

NIST Grant Contractor Report
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Forward-Looking Codes and Standards: Adaptation and Resilience

Workshop Report
Oct. 29–30, 2025, Reston, VA

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Abstract

Forward Looking Codes and Standards: Adaptation and Resilience workshop report includes recommended research needs on the following themes: adaptive design for buildings and infrastructure systems, considering future hazards, material durability, and structural capacity degradation, and strategic planning methods for future conditions.

Keywords

Codes and standards; Building codes; Future hazards; 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 fourth and final workshop on *Forward-Looking Codes and Standards: Adaptation and Resilience* based on contributions to the workshops by 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, 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., F.EWRI, 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 in 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 fourth workshop for *Future-Looking Codes and Standards: Adaptation and Resilience*, held on October 29–30, 2025, and this resulting report, focused on the research and development efforts needed to implement future hazards and conditions in associated design criteria in codes and standards. The workshop also addressed strategic planning for future requirements in the built environment and associated changes to design requirements.

1.2. Workshop Scope and Purpose

The purpose of the workshops was 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 U.S. communities.

The workshop scope covered the broad subject area of future hazards and conditions for codes and standards development. Specifically, the workshop sought to elicit 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 workshop development process 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 identified critical issues for each workshop, and the workshop participants were selected based upon their expertise in these areas.

To help understand the current state of future-looking codes and standards, the WSC pulled reading materials to share with workshop participants, which are listed in Appendix B.3.

The one-and-a-half-day workshop was convened on October 29–30, 2025, to identify the highest-priority needs that form the basis of this report. The WSC, industry-leading experts, and academics attended 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). Twenty-one in-person and 33 virtual participants attended the workshop.



Figure 1-1. In-person participants at the NIST/SEI *Forward-Looking Codes and Standards: Adaptation and Resilience* workshop on October 29, 2025.



Figure 1-2. Virtual participants at the NIST/SEI *Forward-Looking Codes and Standards: Adaptation and Resilience* workshop on October 29, 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 on ongoing, synergistic efforts with time for the participants to ask questions.

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 adaptation and resilience into design standards and codes.

The participants were then divided into four breakout groups: two in-person breakout groups and two virtual breakout groups. The goal of the breakout groups was to define research needs for future-state goals. To do this, the groups were asked to ground their discussions in current reality by considering key factors: barriers to decision-making, challenges to innovative solutions, the balance of risk-reward sharing, and goals and incentives for community and individual project development. Given these considerations, participants were provided with three specific prompts to guide their definition of future-state goals: (1) identify what current practitioners wish they had to advance design practice and building standards for adaptation and resilience, (2) identify next-generation research needs for adaptation and resilience, and (3) define and prioritize the top five research needs.

Each breakout group then reported back to all the workshop participants in a general session and described its prioritized research and development needs. Following these presentations

and subsequent discussions, all the workshop participants prioritized all the identified research and development needs..

1.4. Workshop Framework

The framework for Workshop 4 was developed around key questions and intended outcomes from the WSC. Importantly, the steering committee focused on identifying engineering strategies for enhancing resilience in response to evolving hazards and for enhancing the adaptive capacity of buildings and infrastructure systems under future conditions, including degradation of materials and performance of the built environment. Given this purpose, the WSC organized the scope of the workshop into two main topics.

The first topic concerned developing approaches for resilient buildings and infrastructure, including adaptive design pathways and robust decision-making under nonstationary conditions, considering structural loads and capacity.

The second topic identified barriers to and opportunities for applying adaptive pathways and resilience strategies in practice. Participants were encouraged to discuss standards, codes, and decision frameworks to bridge engineering and community resilience needs and potential solutions.

These topics framed the final set of questions posed to participants, which centered on identifying the data and tools desired for future design guidelines and the next-generation research needed for adaptation and resilience.

1.5. Workshop Report Organization

Following Section 1, Workshop Overview, 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 held during the breakout sessions,
- Section 4 describes the top recommended research needs identified during the breakout sessions,
- Section 5 describes the analysis of research needs identified during the breakout sessions,
- Section 6 lists acronyms and abbreviations, and
- 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 following summarizes the opening series of presentations on Synergistic Efforts.

John van de Lindt (Appendix B.2.1.1) of Colorado State University introduced the Interdependent Networked Community Resilience Modeling Environment (IN-CORE) platform, a cloud-based modeling environment developed in partnership with NIST to support community resilience planning. He emphasized the need to integrate physical, economic, and social system performance. Using a case study from Joplin, Missouri, he demonstrated how, given a hazard scenario, fragility curves for physical damage, economic modeling at the community scale, and population dislocation analysis can be used to align infrastructure design with broader community resilience goals. His work underscores the importance of measuring resilience not just in terms of structural performance but also in terms of community recovery and stability.

Casey Brown (Appendix B.2.1.2) from the University of Massachusetts Amherst followed with a presentation on resilient design methods for water infrastructure under conditions of deep uncertainty. He introduced stress testing and robust decision-making as alternatives to traditional design, where design loads for hazards are assumed to be stationary (i.e., historical hazard frequency and intensity patterns will continue into the future). Through case studies set in Iowa and San Francisco, he illustrated how scenario-based analysis can identify vulnerabilities and inform adaptive strategies without relying on precise climate forecasts. His presentation highlights the value of designing systems that are robust across many plausible futures, rather than optimized for a single predicted outcome.

Erica Fischer (Appendix B.2.1.3) of Oregon State University addressed performance-based design methods, with a focus on wildfire resilience in the wildland-urban interface, a growing concern with intensifying wildfire behavior. She discussed the challenges of modeling wildfire hazards, particularly due to their nonstationary and human-driven nature. Her presentation emphasizes the need for performance-based design approaches that account for ember exposure, structural vulnerabilities, and the critical role of first responders. She also highlighted the importance of understanding how different community layouts, such as wildland-urban interface versus intermix zones, affect fire spread and mitigation strategies.

Michelle Miro (Appendix B.2.1.4) from the RAND Corporation presented the Robust Decision Making (RDM) framework, a method for planning under deep uncertainty. She explained how RDM uses exploratory modeling and scenario discovery to identify strategies that perform well across a wide range of futures. Drawing on case studies from Lima, Peru, and U.S. water utilities, she showed how RDM can guide infrastructure investments and adaptive planning by focusing on performance vulnerabilities rather than future hazard and conditions predictions.

Her work demonstrates how RDM can help decision-makers navigate uncertainty while balancing cost, performance, and resilience.

Kathryn Roscoe (Appendix B.2.1.5) of Deltares introduced the Dynamic Adaptive Policy Pathways (DAPP) approach, a planning method that helps communities sequence adaptation actions over time. Using a case study from Miami-Dade County, she illustrated how tipping points, monitoring indicators, and stakeholder engagement can be used to develop flexible, long-term strategies. She also shared insights from Dutch coastal planning, where DAPP has been used to manage sea-level rise and flood risk. Her presentation emphasized the importance of institutional readiness and the value of staged implementation to avoid maladaptation and stranded investments.

The second set of presentations featured case studies that brought these technical concepts into real-world applications.

Paul Schuman (Appendix B.2.1.6) of Simpson Gumpertz & Heger presented a detailed case study of the Charlestown Bus Facility in Boston, where adaptive flood protection was implemented to safeguard critical transit infrastructure. The project involved stabilizing a deteriorating seawall, improving drainage systems, and planning for future sea-level rise through a phased, embankment-based design. The team prioritized operational continuity and recovery time for flood prevention, incorporating features like tide gates and future-ready foundations for floodwalls should further flood protection be required in the future.

Jack Hogan (Appendix B.2.1.7) of Arup shared a flexible adaptation pathways study for Honolulu, Hawaii, aimed at protecting transit-oriented development zones from sea-level rise. He outlined four conceptual strategies, with various combinations of hard infrastructure and nature-based solutions, and mapped out adaptive pathways. The approach helped city planners visualize decision points, tipping points, and long-term investment strategies, while also integrating cost-benefit analysis to support capital planning under uncertainty.

Milad Roohi (Appendix B.2.1.8) from the University of Nebraska Lincoln described a resilience planning initiative in Salt Lake City using a community-facing app in the IN-CORE platform. The project focused on seismic risk from the Wasatch Fault and the vulnerability of unreinforced masonry buildings. By integrating engineering, economic, and social data, the team developed a community model to support decision-making and prioritize retrofit options. The community model allowed stakeholders to simulate different investment scenarios and evaluate their impact on building functionality, employment, and population displacement.

Finally, Ariane Laxo of HGA (Appendix B.2.1.9) compared how robust decision-making and adaptation planning are applied at different project scales, from buildings to districts. She shared examples from California and Minnesota, illustrating how scenario planning, risk tolerance, and stakeholder engagement inform design strategies. Her work emphasizes the

importance of aligning resilience goals with sustainability and operational needs and demonstrates how even small-scale projects can benefit from structured adaptation planning.

2.2. Goals for Future State

A panel discussion was held featuring two Chief Resilience Officers from South Florida: Dr. Jennifer Jurado, representing Broward County, and Rogelio Madan, from the City of Miami. Both speakers shared insights from their experience in implementing climate adaptation and resilience strategies in their respective communities.

The conversation centered on the realities of resilience planning, moving beyond theoretical frameworks to address practical challenges and solutions. Panelists discussed the barriers to decision-making that local governments face, including funding limitations, regulatory constraints, and the difficulty of aligning short-term priorities with long-term resilience goals.

Panelists stressed that these challenges require innovative approaches and strong collaboration among stakeholders. Examples of these key themes include planning practices that integrate resilience into urban development. The panelists underscored the need for community engagement and governmental cooperation to ensure that adaptation strategies are effective and equitable.

The plenary provided participants with a deeper understanding of how South Florida communities are preparing for next-generation standards, the lessons learned from ongoing projects, and strategies for overcoming obstacles to resilience planning.

Following the discussion about South Florida, the plenary session discussion focused on desirable and needed aspects of effective adaptation and resilience strategies, planning, and design approaches.

The workshop participants envisioned a future design and regulatory environment where adaptation and resilience are at the forefront of civil infrastructure design and funding requirements with full support from infrastructure decision-makers. This vision includes

- Next-generation guidelines, standards, and codes that will provide flexible pathways for adaptive design and compatible policy thresholds that enable resilient infrastructure outcomes for the community;
- Regulations and requirements that local governments and decision-makers can employ with consistent funding and alignment of short-term priorities with long-term goals;
- Engineers and design professionals with access to and understanding of the consensus and flexible design guidelines needed to consider broad, system-wide, adaptable approaches to resilient infrastructure design; and

- Project teams with the ability to systematically and fully engage stakeholders, including the community, in the adaptation design strategy to ensure long-term infrastructure resilience success.

3. Section 3: Discussion of Advancing Adaptation and Resilience

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

Structural adaptation refers to modifying civil structures and infrastructure systems to withstand hazards and moderate potential damages from future extreme events. Adaptation may take two forms: New designs that are intentionally created to be adjustable to accommodate changes should future information indicate deficiencies in our projections of future hazards and methods for strengthening existing structures that were designed based on historic data that are found to be inadequate. Resilience refers to the ability of a structure, an infrastructure system, or an entire community to adapt to and rapidly recover from natural disasters.

This report summarizes the discussion of breakout group 1. Topic 1 identifies missing information that could facilitate the implementation of adaptive designs and the adoption of resilience criteria in structural design processes. Topic 2 reviews issues that require additional research to address existing gaps in the state of the art. Section 4 provides the recommended research needs.

TOPIC 1: What is needed to advance design practice and building standards?

The information needed to help implement processes for structural adaptation and community resilience are categorized as (1) data needs, (2) procedures and methodologies, and (3) Guidelines.

1. Data needs.

Single Hazards. The main needs for developing structural adaptation strategies and implementing resilience criteria in design include reliable observed and recorded hazard data that engineers, planners, and decision-makers can depend on for infrastructure planning. Although ASCE 7-28 work is making progress on assembling future condition hazard data to develop design load maps that can be adopted in the upcoming edition of the standard, these data must be presented in readily accessible platforms and formatted in a manner that can be easily adopted for individual site-specific, performance-based design projects. The data must also include an assessment of their reliability and the levels of uncertainty associated with their use.

Multihazards. Current standards focus on the effects of individual hazards, and load combination factors assume that loads are statistically independent events. A need exists to

assemble data for multihazard analyses and designs. Such data must include probability of simultaneous occurrences of two or more loads, or the occurrence of a sequence of multiple events and their compounding effects and the correlation among the intensities of the loads. This will help engineers develop plausible scenarios for design and safety assessment purposes.

Structural Deterioration. Existing standards assume that structural members are well-maintained and retain their original structural capacity over their intended service life. Data collection from structural health monitoring systems is needed to better account for the deterioration of structural materials over time and to understand the deterioration mechanisms and the factors that accelerate their degradation. Such real-time data are needed to verify the accuracy of analytical models and accelerated laboratory testing.

Damage Assessment. Post-disaster data collection is important to help engineers better assess how historic designs are performing under actual extreme events. The data must be presented in a technical format to evaluate the accuracy of engineering analysis models rather than be solely meant for assessing losses for insurance purposes as is common. Structural engineering simulation and design processes are based on comparing analytical limit states; correlating these limit states with actual physical damage is important. This will help to quantify damage due to expected loads, improve the analysis and safety assessment of damaged structures, and conceive structural repair and functional recovery strategies.

Cost Models. Decision-making processes require a clear assessment of the costs associated with each phase of a structure's life cycle from the initial inception of the design; through construction; monitoring; maintenance; and repair, response, and damage due to various potential hazards; and until the dismantling and disposal of the structure. The cost data should account for tangible and intangible costs associated with the physical structure, including the costs to its owners and users and those incurred by the entire community in which it is located. This will provide answers related to return on investment (ROI) and inform benefit-cost and risk analysis processes that stakeholders, including engineers, developers, planners, and decision-makers, rely on before embarking on a project or assessing the consequences of a disastrous event.

2. Procedures and Methodologies

Post-Disaster Performance. To better develop repair and functional recovery strategies after exposure to extreme events, we need to develop models that associate observed physical damage with structural performance and reduced load-carrying capacity of members and systems. Models that assess the effectiveness of common repair techniques in restoring or improving member and system capacities are also needed. Relating a particular damaged or repaired building's performance to that of the entire community and its ability to recover is also important to ensure resilience. Issues related to ensuring population and industry stabilization following a disaster are also of concern. The post-disaster reconstruction of the response of

individual structures, portfolios of structures, and infrastructure systems after forensic engineering practices, but at a larger scale, would help verify existing analysis models and damage assessment procedures and inform future decision-making.

Structural Health Monitoring (SHM). Engineers can benefit from information on the effectiveness of currently available health-monitoring and remote-sensing techniques in monitoring the performance of different types of structures over time and studying their long-term degradation. Using SHM techniques after extreme events will help assess damage and provide valuable support for evaluating the safety and resilience of damaged structures and the response of communities to disastrous events. That information would alert decision-makers to the consequences of potential disastrous situations and help in preparing contingency plans. Developing modern artificial intelligence (AI) and machine learning (ML) tools for that purpose is of utmost importance to handle the large stream of data and interpret the collected information. These modern tools and techniques should eventually facilitate the development of digital twins for buildings and entire communities to enhance traditional modeling and simulation methods.

Cascading Events. Design codes and standards focus on the performance of structures in response to individual events, although some consideration is given to the possible simultaneous occurrence of multiple, statistically independent events. The vulnerability of structures, systems, and communities that have been damaged by one event to other related or unrelated events is a concern. Community-level contingency planning for such eventualities is important for ensuring resilience.

3. Guidelines

Resilience-Based Design Pathway. An important need is for ASCE and NIST to provide risk-informed decision-making methods that link current structural design standards and codes to the implications of extreme events on infrastructure systems and communities. This requires establishing notional measures for resilience and risk-based acceptance criteria. The approach must address requirements for different hazards and accommodate different types of projects of different scales, considering the size and characteristics of the population. This can be achieved by providing a decision pathway and associated tolerances and thresholds and criteria for acceptable outcomes that can be defined in a standard or model code that communities and jurisdictions can adopt and enforce. The model code should accommodate a performance-based design (PBD) approach for decision-making at the regional development planning level and implementation of individual jurisdictions. The goal is to ensure a quick, full recovery from extreme events so that populations of various scales, ranging from the individual small owner to the developer to the entire community, understand the risks and the importance of compliance.

Application of Modern Tools. Assessing the resilience of structural systems and communities can greatly benefit from modern sensor technologies, image-processing techniques, and advanced computer tools such as AI and ML. In addition to incentivizing the deployment of the most advanced SHM technology that will help communities “monitor” the health of their infrastructure, guidelines are needed to explain how to deploy such tools and identify which ones are most effective for monitoring the damage that an extreme event may cause to the physical infrastructure and the event’s effect on community functionality and population response to disaster. Guidelines on how to deploy and collect SHM data will not only help in responding to the aftermath of a disaster but will also guide the development of digital twins that can be used for “stress tests” to measure the level of preparation for an eventual extreme event, to enable efficient decision-making when responding to an extreme event, and to build robustness in the infrastructure and plan adequate responses to potential future disasters.

TOPIC 2: What are the next-generation research needs for adaptation and resilience?

Incentives and Financial Planning. Owners and developers seek to minimize their initial costs by adopting minimum, code-specified design requirements for their projects. They tend to isolate their needs from those of the community unless required to do otherwise. Research is needed to investigate what financial, behavioral, tax, and policy-based incentives can effectively motivate developers and infrastructure owners to invest in incorporating project resilience criteria that align with community needs and long-term values. Can government tax and other incentives combined with nongovernment incentives through insurers and financiers impose requirements and criteria that link a particular facility’s ROI to the community’s ROI? The research would provide mechanisms to highlight how the vulnerability of a particular building or structure would affect the community and how the structure’s owners and users will benefit from a community’s improved resilience, which would help maintain population and community stability.

Decision-Making, Standards, and Design Guidelines. Creation of design approaches for adaptation, leading to standards, codes, and decision-support tools that integrate resilience into infrastructure planning across diverse stakeholders, is needed. The standards should include approaches applicable to designing adaptive individual projects and resilience decision-making at community levels. The solutions should be tailored for implementation at different scales including state, local, owner, and individual levels.

Resilient Design Support Systems. Due to the complex, multiscale nature of the problem, significant investment should be made to build support systems that allow engineers, planners, and decision-makers to efficiently follow appropriate resilience and adaptive design pathways. The development of appropriate software will create a consistent framework to help users navigate through multiple possible options and optimize the selection of cost-efficient adaptation strategies. Some effort has already been made in that direction. For example, the current version of Economic Decision Guide Software (EDGE\$) provides a rational, systemic

methodology for selecting cost-effective, community-level alternative strategies for resilience planning. Furthermore, IN-CORE is a software platform for modeling the resilience of communities to natural hazards by using a risk-based approach to analyze how disasters affect a community's physical infrastructure, economy, and social systems. The Federal Emergency Management Agency (FEMA) is currently developing a methodology (FEMA P-58) to estimate time to the re-occupancy and functional recovery of buildings following major earthquake damage (FEMA 2012). Extending the work of FEMA and linking the capabilities of IN-CORE and EDGe\$ would constitute a powerful support system that will help owners, planners, and decision-makers to select the most optimum resilience-informed solutions.

