous sites, IEQ, Temperature	HIGH	Determined by site/facility/region M- demand planning, alt. locations H/S- alt. locations C/P- alt. location, comfort range
	Frequency of extremely hot days (high temperatures at or above 90 degrees F)	1960-1990	n/a	↑ 50% to 100% increase	↑ 300% - 700% increase	↑ 300% - 1200% increase	M- Demographics, Continuity of Operations, Site Access H/S- IEQ, site access C/P- Hazardous sites, IEQ, Temperature	HIGH	Determined by site/facility/region M- demand planning, alt. locations H/S- alt. locations C/P- alt. location, comfort range
	Frequency of extreme heat events (yearly likelihood of 20-year event occurrence)	5% yearly chance (20-year event recurrence)	n/a	↓	↓	↑ 50% - 100% yearly chance (1-2 year event recurrence)	M- Demographics, Continuity of Operations, Site Access H/S- IEQ, site access C/P- Hazardous sites, IEQ, Temperature	HIGH	Determined by site/facility/region M- demand planning, alt. locations H/S- alt. locations C/P- alt. location, comfort range
	Average winter air temperature	1961-1979	n/a	↑ Increase of 0.9 to 4.7 degrees F	↑ Increase of 1.8 to 7.9 degrees F	↑ Increase of 3.5 to 12.8 degrees F	M- Demographics, Continuity of Operations, Site Access H/S- IEQ, site access C/P- Hazardous sites, IEQ, Temperature	MED	Determined by site/facility/region M- demand planning, alt. locations



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Information Provided (continued)

Outcome: To provide robust climate ready workplaces for our federal customer agencies and secure the federal real property investment .

Predicted Climate Change Impacts: Northeast Region- Real Property Supporting Occupants									
EXPOSURE		TIME SCALE				SENSITIVITY		ADAPTIVE CAPACITY	
Climate Change Impacts	Relative To	Observed by 2010	Near-Term Projections (2010-2040)	Mid-Term Projections (2040-2070)	Long-Term Projections (2070-2100)	Projected Impacts on Occupants M- Mission H/S- Health/Safety C/P-Comfort/Productivity	Sensitivity of Occupants to Sensitivity of Real Property to Accommodate Projected Impacts With Min. Disruption or Goals	Adaptation Options for Existing Built Environment Adaptive Capacity dependant on context of site/facility/region and occupant	
WATER PRECIPITATION	Snowpack1	2010	n/a	↑	↑	4 to 15 less snow-covered days in Northeast, ↓ 25% to 50% decrease in North, ↓ up to 80% decrease in South	M- Demographics	HIGH	Determined by site/facility/region M- demand planning, alt. locations H/S- alt. locations, water catchment
	Change in summer precipitation	1961-1970	n/a	↑ +2% (ave. prediction) -5% to +10% (very likely range)	↑ +1% to +2% (ave. prediction) 12% to +14% (very likely range)	↓ -1% to +2% (ave. prediction) 24% to +20% (very likely range)	M- Demographics, Continuity of Operations, Site Access H/S- IEQ, site access C/P- Hazardous sites, IEQ	HIGH	Determined by site/facility/region M- demand planning, alt. locations H/S- alt. Locations, enclosure C/P- alt. location
	Change in winter precipitation	1961-1970	n/a	↑ +6% (ave. prediction) 2% to +10% (very likely range)	↑ +6% to +11% (ave. prediction) 4% to +20% (very likely range)	↓ -11% to 17% (ave. prediction) 4% to +30% (very likely range)	M- Demographics, Continuity of Operations, Site Access H/S- IEQ, site access C/P- Hazardous sites, IEQ	HIGH	Determined by site/facility/region M- demand planning, alt. locations H/S- alt. locations, enclosure C/P- alt. location
	Intensity / duration of precipitation1	1961-1970	n/a	↑ 7% intensity ↑ 9% to 12% duration	↑ 8% intensity ↑ 9% to 13% duration	↑ 12% to 13% intensity ↑ 15% to 22% duration	M- Demographics, Continuity of Operations, Site Access H/S- IEQ, site access C/P- Hazardous sites, IEQ	HIGH	Determined by site/facility/region M- demand planning, alt. locations H/S- alt. locations, enclosure C/P- alt. location



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Climate Action Plan

HGA fulfilled **1.) CLIMATE ADAPTATION & RESILIENCY VULNERABILITIES**, to identify 3 primary climate factors which affect the project's ability to reduce GHG emissions, support mission continuity over time and secure the federal investment. HGA identified 3 climate factors:

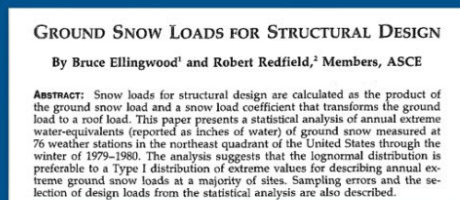
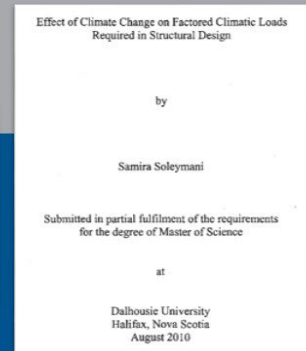
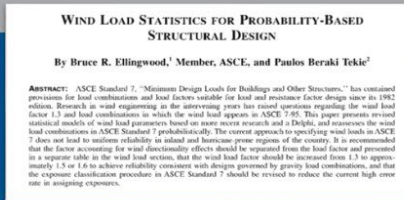
HGA's Climate Factors Identified:	GSA's Climate Factors Most Concerned With:
1. general warming	1. Temperature volatility and extremes (warming & cooling) daily, seasonally, and long term effects on durability
2. increased precipitation	2. increased precipitation frequency, intensity and duration of both rain and snow
3. increased extreme precipitation	3. strong wind gusts, wind driven rain and cold



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

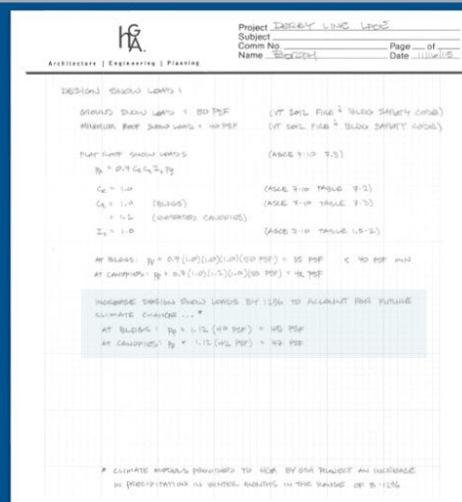
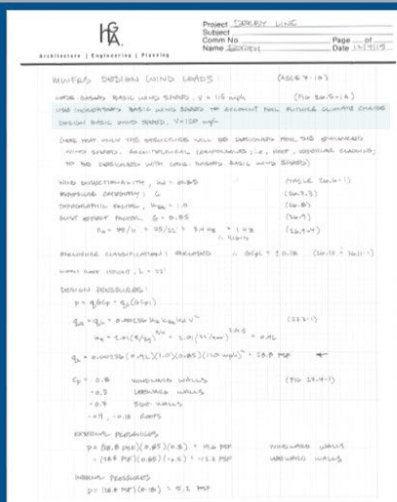
Incorporating Changing Climate



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Incorporating Changing Climate



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Incorporating Changing Climate

CODE-BASED BASIC WIND SPEED, $V = 115$ mph (FIG 26.5-1A)
USE INCREASED BASIC WIND SPEED TO ACCOUNT FOR FUTURE CLIMATE CHANGE
DESIGN BASIC WIND SPEED, $V = 120$ mph
(NOTE THAT ONLY THE STRUCTURE WILL BE DESIGNED FOR THE ENHANCED WIND SPEED. ARCHITECTURAL COMPONENTS; i.e., ROOF, EXTERIOR CLADDING; TO BE DESIGNED WITH CODE-BASED BASIC WIND SPEED)

INCREASE DESIGN SNOW LOADS BY 12% TO ACCOUNT FOR FUTURE CLIMATE CHANGE ... *

AT BLDGS: $P_f = 1.12 (40 \text{ PSF}) = 45 \text{ PSF}$

AT CANOPIES: $P_f = 1.12 (42 \text{ PSF}) = 47 \text{ PSF}$

* CLIMATE MODELS PROVIDED TO HCA BY GSA PROJECT AN INCREASE IN PRECIPITATION IN WINTER MONTHS IN THE RANGE OF 8-12%



DERBY LINE LAND PORT OF ENTRY

Derby Line, Vermont

Incorporating Changing Climate

Mechanical Items:

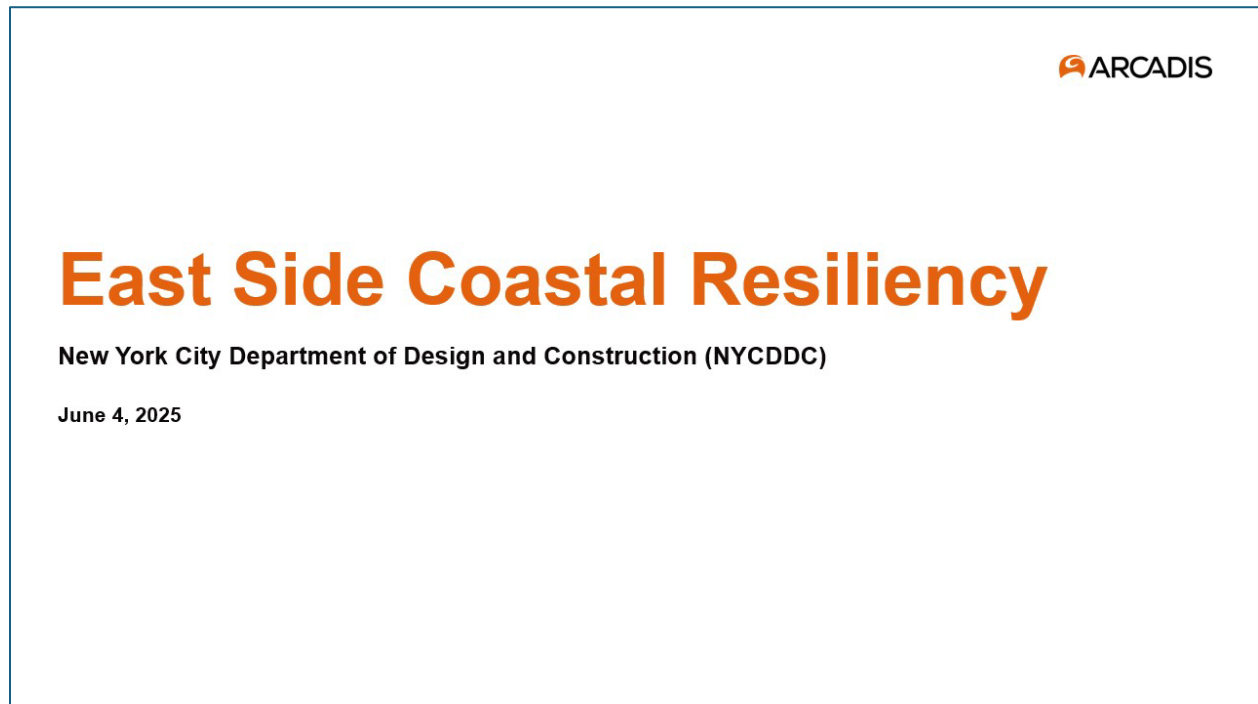
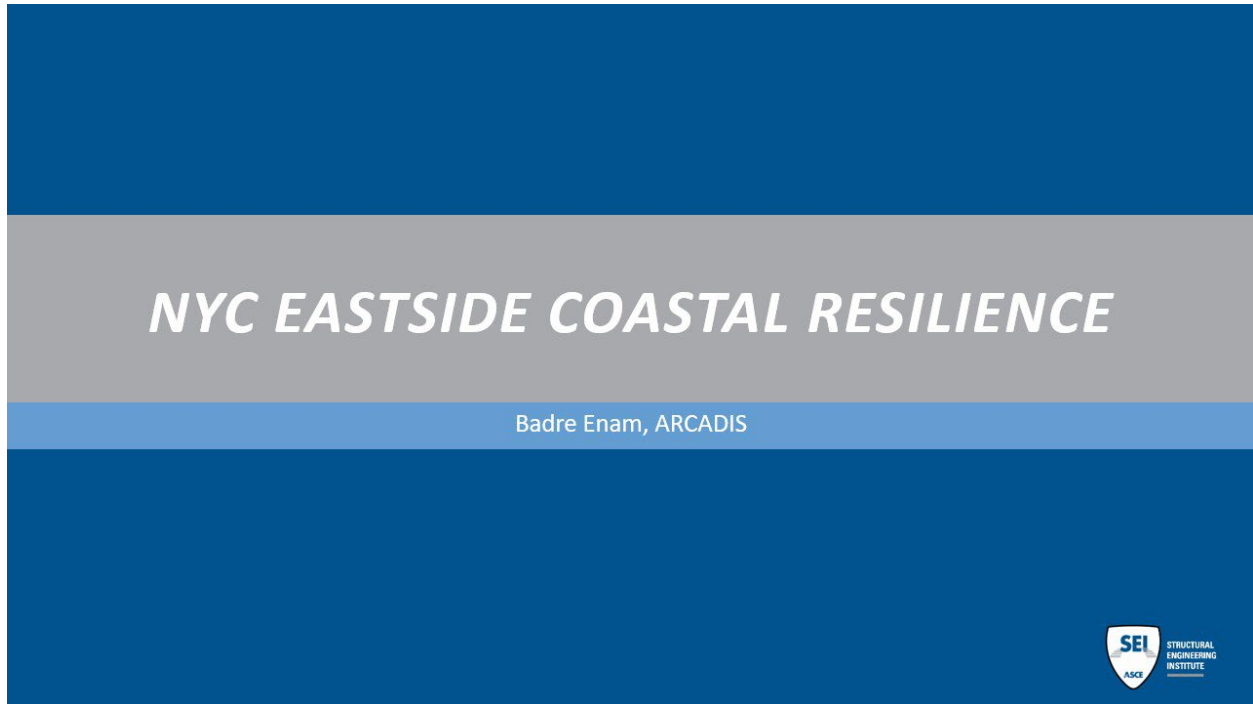
- Upsized the roof drainage piping to accommodate extreme rain events
- Extra capacity in hydronic piping to accommodate future mechanical units "tuned" to future weather conditions





THANK YOU

B.2.1.6. Practice Perspectives: NYC Eastside Coastal Resilience; Badre Enam



Agenda

- 1 **Project Overview
& Location**
- 2 **Challenges with
Hydraulics Design**
- 3 **Structural Design
Decisions**

Our Team



MNLA

Jacobs



Project Description

Project Goals

- Build upon the Rebuild by Design winning concept and NYC Coastal Protection Initiatives
- Provide a reliable, integrated flood protection system; minimize use of deployables.
- Improve waterfront open spaces and access
- Achieve implementation milestones and project funding allocations as established by HUD



Design Approach

Flood Risk Assessment & Engineering Design form the foundation for the design of the flood protection alternatives

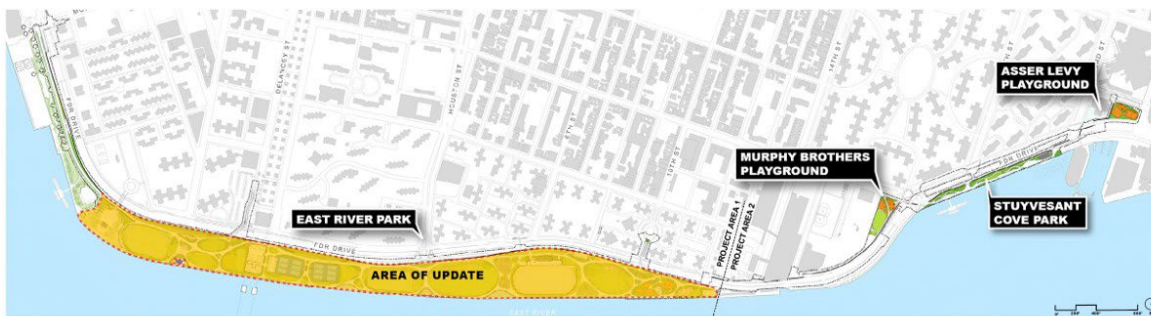
Landscape & Urban Design integrated the design with the waterfront and enhances access

- Addresses community engagement input
- Informed the engineering design elements
- Created layered alternatives to improve access and enhance open spaces

Cost Analysis completed by reach/segment

- Provided comparison tools for evaluation of alternatives
- Prioritized decision making based upon cost information, City agency and community feedback