Hazard Data. Standardized, geographically targeted datasets that are consistent with design standards and codes are needed for use in resilience modeling and performance-based design. Existing datasets must be extended to address multihazard analysis needs for comprehensive resilience planning. ML, other advanced tools, and AI techniques should be leveraged to reconstruct missing data and build synthetic datasets. Data formatting and data reduction and quality assurance techniques are needed to verify data accuracy and reliability for adoption in simulations and resilience assessment.

Measurement and Data Science. As listed under Topic 1, assessing project and community resilience requires (1) the availability of data and models related to future hazards; (2) the response of civil structures and infrastructure systems to these hazards; (3) the long-term degradation and immediate physical damage caused by various hazards; (4) the response of users and communities to disastrous events; (5) repair techniques and functional recovery of structures and of communities; (6) interdependencies of infrastructure systems; and (7) the costs involved in every phase of a structure's or infrastructure system's service life, including the deployment of advanced sensor technologies and health -monitoring systems that help collect and interpret all the necessary data. The application of deep learning and artificial intelligence tools can provide the means to classify, establish correlations, and represent such data in support of resilience decision-making. The goal is to advance, quantify, and measure the factors influencing community resilience outcomes and use measurement science to quantify trends and inform evidence-based guidelines. Such efforts would align well with the Office of Management and Budget's Memorandum 25-34, which provides information for the fiscal year 2027 federal research and development budget to prioritize investments in critical and emerging technologies that enhance the security and well-being of the U.S. population and the environment (OMB 2025).

Understanding and Modeling of Recovery. The functional recovery of structures and communities after extreme events is a topic that receives less attention than other resilience-related topics. Therefore, collecting, updating, and calibrating data and models for incorporating functional recovery of facilities, infrastructure networks, and communities and their interactions into resilience-informed design standards and tools should be considered an important topic for research. At this time, FEMA is developing a performance-based seismic

assessment methodology that quantifies a building's performance after an earthquake by estimating potential damage, repair costs, repair time, life safety, and environmental impact for FEMA P-58. In a first step, researchers should investigate the adaptability of the FEMA P-58 framework and other seismic functional recovery frameworks to other hazards. Those efforts must also be extended beyond the recovery of individual buildings and other structures to the multiple scales that allow for studying community recovery patterns and delineating the conditions that have historically facilitated the recovery of many communities when others did not. The enumeration and quantification of recovery factors can benefit from advanced measurement science to analyze historic trends and develop guidelines for the future. The research must also leverage remote-sensing technology and AI tools to quantify and classify building and infrastructure inventory, analyze previous damage, and encourage the deployment of necessary sensors to monitor the response to future events. Developing a full understanding of damage and recovery patterns will help the assessment of community resilience and will support the implementation of resilience-informed designs.

3.2. Breakout 2

Breakout group 2 included experts from the private sector, academia, federal agencies, and the insurance industry who discussed the needs of structural engineering practitioners to advance design practice and building codes for adaptation and resilience and to identify and prioritize next-generation research requirements. In summary, advancing adaptation and resilience in structural design will require a combination of improved hazard data, advances in performance monitoring, a wider array of design methodologies and support tools, and continued research on future conditions. For the final list of top recommended priority needs from this breakout group, please see Section 4.

Uncertainty. The participants noted that today's design field is challenged by deep uncertainty. Engineers design for a wide range of hazards and criteria, but the information underpinning these criteria is based on historical hazard data and events. Designers require more current and forward-looking hazard maps and studies that capture present conditions and evolving risks, including but not limited to wildfire exposure, coastal wind hazards, sea-level rise, extreme precipitation, and compound flooding. Designers must also be able to quantify and address other nonstationary design considerations such as scour, erosion, groundwater salinity, and corrosion-related degradation. Currently available data for many of these hazards lack high-resolution or future-condition datasets, particularly for extreme or sub-daily events, which are critical for structural design.

Design Tools. The engineering community needs simplified and accessible tools, grounded in decision-making under deep uncertainty (DMDU), to address the gaps in hazard data. The participants noted that practitioners, especially those in communities with limited resources, need tools that are easy to use and understand. Such tools must be based on a common framework and capable of providing design values informed by future hazard projections.

PBD will be an essential tool for designer professionals to utilize in the future, particularly in environments with nonstationary and evolving hazards. Participants discussed the importance of expanding PBD beyond seismic and wind hazards, including ASCE's recent initiative to develop PBD for flood-resistant design and other efforts aimed at defining clearer performance objectives. To support this effort, research is needed to develop fragility curves for structural and nonstructural systems, particularly mechanical, electrical, and plumbing components and architectural finishes, as these elements critically affect functionality and recovery. The participants noted that functional recovery research should be extended to all hazard types, not just seismic, and should incorporate considerations related to future hazard conditions and the existing building stock.

A recurring point throughout the discussion was the discrepancy between observed performance and design assumptions. Some insurers have asserted that most flood insurance claims in recent flood events occur at properties outside of FEMA Special Flood Hazard Areas, which illustrates how current hazard maps fail to capture real risk. Research is needed to align first-hand observed hazard effects with design maps, improving the reliability of hazard characterization and reducing uncertainty.

Building Performance Database. Participants identified the lack of a comprehensive database of building performance under extreme events as a significant gap in the industry. Such a database may consist of a national repository that documents failures and successes, including data on system degradation, nonstructural systems' performance, and cost-benefit outcomes. The database would mirror the benefits seen in the seismic engineering community and give regulators, owners, and practitioners confidence in new design approaches.

Adaptive Pathways. Durability and long-term building performance are important considerations. A potential conflict exists between the need for practitioners to design for long-term or forward-looking conditions, such as corrosion in coastal foundations, and the reality that operations and maintenance play a significant role in determining building performance. These latter factors are typically under the purview and control of building owners and, in many cases, are beyond the practical reach of designers to address. Adaptive pathways or design strategies must be planned for future upgrades activated by well-defined triggers. Adaptive pathways should be integrated into PBD and potentially into future building codes and standards, especially given the uncertainty in future funding and hazard trajectories.

Existing Buildings. When evaluating research needs for the next generation of standards and codes, participants noted the importance of addressing new and existing building stock. Existing guidelines and standards for other hazards, such as ASCE 41, *Seismic Evaluation and Retrofit of Existing Buildings* (2023), could serve as a model for systematically addressing older buildings; however, much more research is needed to understand how future hazards will interact with an aging inventory of existing buildings and structures.

3.3. Breakout 3

During introductions, the participants shared the priority concerns they wanted to bring to the discussion: (1) understanding climate data needs and tipping points; (2) improving how people respond to climate hazard information; (3) bringing diverse approaches together into unified standards; (4) ensuring standards are implementable by practitioners; (5) standardizing uncertainty communication; (6) incorporating time factors in life-cycle performance; (7) having data to support code adoption and enforcement; (8) developing common hazard and risk language across disciplines, particularly for wildfire; and (9) creating structures that can adapt to unknown situations. The final session focused on consolidating topics into priority research areas. Section 4 lists the top six priorities put forward by this breakout group.

Future Hazards. The session began with a discussion of practical hazard data needs, with the specific example of the difficulty in obtaining flood depths at multiple recurrence intervals (100-, 500-, 750-, and 1,000-year events) at any location, with time horizons of 25 to 50 years or longer for infrastructure planning. This established a theme of data needs for changing conditions that informed the rest of the discussion.

Snow and ice hazards were also mentioned as needing more data, particularly for rail infrastructure and bridges, which lack climate projection data for these types of extreme events. While this type of hazard primarily informs operational (versus structural) specifications such as speed reductions, forward looking extreme hazard data for rail infrastructure do not exist.

The group identified wildfire as a particularly challenging hazard due to the large uncertainty in climate and wildfire impact modeling and multiple contributing factors (ignition sources, land use and development, climate factors). One practitioner noted that planning for future wildfire felt like “throwing darts at a wall” due to the uncertainty. The critical need for improved wildfire hazard categorization was discussed, noting the lack of intensity scales and a common language and vocabulary on wildfire type. As recent events illustrate, a distinction needs to be made for wind-driven fires relative to other types. The importance of emerging in situ sensing technology for monitoring structures during wildfire is seen as a promising advance in characterizing wildfire risk to structures. Current satellite remote sensing is too infrequent to capture even community-level fire impacts on the time scale of rapid fire spread. Such characterization would improve communication with individuals and communities to help them understand the impacts of different fire scenarios and their probabilities.

Performance-Based Design. The topic then shifted to the benefits of nonprescriptive, performance-based standards rather than prescribed methods, allowing flexibility in adaptation approaches. Prescriptive approaches may apply to new construction but create challenges for retrofits. They may also stifle innovation. For better flexibility in design, the focus should be on

performance requirements rather than the specific means of achieving them. However, trade-offs were noted and discussed later in the breakout session.

Risk Reduction. The group raised the topic of operational versus physical measures to reduce risk. Operational measures, such as speed reductions on rail lines or changes in other operational protocols, rely on adequate warning time to implement those changes and the availability of resources to implement them given those lead times. This led to debate about passive versus active mitigation: whether structures should rely on human intervention (active) or built-in protection (passive). Passive measures for wildfire include the use of fire-resistant materials, impact-resistant glazing, and self-activating barriers, whereas active measures might include firefighting resources, manual shutters, and passive measures for flood risk include deployed flood barriers. The distinction between active and passive measures may not be clean, as illustrated by automated sprinklers or other fire suppression systems that may potentially fail. At the community level, the viability of active measures depends strongly on the community's capability and resources and can vary widely among neighboring communities.

Life-Cycle Management. Finally, the time dimension was raised as a concern, emphasizing how resilience depends not only on the changing hazard level but also on when hazard events occur relative to system conditions, maintenance schedules, community resource availability, and the lifetime of the structure.

Adaptive Design. The session resumed with deeper exploration of what would be needed to operationalize adaptive design. The group delved into prescriptive versus nonprescriptive approaches, noting the balance needed between the two—prescriptive measures help to justify costs to clients as they are required, but they also limit design flexibility. Discussion evolved toward a tiered approach, similar to that used in seismic design, where prescriptive baselines exist, but performance-based alternatives are available for qualified engineers working with knowledgeable communities.

The conversation then moved toward discussing critical liability concerns for engineers designing for nonstationary hazards and future implementations of adaptive designs they cannot control once buildings are turned over to owners. This could be a possible barrier to the adoption of adaptive design. Liability currently (typically) extends for seven years post-design, but this assumes stationary hazards. A primary question raised is “How will engineers’ standard of care need to evolve under a changing climate?” This question may ultimately be decided outside the engineering profession, perhaps by insurers’ comfort with an engineer stamping and sealing adaptive designs.

Resilience. The group grappled with community resilience, with an overriding desire for developing guidelines that integrate community-scale resilience into individual projects for the practicing engineer. Community capacity assumptions are critical. Wildfire research has found that risk calculations are invalid without considering firefighting resources, which correlate with

social vulnerability. These capacity issues extend beyond wildfire. More generally, what are engineers assuming about the operational agencies and resources available through the full disaster cycle? Likewise, the balance between passive versus active measures depends on community capacity and warning systems. Critical infrastructure, such as electrical utilities, should prioritize passive protection, but research is needed into how this would be accomplished and what would be most effective.

Multiple community preferences create challenges when projects span multiple communities with different vulnerabilities and resilience objectives. Rail projects passing through 70 km may cross diverse communities—how do practitioners balance comprehensive assessment versus minimum requirements focused on the most vulnerable communities given budget constraints? Research needs to develop guidelines for integrating community resilience into projects when multiple communities have conflicting preferences and resource limitations. Finally, spatial and governance scales matter. Authorities managing 100 bridges face different decisions than those managing a portfolio of 100,000 bridges. Scale affects decision-making processes and resource allocation.

The group then turned to how to achieve resilience with limited resources. In particular, the group discussed the trade-off between investing in resistance (to a hazard) and recovery (following a disaster) given limited community resources and the challenge of ensuring adaptive strategies persist through changing governance. The temporal perspective was expanded, with discussions about intergenerational resilience and the need for life-cycle frameworks extending beyond traditional planning horizons to support resilience. This part of the discussion also emphasized the need to understand the benefits of designing for resilience so that standards are adopted into codes and then enforced. These social and economic factors were seen as sufficiently critical that the group decided to include the “business case,” interpreted broadly to include social and economic benefits, as a sixth priority need.

Other Considerations. While the group successfully crystallized six priority research areas for adaptive design methods, several important themes for additional considerations emerged during discussions that warrant attention from the research community, which include the following.

Modeling, Monitoring, and AI. The rapid advancement of artificial intelligence and digital twin technologies presents opportunities and uncertainties for adaptive design. The mention of digital twin technology sparked a lively discussion with the full workshop audience noting examples where tech companies are already offering this. AI-driven simulation and digital twins could be “game changers” for future climate planning, enabling real-time scenario projection and structural adaptation. However, the group recognized that research is needed to understand which technologies can be reliably incorporated into resilience planning and which may introduce unacceptable vulnerabilities or errors. This technological dimension cuts across

all hazard types and design approaches, suggesting the need for frameworks to evaluate and integrate emerging tools into professional practice.

Structural health monitoring emerged as a potentially transformative capability for adaptive design, particularly in contexts where real-time data could inform operational responses. The discussion revealed dual applications: quantifying actual structural demands during hazard events to validate design assumptions, enabling structures to become “active responders” through automated systems. For hazards like wildfire where field data are scarce, embedded sensors could provide critical information about thermal loads, smoke infiltration, and structural response. However, questions remain about the reliability, maintenance, and long-term viability of sensor networks in harsh environments.

Maintenance and Operational Procedures. The role of maintenance and operational protocols in adaptive strategies surfaced repeatedly. Unlike traditional design approaches that focus on initial construction, adaptive methods require sustained attention to operational measures throughout a structure’s lifespan. This includes developing protocols that can evolve with changing hazard profiles, training requirements for facility managers, and integration with community emergency response systems. The challenge intensifies when considering that operational knowledge must transfer across multiple generations of owners and operators.

Spatial Scale and Network Effects. While individual building resilience dominated discussions, participants recognized that many critical infrastructure systems operate as interconnected networks, where spatial relationships fundamentally affect vulnerability and adaptive capacity. Adaptive strategies must account for portfolio effects, a cascade of failures, and system-wide optimization and/or disruption. This network perspective becomes particularly important for linear infrastructure like transportation and utilities that span multiple hazard zones and jurisdictions.

3.4. Breakout 4

Discussions in breakout group 4 centered on the limitations of current codes in addressing dynamic problems; the essential need for multidisciplinary integration; and the prioritization of research to create actionable, implementable guidelines for the engineering community. Participants emphasized a need to consider how to shift toward PBD and the necessity of incorporating time-dependent capacity changes, future climate effects, and community-specific risks into updated codes and standards. Section 4 provides the final list of recommended research priorities.

While much research supporting code and standard development has been completed over the past two decades, it has been premised on time-invariant load and resistance. Yet, different material degradation mechanisms affecting structural resistance impact infrastructure; these mechanisms increase at higher temperatures, for example, the corrosion rate of reinforced

concrete structures, or the rate of chloride ingress with respect to increasing deicing salt or saltwater. Earlier workshops considered nonstationary loads; however, structural resistance is also nonstationary, introducing more complexity to the design problem.

TOPIC 1: What is needed to advance design practice and building standards?

Change in Design Philosophy. The adaptation paradigm needs to change from being the preserve of well-financed and complex structural designs within the purview of a limited number of design professionals, to being practical and applicable to common structures. This would be supported by a change in design philosophy that allows flexibility in future designs to incorporate future adaptation measures, rather than incurring significant retrofitting efforts and costs to accommodate changes in future conditions. Current design codes do not facilitate dealing with the dynamic problems posed by nonstationary loads or deep uncertainty about future conditions.

Introducing future climate in typical prescriptive code has many challenges due to the complexity, deep uncertainties, and potential increase in construction cost. Performance-based design might be an optional approach to address some of the requirements but might limit the design for certain applications and types of structures and mainly deal with the probability of failure of structural members.

The role of private-public partnerships should be further explored. These partnerships can play an important role in building community resilience for infrastructure systems. Horizontal infrastructure often has much longer, continuous ownership that benefits from public-private partnerships, unlike vertical infrastructure, for example, commercial buildings, which might change ownership multiple times.

Time-Dependent Capacity and Dynamic Problems. Participants identified several key areas where current codes and standards fall short and proposed solutions to better incorporate resilience and adaptation:

- Time-invariant assumption: Current codes assume that the capacity of structures is time invariant and do not account for the potential acceleration of material degradation mechanisms. Monitoring and assessment of changing rates and mechanisms of degradation affecting resistance and structural capacity are needed.
- Static codes versus dynamic problems: The static nature of design codes cannot effectively deal with the dynamic problem of adapting a structure to accommodate future conditions at different points of its design life (e.g., dynamic adaptive pathways). A fundamental design philosophy change is required to accommodate flexibility in design and routine monitoring and inspection for future adaptation measures. Adaptive design processes need to be supported by the different scenarios that may be encountered during the lifespan and operation of the structure and infrastructure. Participants recommended the adoption of an “adaptation plan” at the design stage,

incorporating some of these assumptions, that can be revisited at frequent intervals and shared with future owners and/or occupiers.

- **Functionality expectations:** Resilient-based design is inherently tied to functionality expectations of the built world and is thus difficult to codify. An open research area relates to understanding the minimum level of structural functionality tied to community perceptions and public expectations and the applicability and affordability of such criteria to various communities.
- **Code updates and guidelines:** This was another of the key areas, containing discussions on PBD, specific guidelines, supporting activities, and risk metrics.
 - **PBD:** PBD could provide an opportunity to accommodate adaptive design practices. However, an overarching code or guideline needs to relate PBD for specific hazards to climate adaptation and resilience principles. Individual PBD guidelines for specific hazards, for example, flood, wind, or fire, could follow those already established for performance-based seismic design. PBD also needs to look beyond simple failure and consider risk, fragility of the infrastructure, and the failure of the network.
 - **Specific guidelines:** Even with the suggested shift to PBD, a need remains for prescriptive documents for common engineering practices that do not require advance analysis. Also, professional knowledge should be embedded in asset documentation to ensure that owners are aware of resilience measures and assumptions and that these persist for the life of the building regardless of ownership life cycles.
 - **Supporting activities:** The Canadian Highway Bridge Design Code was released in July 2025 and introduced design for bridges corresponding to a 2 °C global warming level over 75 years of design life. The National Building Code of Canada 2025 was published in December 2025 and included future condition design loads for wind and snow. The next step is to address changes in capacity arising from temperature-driven acceleration in degradation.
 - **Risk metrics:** The discussion highlighted the need to move beyond traditional failure-based metrics toward a more holistic understanding of risk and resilience that integrates exposure, vulnerability and consequence metrics. Resilience indices, analogous to reliability indices, could enable practitioners to quantify and incorporate community-level functionality and economic impacts into structural design. Monitoring, inspection, and maintenance protocols were also identified as critical components of long-term resilience.

TOPIC 2: What are the next-generation research needs for adaptation and resilience?

Hazards. The next generation of hazards research should focus on flooding, wildfire, tornado, and extreme weather with a very low probability of occurrence. Also worth exploring are alternative failure paths to reduce induced loads, such as from flooding. For example, concepts such as graceful failure thinking could be adopted to mitigate risk and to support community-

scale adaptive pathways. Designs should consider not only the specific structure but also its impact on neighboring structures at the community level and avoid maladaptation. A shared database on community impacts is needed to evaluate and assess the consequences of failure, including the social impact, and the probability of failure.

Resilience. Achieving climate-adaptive and resilient infrastructure requires multidisciplinary collaboration. Engineers must work alongside climate scientists, economists, social scientists, urban planners, insurers, and policymakers. The breakout group stressed the importance of aligning technical design with community priorities, risk appetites, and social definitions of resilience. This approach ensures that infrastructure not only withstands hazards but also supports essential community functions during and after disruptive events. Research informed by economists will enable financial considerations to be incorporated into codes and help minimize the influence of special interest groups seeking to prevent code adoption.

An overarching code, beyond ASCE/SEI 7-22, might be needed to coordinate the multidisciplinary subjects and multifaceted design requirements, including but not limited to minimum loads for structural design. American Association of State Highway and Transportation Officials standards, which cover multiple infrastructure components, could serve as a model for a single, comprehensive document.

Existing Buildings. In the near term, the behavior and load capacity of existing buildings, which make up the majority of the building stock, must be understood. Research is needed to understand the real capacity and redundancy of existing buildings that do not comply with current codes, as this will both inform retrofitting strategies and support assumptions about current and future loads and capacity. Anticipating increasing loads under future conditions, knowledge on how existing buildings perform in response, is limited. More research and development are needed to measure, collect, and establish a large database of the performance of existing structures. This may be achieved through the support of private-public partnerships. Monitoring and maintenance need to be planned in the adaptation strategy to mitigate deterioration risks. Criteria built into property sales for the clear transfer of residual risk and necessary maintenance could be beneficial and could serve as a mechanism to engage with the insurance industry. AI could also be leveraged to pool environmental and performance-monitoring data and translate such information into structural design requirements.

4. Section 4: Recommendation of Research Needs

In their discussions, each breakout group identified the top five priority items and/or research needs to address the next-generation goals for adaptation and resilience.

4.1. Breakout 1

Breakout group 1 discussed five priorities to incorporate tools, data, and models into policy and actionable design:

- *Incentives and Financial Mechanisms.* Investigate how financial, behavioral, and policy-based incentives can effectively motivate infrastructure owners to invest in resilience that aligns with community needs and long-term value;
- *Decision-Making, Standards, and Design Guidelines.* Create design approaches for adaptation, leading to standards, codes, and decision-support tools that integrate resilience into infrastructure planning across diverse stakeholders;
- *Design-Ready Hazard Data.* Establish standardized, geographically targeted datasets that are consistent with design standards and codes for use in resilience modeling and performance-based design;
- *Quantification through Measurement Science.* Advance, quantify, and measure the factors influencing community resilience outcomes and use measurement science to quantify trends and inform evidence-based guidelines; and
- *Understanding and Modeling of Recovery.* Develop, update, and calibrate data and models for incorporating functional recovery of facilities, infrastructure networks, and communities and their interactions into resilience-informed design standards and tools.

4.2. Breakout 2

Breakout group 2 priorities focused on addressing tools and research to better address design issues, including uncertainty, adaptive pathways, building performance, future hazards, and functional recovery:

- *Uncertainty in Design.* Research to identify and reduce uncertainties to better define future hazard levels for design. This includes characterizing deep uncertainty, improving hazard projections, reconciling modeled and observed risk, and understanding multihazard interactions and material degradation.
- *Adaptive Design.* Research to develop methodologies for adaptive pathway designs, including integration of multihazard scenarios, development of fragility curves, modeling of system degradation, and incorporation of these methods into PBD frameworks.
- *Building Performance Database.* Development of a database of actual building performance under extreme events, capturing failures and successes and including cost-benefit analyses and metrics that reflect structural, nonstructural, operational, and social outcomes.

- *Future Hazards.* Development of simplified, accessible tools based on a common hazard and design framework, enabling practitioners and building owners to evaluate future risk conditions and derive appropriate design values, even in communities with limited technical capacity.
- *Functional Recovery.* Extension of functional recovery research across all hazards and for new and existing buildings, ensuring that performance objectives reflect not only life safety but also building operability and community resilience under future hazard conditions.

4.3. Breakout 3

Breakout group 3 focused on hazard characterization, scaling of risk and resilience design parameters between project and community levels, and prescriptive versus performance-based design trade-offs:

- *Hazards.* Improve and standardize the characterization of current and projected hazard levels, including metrics and indicators for implementing adaptive strategies over time, in particular for hazards not included in available climate projections (such as hail), emerging hazards (such as wildfire), and multiple annual exceedance probabilities beyond those usually provided.
- *Scaling of Risk and Resilience.* Improve understanding of preferences around risk and resilience from individual to community levels and the implications for practical engineering design at the project scale. Specific needs include designing for multiple risk and resilience preferences, creating scalable solutions from community-led resilience efforts, and considering resilience in the full disaster cycle including testing assumptions about community capacity.
- *Prescriptive versus Performance-Based Design Trade-Offs.* Investigate the conditions under which prescriptive or performance-based approaches are preferred and their relative benefits and trade-offs for adaptive building design, including understanding the risk of locking in obsolete technological solutions, and the ability of prescriptive methods to handle multiple options. As an illustration, requirements could be developed for early warning times or response times as part of active solutions for different hazards and building types.
- *Wildfire Adaptive Design.* Support broad-based research to inform adaptive design for wildfire including better hazard characterization (common descriptive language, intensity metrics, etc.) and better quantification of demands on structures through real-time structural health monitoring and improved sensor technology.
- *Barriers to Adaptive Design.* Improve understanding of the legal, political, and policy challenges and barriers to implementation of adaptive strategies over time and the implications for engineers' liability and standard of care under nonstationarity and deep uncertainty about future conditions. Determine how best to design for adaptive

measures when the owner(s), not the engineers, are responsible in the long term. Are standards and practices formulated so that design professionals can be confident in signing and sealing given uncertainty over project lifespan?

- *Resilience*. Determine the benefits of resilience to improve the likelihood of adoption into codes and standard development. Examples discussed included economic analysis, insurability, role of public-private partnerships, and allocation of resources across different elements of resilience (for example, resistance versus recovery), and life-cycle analysis of long-term (intergenerational) resilience.

4.4. Breakout 4

Breakout group 4 discussed improvements to data, frameworks, and collaboration to reach future goals in adaptation and resilience:

- *Structural Capacity Degradation*. Integrate time-dependent structural capacity degradation with nonstationary load effects into a reliability-based design standard;
- *Performance-Based Design*. Develop performance-based design approaches for hazards not currently addressed (e.g., fire and flood), while maintaining minimum design standards for common or small-scale projects;
- *Economic Impacts*. Incorporate risk, financial, and consequence metrics—including exposure and vulnerability—into design frameworks to enable assessment of the economic impacts of failure;
- *Multidisciplinary Approach*. Foster multidisciplinary collaboration and integration, including community-driven priorities and social definitions of risk and resilience; and
- *Data Analytics with AI*. Leverage AI to analyze historical hazards and past building performance to inform performance-based design and predict future loads and structural behavior.

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 *

Topic	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
Investigate how financial, behavioral, and policy-based incentives can effectively motivate infrastructure owners to invest in resilience that aligns with community needs			2	1		

and long-term value.						
Create design approaches for adaptation—leading to decision-support tools, design guidelines, standards, and codes—that integrate resilience into infrastructure planning across diverse stakeholders.			2	1		
Establish standardized, geographically targeted datasets that are consistent with design standards and codes for use in resilience modeling and performance-based designs.	2	1		2		3
Identify, quantify, and measure the factors influencing community resilience outcomes and use measurement science to establish trends and develop evidence-based guidelines.				1	2	

Develop, update, and calibrate data and models for incorporating functional recovery of facilities, infrastructure networks, and communities and their interactions into resilience-informed design standards and tools.			1	2		3
Research to identify and reduce uncertainties to better define future hazard levels for design.		1	2			
Research associated with developing methodologies for adaptive pathway designs including multihazards, fragility curves, system degradation, and implementation in performance-based design.		2	2	1		
Develop a database of actual building performance (failures and successes) under extreme events including cost-benefit analysis.		2	1			

Develop simplified tools based on a common framework and accessible data to define future hazard risks and provide design values to practitioners and building owners for implementation on projects.				1	2	
Extend functional recovery research for current and future hazards for new building design and existing buildings.			2	1		
Improve and standardize the characterization of current and projected hazard levels, including metrics and indicators for implementing adaptive strategies over time.	1			2		
Improve understanding of how preferences around risk and resilience scale from individual to community and the implications for practical engineering				1	2	

design at the project scale.						
Investigate the conditions under which prescriptive or nonprescriptive approaches are preferred, their relative benefits, and trade-offs for adaptive building design.				1	2	
Support broad-based research to inform adaptive design for wildfire.			2	1		
Improve understanding of the legal, political, and policy challenges and barriers to implementation of adaptive strategies over time.			2	1	3	
Integrate time-dependent structural capacity degradation with nonstationary load effect.			2	1	3	
Develop performance-based design where appropriate for hazards such as fire and flood that are not			2	1	3	

already addressed while maintaining flexibility for minimum design code on smaller projects.						
Incorporate risk and resilience metrics into current design frameworks to enable consideration of exposure and vulnerability and assessment of the economic impacts of failure.				2	1	
Foster multidisciplinary collaboration and integration that includes community-driven risks and priorities.				1	2	
Leverage existing hazards and building performance data to inform performance-based design and incorporate better translation of existing research into design practice.			1	2		
Understand the benefits of resilience to improve likelihood of adoption into				1	2	3

codes so that it can be incorporated into standard development up front.						
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*Table Key:

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

5.2. Discussion of Results

Workshop 4 on adaptation and resilience convened researchers and practitioners to explore how climate adaptation and resilience can be more effectively integrated into future codes and standards. The workshop covered emerging decision-making frameworks for nonstationarity and uncertainty (e.g., decision scaling, robust decision-making, and adaptive pathways), showcased real-world case studies applying flexible and adaptive design approaches, and examined barriers faced by communities and practitioners. Through plenary discussions and facilitated breakout sessions, participants identified gaps in current practice; outlined next-generation research needs; and defined the prioritized research directions necessary to advance adaptive, resilient design guidelines, standards, and codes.

5.2.1. Future Hazard Data and Information

Priority research in this theme focuses on the critical challenge that future hazard information needed by engineers and planners is not readily available. Specifically, the focus is on improving how future hazards are described, quantified, and shared, especially as climate conditions continue to change. This includes developing consistent, regionally relevant datasets that reflect nonstationary conditions, compound hazards, and extremes. The workshop participants emphasized the need to better integrate observations, historical records, and climate model projections into datasets that are transparent, reproducible, and usable for design. Other topics build on this foundation by addressing how hazard data are processed, maintained, and accessed over time. Creation of benchmark datasets for testing models, defining minimum data requirements for different hazard applications, and improving documentation were also identified. Topics include new ways to represent hazards, for example, by expanding the use of

remote-sensing and novel monitoring techniques, improvement of methods to represent interacting hazards, and the development of visualization tools to benefit the practitioners.

5.2.2. Future Load Effects and Infrastructure Conditions

Topics in this theme focus on how changing hazards actually translate into stresses on infrastructure. While future hazard projections are becoming more common, understanding how those hazards convert into loads remains unclear. Priority topics include improving methods to estimate future hydraulic, hydrologic, wind, wave, and thermal loads, and understanding how these loads interact with aging infrastructure and evolving environmental conditions. They also address infrastructure condition and performance. These research needs address how deterioration, maintenance practices, and retrofits influence vulnerability under future hazards. The group also strongly emphasized monitoring and inspection, which include the development of better ways to track how infrastructure capacity changes and how that information can be incorporated into performance assessments and design decisions.

5.2.3. Design Guidelines, Criteria, and Tools

The topics in this theme include developing clear methodologies that translate complex climate and hazard data into design criteria, performance targets, and decision thresholds. They include tools that are transparent and explainable, helping engineers understand why a particular result is produced rather than treating models as black boxes. In addition, topics include standardizing workflows, promoting open-source and interoperable tools, and providing clarity on model selection and assumptions. Improving communication around uncertainty and limitations is also a key theme, helping practitioners make informed choices rather than defaulting to overly conservative approaches.

5.2.4. Resilience and Adaptation

Research topics in resilience and adaptation focus on designing under nonstationarity. These topics emphasize adaptive design frameworks that account for uncertainty, evolving risk, and long time horizons. They include how to define triggers, thresholds, and pathways for adaptation, ensuring infrastructure can perform acceptably today while remaining flexible for future conditions. The group also strongly emphasized incorporating economic, institutional, and behavioral considerations. Other topics expand to systems and communities by understanding how interconnected infrastructure behaves under future conditions, evaluating trade-offs among adaptation strategies, and developing metrics that capture resilience benefits

over an asset's full life cycle. In addition, life-cycle cost analysis and benefit-cost frameworks play an important role.

5.2.5. Planning and Design Frameworks

The topics in this theme focus on integrating science, engineering, and decision-making. They include systems-based approaches that account for spatial risk patterns, infrastructure interdependencies, and interactions between natural and built systems. A key theme is co-production, working with agencies, practitioners, and communities to ensure frameworks are practical, credible, and aligned with real planning needs. Selected topics also address how planning processes can better incorporate future information, which may include using scenario-based planning methods and clarifying how climate projections should be used in investment and regulatory decisions.

5.2.6. Codes and Standards

Research topics related to codes and standards focus on ways to introduce flexibility into the code development process, including interim requirements, supplements, and performance-based alternatives that can be updated more rapidly without undermining consistency or enforceability. Establishing clear pathways from research findings to code provisions is identified as a central need. These research areas focus on clarifying roles among researchers, standards bodies, industry groups, insurers, and regulators, and ensuring requirements are communicated clearly and applied consistently across jurisdictions.

5.3. Summary

Across all six themes, the research priorities consistently point to the need for **better integration**, connecting future hazard data to loads, infrastructure performance, design tools, planning frameworks, and codes. Together, these topics outline a research agenda that not only advances scientific understanding but also provide guidelines for the development of the practical foundations needed to design, manage, and adapt infrastructure in an uncertain and changing climate.

6. Section 6: Acronyms and Abbreviations

AI	Artificial Intelligence
ASCE	American Society of Civil Engineers
DAPP	Dynamic Adaptive Policy Pathways
EDGE\$	Economic Decision Guide Software
FEMA	Federal Emergency Management Association
IN-CORE	Interdependent Networked Community Resilience Modeling Environment
ML	Machine Learning
NIST	National Institute of Standards and Technology
PBD	Performance-Based Design
RDM	Robust Decision-Making
ROI	Return on Investment
SEI	Structural Engineering Institute
SHM	Structural Health Monitoring
WSC	Workshop Steering Committee

7. Section 7: References

- ASCE. 2022. *Minimum design loads and associated criteria for buildings and other structures*. ASCE 7-22. Reston, VA: ASCE.
- ASCE. 2023. *Seismic evaluation and retrofit of existing buildings*. ASCE 41-23. Reston, VA: ASCE.
- Canadian Highway Bridge Design Code. 2025. CSA Group. *CSA S6:25 Canadian Highway Bridge Design Code*. Toronto, ON: Canadian Standards Association, 2025.
- FEMA (Federal Emergency Management Agency). 2012. P-58. *Seismic Performance Assessment of Buildings: Volume 1 – Methodology (FEMA P-58-1)*. Washington, DC: FEMA, 2012.
- NBC 2025. Canadian Board for Harmonized Construction Codes, *National Building Code of Canada 2025* Ottawa, ON: National Research Council of Canada, 2025, <https://doi.org/10.4224/26fz-gg26>.
- Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, K. Dixon, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, A. McCarty, M. Tye (2026) Forward-Looking Codes and Standards: Future Hazards: Workshop Report, June 4–5, 2025. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-071. <https://doi.org/10.6028/NIST.GCR.26-071>
- Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, K. Dixon, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, A. McCarty, M. Tye (2026) Forward-Looking Codes and Standards: Future Load Effects: Workshop Report, July 29–30, 2025. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-072. <https://doi.org/10.6028/NIST.GCR.26-072>
- Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, K. Dixon, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, A. McCarty, M. Tye (2026) Forward-Looking Codes and Standards: Engineering Design Guidelines and Criteria: Workshop Report, Sept. 25–26, 2025. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-073. <https://doi.org/10.6028/NIST.GCR.26-073>
- Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, K. Dixon, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, A. McCarty, M. Tye (2026) Forward-Looking Codes and Standards: Adaptation and Resilience: Workshop Report, Oct. 29–30, 2025. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-074. <https://doi.org/10.6028/NIST.GCR.26-074>
- Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, K. Dixon, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, A. McCarty, M. Tye (2026) Forward-Looking Codes and Standards: Final Report, March 31, 2026. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-075. <https://doi.org/10.6028/NIST.GCR.26-075>

Office of Management and Budget. 2025. *M-25-34: Fiscal Year (FY) 2027 Administration Research and Development Budget Priorities and Cross-Cutting Actions*. Washington, DC: Executive Office of the President.

Appendix A. Discussion of Priority Research Needs

The following analysis details participant prioritization across the research topics. Table A-1 shows that nearly all rating concentrated on the “Priority” and “Highest Priority” categories. Notably, as highlighted in Table A-2, several key topics received more than 34% of “Highest Priority” ratings, receiving the top across all prioritization efforts. Table A-2 also shows all topics that received more than 45% of “Priority” ratings.