Project Map



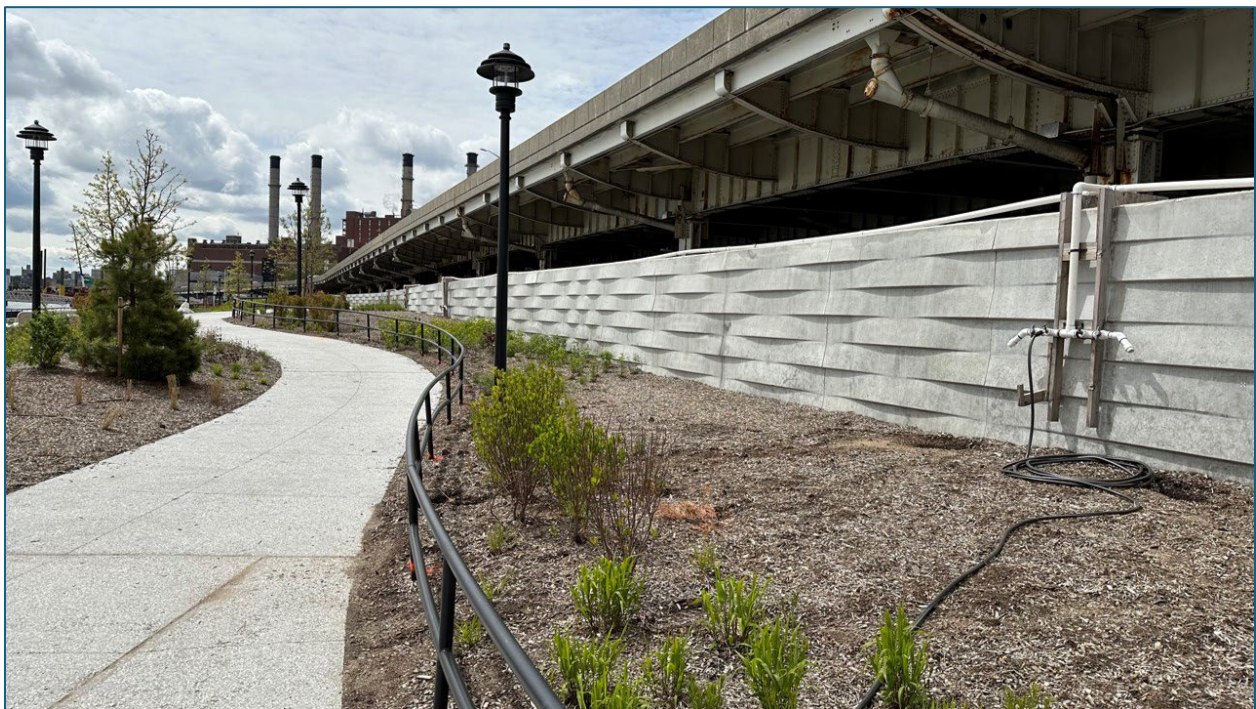
Project Rendered View

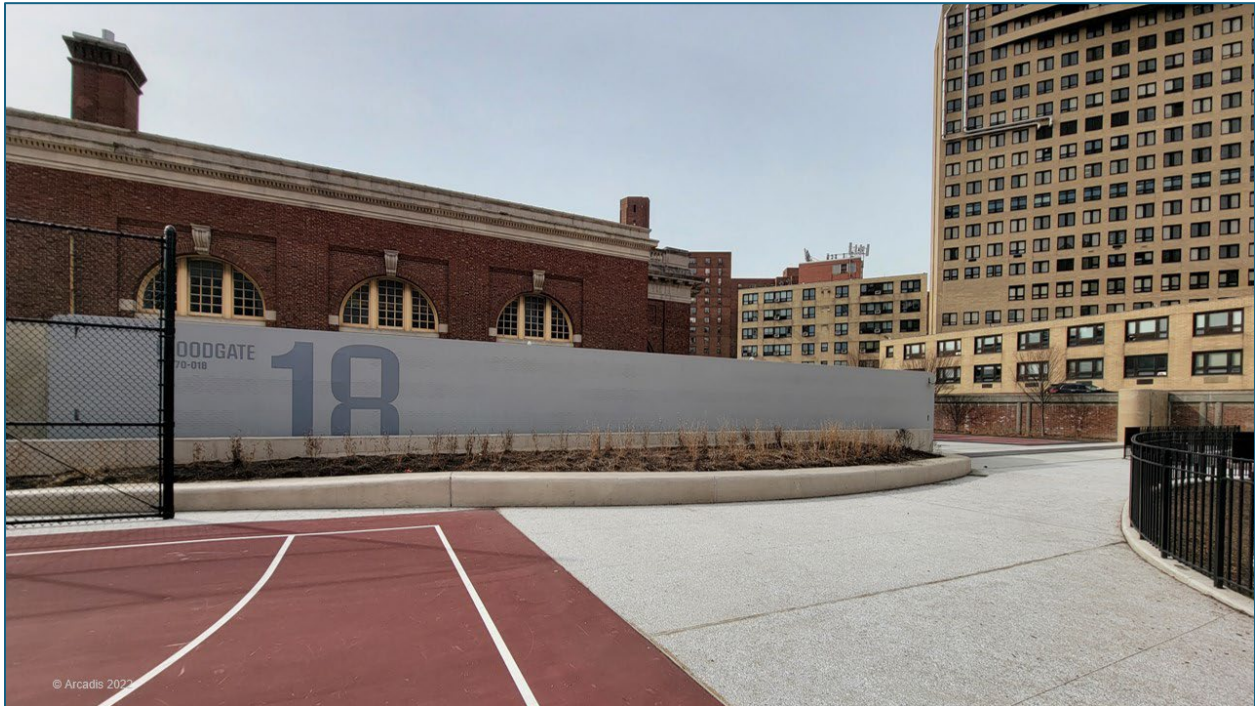


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Hydraulic Design Challenges

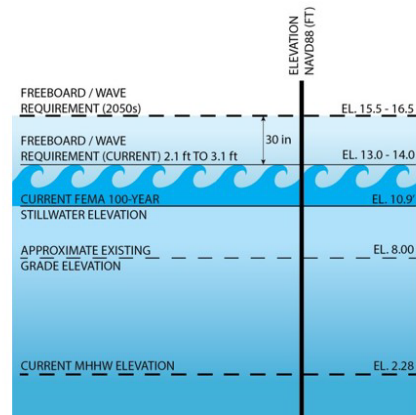
Flood Protection / Drainage Design

Flood Risk Assessment

- 15.5 ft. to 16.5 ft. NAVD 88 design elevation
- 100-year coastal flood event
- Future resiliency – 30 in. sea level rise (NPCC 2015)
- FEMA Levee Standards – meets elevation requirements into 2050s
- Future adaptability EL is 18.0 considering 500 yr. 50th percentile (Still Water Case)

Structural Design Guidance

- Foundation design done for EL 18.0
- Wall and gate elevations kept at EL 16.5



Design Challenges

Adjacent Flood Resiliency Structures

- Gouverneur Gardens
- Pier 42
- Lower East Side Ecology Center Composting Site
- VA Medical Center
- Metropolitan Transit Authority Tunnel (East River)
- Con Edison

Different Protection EL for Existing Structures

- Different structural materials, concrete, masonry, architectural facades
- Ages of older structures, material deficiency (concrete strength)
- Operation & Maintenance (O&M) challenges.

Structural Design Challenges

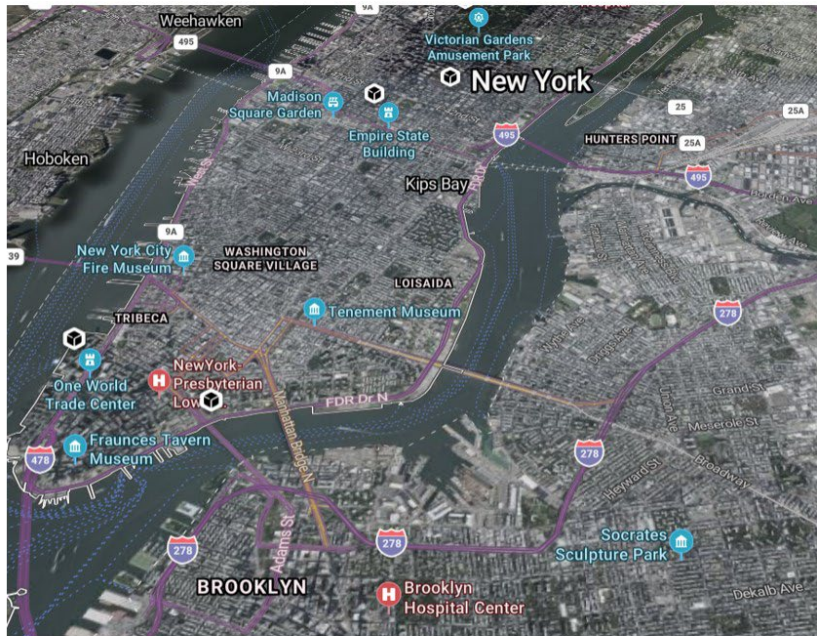
Loading Challenges

Vessel Impact Load

- No guidance in ASCE or USACE EMs
- Maritime area with high volume of navigation traffic.
- Flood resiliency structures susceptible to impact

Workaround

- Coast Guard Severe Weather Plan guideline during storm event investigated.
- Due to location inland, only light vessel impact was anticipated.
- 50 kips load applied during design.



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Vehicle Impact Load for Flood Gates

- Flood gates will be deployed in urbanized area.
- There is potential of vehicles hitting deployed gates.
- No guidance in ASCE about such loading
- AASHTO was consulted for vehicle impact loading
- A transverse load of 54 kips was applied to gate columns.
- A head on impact loading of 200 kips was applied to steel gates.
- Head on impact load was derived using overstress factors resulting from probabilistic considerations.

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Load Combinations

- ASCE Loads combinations did not always produce the most conservative loading.
- ASCE combinations did not include vessel impact loads or vehicular impact loads.
- USACE design documentations were used side by side of ASCE.
- Hurricane Storm Damage Risk Reduction System (HSDRRS) design guideline load combinations were adopted in addition to ASCE.

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Interaction with Existing Structure

- Floodgates were put close to elevated FDR expressway, sometimes underneath the bridge.
- Installing micro-piles and drilled shafts under the bridge deck was challenging.
- Proximity of new foundation to FDR piles was a design challenge that required not loading the existing bridge foundation.
- Jet grout and soil mixing were used as seepage cut-off alternatives within areas with large underground utilities.



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Standardization of Floodwalls and Floodgates

- Floodgates of different spans were required to have standardized operating equipment.
- Locking mechanism was standardized for facilitating stocking up and easy replacement.
- Uniform architectural requirements required placing skin plate on both flood and protected side.
- Urban environment required unique O&M challenges like anti-graffiti measures and wall treatments.

B.2.1.7. Practice Perspectives: West Coast High Speed Rail; Meg Ackerson

WEST COAST HIGH SPEED RAIL

Meg Ackerson, ARUP



WEST COAST HIGH SPEED RAIL

Meg Ackerson, PE | Arup



OVERVIEW

Approach
Process
Example
Challenges



APPROACH

Prescriptive

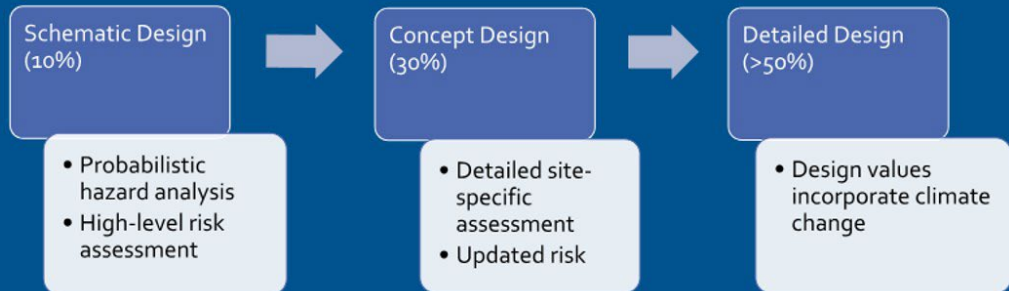
- Future climate scenarios & hazards
- Minimum defensible space for wildfire

Risk-informed

- Detailed risk matrices
- Site-specific assessments only for Intolerable risks
- Leeway for designer decisions with authority approval



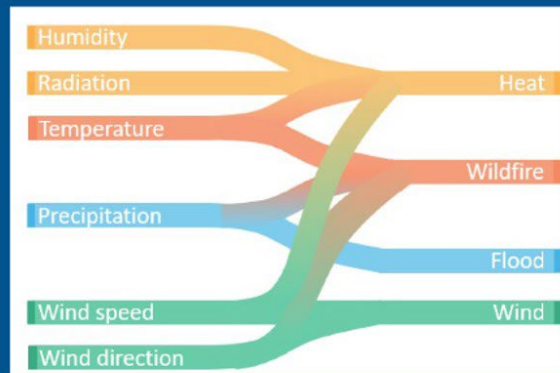
PROCESS



PROCESS: HIGH-LEVEL RISK ASSESSMENT

📌 List of hazards (prescriptive)

└──────────┘
Probabilistic hazard assessment



PROCESS: HIGH-LEVEL RISK ASSESSMENT

👤 List of hazards (prescriptive)

👤 Align on timeline for evaluation (risk-informed)

	2050 (2035-2065)	2100 (2070-2100)
SSP2-4.5	X	X
SSP5-8.5	X	X

Probabilistic hazard assessment



PROCESS: HIGH-LEVEL RISK ASSESSMENT

👤 List of hazards (prescriptive)

👤 Align on timeline for evaluation (risk-informed)

👤 Climate scenarios (~prescriptive)

	2050 (2035-2065)	2100 (2070-2100)
SSP2-4.5	X	X
SSP5-8.5	X	X

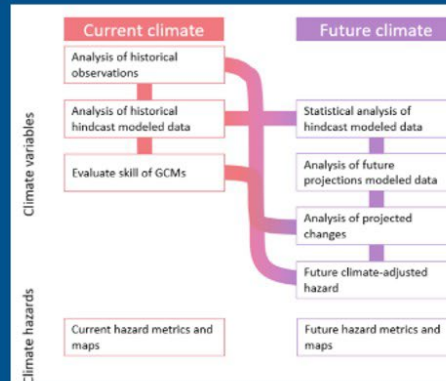
Probabilistic hazard assessment



PROCESS: HIGH-LEVEL RISK ASSESSMENT

- 👤 List of hazards (prescriptive)
- 👤 Align on timeline for evaluation (risk-informed)
- 👤 Climate scenarios (~prescriptive)

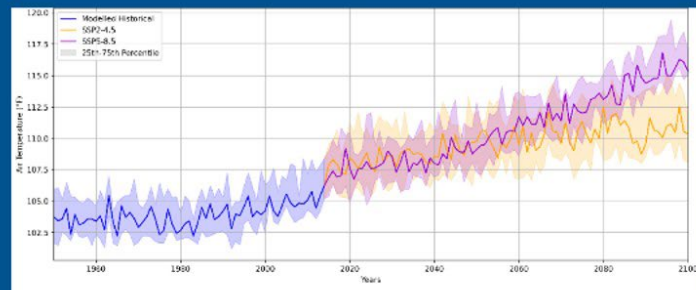
Probabilistic hazard assessment



PROCESS: HIGH-LEVEL RISK ASSESSMENT

- 👤 List of hazards (prescriptive)
- 👤 Align on timeline for evaluation (risk-informed)
- 👤 Climate scenarios (~prescriptive)