Table A-1. Participant Ratings of Research Topics: Percentage Breakdown

Topic	Neutral	Lower priority	Priority	Highest priority
Investigate how financial, behavioral, and policy-based incentives can effectively motivate infrastructure owners to invest in resilience that aligns with community needs and long-term value.	6.1%	27.3%	33.3%	33.3%
Create design approaches for adaptation—leading to decision-support tools, design guidelines, standards, and codes—that integrate resilience into infrastructure planning across diverse stakeholders.	3%	9.1%	48.5%	39.4%
Establish standardized, geographically targeted datasets that are consistent with design standards and codes for use in resilience modeling and performance-based designs.	9.1%	18.2%	36.4%	36.4%
Identify, quantify, and measure the factors influencing community resilience outcomes and use measurement science to establish trends and develop evidence-based guidelines.	24.2%	30.3%	24.2%	21.2%
Develop, update, and calibrate data and models for incorporating functional recovery of facilities, infrastructure networks, and communities and their interactions into resilience-informed design standards and tools.	12.1%	24.2%	33.3%	30.3%
Research to identify and reduce uncertainties to better define future hazard levels for design.	12.1%	24.2%	39.4%	24.2%
Research associated with developing methodologies for adaptive pathway designs including multihazards, fragility curves, system degradation, and implementation in performance-based design.	3%	9.1%	51.5%	36.4%
Develop a database of actual building performance (failures and successes) under extreme events including cost-benefit analysis.	9.1%	30.3%	30.3%	30.3%
Develop simplified tools based on a common framework and accessible data to define future hazard risks and provide design values to practitioners and building owners for implementation on projects.	21.2%	9.1%	45.5%	24.2%
Extend functional recovery research for current and future hazards for new building design and existing buildings.	21.2%	27.3%	33.3%	18.2%
Improve and standardize the characterization of current and projected hazard levels, including metrics and	0%	12.1%	54.5%	33.3%

indicators for implementing adaptive strategies over time.				
Improve understanding of how preferences around risk and resilience scale from individual to community and the implications for practical engineering design at the project scale.	21.2%	30.3%	30.3%	18.2%
Investigate the conditions under which prescriptive or nonprescriptive approaches are preferred, their relative benefits, and trade-offs for adaptive building design.	27.3%	24.2%	30.3%	18.2%
Support broad-based research to inform adaptive design for wildfire.	18.2%	30.3%	21.2%	30.3%
Improve understanding of the legal, political, and policy challenges and barriers to implementation of adaptive strategies over time.	24.2%	15.2%	39.4%	21.2%
Integrate time-dependent structural capacity degradation with nonstationary load effect.	21.2%	27.3%	36.4%	15.2%
Develop performance-based design documents where appropriate for hazards such as fire and flood that are not already addressed while maintaining flexibility for minimum design code on smaller projects.	12.1%	15.2%	39.4%	33.3%
Incorporate risk and resilience metrics in current design frameworks to enable consideration of exposure and vulnerability and assessment of the economic impacts of failure.	18.2%	9.1%	42.4%	30.3%
Foster multidisciplinary collaboration and integration that includes community-driven risks and priorities.	12.1%	42.4%	24.2%	21.2%
Leverage existing hazards and building performance data to inform performance-based design and incorporate better translation of existing research into design practice.	9.1%	9.1%	66.7%	15.2%
Understand the benefits of resilience to improve likelihood of adoption into codes so that it can be incorporated into standard development up front.	24.2%	15.2%	39.4%	21.2%

Table A-2. Rating of Research Needs: Highest Priority (>34%) and Priority (>45%) Topics

Topic	Highest priority	Priority
Create design approaches for adaptation—leading to decision-support tools, design guidelines, standards, and codes—that integrate resilience into infrastructure planning across diverse stakeholders.	39.4%	48.5%
Establish standardized, geographically targeted datasets that are consistent with design standards and codes for use in resilience modeling and performance-based designs.	36.4%	36.4%
Research associated with developing methodologies for adaptive pathway designs including multihazards, fragility curves, system degradation, and implementation in performance-based design.	36.4%	51.5%

Leverage existing hazards and building performance data to inform performance-based design and incorporate better translation of existing research into design practice.	15.2%	66.7%
Improve and standardize the characterization of current and projected hazard levels, including metrics and indicators for implementing adaptive strategies over time.	33.3%	54.5%
Develop simplified tools based on a common framework and accessible data to define future hazard risks and provide design values to practitioners and building owners for implementation on projects.	24.2%	45.5%

Appendix B. Workshop Materials

B.1. Workshop Agenda



SEI NIST Forward-Looking Codes and Standards: Adaptation and Resilience Workshop

DATE: October 29–30, 2025

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

VIRTUAL: Zoom and Teams links sent separately

Workshop Agenda – FINAL2

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

WORKSHOP MATERIALS: Link to Digital Materials Package (password: adaptationresilience)

Day 1: October 29, 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–11:00am: Synergistic Efforts

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

- **Incorporating Community Resilience into Codes and Standards;**
John van de Lindt, Ph.D.; Colorado State University [15 min]
- **Decision Scaling;**
Casey Brown, Ph.D., P.E.; University of Massachusetts [15 min]
- **Barriers for Handling Nonstationarity in Applied Performance Based Design;**
Erica Fischer, Ph.D., P.E.; Oregon State University [15 min]
- **Robust Decision Making;**
Michelle Miro, Ph.D., RAND [15 min]
- **Dynamic Adaptive Policy Pathways;**
Kathryn Roscoe; Deltares [15 min]

- **Q&A Discussion;** Moderator: Jayantha Obeysekera [15 min]

11:00am–11:15am: PICTURE + COFFEE BREAK

11:15am–12:30pm: CASE STUDIES

Presentations of projects that used adaptive pathways for design and panel discussion of “What do you wish you had?” to prime thinking for breakout sessions.

- **Charlestown Bus Facility Shoreline Stabilization;** Paul Schuman, Ph.D., P.E.; SGH [15 min]
- **Honolulu Flexible Adaptation Pathways;** Jack Hogan, P.E.; Arup [15 min]
- **Resilience Planning with Salt Lake City;** Milad Roohi, Ph.D.; University of Nebraska [15 min]
- **A Comparison of Robust Decision-Making Approaches for Community vs Asset-Based Projects;** Ariane Laxo; HGA [15 min]
- **Q&A Discussion;** Moderator: Jayantha Obeysekera [15 min]

12:30pm–1:00pm: WORKING LUNCH PROVIDED

1:00pm–2:00pm: Plenary Discussion

Session to define the goals for the future state, followed by instructions for the breakout sessions.

- **Next-Generation Goals; ALL**
Moderators: Jayantha Obeysekera, Therese McAllister
Discussion to prepare for breakouts.

PLENARY PANEL DISCUSSION: Reality on the Ground: If I had a magic wand...

Barriers to decision-making, challenges to innovative solutions, risk-reward sharing, community versus individual development goals and incentives.

Speakers:

- Rogelio Madan, Resilience Officer, Planning Department, Miami Beach [15 min]
- Jennifer Jurado, Ph.D., Chief Resilience Officer, Broward County, Florida [15 min]

Plenary Discussion: Moderator: Jayantha Obeysekera [20 min]

- **Charging Breakouts;** Jennifer Goupil [10 min]
Instructions on how the breakouts will work.

GOAL:

PROMPTS:

1. *What do you wish you had to advance design practice and building standards for adaptation and resilience?*
2. *What are the next-generation research needs for adaptation and resilience?*
3. *Define and PRIORITIZE the research needs that are required to advance the next generation of standards and codes for adaptation and resilience. List the top five research needs. (Each one written as a complete sentence.)*

2:00pm–2:15pm” Move to assigned breakout rooms (see following plan)



2:15pm–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: October 30; 9:00am–12:00pm ET

8:30am–9:00am: NETWORKING CONTINENTAL BREAKFAST PROVIDED

9:00am–9:15am: Welcome

- Purpose and Goals of Day 2

9:15am–11:00am: Report Out

- Breakout Session Report Out: [15 min EACH = 10 min + 5 min Q&A]

15-minute COFFEE BREAK (10:15am)

- Moderated Discussion of Breakout Reports [30 min]
Moderator: Jayantha Obeysekera

11:00am–11:45am: Prioritization

- Prioritization of Research Needs—Survey [15 min]
- Discussion of Survey Results [30 min]

11:45am–12:00pm: Conclusion

- Summary and Adjourn Day 2

12:30–3:00pm: Workshop Steering Committee Meeting

B.2. Workshop Presentations

B.2.1. Day 1: Overview Presentations

ADAPTATION AND RESILIENCE

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

Oct 29-30, 2025

SEI/NIST Forward Looking Codes and Standards Workshop #4



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



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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, and structural impacts for design:
 - **Future Conditions**
 - Temperatures (atmospheric, sea surface); Humidity; Drought
 - **Future Hazards**
 - Precipitation (rain, snow, ice, hail); Flood (sea level; flooding)
 - Wind (convective storms, hurricanes); Earthquake (landslides, liquefaction)
 - Wildland-urban interface (WUI) fires
 - **Structural Impacts**
 - Material/Structural degradation; Adaptation and Resilience
- Identify and prioritize *next generation* 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.



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

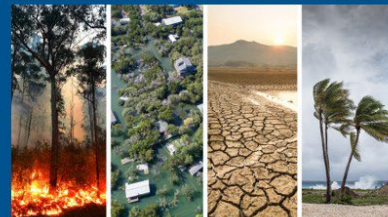
- **Jennifer Goupil**, P.E., ASCE Chief Resilience Officer and Managing Director, Structural Engineering Institute of ASCE
- **Katie Stueckle**, Structural Engineering Institute of ASCE
- Jessica Jun, Structural Engineering Institute of ASCE
- Addie Gordon, Structural Engineering Institute of ASCE



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. **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. **Sep 25-26: Engineering design guidance and criteria** - non-stationary reliability, service life, design loads, resistance, deterioration
4. **OCT. 29-30: 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,
MSSD Deputy Chief, Research Structural Engineer for
Community Resilience Group; 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 future hazards and conditions for design*** (beyond ASCE 7-28)
 - 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

- **National Building Code of Canada (NBCC) 2025**

The 2025 version addresses Future Conditions

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

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/NOAA Grants to support ASCE 7-28**

Hazards and Conditions

- Wind, snow, rain, atmospheric ice hazards and loads

Structural Capacity and Performance

- Nonstationary reliability methods
- 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

Hurricane
Michael
2018



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 7-28 Future Conditions Subcommittee

ASCE-NOAA Task Force Summit -- Feb 2023

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

ASCE-NOAA Summer Workshop: Building the Resiliency Business Case -- Jun 2025

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*



WORKSHOP #4 GOALS FOR ADAPTATION AND RESILIENCE

Current State of the Art

Guidelines and Standards

- Canadian Approach in NBCC 2025
- ASCE/SEI 7-28 Future Hazards & Load Effects
- ASCE Manuals of Practice
- Material Standards (concrete, steel, wood, etc.)
- Existing structures assessment

Structural Capacity and Adaptation

- Structural and materials degradation
- Lifecycle and condition assessment
- Structural modifications and adaptation

Next Generation Goals

PURPOSE: *Identify engineering strategies for enhancing resilience to evolving hazards and adaptive capacity of buildings and infrastructure systems under uncertain future conditions, including degradation of materials and performance of the built environment. **Note we are not including Nature Based Solutions for this workshop.***

SCOPE:

- *Develop approaches for resilience including adaptive design pathways and robust decision-making under nonstationary conditions, considering both loads and structural capacity.*
- *Identify barriers and opportunities for applying adaptive pathways and resilience strategies in practice. Discuss standards, codes, and decision frameworks to bridge engineering and community resilience needs, and potential solutions.*

FORWARD-LOOKING CODES AND STANDARDS: AGENDA AND GOAL

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

ASCE Chief Resilience Officer and Managing Director, Structural
Engineering Institute of ASCE



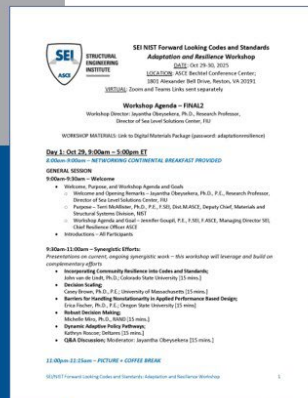
AGENDA

**Fully Hybrid = PLEASE
STATE YOUR NAME WHEN
YOU ARE SPEAKING!**

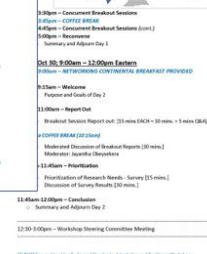
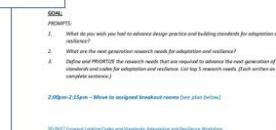
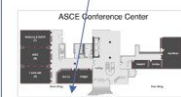
Digital Package

(password: adaptationresilience)

- AGENDA
- Participant List
- Slide Decks



Asking for a
VOLUNTEER for
Day 2 Report Outs



SELF INTRODUCTION

Name, Organization



PARTICIPANTS SELF INTRODUCTIONS:

- **NAME**
- **ORGANIZATION**

IN-PERSON:

We will go around
the room

VIRTUAL:

We will go down the
list, so you know
when to unmute!

IN- PERSON

Ann Kosmal
Catalina Gonzalez-Duenas
David Mizzen
Elisabeth Gilmore
Irem Efe
Jayantha Obeysekera
Jennifer Goupil
Joel Good
John W. van de Lindt
Joseph Barsugli
Julie Pietrzak
Kevin Borth
Kingsley Lau
Manuel Perotin
Matt Gilbertson
Michel Ghosn
Milad Roohi
Ming Liu
Paul Schuman
Robin A. Kemper
Seth Thomas
Sihan Li

VIRTUAL

Abby Beck
Adam Reeder
Ahmed Attar
Ayse Hortascu
Bilal Ayyub
Bill Coulbourne
Brenda Hoppe
David Frost
Erica Fischer
Erik Zuker
Eun Cha
Fabio Biondini
Jack Hogan
Jennifer Jurado
Joseph Ackroyd
Kathryn Roscoe
Kenneth Kunkel
Kris May
Lakshmana
Doddipatla
Lauren Mudd
Mari Tye
Michele Barbato
Michelle Miro
Nasim Uddin
Ning Lin
Norma Jean Mattei
Rahemeen Ahmed
Rogelio Madan
Roy Lobo
Ruohua Guo
Teng Wu
Zoubir Lounis

SYNERGISTIC EFFORTS

9:30 am – 11:00 am



PRESENTATIONS

- **Incorporating Community Resilience into Codes and Standards;**
John van de Lindt, Ph.D.; Colorado State University [15 mins.]
- **Decision Scaling;**
Casey Brown, Ph.D., P.E.; University of Massachusetts [15 mins.]
- **Barriers for Handling Nonstationarity in Applied Performance Based Design;**
Erica Fischer, Ph.D., P.E.; Oregon State University [15 mins]
- **Robust Decision Making;**
Michelle Miro, Ph.D., RAND [15 mins.]
- **Dynamic Adaptive Policy Pathways;**
Kathryn Roscoe; Deltares [15 mins.]
- **Q&A Discussion;** Moderator: Jayantha Obeysekera [15 mins.]



B.2.1.1. Synergistic Efforts: Incorporating Community Resilience into Codes and Standards;
John van de Lindt

INCORPORATING COMMUNITY RESILIENCE INTO CODES AND STANDARDS

John van de Lindt, Ph.D.; Colorado State University



Incorporating Community Resilience into Codes & Standards

John W. van de Lindt

Co-Director, NIST Center for Risk-Based Community Resilience Planning

Harold H. Short Chaired Professor

Colorado State University

Director, Project IN-CORE

"Helping communities with climate adaptation at no cost to them!"



Community Resilience

- Infrastructure resilience versus community resilience
- Dimensions of community resilience

How do we decide on design code calibration such that we can achieve specified community-level goals ?

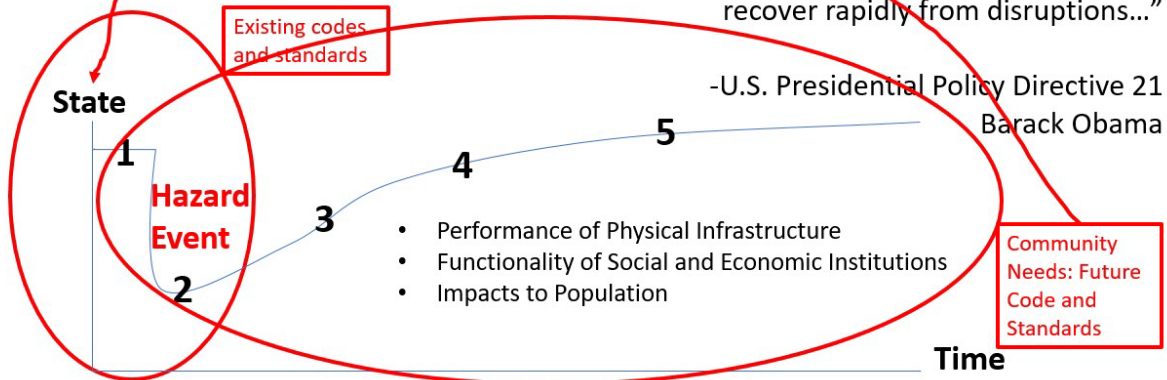


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Resilience

“...the ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions...”



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NIST-CoE Community Resilience

- Improve the performance of built environment for natural hazards at the community scale
- Characterize interdependencies between social, economic, and physical systems
- Develop science-based tools that communities can use to assess/improve their resilience

First 5 years (2015-2020)

- **Open-source multi-disciplinary computational environment (IN-CORE)** to assess community resilience and support policies and decisions to advance community resilience goals.
- **Standardized data ontologies** through robust architecture and management tools that support IN-CORE.
- **Comprehensive set of testbeds and hindcasts** to validate IN-CORE.

Second 5 years (2020-2025)

- **Measurement and decision science through IN-CORE**, including interdependencies, uncertainty, intermodal systems, and risk-informed decision support.
- **Data science and architectural verification and validation**, including integrated databases and longitudinal knowledge from field studies.
- **Decision support and implementation** of resilience science through **technology transfer**.



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Ideally we can:

- predict damage probabilities at the individual building level using physics so it is transferrable anywhere
- predict not just how many, but which households will dislocate based on their race/ethnicity, income, and other characteristics; synthetically allocate to household level to maintain privacy
- predict changes in community-level incomes by household demographics, changes in gross product, and changes in tax base by sector as a result of a hazard
- have the information to make resilience-informed socially equitable decisions

Fragilities = ✓

HUA = ✓

CGE = ✓

IN-CORE = ✓



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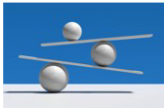
In Community Resilience: Areas of Community Stability that must be measured



- **Population Stability** (e.g., measured by percent of people remaining in their homes)



- **Economic Stability** (e.g., measured by household income; employment rate)



- **Social Services Stability** (e.g., metrics to quantify availability of healthcare and educational facilities)

- **Physical Services Stability** (e.g., percentage of buildings remaining functional, metrics to quantify availability of utility and transportation services)



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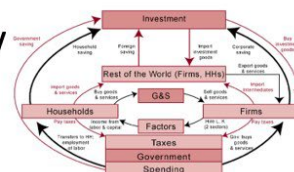
27

It begins with an integrated community model

Buildings...



Economy

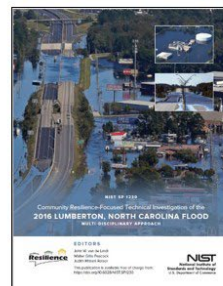
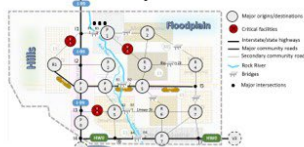


Physical infrastructure

Water...



Transportation



Social (e.g. households, institutions)



van de Lindt, J. W., J. Kruse, D. T. Cox, P. Gardoni, J. S. Lee, J. Padgett, T. P. McAllister, A. Barbosa, H. Cutler, S. Van Zandt, N. Rosenheim, C. Navarro, E. J. Sutley, and S. Hamideh. (2023). "The interdependent networked community resilience modeling environment (IN-CORE)." *Resilient Cities and Structures*, Vol 2 (2). Pp 57 – 66, doi.org/10.1016/j.rcns.2023.07.004.



28

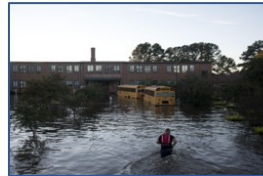
Interdependent Networked-Community Resilience Modeling Environment

- Physical infrastructure
- Economic health
- Social services
- Information science

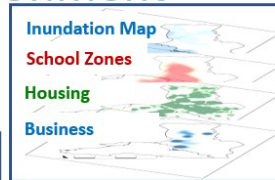


<https://incore.ncsa.illinois.edu>
<https://github.com/IN-CORE/>

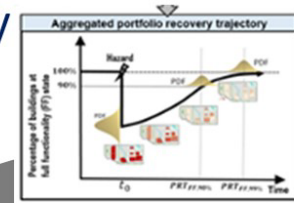
IN-CORE



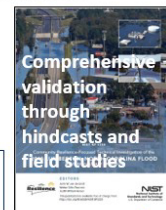
Damage and loss;
impacts of natural
hazards on
communities



Multidisciplinary
recovery with fully
integrated supporting
databases



Alternative actions
to enhance community
resilience & inform
planning



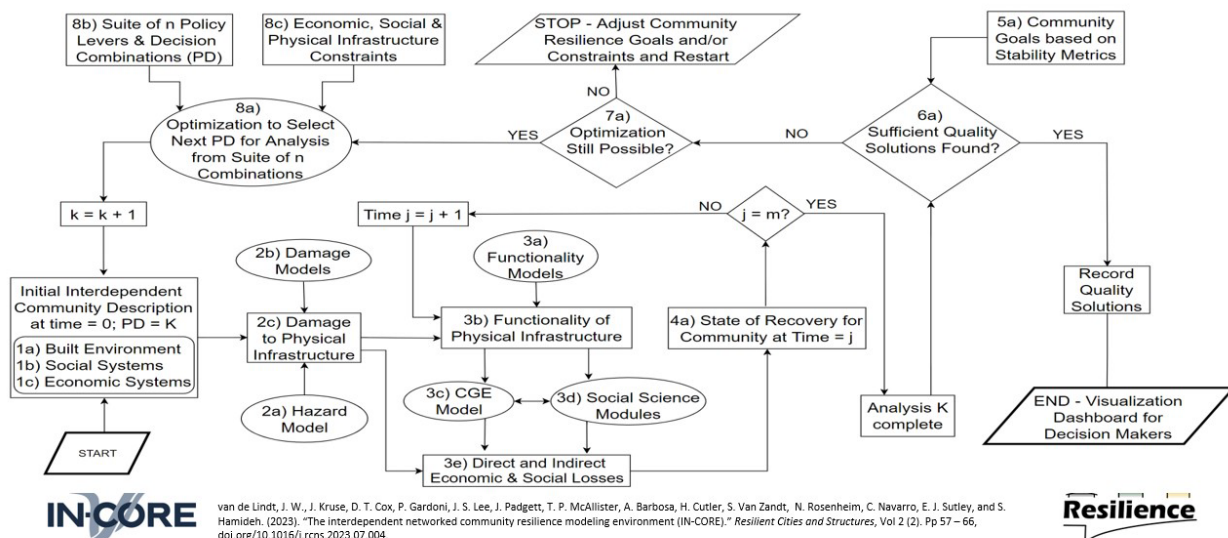
Over the last 10 years: 220+ Journal papers
across 12-university team that documents
the peer-reviewed science for IN-CORE

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Email: <http://www.in-core.org> <http://resilience.colostate.edu>

NIST Financial Assistance Awards Number:
70NANB15H044 & 70NANB20H008 29

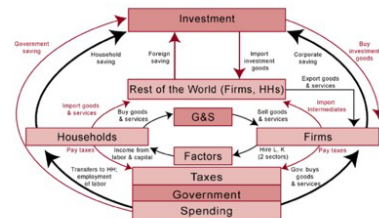
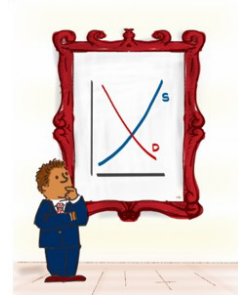
Resilience

Modeling community resilience



Economic Models

- Spatial dynamic computable general equilibrium model (SD-CGE)
- Incorporate infrastructure damage and population disruptions
- Provide range of economic and fiscal impact
 - Code changes, scenario type
- Includes:
 - Losses in production, wages, jobs in local econ sectors
 - Investigates with policy levers; optimal allocations of resources



Attary, N. H. Cutler, M. Shields, and J.W. van de Lindt (2020). "The Economic Effects of Financial Relief Delays Following a Natural Hazard.", *Economic Systems Research*, Vol 32 (3), doi.org/10.1080/09535314.2020.1713729.



Social Science Models

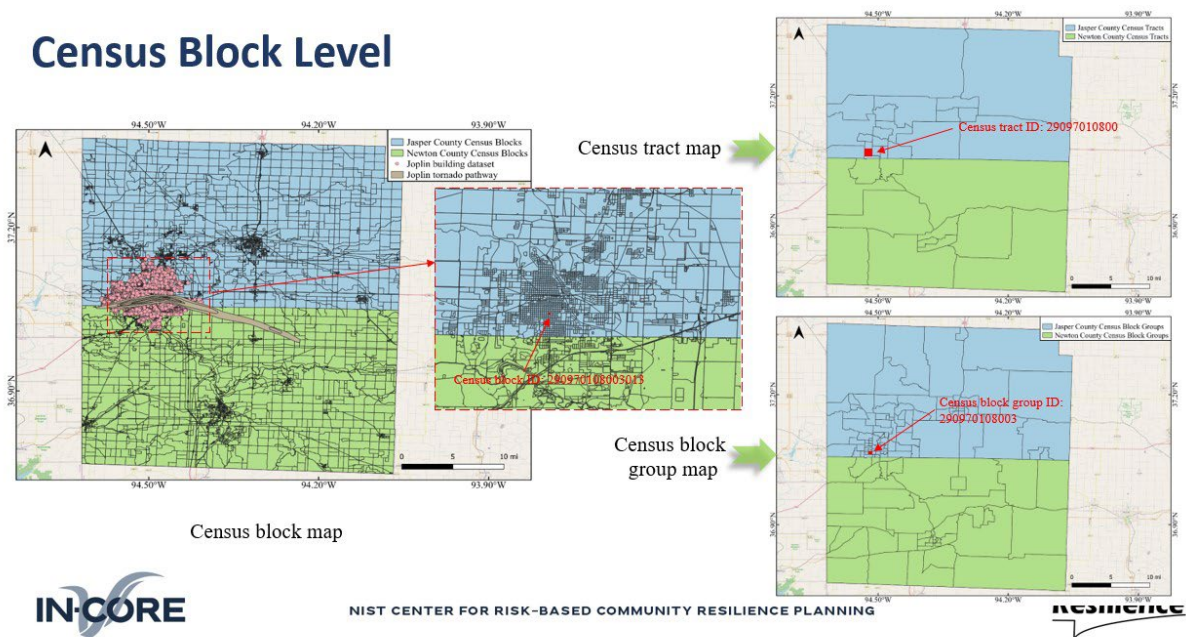
- Important Considerations:
 - Population and employee dislocation
 - Housing restoration and recovery
 - Business interruption and restoration
- Suite of tools
 - Identify socio-demographic and socio-economic vulnerability characteristics



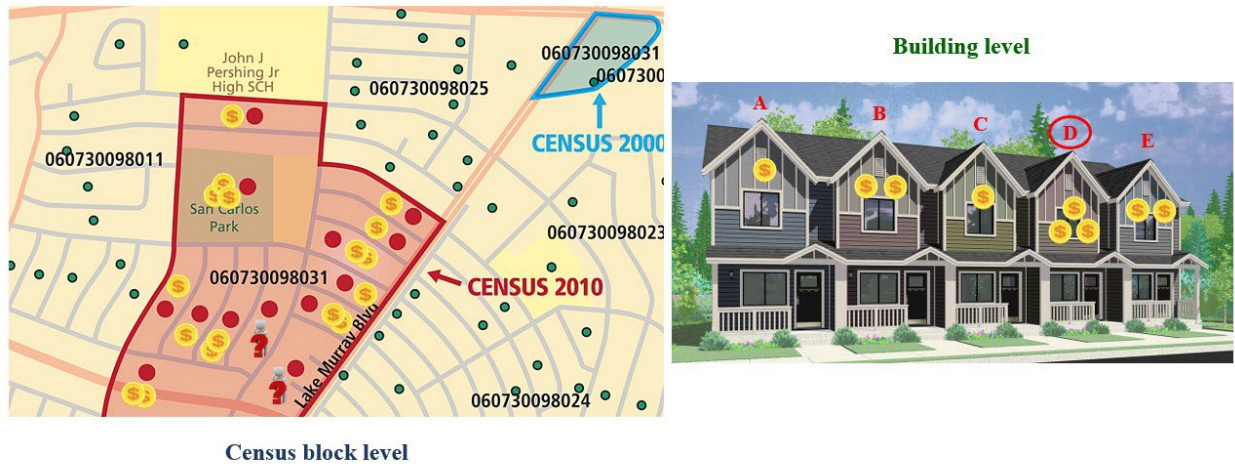
Rosenheim, Nathanael (2021). Detailed Household and Housing Unit Characteristics: Alpha Release of Housing Unit Inventories. *DesignSafe-CI* DOI: [10.17603/ds2-jwf6-s535](https://doi.org/10.17603/ds2-jwf6-s535)



Census Block Level



Household incomes (any socio-demo) – synthetically deaggregated



One Illustrative Example

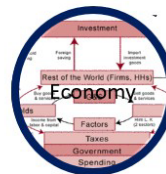
- Wind:
Deaggregating
community
goals for
building
decisions/policy



Challenge: Select a Policy based on Limit States for Community Stability Areas

- Economic Stability
- Population Stability
- Physical Infrastructure Stability
- A Single Design Level to hit targets for all stability areas!

Structural elements	Selections	Original design	Retrofit design
Roof covering	Asphalt shingles	X	X
	Clay tiles		
Roof sheathing nailing pattern	8d C6/12	X	
	8d C6/6		X
Roof-to-wall connection type	Two 16d toenails	X	
	Two H2.5 clips		X



Masoomi, H., M. R. Ameri, and J.W. van de Lindt. (2018). "Wind Performance Enhancement Strategies for Woodframe Buildings." *ASCE Journal of Performance of Constructed Facilities*, 32 (3), 10.1061/(ASCE)CF.1943-5509.0001172.

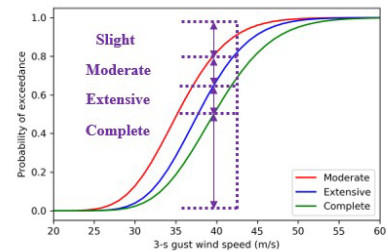




Building Portfolio

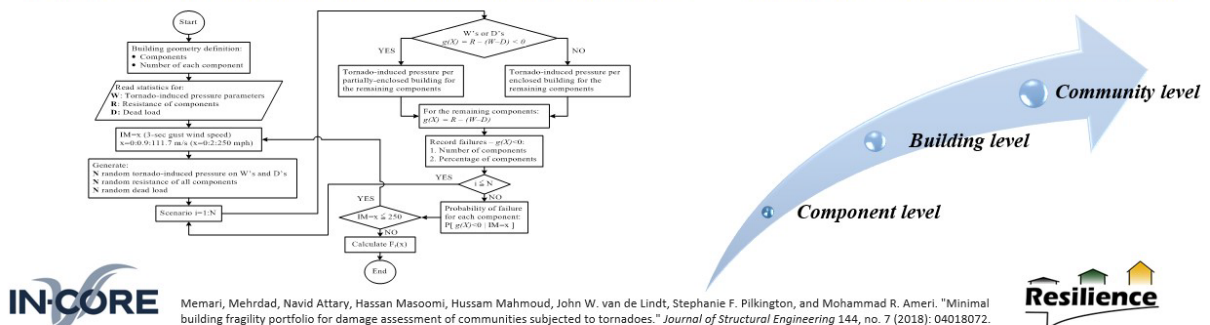
Damage states for wood-frame residential buildings

Damage combination	Description of damage combination			
	Roof cover failure	Window/door failures	Roof sheathing failure	Roof truss failure
DS1	-	-	-	-
DS2	>2% and ≤15%	1	No	No
DS3	>15% and ≤50%	2 or 3	1-3 panels	No
DS4	>50%	>3	>3 panels and ≤35% by area	No
DS5	Typically >50%	Typically >3	>35% by area	Yes



The framework of the development of tornado component-level fragility curves

Fragility curves for wood-frame residential buildings



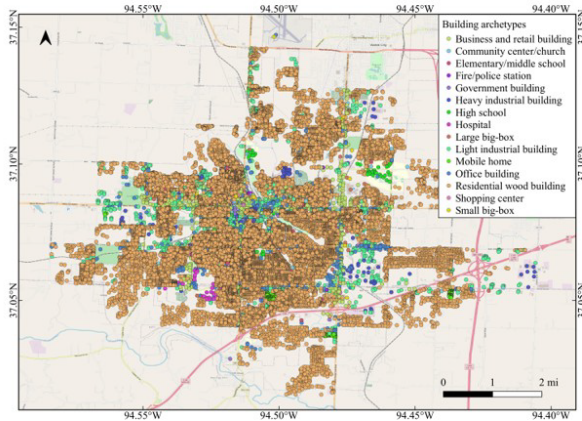
IN-CORE

Memari, Mehrdad, Navid Attary, Hassan Masoomi, Hussam Mahmoud, John W. van de Lindt, Stephanie F. Pilkington, and Mohammad R. Ameri. "Minimal building fragility portfolio for damage assessment of communities subjected to tornadoes." *Journal of Structural Engineering* 144, no. 7 (2018): 04018072.

Resilience

Multi-disciplinary community resilience metrics

Built environment



Archetypes	Building description	Occupancy classification	Joplin buildings
T1	Residential wood building, small rectangular plan, gable roof, 1 story	Residential	24,757
T5	Residential wood building, large rectangular plan, gable roof, 2 stories	Residential	146
T6	Business and retail building (strip small)	Commercial	736
T7	Light industrial building	Commercial	963
T8	Heavy industrial building	Commercial	155
T9	Elementary/middle school (unreinforced masonry)	Social Institutions	39
T10	High school (reinforced masonry)	Social Institutions	50
T11	Fire/police station	Social Institutions	8
T12	Hospital	Social Institutions	41
T13	Community center/church	Social Institutions	88
T14	Government building	Commercial	28
T15	Large big-box	Commercial	21
T16	Small big-box	Commercial	30
T17	Mobile home	Residential	379
T18	Shopping center	Commercial	10
T19	Office building	Commercial	701
Total number			28,152

19 archetype buildings in the city



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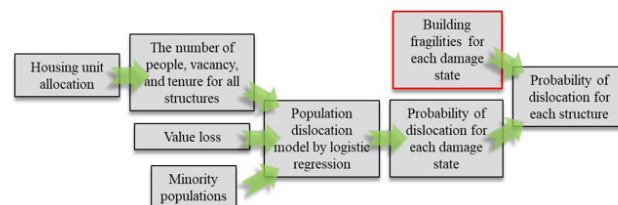


Multi-disciplinary community resilience algorithms

Housing unit inventory

	Owner-occupied	Renter-occupied	Housing unit count
1-person household	3,135	3,788	6,923
2-person household	4,398	2,564	6,963
3-person household	1,658	1,414	3,072
4-person household	1,255	944	2,199
5-person household	566	433	1,000
6-person household	206	194	403
7-person household	126	98	224
Group Quarters	-	-	22
Vacant	-	-	2,455
Total housing units	11,344	9,435	23,261
Total population	26,873	20,949	49,810

Population dislocation algorithm



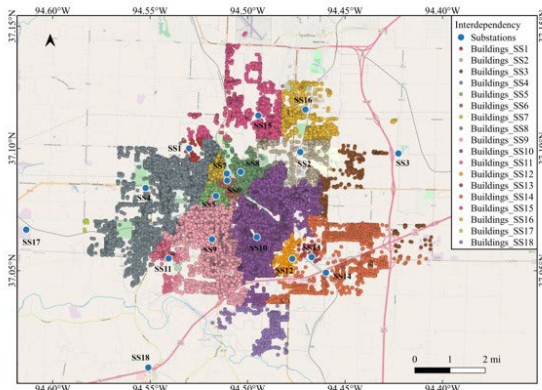
Rosenheim, Nathanael (2021). Detailed Household and Housing Unit Characteristics: Alpha Release of Housing Unit Inventories. *DesignSafe-CI* DOI: [10.17603/ds2-wwf6-s535](https://doi.org/10.17603/ds2-wwf6-s535)



Wang, Lisa (Wanting), John W. van de Lindt, Nathanael Rosenheim, Harvey Cutler, Brad Hartman, Jong Sung Lee, and Diego Calderon. "Effect of Residential Building Wind Retrofits on Social and Economic Community-Level Resilience Metrics." *Journal of Infrastructure Systems* 27, no. 4 (2021): 04021034.



Multi-disciplinary community resilience algorithms



Dependency between buildings and electric power network

	Sectors			Labor Groups			Households			Housing Services			Government						
	Goods	Trade	Other	L1	...	L3	Capital	HH1	...	HH5	HS1	...	HS3	Taxes	Federal	State	City	ROW	
Goods	Input-Output							Household Consumption						Government Purchases				Exports	
Trade	Wage Payments by Firms																		
Other	L3																		
L1	Capital Payments										Capital Payments								
...																			
L3																			
Capital	Capital Payments										Capital Payments								
HH1																			
...																			
HH5																			
HS1																			
...																			
HS3																			
Taxes	Tax Payments							Mortgage Service and Rent											
Federal																			
State																			
City																			
ROW	Imports							Imports											

Simplified Social Accounting Matrix example

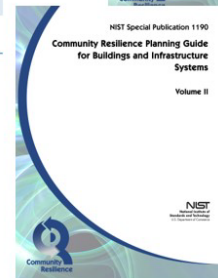
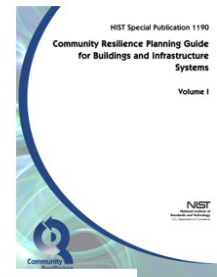


Wang, Wanting, John W. Van De Lindt, Nathanael Rosenheim, Harvey Cutler, Brad Hartman, Jong Sung Lee, and Diego Calderon. "Effect of Residential Building Wind Retrofits on Social and Economic Community-Level Resilience Metrics." *Journal of Infrastructure Systems* 27, no. 4 (2021): 04021034.



Community goals	Tornado intensity (NCRPG hazard level)	Physical service metrics		Population stability metrics		Economic stability metrics		
		% buildings remaining functional (due to damage)	% buildings remaining functional (due to damage + electrical power)	% households dislocated (unit: households)	% population dislocated (unit: people)	% change in employment	% change in domestic supply	% change in mean household income
Goal A	EF2 (Routine)	98%	95%	1%	1%	0.2	0.5	0.2
Goal B	EF3 (Design)	96%	89%	3%	3%	0.5	1.0	0.5
Goal C	EF4 (Extreme)	94%	83%	5%	5%	0.8	1.5	0.8

What percent of residential woodframe structures do I need to retrofit in Joplin to achieve these levels of stability for this range of tornadoes ?