Probabilistic hazard assessment



PROCESS: HIGH-LEVEL RISK ASSESSMENT

👤 List of hazards (prescriptive)

👤 Align on timeline for evaluation (risk-informed)

👤 Climate scenarios (~prescriptive)


Probabilistic hazard assessment

Return Period (years)	Max daily temperature (°F) – median value				
	Historical (1992-2022)	Mid-century		End-of-century	
		SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
2	105.8	108.9	109.9	110.8	114.6
5	107.6	110.8	112.1	112.7	116.9
10	108.8	112.1	113.5	113.9	117.8
50	111.5	114.9	116.8	117.3	121.2
100	112.6	116.1	118.2	118.0	122.2
200	113.7	117.3	119.6	119.0	123.4



PROCESS: HIGH-LEVEL RISK ASSESSMENT

👤 Probabilistic hazard assessment

👤 Components and subsystems to assess (prescribed)


Risk assessment

Structure

Shell

Interiors

Contents

Site

Platform



PROCESS: HIGH-LEVEL RISK ASSESSMENT

- Probabilistic hazard results
- Components and subsystems to assess (prescribed)
- Risk matrices (prescribed)

Risk assessment

Risk rating	Hazard risk index	Action required
Unacceptable	1A, 1B, 1C, 2A, 2B, 3A	Risk must be reduced and managed
Undesirable	1D, 2C, 2D, 3B, 4A	Risk is acceptable only where further risk reduction is impracticable. Authority decision at the executive level is required to accept residual risk.
Tolerable	1E, 2E, 3C, 3D, 4B	Apply mitigations where reasonably practicable. Risk can be tolerated and accepted with adequate controls. Authority review at the SSOC level is required to accept residual risk.
Acceptable	3E, 4C, 4D, 4E	No further risk reduction required.
Eliminated		None.



PROCESS: HIGH-LEVEL RISK ASSESSMENT

Tied to specific consequences by order of magnitude (e.g., >\$10M, >\$1M, >\$100k)

	Severity			
Frequency	1 Catastrophic	2 Critical	3 Marginal	4 Negligible
(A) Frequent	1A	2A	3A	4A
(B) Probable	1B	2B	3B	4B
(C) Occasional	1C	2C	3C	4C
(D) Remote	1D	2D	3D	4D
(E) Highly unlikely	1E	2E	3E	4E
(F) Eliminated				

Risk rating
Unacceptable
Undesirable
Tolerable
Acceptable
Eliminated

Tied to specific return periods (e.g., >100yr, >10yr, >1yr)



PROCESS: HIGH-LEVEL RISK ASSESSMENT

👤 Outcome =
👤 risk rating for each hazard & direction for next steps following ALARP principles

👤 Next steps =
👤 explore risk reduction through design for **Unacceptable** and **Undesirable** hazards
👤 apply mitigations where reasonably practicable for **Tolerable** hazards

👤 All decisions on reasonable practicability made with Authority.

Hazard	Time Frame
Heat	Present Future
Flood	Present Future
Wildfire	Present Future
Wind	Present Future

Risk rating
Unacceptable
Undesirable
Tolerable
Acceptable
Eliminated



PROCESS: SITE-SPECIFIC ASSESSMENT



Outcome =

👤 Refined design with mitigations incorporated to address high risks



EXAMPLE: RIVERINE FLOODING

1. High Level Risk Assessment

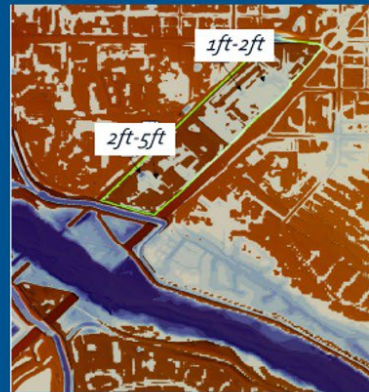
- Unacceptable/undesirable risk rating → further study required to mitigate

Max daily precipitation (inches)						
Return Period (years)	Historical (1992-2022)	Mid-century		End-of-century		
		SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	
2	1.4	1.9	1.8	1.9	2.0	
5	1.9	2.8	2.7	2.9	2.9	
10	2.3	3.4	3.3	3.5	3.5	
50	3.0	4.7	4.5	5.0	4.9	
100	3.4	5.3	5.0	5.6	5.4	
200	3.7	5.9	5.5	6.2	6.0	
500	4.1	6.5	6.2	6.9	6.7	
1000	4.5	6.9	6.7	7.3	7.2	

Outputs from the probabilistic hazard assessment included precipitation values at specific return periods that tied directly to design events.

2. Site-specific Assessment

- Incorporate climate change into analysis



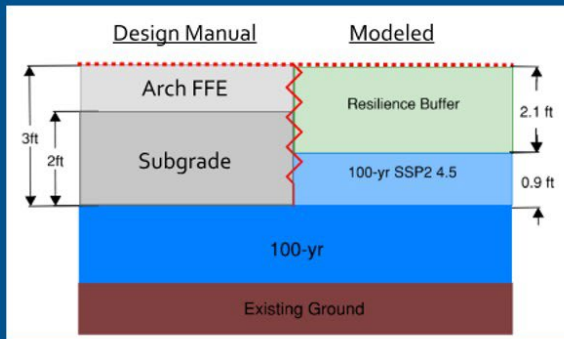
Detailed flood hazard model evaluated the present & future 100yr and 500yr events.



EXAMPLE: RIVERINE FLOODING

3. Development of design values

- FFE based on prescriptive present-day values & checked against future flood levels



4. Confirm risk is now Acceptable or Tolerable

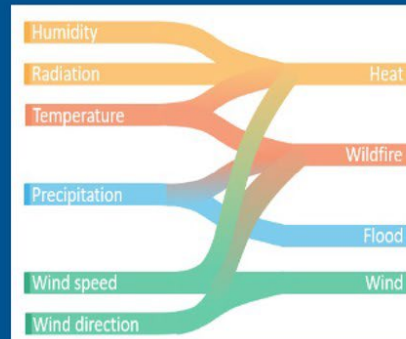
- Cross-check with risk tables

Frequency	Severity			
	1 Catastrophic	2 Critical	3 Marginal	4 Negligible
(A) Frequent	1A	2A	3A	4A
(B) Probable	1B	2B	3B	4B
(C) Occasional	1C	2C	3C	4C
(D) Remote	1D	2D	3D	4D
(E) Highly unlikely	1E	2E	3E	4E
(F) Eliminated				



CHALLENGES / THEMES

1. When to incorporate climate resilience into design?
2. At what level of detail to incorporate climate?
3. How to communicate & track climate risk implications of design decisions?
4. Connectivity to wider resilience goals € emergency evacuation, reliance on utilities



Risk rating
Unacceptable
Undesirable
Tolerable
Acceptable
Eliminated



THANK YOU

Meg Ackerson, PE | Arup



PANEL DISCUSSION

Moderator:

- Jayantha 'Obey' Obeysekera

Panelists:

- Kevin Borth, HGA
- Badre Enam, ARCADIS
- Meg Ackerson, ARUP



LUNCH

12:00 – 12:30 pm

CONCLUSION of ZOOM Broadcast

Virtual attendees – PLEASE switch to Teams meeting



PLENARY DISCUSSION

12:30 pm – 1:30 pm



PLENARY DISCUSSION

Session to define the State-of-the-Art and the Ideal-State, followed by instructions for the breakout sessions.

- **Current State-of-Art**; ASCE-NOAA Summer Workshop 2024 [15 mins.]; Joe Barsugli
Overview of co-evolution of climate science and engineering standards/practice
- **Goals for Future State** – [30 mins.]; ALL
Discussion of goals for characterizing future hazards for engineering applications
- **Research Agenda for Advancing Future Hazard Characterization and Design** [15 mins.]
Discussion of process to identify and prioritize research needs:



B.2.1.8. Current State of the Art: ASCE-NOAA Summer Workshop 2024; Joe Barsugli

CURRENT STATE-OF-THE-ART; ASCE-NOAA SUMMER WORKSHOP 2024

Joe Barsugli



The Co-Evolution of Engineering Practice and Climate Science:

What we learned in the ASCE-NOAA Workshops on climate hazards for civil engineering

Joseph J. Barsugli, University of Colorado Boulder

June 4-5, 2025

Future Hazards in Design

SEI/NIST Forward Looking Codes and Standards Workshop #1

Outline

Co-evolution?

2024 ASCE-NOAA Workshop technical breakouts

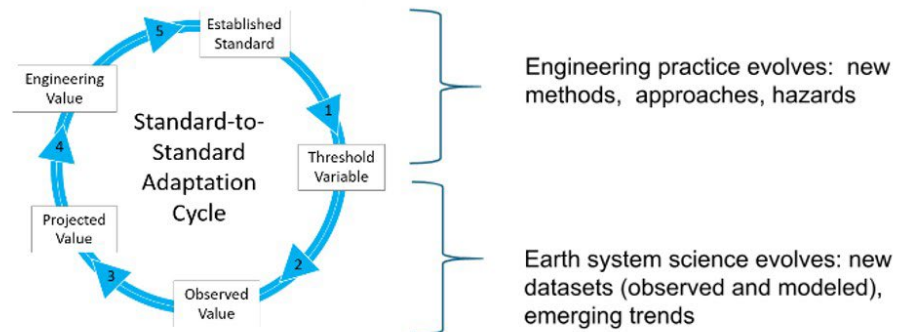
- Scope
- Use Case Examples
- Considerations for Data Needs
- Cross-cutting data needs

Drivers of increased needs for climate weather hydrology data

A note on usage: “weather”, “climate” ...
... also hydrologic, oceanographic, cryospheric....

“earth system” refers to all these interacting components.

Why Co-evolution?



Note: "value" = quantity

Practice-to-Practice Cycle. The cycle explains the feedback loop of determining the earth system data and modeling needed to support engineering standards, one aspect of engineering practice (adapted from Walker and DeAngelo, 2024).

Beyond needs and gaps, there is the communication of what is possible...

ASCE-NOAA Summer Workshop on Climate Risk Reduction: Hazards and Process

June 25-26, 2024
ASCE Headquarters, Reston, VA

Scope and Purpose

- Broaden the scope beyond needs for ASCE 7-28 (the main focus of the 2022 workshops)
- Participation from SEI, EWRI, COPRI, G-I
- Beyond standards to MOPs and other engineering use cases
- Equal focus on process and technical needs
- Anticipate future needs and the research-to-standards process

ASCE-NOAA 2024 Summer Workshop on Climate Risk Reduction: Hazards and Process

Goal of the 90-minute technical breakouts was a broad survey of engineering use cases related to each hazard

Gather general information on characterizing hazards for these use cases for future conditions

Identify relevant ASCE standards, manuals of practice and other guidance documents=

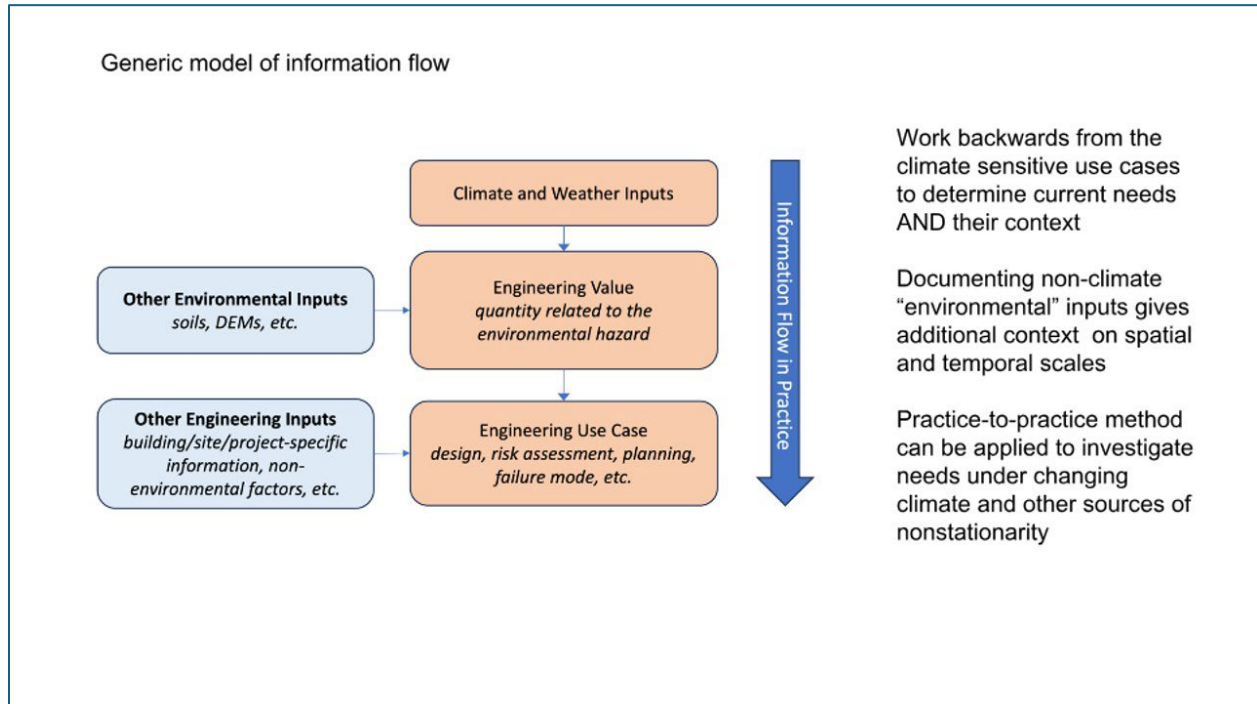
Group use cases by common sets of climate variables and common approaches, if possible

Find climate data needs that would serve several use cases

Creating detailed specifications was beyond the scope – we envision that this would require focused working groups

Highlights of Hazard Breakout Sessions

Breakout Sessions by Environmental Hazard	Highlighted Use Cases/topics
Temperature extremes (emphasis on Cold Regions)	Thermal management for permafrost Cold Regions Utilities Frost-Protected Foundations Building envelope design
Heavy Precipitation (beyond ASCE 7-28 needs)	Building External Loads Stormwater control Hydrological and Hydraulic Modeling Reservoir Operations
Compound Flooding	Inland Lakes & Coastal Groundwater flooding Rain-on-snow flooding
Impacts on earth materials	Groundwater loading, uplift Soil Liquefaction Mass movement of Rock Frost Heave
Snow	Basic Roof Snow Loads Drifting Snow Rain on Snow Roof Loads
Wind Extremes	Thunderstorm winds Tropical Cyclone winds Tornado (future)



Example of 2024 Breakout Information Captured

Breakout	Use Case	Hazard	Key Design Variable (i.e., Engineering Value)	Relevant ASCE Standards/Codes/MOPs	Primary Weather or Climate Input Value	Secondary Weather or Climate Input Value	Tertiary Weather or Climate Input Value	Needed Spatial Scale/Resolution	Design or Service Life Length	Necessary Data Characteristics (e.g., distribution, average, maximum, or minimum)	Comments
ASCE 7 Snow Load											
Snow	ASCE7-Snow Load-basis	Snow load	Snow load (snow water equivalent) - daily scale	ASCE-7	SWE (maximum annual, whole distribution)			4km or less (or way to downscale for the mountains)	~50 years for buildings	Annual Maxima, whole probability distribution of tails. East of Rockies: regional summer (if change), west of Rockies: more specific data needed	Target snow load is determined from a probabilistic reliability analysis for a simple steel structure. The values are chosen from an analysis using extreme value theory, but the return level is chosen based on the probability of failure. Therefore, the entire tail of the distribution needs to be characterized. Guidance from local communities would be helpful, particularly for spatial scale/regionalization of change factors.
Snow	ASCE7-Snow load - drifting	Snow drift	peak snow load within drift	ASCE-7	SWE (maximum annual, whole distribution)	Winter wind (percent of hourly winds above 10mph during winter months)		As fine as possible, with consideration for geography and topography	~50 years for buildings		
Temperature Effects on Exposed Materials and Structures											
Temperature	Construction material expansion, Construction material performance, Building enclosure design	Excessive temperature and temperature range	Maximum air temperature, Maximum material temperature		Temperature (range of temps)	Insolation		Regional	5 (asphalt), 75 - 100 (building enclosures)	Extreme temperature duration (prolonged exposure) Typical temperature at a time period (e.g. temperature when material was installed), extreme high, extreme low.	Construction material expansion (asphalt, steel, concrete), Construction material performance (Sealants, adhesives), Building enclosure design

[embedded]

Example of Breakout Information Gathered

Breakout	Use Case	Hazard	Key Design Variable (i.e., Engineering Value)	Relevant ASCE Standards/C odes/MOPs	Primary Weather or Climate Input Value	Secondary Weather or Climate Input Value	Tertiary Weather or Climate Input Value
ASCE 7 Snow Load							
Snow	ASCE7-Snow Load--basic	Snow load	Snow load (snow water equivalent) - daily scale	ASCE-7	SWE (maximum annual, whole distribution)		
Snow	ASCE7- Snow load -- drifting	Snow drift	peak snow load within drift	ASCE-7	SWE (maximum annual, whole distribution)	Winter wind (percent of hourly winds above 10mph during winter months)	
Temperature Effects on Exposed Materials and Structures							
Temperature	Construction material expansion, Construction material performance, Building enclosure design	Excessive temperature and temperature range	Maximum air temperature, Maximum material temperature		Temperature (range of temps)	Insolation	

[.png]

Example of Breakout Information Gathered [.png]

Breakout	Use Case	Needed Spatial Scale/Resolution	Design or Service Life Length	Necessary Data Characteristics (e.g., distribution, average, maximum, or minimum)	Comments
ASCE 7 Snow Load					
Snow	ASCE7-Snow Load--basic	4km or less (or way to downscale for the mountains)	~50 years for buildings	Annual Maxima, whole probability distribution of tails. East of Rockies: regional summaries, west of Rockies: more specific data needed	Target snow load s determined from a probabilistic reliability analysis for a simple steel structure. The values are chosen from an analysis using extreme value theory, but the return level is chosen based on the probability of failure. Therefore, the entire tail of the distribution needs to be characterized. Guidance from local communities would be helpful, particularly for spatial scale/regionalization of change factors.
Snow	ASCE7- Snow load -- drifting	As fine as possible, with consideration for geography and topography	~50 years for buildings		
Temperature Effects on Exposed Materials and Structures					
Temperature	Construction material expansion, Construction material performance, Building enclosure design	Regional	5 (asphalt) 75 - 100 (building enclosure)	Extreme temperature duration (prolonged exposure). Typical temperature at a time period (e.g. temperature when material was installed); extreme high, extreme low.	Construction material expansion (asphalt, steel, concrete), Construction material performance (Sealants, adhesives), Building enclosure design

[.png]

Selected cross-cutting data needs

- Completion of NOAA Atlas 15 for short duration rainfall extremes
- Projections of Air Freezing Index (now grant funded) and other temperature indicators used by cold regions engineers
- Provision of input variables for use in watershed-scale hydraulic modeling of flooding.
- Development of projections of changes in groundwater/soil water (perhaps only directional risk)
- Continued development of data products to support compound flooding, including NOAA's Coastal Reanalysis

Drivers of increased climate data needs...

Move from observational to model-based estimates necessitated by projections/non-stationarity.

- Example: Ice deposition (ASCE7-28 Ch 36— estimates of future freezing rain).
- Data needs: high temporal and spatial resolutions model data at multiple atmospheric levels

Reliability-targeted loads for standards require more climate information and more sophisticated treatment of tails of probability distribution than before.

- Example: Reliability-targeted snow loads
- Data needs: Characterizing entire upper tail of distribution

Performance-based design

Drivers of increased climate data needs

Changing treatment of combined loads. (that is, loads from multiple hazards)

- Example: moving from arbitrary point in time -> copula treatment. Correlated loads may lead to increased combined loads compared to APT approach.
- Data needs: Timeseries of multiple hazards in consistent format.

Compound events*

- Example: Needs for compound flooding and other hazards that combine multiple mechanisms to generate a single set of design loads (water depth/level, velocity, ..).
- Data Need: coordinated/unified datasets across multiple earth system components (river stage, coastal water level, waves, etc).

Adaptive design strategies (dynamic adaptive pathways, for example, where time evolution of various indicators under different future scenarios is considered).

*Note: Compound events can refer to multiple hazards and/or multiple drivers of a hazard and come in many types.

Final Thought

Successful examples of research-to-applications identified in the workshop were focused efforts on a small number of products (wind maps, tsunami hazard, seismic hazard...) that were driven by clear engineering requirements.

B.2.2. Plenary: Goals for Future State

PLENARY DISCUSSION

Moderators: Jayantha Obeysekera, Terri McAllister

• **Goals for Future State** – [30 mins.]; ALL

What are your ideas for the next generation of future hazards and engineering design?



GOALS FOR FUTURE STATE

- How can we use current climate data better?
- Need to better account for future time horizons in design?
- Engineers aren't aware of current data that are available, and its basis for development. Need to improve co-production of climate and engineering needs.
- General vs extreme climate data – compensate for climate data models ability to capture extreme events.
- Regional vs local models – when is downscaling appropriate? How to determine if downscaled results are credible?
- How can climate data be made more scalable – as a published resource?
- National agreement between climate and design communities on what data is best used by engineering & design workflows, and how it should be used.
- Nonstationary approaches with defined reference periods.
- Need multiple future states, guidance on how to pursue approaches for projects, how to evaluate products (downscaling example)
- Find ways to acknowledge limitations and not getting stuck.