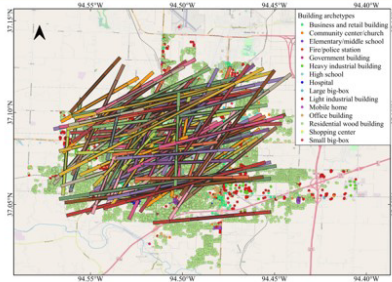
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De-aggregation of multi-disciplinary community resilience goals

Community resilience goals

Community goals	Tornado intensity (NCRPG hazard level)	Physical service metrics		Population stability metrics		Economic stability metrics		
		% buildings remaining functional (due to damage)	% buildings remaining functional (due to damage + electrical power)	% households dislocated (unit: households)	% population dislocated (unit: people)	% change in employment	% change in domestic supply	% change in mean household income
Goal A	EF2 (Routine)	98%	95%	1%	1%	0.2	0.5	0.2
Goal B	EF3 (Design)	96%	89%	3%	3%	0.5	1.0	0.5
Goal C	EF4 (Extreme)	94%	83%	5%	5%	0.8	1.5	0.8



Generic tornado models of 100 EF2 scenarios

Retrofit design for residential buildings

Structural elements	Selections	Original design	Retrofit design
Roof covering	Asphalt shingles	X	X
	Clay tiles		
Roof sheathing nailing pattern	8d C6/12	X	
	8d C6/6		X
Roof-to-wall connection type	Two 16d toenails	X	
	Two H2.5 clips		X



Standohar-Alfano, C. and J.W. van de Lindt. (2015). "An Empirically-Based Probabilistic Tornado Hazard Analysis of the U.S. using 1973-2011 Data." *ASCE Natural Hazards Review*, 16 (1), 04014013.

Wang, Wanting "Lisa, John W. van de Lindt, Brad Hartman, Harvey Cutler, Jamie L. Kruse, Therese P. McAllister, and Sara Hamideh. "Determination of Individual Building Performance Targets to Achieve Community-Level Social and Economic Resilience Metrics." *Journal of Structural Engineering* 148, no. 5 (2022): 04022045.



De-aggregation of multi-disciplinary community resilience goals

Residential building retrofits



This can also be done by varying building performance for all buildings and determining what is required to achieve community level resilience goals

(Roohi and van de Lindt working on this with the NIST earthquake group currently using IN-CORE)

Community goals	intensity (NCRPG hazard level)	% buildings remaining functional (due to damage)	% buildings remaining functional (due to damage + electrical power)	% households dislocated (unit: households)	% population dislocated (unit: people)	% change in employment	% change in domestic supply	% change in mean household income
Goal A	EF2 (Routine)	3.4%	12.0%	34.2%	33.3%	28.7%	13.1%	19.4%
Goal B	EF3 (Design)	8.0%	6.0%	17.5%	14.0%	21.5%	18.7%	11.6%
Goal C	EF4 (Extreme)	15.1%	16.0%	19.8%	15.4%	29.0%	29.0%	18.0%

Goal A: the household dislocation metric controlled the retrofit level and at least ~34% of residential buildings would need to be retrofitted



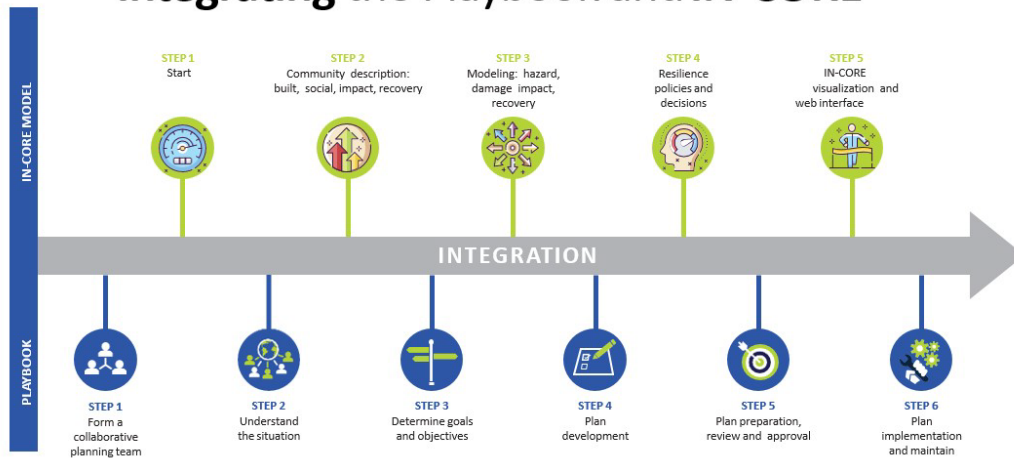
Playbook: Community Resilience Planning



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Integrating the Playbook and IN-CORE



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In closing ...



- Current codes and standards target safety (and performance) at the individual facility level
- Communities rely on codes and standards as a minimum but these do – not necessarily – result in goals and objectives for people
- This disparity means infrastructure resilience is not enough and community resilience must be considered; community resilience necessitates:
 - Consideration of interacting disciplines in the recovery process
 - Models that incorporate more than physical performance
- Future codes will look at calibration not with reliability targets, but with resilience goals and objectives at the community level



NIST CENTER FOR RISK-BASED COMMUNITY RESILIENCE PLANNING



Thank you!

The Center for Risk-Based Community Resilience Planning is a NIST-funded Center of Excellence; the Center is funded through a cooperative agreement between the U.S. National Institute of Standards and Technology and Colorado State University (NIST Financial Assistance Award Numbers: 70NANB15H044 & 70NANB20H008). The views expressed are those of the presenters and may not represent the official position of the National Institute of Standards and Technology or the U.S. Department of Commerce.

A special thank you to all of the colleagues, students, and staff involved in the CoE for the last decade and their contributions!



Center for Risk-Based Community Resilience Planning
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NIST CENTER FOR RISK-BASED COMMUNITY RESILIENCE PLANNING



B.2.1.2. Synergistic Efforts: Decision Scaling; Casey Brown



Resilience by Design for Water Systems

Nonstationarity of exogenous factors (e.g., climate, demand, finance) has not been addressed in water system design

Resilience by Design optimizes for robustness to external stresses and recovery from shocks and surprise

Stress test (external factors) and Options Assessment (internal factors) reveals vulnerabilities and opportunities for resilience

Resilience can be a specified design objective

Future of Extreme Precipitation and Floods?

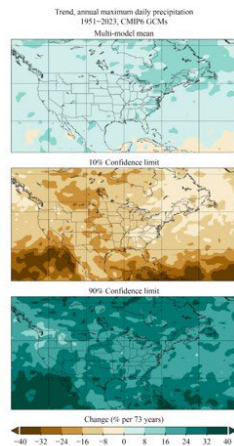


Fig. 3 Magnitude of the multi-model mean trend in Annual Maximum Series for 1951–2023 from 37 CMIP6 GCMs over the contiguous US and adjacent regions, in units of percent change over the 73-yr period of analysis. Panels are (top) mean, (middle) 10% confidence limit, and (bottom) 90% confidence limit.

Mean
Projection

10% Quantile

90% Quantile

Kunkel, K.E., Sun, X. and Sun, L., 2025. Projected changes in rare extreme precipitation design values in the United States due to global warming. *Frontiers of Earth Science*, pp.1–15.

Water Resources Research

Commentary Free Access

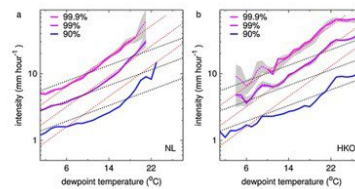
If Precipitation Extremes Are Increasing, Why Aren't Floods?

Ashish Sharma , Conrad Wasko, Dennis P. Lettenmaier

First published: 05 November 2018 | <https://doi.org/10.1029/2018WR023749> | Citations: 366

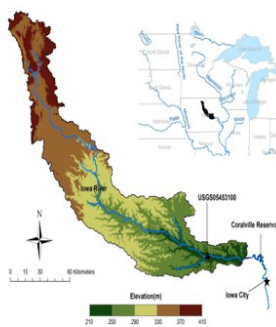
Future changes to the intensity and frequency of short-duration extreme rainfall

S. Westra , H. J. Fowler, J. P. Evans, L. V. Alexander, P. Berg, F. Johnson, E. J. Kendon, G. Lenderink, N. M. Roberts

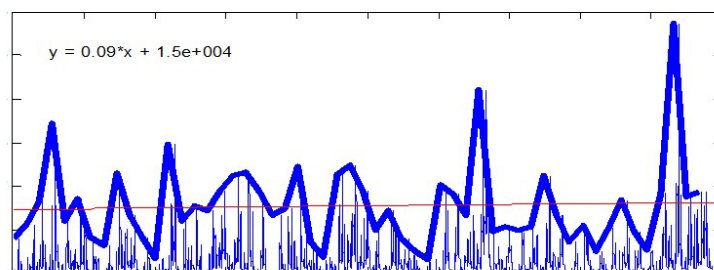


52

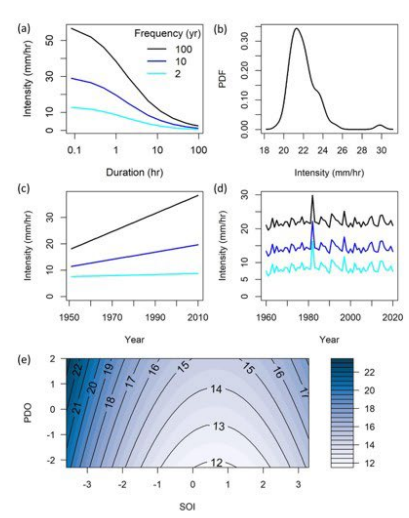
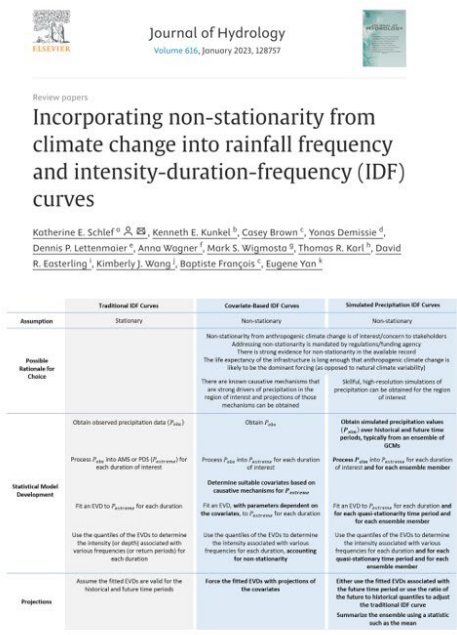
Robust to Uncertain Future Flood Risk



Annual Peak Streamflow at Coralville, IA



54

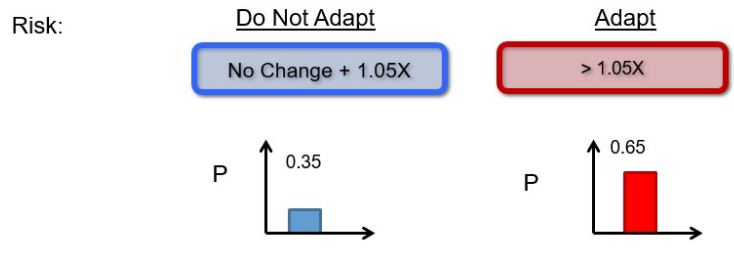


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Adaptation as Function of Credibly Projected Variables

	Flood Magnification Factor				
Risk	No Change	1.05X	1.1X	1.15X	1.2X
Levee System	-100	100	200	300	200

Threshold: > 150 Net Present Value



55



56

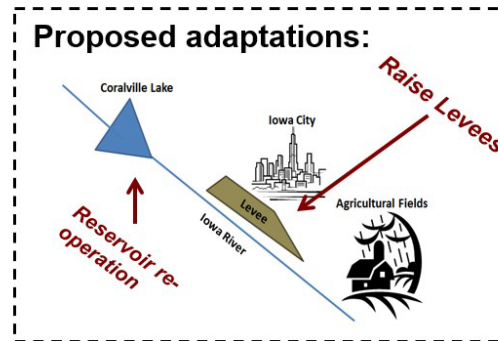
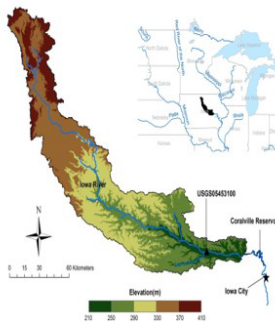
Flood Risk and Climate Adaptation

Water Resources Research

RESEARCH ARTICLE Nonstationary decision model for flood risk decision scaling

10.1002/2016WR018981

Caitlin M. Spence¹ and Casey M. Brown¹

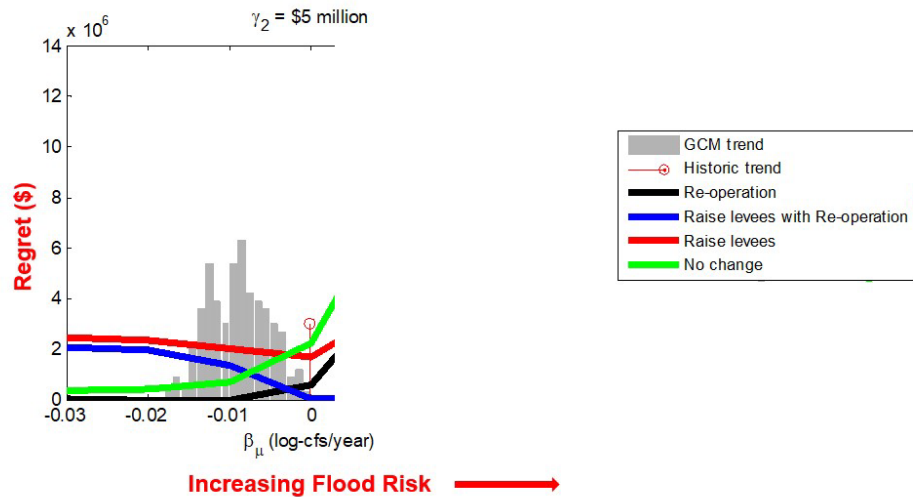


Should Iowa City raise levees, change reservoir operations, combine both, or do nothing? What is most cost-effective?

56

Selecting Climate Informed, Robust Options for Flood Management

Regret : less is good



Spence, C.M. and Brown, C.M., 2016. Nonstationary decision model for flood risk decision scaling. *Water Resources Research*, 52(11), pp.8650-8667.

57



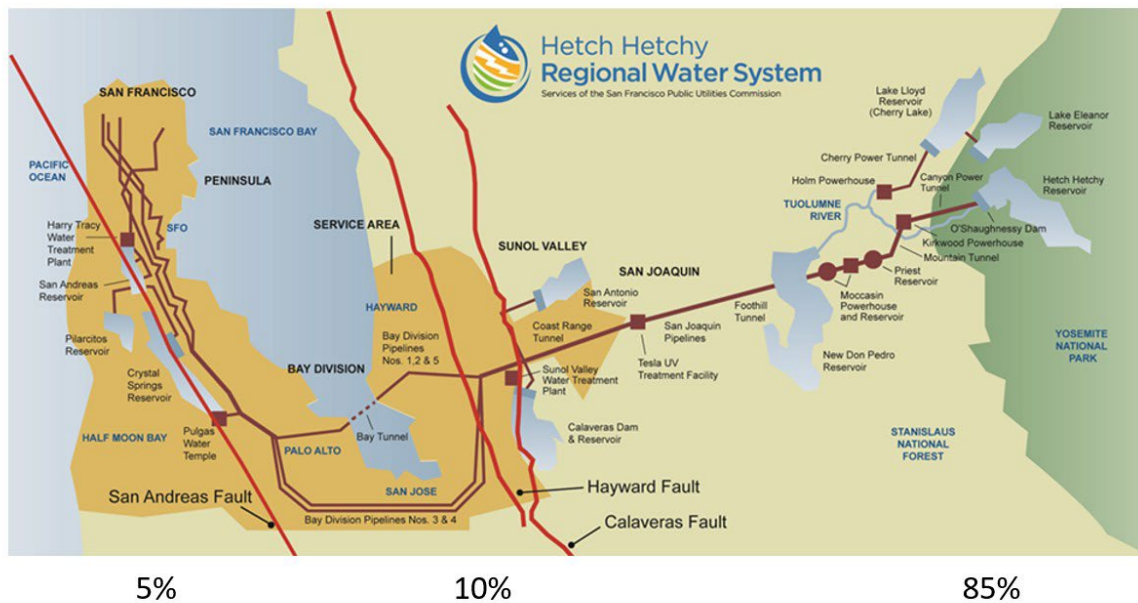
Long-Term Vulnerability Assessment of San Francisco Regional Water System



UMassAmherst

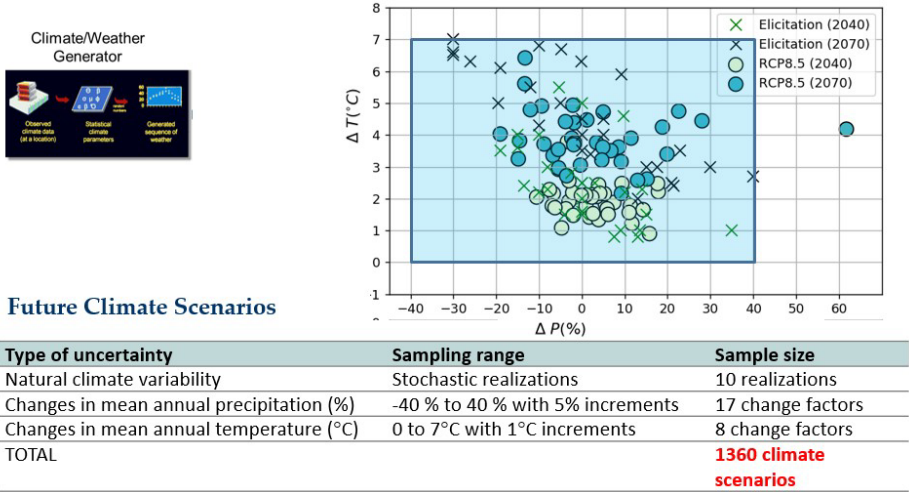


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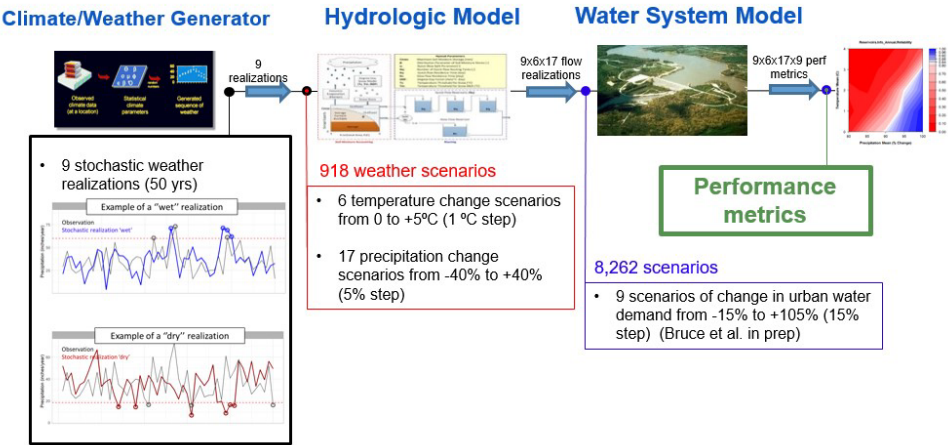