GOALS FOR FUTURE STATE

- Need to mitigate 'punishments' of statistics and models relative to uncertainty.
- Canada did not use downscale data for design purposes; found model data can provide more data but is not usable; more about how to integrate information and knowledge.
- When stressors are a result of multiple variables, to determine what is fit for purpose needs to be addressed by project team. Need guidelines for climate data sets as to its appropriate applications and their limitations.
- What is the process for incorporating future hazard data into project design?
- Observed distributions for hazards are sometimes extended with future projections. How should these processes be combined?
-



GOALS FOR FUTURE STATE

- This isn't a question or a specific goal, but rather a general comment.
- I've heard a lot of the speakers today refer to the need for local scale projections and the fact that global and regional climate models may not provide outputs at the scale required for engineering use or particular projects. The use of statistical downscaling and bias adjustment have also been mentioned. Beyond issues around representativeness (e.g., grid vs. point), I really wanted to caution that just because data are available at a nominally higher resolution, that doesn't guarantee that the results are credible or fit for a particular purpose.
- This also applies to convection-permitting and km-scale dynamical downscaling. Outputs are certainly very detailed, but if important processes aren't incorporated or resolved (for example, use of interactive lake models when dealing with the Great Lakes) then results may be questionable. Here, the computational cost really prohibits large ensembles of simulations, so you're dealing with a very restricted sampling of uncertainty as well.
- Overall, there is a really strong need for scientific assessment and guidance by climate scientists and modellers on topics related to downscaling, uncertainty, and process understanding.



PLENARY DISCUSSION

Moderators: Jennifer Goupil

• Research Agenda for Advancing Future Hazard Characterization and Design [15 mins.]

Discussion of process to identify and prioritize research needs:

- Project data needs for hazards (such as but not limited to, level of detail (spatial, temporal), planning horizon, etc.)
- Hazard design needs by phase: (1) Planning (concept permits, feasibility); (2) Final design
- Science/analysis capabilities needed to address gaps in hazard data by phase

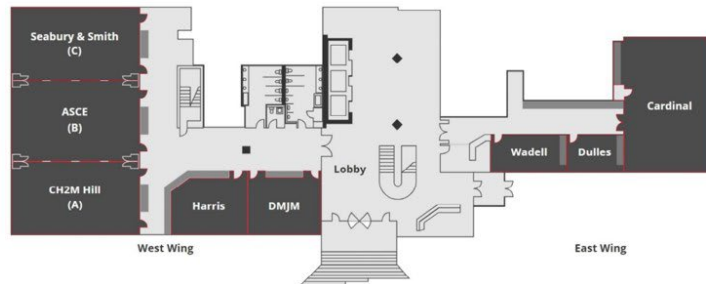
GOAL: Identify and prioritize the top 3-5 needs to address the gaps in hazard data by phase



BREAKOUT GROUPS

Group	Room	Moderator	Note Takers
1	ASCE/ CH2MHill	Matt Gilbertson	Joe Ackroyd Katherine Johnson
2	Seabury & Smith	Meg Ackerson	Mari Tye Scott Jones
3	VIRTUAL - Harris	Jennifer Goupil	Elizabeth Gilmore
4	DMJM	Marc Levitan	Michel Ghosn Yating Zhang
5	Cardinal	Sihan Li	Kevin Borth Sissy Nikolaou
6	VIRTUAL - Wadell	Jennifer Helgeson	Chris Clavin

ASCE Conference Center



BREAKOUT SESSIONS

1:45 pm – 4:45 pm



STRUCTURAL
ENGINEERING
INSTITUTE

SUMMARY & ADJOURN

4:45 – 5:00 pm



B.2.3. Day 2 Slides: Overview Presentation

FUTURE HAZARDS IN DESIGN

June 4-5, 2025
SEI/NIST Forward Looking Codes and Standards Workshop #1



FORWARD-LOOKING CODES AND STANDARDS: WELCOME

Jayantha 'Obey' Obeysekera, Ph.D., P.E.
Research Professor & Director, Sea Level Solutions Center,
Florida International University
Project Director, SEI/NIST Workshops



ASCE/NIST FORWARD LOOKING CODES & STANDARDS WORKSHOPS

1. **JUNE 4-5: Future hazards for design** - confidence/uncertainty in hazard projections, downscaling of global models, converting hazard projections to design criteria
 2. **JULY 29-30: Future load effects on the built environment** - (a) load effects for future hazards, (b) changes in load effects relative to historical basis, (c) changes in structural performance, material properties, soils.
 3. **SEPT. 25-26: Engineering design guidance and criteria** - non-stationary reliability, service life, design loads, resistance, deterioration
 4. **OCT. 28-29: Adaptation and resilience** - buildings and infrastructure system assessment, material durability, mitigation, retrofit.
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AGENDA

Digital Package

(password: futurehazards)

- *AGENDA*
- *Participant List*
- *Slide Decks*



**SEI Forward Looking Codes and Standards
Future Hazards Workshop**
DATE: June 4-5, 2025
LOCATION: ASCE Member Conference Center
1801 Alexander Bell Drive, Reston, VA 20191

[Website](#) | [Access and Travel Links](#) sent separately

Workshop Agenda_v8

Workshop Director: Jayantha Vitharanayake, Ph.D., P.E., Research Professor,
Director of Sea Level Solutions Center, Institute of Environment & FU

WORKSHOP MATERIALS [Link to Digital Materials Package](#) (password: FutureHazard)

Day 2, June 5, 8:00am – 12:00pm Eastern
7:30am-8:00am – NETWORKING CONTINENTAL BREAKFAST PROVIDED

8:00am-8:30am – Welcome

- Parag and Sanku Day 2

8:30am-11:45am – Report Out and Presentation

- Evolution Science Report out (25 mins) ASCE + 15 mins (SEA)
- Visualization of Research Results (20 mins)

10 activities COFFEE BREAK

- Moderated Panel Discussion of WSC (30mins.)
- Moderator: Jayantha Vitharanayake
- Facilitator: Workshop Steering Committee

11:45am-12:00pm – Conclusion

- Summary and Adjourn Day 2

12:30-3:30pm – Workshop Steering Committee Meeting

- Clear study Vermont Part of Entry (snow/wind/temperature) [15 mins.]
- Open South, USA
- Clear study NYC: Extreme Coastal Resilience (coastal inundation/food/SEA [15 mins.]
- South Coast, USA/SEA
- Clear study California High Speed Rail (temperature, marine flooding) [15 mins.]
- Big Science, ASCE
- Clear study Moderated Panel Discussion with Case Study Options and Q&A [15 mins.]
- Facilitator: Jayantha Vitharanayake

4+ WORKING LUNCH PROVIDED

- Plenary Discussion
for issue of the day and the local context, followed by instructions for the panel/Chair/Observer, Team Moderator, Invited Guest

Joint set of ASCE/ASCE/ASCE Summer Workshop 2024 [15 mins.], Joint through
a combination of climate science and engineering (interdisciplinary)
Future Hazards (20 mins.) Q&A

10 Panel for discussing Future Hazards for engineering applications
Workshop for Advancing Future Hazard Research and Design [15 mins.]

- 20 minutes for each presentation research results
- 10 minutes for research results (but not limited to level of detail (spatial, temporal, technical, etc.))
- Design results by phase (1) Planning (concept plans, feasibility) (2) Final design (design/analysis results) (3) Addressing gaps in hazard data by phase
- 10 minutes for the final 30 minutes to address the gaps in hazard data by phase

How to assign/assign final results from your presentation

ASCE Conference Center



Concurrent Breakfast Sessions
COFFEE BREAK
Concurrent Breakfast Sessions (Joint)
Registration
Adj Adjourn Day 1

Work Codes and Standards Future Hazards Workshop

SEI Forward Looking Codes and Standards Future Hazards Workshop

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REPORT OUT & PRIORITIZATION

8:15 am – 11:45 am



B.2.3.1. Breakout Session Reports

BREAKOUT ₁



BREAKOUT # 1 1:45PM – 2:00PM

MODERATOR: Matt Gilbertson

NOTE TAKER: Joe Akroyd, Katherine Johnson

REPORT OUT SLIDES: Dan Cox



ATTENDEES:

1. Matt Gilbertson
2. Joe Ackroyd
3. Dan Cox
4. Ruohua Guo
5. Katherine (Jo) Johnson
6. Greg Soules
7. Peter Vickery
8. Ahmed Attar
9. Terri McAllister

TOPIC 1: Project data needs for hazards (such as but limited to, level of detail (spatial, temporal), planning horizon, etc.) 2:00PM – 2:45PM

- In Canada, scaling factors for future conditions are by province, not downscaled. For wind and snow, scale factors are small 5 to 10%; factors are revisited every 5 years
- The time horizon is important, and so is the climate model. Time horizon: design life for building element may vary. For example, building structure is 50 years, but HVAC system may be less
- The level of detail needed varies by hazard. For wind, in order to capture very localized thunderstorms, to analyze very locally. Need to capture events that are excluded by our current global models in order to capture future conditions
- Uncertainty in historic data is much smaller than the modeling uncertainty for future conditions.
- Reflecting on climate change in design standards should include the extreme future events
- For flood, the current state of practice is that individual jurisdictions take on the future conditions hazards and regulations (e.g., NYC, Norfolk, Houston, etc.)
- Load combinations need to consider future conditions of hazards in tandem with each other (e.g., wind and flood)
- Need to consider whether the past observations are stationary or not. SLR is not; recent years have measured nonlinearities.
- Risk Category – should different climate scenarios be considered based on Risk Category / Use
- Extreme events are necessarily incorporated into climate models
- Climate models generally don't consider the built environment, and the hazard that we experience is affected by the built environment (e.g., runoff from paved surfaces, culverts, etc.)



TOPIC 2: Hazard design needs by phase: (1) Planning (concept permits, feasibility); (2) Final design 2:45PM – 3:30PM

- Flood: siting considerations (e.g., riverine erosion, future flood extents) are more important early on than specific elevation, velocity, etc.
- Wind: late-stage design is more dependent on structure design development rather than climate change
- Other hazards: the level of detail needed is more consistent throughout the design; what you need at the start of the project is rough
- Flood example: Linear SLR bathtub approach may be appropriate for planning, but for final design, would prefer a detailed coastal model looking at future water levels and future storms (i.e., an approximation at the beginning and refined analysis later on)
- Geographic considerations: more refined analysis and modeling may be more necessary in some areas than others (e.g., snow and wind special regions)
- High-level risk assessments: What do you need early on?
 - Will the hazard go up or down? (the exact amount is less important at the onset)
 - Siting limitations?
 - Screening maps?
- Use AI to streamline data documentation, develop maps, etc.



TOPIC 3: Science/analysis capabilities needed to address gaps in hazard data by phase 3:45PM – 4:30PM

- For flood, the challenge is the site-specific nature of the hazard. Once the future condition is determined (SLR, future precipitation), the local analysis needs to be performed to define the hazard. So, it is a major effort to develop maps and criteria
- Future coastal flood velocity needs to be better understood
- All hurricane models are currently developed by private industries (e.g. CatRisk). Need published, publicly available, transparent model(s) that consider future conditions. That would be used to develop the hazard data for design.
- Compound flooding models that consider future conditions
- Develop a methodology to estimate the non-linearity of future flood conditions with SLR rather than simply adding SLR to current conditions
- Improve rainfall and stream gages (measuring and recording) to capture hyper-localized events (e.g., micro-bursts)
- Flood modeling needs to be separated from the NFIP and flood insurance rate maps
- AI tools to help navigate code/walkthrough hazard data/ and do design



Identify and prioritize Top 3-5 NEEDS 4:30 – 4:45PM

1. Develop more efficient ways to identify site-specific hazard data and design criteria (e.g., riverine and urban flood hazards, microbursts, etc.)
2. Standardized methodologies for national, transparent, open-source models to develop hazard data and maps for present-day and future conditions (e.g., hurricane models, flood maps independent from NFIP).
3. Methods to combine observational data and models (i.e., model verification)
4. Determine how to transition between stationary and non-stationary hazards for reliability analysis.
5. Quantify how future changes to the built environment affect hazards.



BREAKOUT 2



BREAKOUT 2 1:45PM – 2:00PM

MODERATOR: Meg Ackerson
NOTE TAKER: Mari Tye/Scott Jones
REPORT OUT SLIDES: DJ Rasmussen



ATTENDEES:

1. Meg Ackerson
2. Mari Tye
3. Scott Jones
4. Andy Newman
5. Aron Newman
6. Tayo Opabola
7. DJ Rasmussen
8. Ayse Hortascu
- 9.
- 10.
- 11.
- 12.

Identify and prioritize Top 3-5 NEEDS 4:30 – 4:45PM

1. Better communication to engineers what the hazard is, metrics and stats used to quantify it and how they are computed
 - o Uncertainty is wide, how to characterize or reconcile?
2. Develop a framework on processing data (less emphasis on the data itself) & centralized repository/compendium for data
3. Need for machine learning to fill gaps in uncertainty, downscaling, treatment of observable data and perhaps in implementing a process.
 - o Trustworthy AI models will require input from computer science as well as climate science, statisticians and engineers.
4. Low hanging fruit – planning level data are so close, but could be improved with novel statistics (e.g., flood maps)

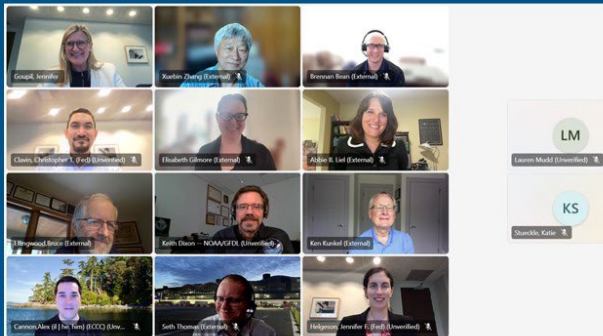


BREAKOUT ₃ & 6



BREAKOUT # ₃ & 6 1:45PM – 2:00PM

MODERATOR: Jennifer Goupil
NOTE TAKER: Elisabeth Gilmore
REPORT OUT SLIDES: Seth Thomas



IF you were a superhero what is your superpower??

ATTENDEES:

1. Seth Thomas
2. Keith Dixon
3. Alex Cannon
4. Bruce Ellingwood
5. Abbie Liel
6. Xuebin Zhang
7. Lauren Mudd
8. Brennan Bean
9. Jennifer Helgeston
10. Chris Clavin

TOPIC 1: Project data needs for hazards such as but not limited to,
level of detail (spatial, temporal), time frame/horizon, etc.)

2:00PM – 2:45PM

- Bridging the gap between observations and modeled climate data
- Assigning levels of confidence to different variables
- Clear definition of available data and what all the data entails to communicate with stakeholders and other engineers
 - Understand the uncertainties within data sets
- Understanding different scenarios and their likelihood of occurrence
- Assigning uncertainties based on historical data vs. climate models – comfort levels with each
- Understanding what triggers the big steps in design changes – how does that change the modeling approach
- A need to better understand the mechanism that triggers the maximum event/scenario
- Scenario based (similar to EQ)



TOPIC 1: Project data needs for hazards such as but not limited to,
level of detail (spatial, temporal), time frame/horizon, etc.)

2:00PM – 2:45PM

- Actionable uncertainty – not have to solve all uncertainty for all aspects; could decide what needs to be designed for what
- Plausible scenarios linked to project-specific needs
- Which uncertainties do we want to be comfortable with?
- PBD may have a larger role to play – life safety is the basis of the regulatory framework



TOPIC 2: Hazard design needs by phase: (1) Planning (concept permits, feasibility); (2) Final design 2:45PM – 3:30PM

- Do we have to do all of it? Can we just do some of it?
- Would we consider a subset of hazards to include in a concept risk-informed design vs all of the requirements in the standard for final design?
- Buy-in for even simple advancements in standards/provisions (design) may be more important than complex advancements for some stakeholders (specifically for regulatory stakeholders) – education aspect, but also perception/trust issues often prevail
- Planning (communication/understanding) = what is important and why we are doing it (for all stakeholders owner-design team-climate professionals) – and why we are not doing something else
- Final design (Technical designs) = how to actually do the design – more technical in needs
- ***SCOPE Q = Residential structures have not been and are not considered with the same robustness of thought and provisions for commercial construction – how does this affect the ability to proceed with community resilience for climate impacts



TOPIC 3: Science/analysis capabilities needed to address gaps in hazard data by phase 3:45PM – 4:30PM

Many ensemble members of multi-decadal global climate model simulations at convection permitting model resolution

- WHY = we want higher spatial resolution (more detail), we want large ensembles/multi-decadal in order to sample plausible model outcomes – sample the three traditional sources of uncertainty well
- THIS has an immediate direct application as this output is needed to provide appropriate data for engineering purposes
- We want global to have it all – but if wanted just CONUS then we could do dynamic downscaling

Engineering software that could quickly assess the impacts on the reliability of the design

- WHY = so we can interrogate the climate model impacts at scale, quickly
- We need to understand the tolerance for new uncertainties
- Evaluate implications – such as costs

Make good/better use of the data sources and methodologies we are currently using – what is achievable in 10 years?

Particular need for the engineering community to align thinking with the historical records of environmental hazards – how to feel more comfortable with models of future; how to determine when data is fit for the design purpose



TOPIC 3: Science/analysis capabilities needed to address gaps in hazard data by phase 3:45PM – 4:30PM

Need for improved communication on hazards and climate model results so they can evaluate/interpret the results

- Climate literacy and how we think about managing the risk – how to communicate to engineers and then to clients/owners/community

Part of the education is to understand the costs, risks, ROI on investments – lifecycle costs

Climate boundary organizations? Who is this entity? What do we need them to do? Is this sector specific or encompassing

- Will need resources - \$, experts, leadership

Robust connections between engineering needs and science capability – discussion and consensus on specific design needs (select key engineering needs – not ALL outputs, but what is relevant and needed for engineering design – at the particular phases needed)

- Understand needs from model outputs so we can easily consume the outputs (ie USGS into PUC process); potentially set up as experiment thru the WCRP (as one of various work streams)



Identify and prioritize Top 3-5 NEEDS 4:30 – 4:45PM

1. Engineering **software that could quickly assess the impacts** on the reliability of the design
WHY = so we can interrogate the climate model impacts at scale, quickly; Evaluate implications – such as costs
2. Make **good/better use of the data sources** and methodologies we are currently using within actionable timescales – **Understand needs from model outputs** so we can easily consume the outputs (i.e. USGS into PUC process) – including **boundary organizations for infrastructure decisions**
3. Need for **improved communication on hazards and climate model results** so design teams can evaluate/interpret the results across all stakeholders – evaluation of impacts especially costs
4. **Many ensemble members of multi-decadal global climate model simulations at convection permitting model resolution**
WHY = we want higher spatial resolution (more detail), we want large ensembles/multi-decadal in order to sample plausible model outcomes – sample the three traditional sources of uncertainty well
5. Need for the engineering community to **align future conditions thinking with the historical records of environmental hazards** – how to feel more comfortable with models of future; how to determine when data is fit for the design purpose



BREAKOUT 4



BREAKOUT #4 1:45PM – 2:00PM

MODERATOR: Marc Levitan
NOTE TAKERS: Michel Ghosn, Yating Zhang
REPORT OUT SLIDES: Don Scott



ATTENDEES:

1. Ahmed Abdelaal
2. Joseph Barsugli
3. Subhadarsini Das
4. Michel Ghosn
5. Marc Levitan
6. Siamak Sattar
7. Don Scott
8. Yating Zhang
9. Hanping Hong
- 10.

TOPIC 1: Project data needs for hazards such as but not limited to, level of detail (spatial, temporal), time frame/horizon, etc.

2:00PM – 2:45PM

- Determination of Service Life – Window of future hazard data to deal with the extension of service life beyond 50 years.
 - Understand the priorities of the owner of the project. Data needs depend on their priorities. Understanding the risk associated with the project.
- From a temporal consideration the primary hazard can change for the site with changes in future climate conditions.
- Data for concurrent/compounding hazards.
- Site specific flood hazard data at the beginning of the design process.
 - Effects location of structure on site and floor level elevation.



TOPIC 2: Hazard design needs by phase: (1) Planning (concept permits, feasibility); (2) Final design

2:45PM – 3:30PM

- Hazard data needed to develop load combination for concurrent hazards.
 - Duration of event, frequency of event, and intensity of event (not only extremes).
- Data for more frequent/less extreme hazards versus single extreme hazards for design.
 - Design for extreme hazard might not govern.
 - Serviceability controls many design of structures.
- Building Envelope design – are there different data needs? Service life?
- Hazard data to support a life-cycle cost evaluation.
 - Future hazard data to determine the material used for the exterior envelope, bridge construction material, etc.