© 2022 The Water Research Foundation. ALL RIGHTS RESERVED. 59

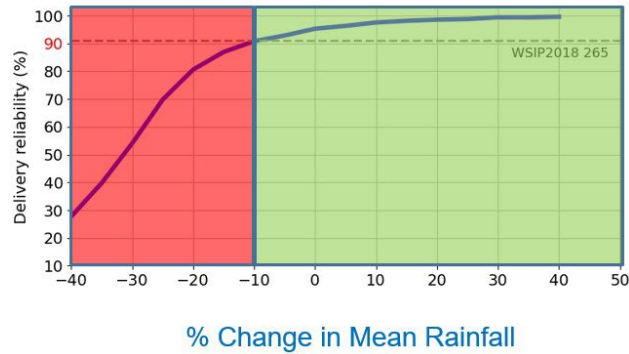
Climate Stress Test Scenarios



Modeling Infrastructure Performance under Stress



Vulnerability of Water Supply Reliability to Precipitation Change

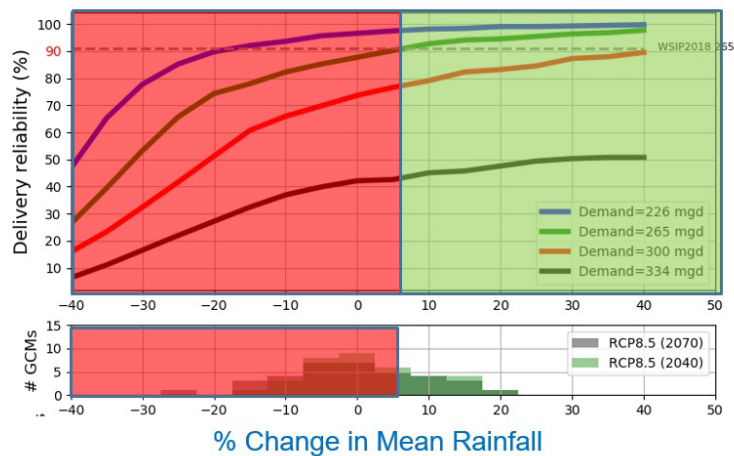


Vulnerable if precipitation decreases by more than 10%

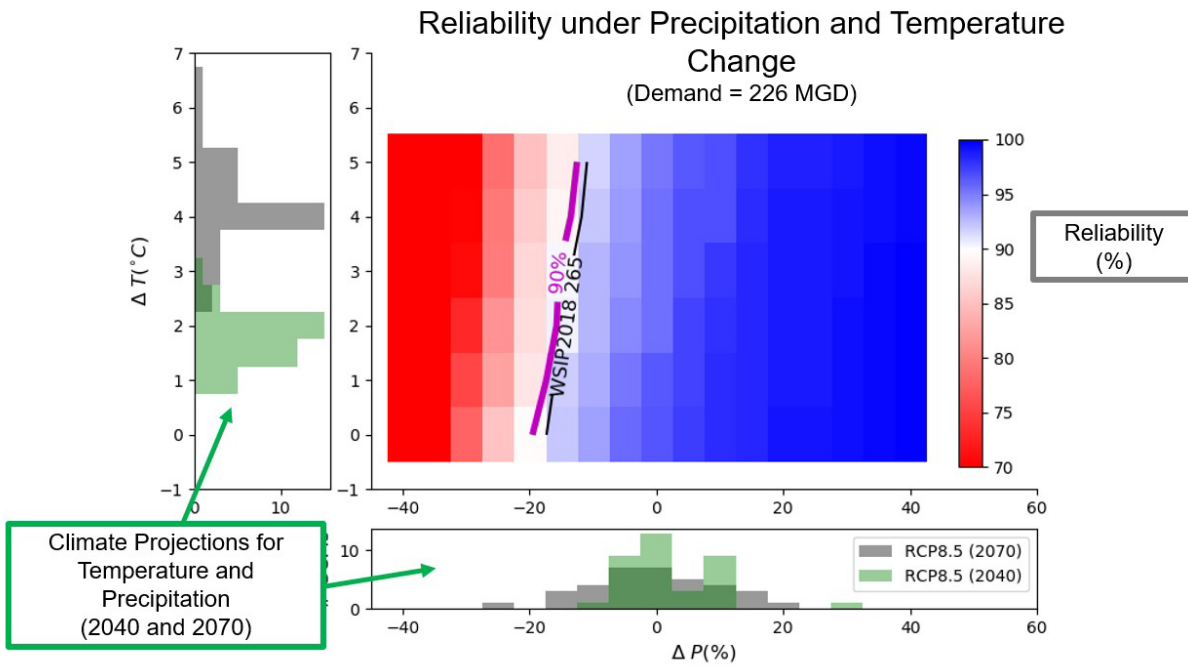
62

Water System Reliability under Precipitation and Demand Change

- Very sensitive to changes in demand
- If demand increases by 15%, target not met unless precipitation increases by 10%
- If demand increases by 30%, target cannot be met



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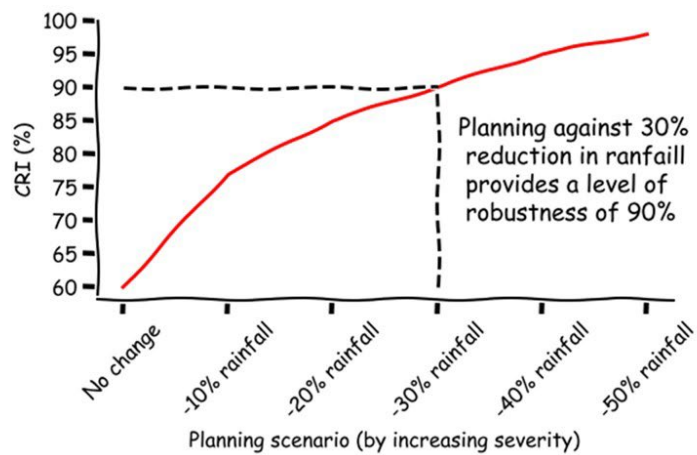
64



CRI = Climate Robustness Index
= percent of scenarios with acceptable performance



One Scenario to Conquer them All



65



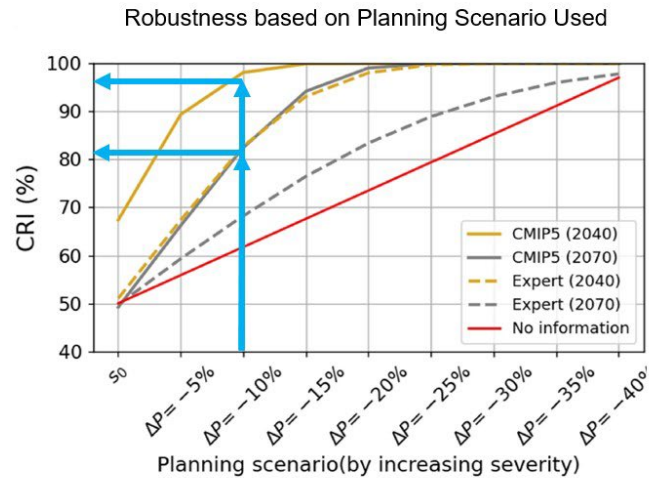
Baptiste François, Alexis Dufour, Thi Nhu Khanh Nguyen, Alexa Bruce, Dong Kwan Park & Casey Brown

Planning for a 10% reduction in Precip provides 90% Robustness for 2040

Planning for a 10% reduction in Precip provides 82% Robustness for 2070



One Scenario to Conquer them All



66

Conclusions

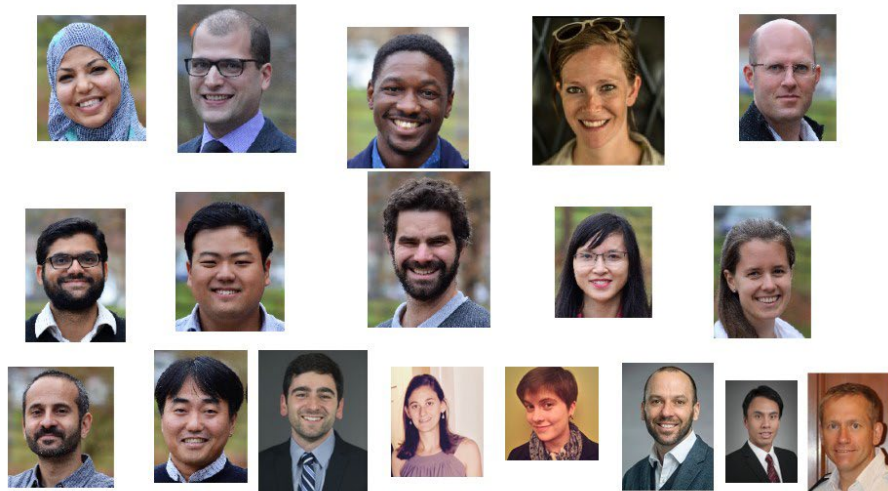
- Society is ill-prepared for the impacts of climate change on infrastructure systems designed for stationarity
- Focusing on the sensitivity of infrastructure systems can identify design variables for instilling resilience
- Climate adaptation will depend on improvements in provision of climate information for design-relevant variables, including stress testing
- Updating Standards Not Enough. Dynamic infrastructure design evaluation is needed

67

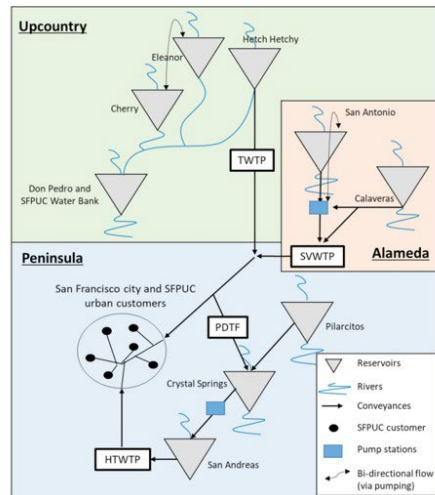
Thanks

68

HydroSystems Research Group (past and present)



69



70

STOP STOP STOP

71

B.2.1.3. Synergistic Efforts: Barriers for Handling Nonstationarity in Applied Performance Based Design; Erica Fischer

BARRIERS FOR HANDLING NONSTATIONARITY IN APPLIED PERFORMANCE BASED DESIGN

Erica Fischer, Ph.D, P.E.; Oregon State University



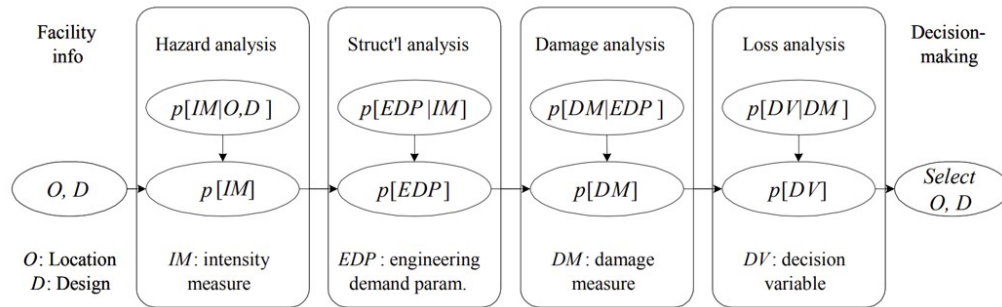
Barriers for Handling Nonstationarity in Applied Performance-Based Design

Erica Fischer
Oregon State University

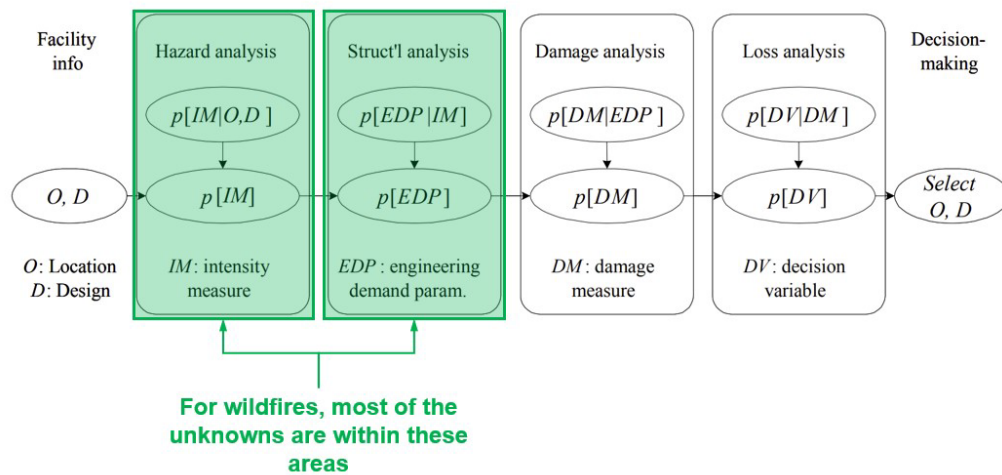


Malibu, CA. 2025 Palisades Fire. Photo credit: Erica Fischer

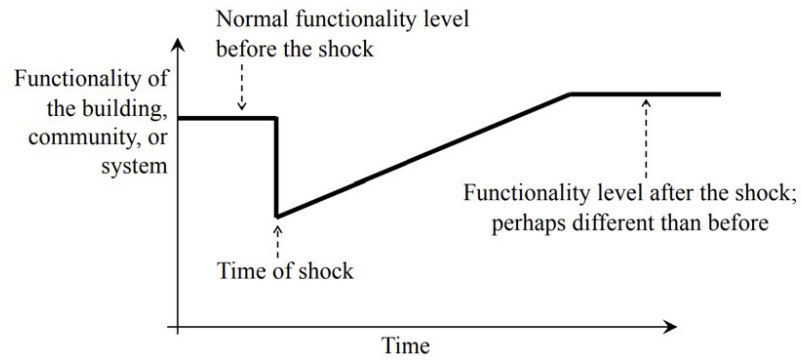
Performance-based design



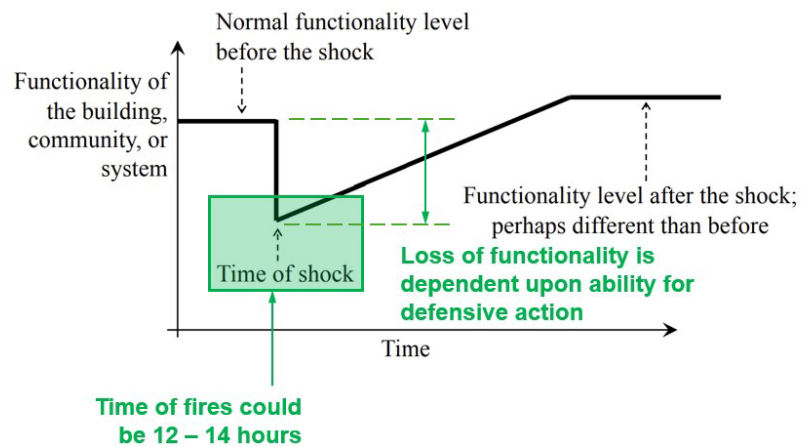
Performance-based design



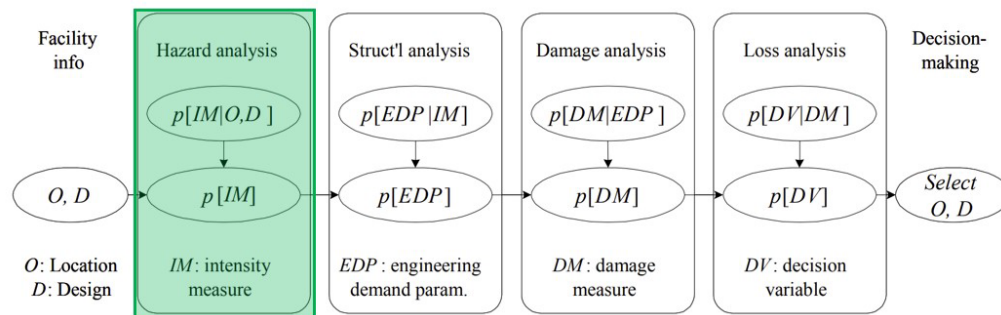
Resilient design concept



Resilient design concept



Performance-based design



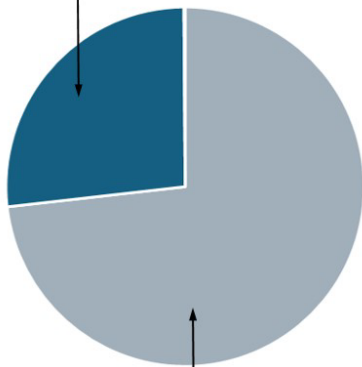
Hazard Quantification



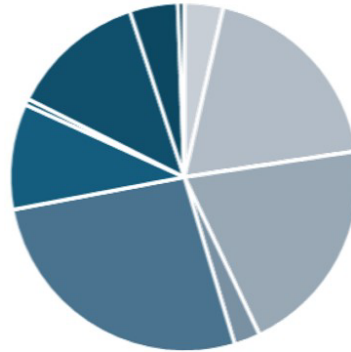
Blue River, Oregon. 2020 Holiday Farm Fire. Photo credit: Erica Fischer

Ignition causes

Lightning caused fires
(26.7%)



Human caused ignitions
(73.2%)



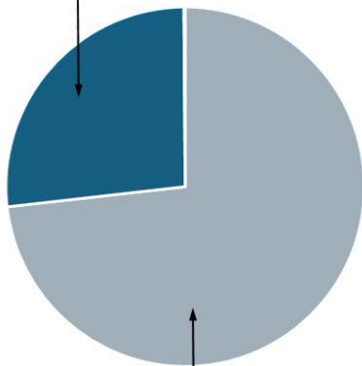
- Arson
- Debris Burning
- Equipment Use
- Juveniles
- Lightning
- Miscellaneous
- Railroad
- Recreation
- Smoking
- Under Invest



Data from <https://data.oregon.gov/stories/s/ODF-Fire-History-2000-2022-Dashboard/92y3-mdk3/>

Ignition causes

Lightning caused fires
(26.7%)



Human caused ignitions
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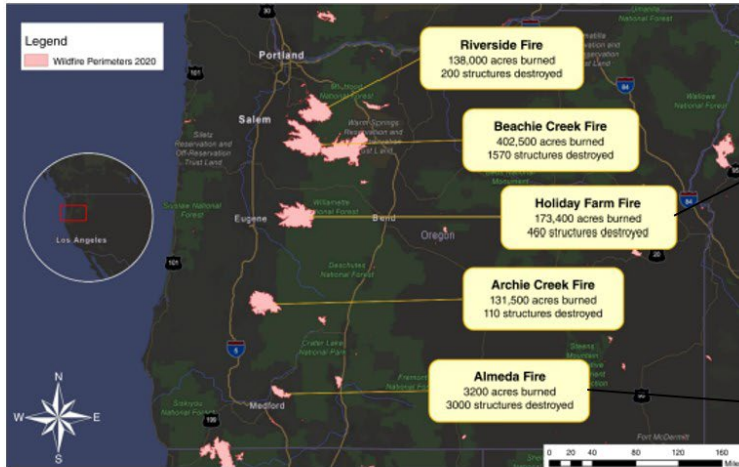


A banana truck caught fire in Southern Oregon. Again.