TOPIC 3: Science/analysis capabilities needed to address gaps in hazard data by phase

3:45PM – 4:30PM

- Preliminary Design Phase: Some hazards need higher resolution data on a grid scale, some need higher resolution data on a vertical scale (atmospheric layers).
- Final Design Phase: With anticipated increase in size, frequency, and spatial shift of future hail storms, we need to start designing for hail. Need to develop the design data.
 - Second largest value of insured losses.
 - Needed for selection and design of building envelope materials and systems
- Improved measurement science for uniform determination of historical data.
 - Better data collection/estimation of freezing rain, rain fall rate, snow, wind speed, etc.
- With anticipated increase in rain fall rates, hurricane wind speeds and slower translational speed of the tropical storms, we need data to support climatology and design methods for wind driven rain.
- Develop climatology for wind downbursts, thunderstorms.
- Understanding of the effects of changing climate on how it affects earthquakes.
 - Sea level rise and the effect on liquefaction.
 - Landslide hazard from earthquakes, rainfall, etc.



Identify and prioritize Top 3-5 NEEDS

4:30 – 4:45PM

1. Hazard data to support a life-cycle cost evaluation.
 - Future hazard data to determine the material used for the exterior envelope, bridge construction material, etc.
2. Data for concurrent/compounding hazards.
 - Hazard data needed to develop load combination for concurrent hazards.
 - Duration of event, frequency of event, and intensity of event (not only extremes).
 - Data for more frequent/less extreme hazards versus single extreme hazards for design.
3. Improved measurement science for uniform determination of historical data.
 - Better data collection/estimation of freezing rain, rain fall rate, snow, wind speed, etc.
4. Determination of Service Life – Window of future hazard data to deal with the extension of service life beyond 50 years.
 - Understand the priorities of the owner of the project. Data needs depend on their priorities. Understanding the risk associated with the project.
5. Data and design methods for hazards not fully considered now but projected to increase including wind driven rain and hail.
 - Needed for selection and design of envelope systems and materials.



BREAKOUT 5



BREAKOUT 5 1:45PM – 2:00PM

MODERATOR: Sihan Li

NOTE TAKER: Kevin Borth, Sissy Nikalou

REPORT OUT SLIDES: (Dr. Ning Lin)



ATTENDEES:

1. Kevin Borth
2. Sihan Li
3. Eun J. Cha
4. Ning Lin
5. Zoubir Lounis
6. Sissy Nikalou
7. Irem Efe
8. Obey Jayantha

TOPIC 1: Project data needs for hazards such as but not limited to, level of detail (spatial, temporal), time frame/horizon, etc.) 2:00PM – 2:45PM

Key points:

- 1. Canada investigated RCP2.5 to RCP 8.5 and adopted RCP8.5 for building design and RCP6.0 for bridge design based on consensus from code committee and stakeholders. ASCE will use 3-degree GWL as the assumed climate condition. We need better understanding of these adopted climate conditions/scenarios from both scientific and reliability perspectives. Average global warming level may not be highly correlated with local hazards, depending on hazard types. Various emission scenarios should be allowed to use by engineers.
- 2. Climate model was not used for design before. Simulation under past climates is needed for model validation. Which models are good models? -- need to understand and correct model biases for individual hazards, considering also the correlation of the hazards (for multi-hazard design and risk analysis).
- 3. How to weigh different climate models? Need to discuss how to combine models (e.g., simple average, GWL weighted, or weighted based on accuracy)?
- 4. High-resolution spatial-temporal data are needed. Need to identify the minimum resolution (spatial and temporal) needed for each hazard based on current building code and practice, and investigate if the same resolution will be sufficient under climate change conditions.
- 5. Extremes data – long time horizon modeling to generate enough extremes to deal with design level exceedance probability.
- 6. Hazards may be driven by different climate extremes (e.g., winds from TCs, synoptic systems, and convective systems). Future projections of the hazards need to combine projections of these extremes consistently.



TOPIC 2: Hazard design needs by phase: (1) Planning (concept permits, feasibility); (2) Final design 2:45PM – 3:30PM

- 1. Nonstationarity needs to be incorporated. Concept can be proposed: cumulative lifetime exceedance probability during the service life (shortcoming is that the annual exceedance probability can be above criteria for some years), or maximum annual exceedance probability during service life. Design life needs to be part of the hazard design explicitly.
- 2. Climate data is continuously changing. How to capture that between code cycles?
- 3. Most jobs went through initial design to final design within 6 months. The hazard design needs are mostly the same.
- 4. Design life needs to be part of the hazard design explicitly as the time horizon will affect the design hazards in nonstationary conditions.
- 5. The requirements for data depends on the type of project (structure/building vs infrastructure). Large infrastructure project takes long time (several years). Need to determine the minimum allowed time lag.
- Main recommendation: For typical design practices, different design stages do not require different design hazards level. The design life needs to be an explicit parameter to consider in design.



TOPIC 3: Science/analysis capabilities needed to address gaps in hazard data by phase 3:45PM – 4:30PM

- 1. Better understanding how small-scale extremes (e.g., thunderstorms and tornados) will change
- 2. Need frameworks to incorporate continuous observations to support adaptive strategies (Adaptation Pathway).
- 3. Structures are currently designed by different criteria for different hazards. Under climate change, the hazards will jointly evolve. It is important to provide consistent projection of the hazards to support multi-hazard designs.
- 4. Need continuous data to support resilience design objectives and analysis requirements (e.g., short term recovery and long-term reliability).
- 5. Requirements for resilience performance through monitoring within the life cycle of the project.



Group 5 -Identified and prioritized NEEDS

- 1. Investigating uncertainties associated with chosen climate conditions (e.g., 3-degree warming).
- 2. Evaluating climate models in terms of their hazard estimation compared with historical observations.
- 3. Better understanding and projecting "extremes" (e.g., wind speeds with 1/1000 annual exceedance probability) from climate science perspectives.
- 4. To understand the ideal as well as minimum requirements for spatial/temporal resolution and projection time periods by hazard types.
- 5. Need temporally continuous data to support non-stationarity design criteria, such as replacing return period by lifetime exceedance probability, annual exceedance probability, and including design life (start-end period and length) as a design parameter.



PRIORITIZATION OF RESEARCH NEEDS

20 minutes



REVIEW OF THE PRIORITIZED LIST



COFFEE BREAK

10 minutes



DISCUSSION – 30 MINUTES

Moderator:

Jayantha 'Obey' Obeysekera – Workshop Director

- Review of findings
- Discussion (ALL PARTICIPANTS)



HIGHEST PRIORITY

- Other significant priorities

Clarify **how uncertainty could be considered** in future conditions decisions for engineering approaches.

Understand the **minimum requirements for spatial/temporal resolution**, length (past and future) and continuousness of the projections by hazard types.

Improve **communication to engineers** and design teams on what the hazard is, climate model results, metrics, and stats used to quantify it and how they are computed.

Develop more efficient ways to identify fit-for-purpose, **site-specific hazard data** and design criteria (e.g., riverine and urban flood hazards, microbursts, etc.)

Better understanding about "extremes" from climate science perspective (e.g., 1/1000 annual exceedance probability).



SUMMARY & ADJOURN

11:45 am – 12:00 pm



ASCE/NIST FORWARD LOOKING CODES & STANDARDS WORKSHOPS

1. **JUNE 4-5: Future hazards for design** - confidence/uncertainty in hazard projections, downscaling of global models, converting hazard projections to design criteria
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3. **SEPT. 25-26: Engineering design guidance and criteria** - non-stationary reliability, service life, design loads, resistance, deterioration
4. **OCT. 28-29: Adaptation and resilience** - buildings and infrastructure system assessment, material durability, mitigation, retrofit.





STRUCTURAL
ENGINEERING
INSTITUTE

THANK YOU to all participants and
to the Workshop Steering
Committee!!!

SUMMARY & ADJOURN

12:00 pm

PLEASE recycle your Name Badges



Appendix C. Workshop Reading Material

ASCE and NOAA. 2023. ASCE–NOAA Workshops on Leveraging Earth System Science and Modeling to Inform Civil Engineering Design. Ayyub, B.A., DeAngelo B., Walker, D., and Barsugli, J. (editors) <https://doi.org/10.25923/e8kn-n884>

Barsugli, J. J., D. Walker, M. N. Edwards, B. M. Ayyub, C. J. Anderson, D. B. Barrie, B. Bean, M. T. Bensi, H. M. Brooks, B. J. DeAngelo, F. T. Lombardo, B. K. Parsons, and M. R. Tye. 2024. Climate Risk Reduction: Hazards and Processes for Operationalizing Climate Information into ASCE Standards and Manuals of Practice. ASCE-NOAA Summer Workshop Series. <https://doi.org/10.25923/0d8c-dw27>.

Appendix D. Workshop Participants

Following is the list of workshop participants including their self-identified organization, listed in alphabetical order.

Ahmed	Abdelaal	SUNY Polytechnic Institute
Meg	Ackerson	Arup
Joe	Ackroyd	Department of Buildings
Ahmed	Attar	National Research Council Canada
Michele	Barbato	University of California, Davis CITRIS and the Banatao Institute
Joe	Barsugli	University of Colorado Boulder
Walter	Baumy	Arcadis
Brennan	Bean	Utah State University
Kevin	Borth	HGA
Alex	Cannon	Climate Research Division, Environment and Climate Change Canada
Eun	Cha	University of Illinois at Urbana-Champaign
Christopher	Clavin	NIST
Daniel	Cox	Oregon State University
Subhadarsini	Das	Central Michigan University
Keith	Dixon	NOAA Geophysical Fluid Dynamics Laboratory
Irem	Efe	NIST
Bruce	Ellingwood	Colorado State University
Badre	Enam	Arcadis
Michel	Ghosn	The City University of New York (CUNY)
Matt	Gilbertson	Simpson Gumpertz & Heger
Elisabeth	Gilmore	Carleton University
Jennifer	Goupil	ASCE/SEI
Ruohua	Guo	Reliability Equity LLC
Jennifer	Helgeson	NIST
Hanping	Hong	University of Western Ontario
Ayse	Hortacsu	Applied Technology Council
Katherine	Johnson	NIST

Scott	Jones	National Institute of Standards and Technology
Kenneth	Kunkel	North Carolina State University
Ariane	Laxo	HGA
Marc	Levitan	NIST
Sihan	Li	RWDI
Abbie	Liel	University of Colorado
Ning	Lin	Princeton University
Zoubir	Lounis	National Research Council Canada
Therese	McAllister	NIST
Amanda	McCarty	NOAA
Lauren	Mudd	Applied Research Associates
Andrew	Newman	NSF NCAR
Aron	Newman	NIST
Sissy	Nikolaou	NIST
Jayantha	Obeysekera	Florida International University
Eyitayo	Opabola	University of California, Berkeley
D.J.	Rasmussen	Degree Day LLC
Siamak	Sattar	NIST
Don	Scott	Consultant
Greg	Soules	CB&I
Katie	Stueckle	SEI
Seth	Thomas	KPFF
Mari	Tye	Johns Hopkins University
Peter	Vickery	Consultant
Dan	Walker	University of Maryland
Yating	Zhang	NIST
Xuebin	Zhang	Pacific Climate Impacts Consortium, University of Victoria
Erik	Zuker	HNTB