Data from <https://data.oregon.gov/stories/s/ODF-Fire-History-2000-2022-Dashboard/92y3-mdk3/>

Hazard intensity definition



2020 Labor Day Fires, Oregon



Holiday Farm Fire
(Intermix & Wildland)



Almeda Drive Fire
(Interface)

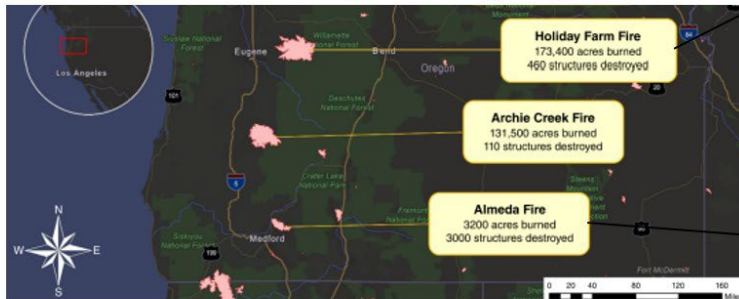


Kang, D.K., Fischer, E.C., Olsen, M.J., Adams, J.A., and O'Neil-Dunne, J. (2024). "Optimizing Disaster Response: Opportunities and Challenges with Uncrewed Aircraft System (UAS) Technology in Response to the 2020 Labor Day wildfires in Oregon," *International Journal of Wildland Fire*, 33, WF23089

Hazard intensity definition



Low probability/High consequence events



2020 Labor Day Fires, Oregon



Holiday Farm Fire
(Intermix & Wildland)

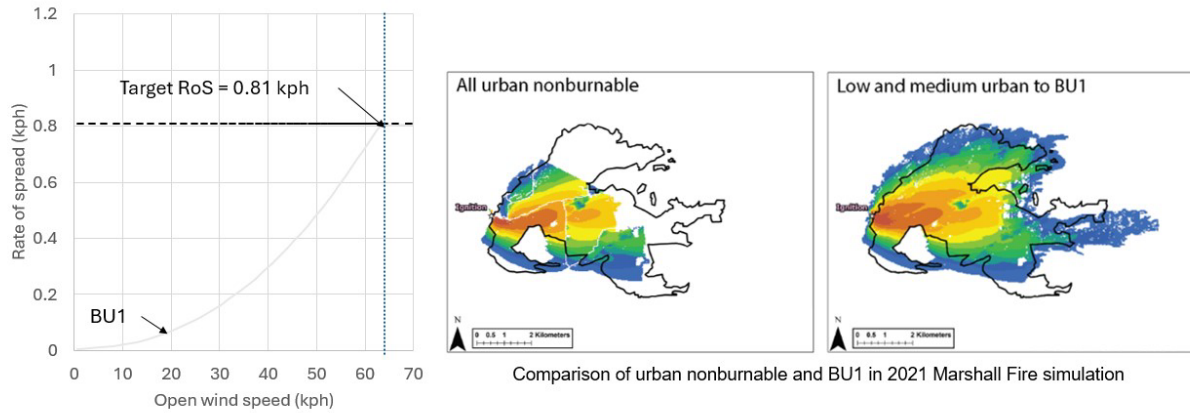


Almeda Drive Fire
(Interface)



Kang, D.K., Fischer, E.C., Olsen, M.J., Adams, J.A., and O'Neil-Dunne, J. (2024). "Optimizing Disaster Response: Opportunities and Challenges with Uncrewed Aircraft System (UAS) Technology in Response to the 2020 Labor Day wildfires in Oregon," *International Journal of Wildland Fire*, 33, WF23089

Hazard intensity definition



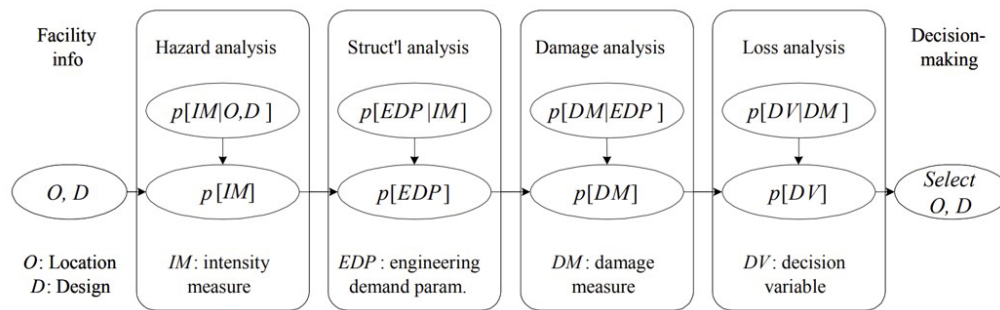
Comparison of urban nonburnable and BU1 in 2021 Marshall Fire simulation

Custom fuel model rate of spread (ROS) curve adapted from



P. L. Andrews, *Modeling Wind Adjustment Factor and Midflame Wind Speed for Rothermel's Surface Fire Spread Model*, Gen. Tech. Rep. RMRS-GTR-266. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2012. [Online].

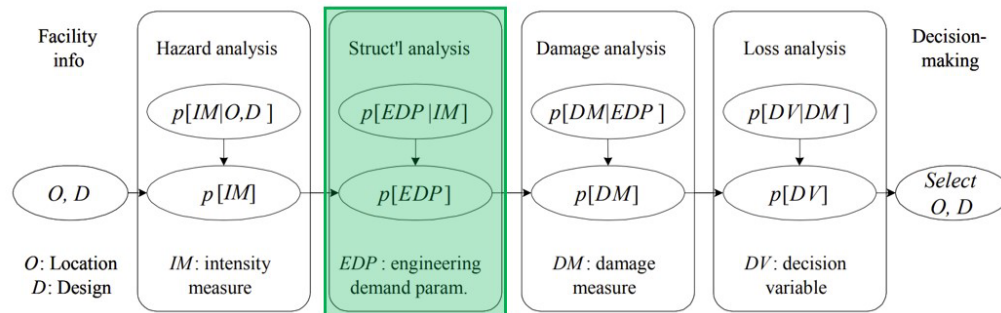
Performance-based design



- Define a hazard intensity to compare wildfire to one another
- Define hazard intensity metrics that we are designing community infrastructure for



Performance-based design



Characteristics of homes that influence survivability in a wildfire

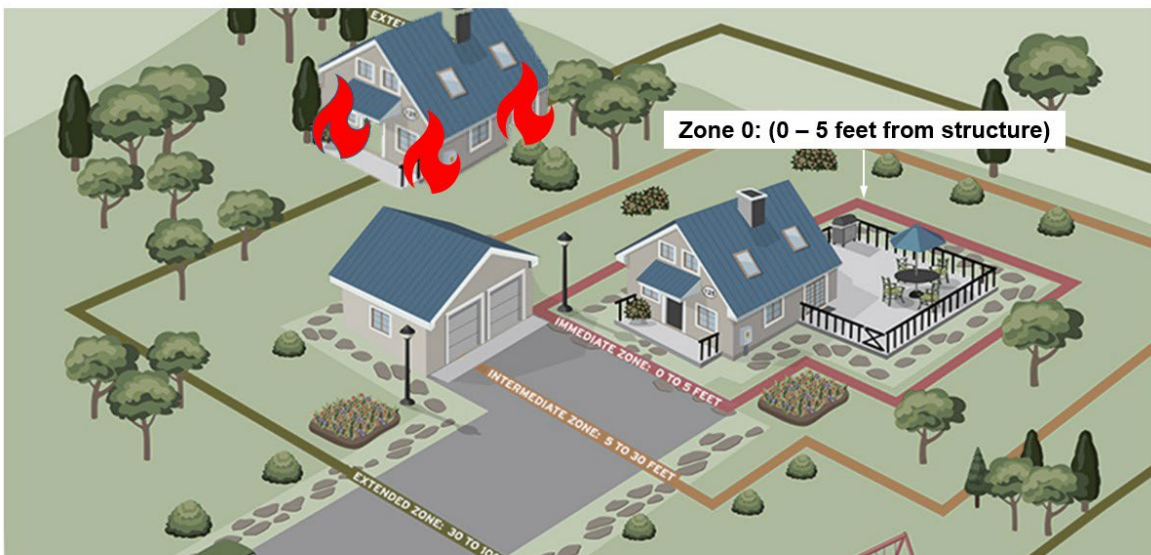


Photo information: Palisades Village. 2025 Palisades Fire. Photo credit: Erica Fischer

Fire spread within communities



Fire spread within communities



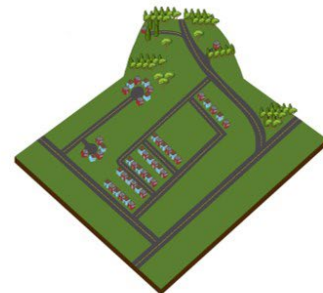
Fire spread within communities



House

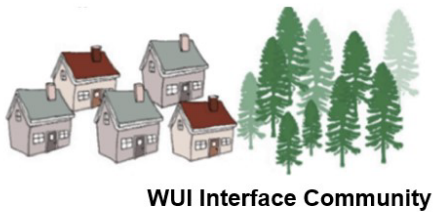
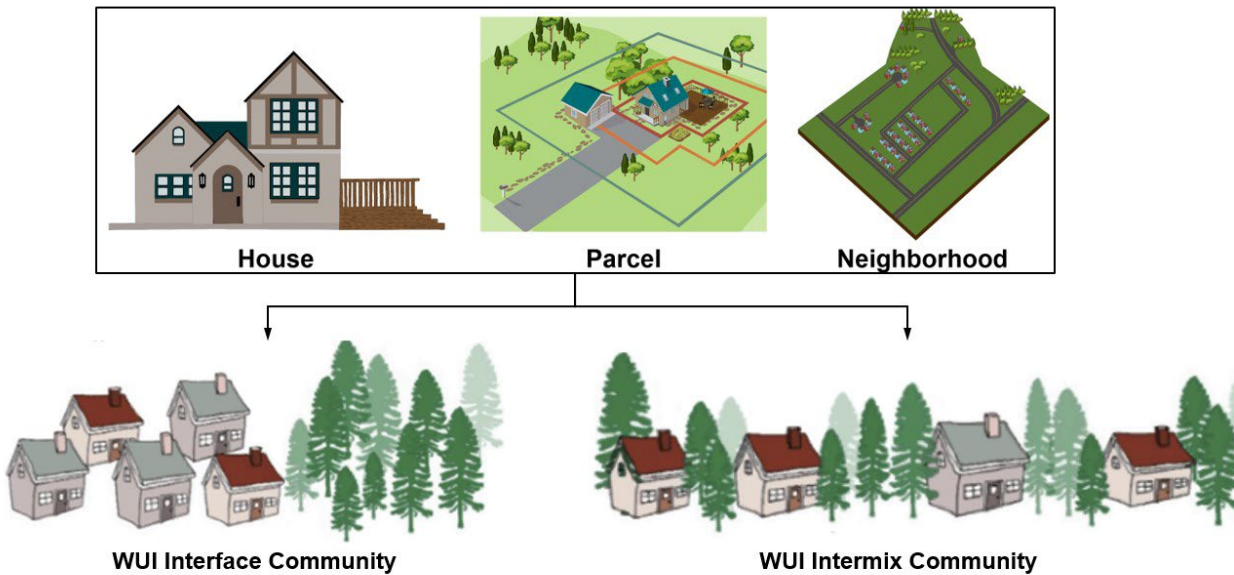


Parcel



Neighborhood





- ✓ Varying densities (low, moderate, high)
- ✓ Smaller lot sizes
- ✓ Small distance between houses
- ✓ Clustering of homes
- ✓ Potential for higher housing density

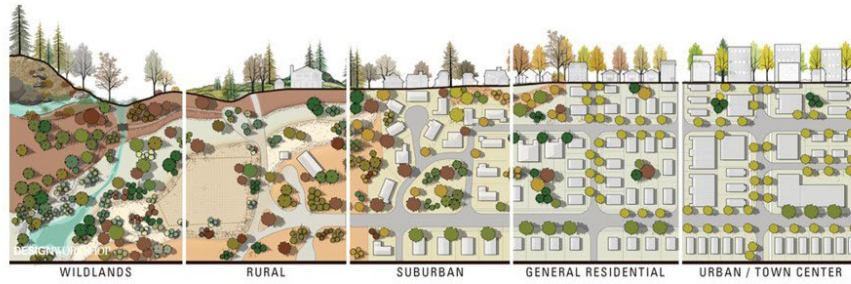
In high dense WUI Interface communities, fire spreads because of characteristics of homes.



- ✓ Varying densities (low, moderate, high)
- ✓ Larger lot size
- ✓ Larger distance between homes

In WUI Intermix communities, fire spreads because of characteristics of vegetation between homes.





Housing characteristics become more important in moderate and high-density WUI interface communities



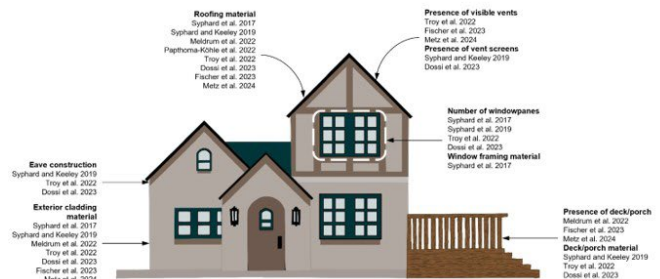
Metz, A.J., Fischer, E.C., and Liel, A.B. (2024). "The influence of housing, parcel, and neighborhood characteristics on housing survival in the Marshall Fire," *Fire Technology*. <https://doi.org/10.1007/s10694-024-01616-7>

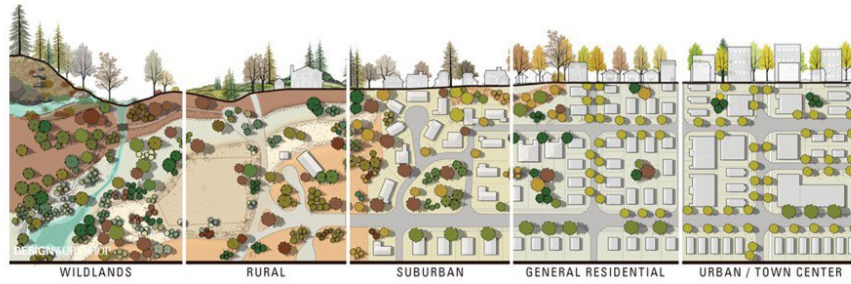
Fields, R., Fischer, E.C., and Dunn, C.D. "Still standing: A synthesis of local characteristics influencing housing survivability during WUI wildfires," *Under Review*



Housing characteristics become more important in moderate and high-density WUI interface communities

- Construction year
- Presence of deck/porch & deck/porch material
- Eave construction
- Presence of vents and vent screens
- Exterior cladding material
- Number of windowpanes





Housing characteristics become more important in moderate and high-density WUI interface communities

Resilient Rebuilding: A Path Forward for Los Angeles

April 8, 2025¹

Recommended Action 1: Los Angeles County should extend the applicability of Chapter 7A and develop a Zone 0 standard and apply them to the entirety of the Eaton Fire footprint.

Recommended Action 2: The City of Los Angeles should develop a Zone 0 standard and apply it to the entirety of the Palisades Fire footprint.



<https://ibhs1.wpenginepowered.com/wp-content/uploads/LA-Resilience-Rebuilding.pdf>

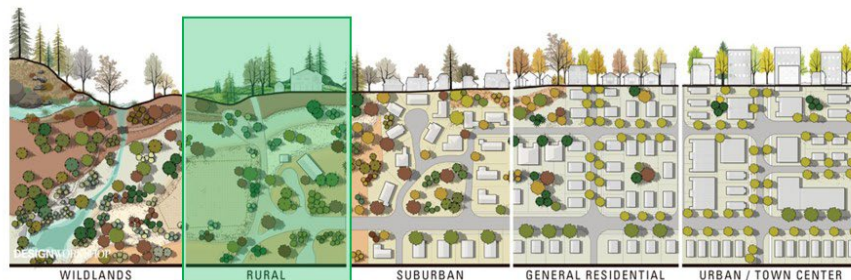
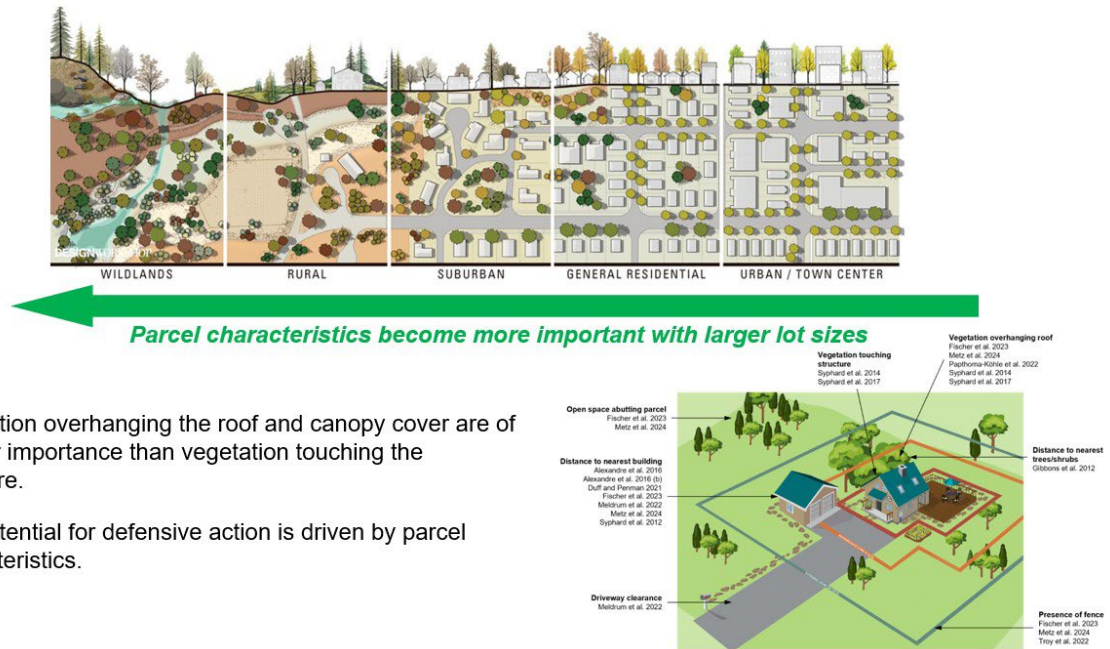


Parcel characteristics become more important with larger lot sizes



Metz, A.J., Fischer, E.C., and Liel, A.B. (2024). "The influence of housing, parcel, and neighborhood characteristics on housing survival in the Marshall Fire," Fire Technology. <https://doi.org/10.1007/s10694-024-01616-7>

Fields, R., Fischer, E.C., and Dunn, C.D. "Still standing: A synthesis of local characteristics influencing housing survivability during WUI wildfires," *Under Review*



In **low-density** neighborhoods, **wildland fuels drive spread**. These areas may also be difficult to defend if the neighborhood is isolated.



Fields, R., Fischer, E.C., and Dunn, C.D. "Still standing: A synthesis of local characteristics influencing housing survivability during WUI wildfires," *Under Review*

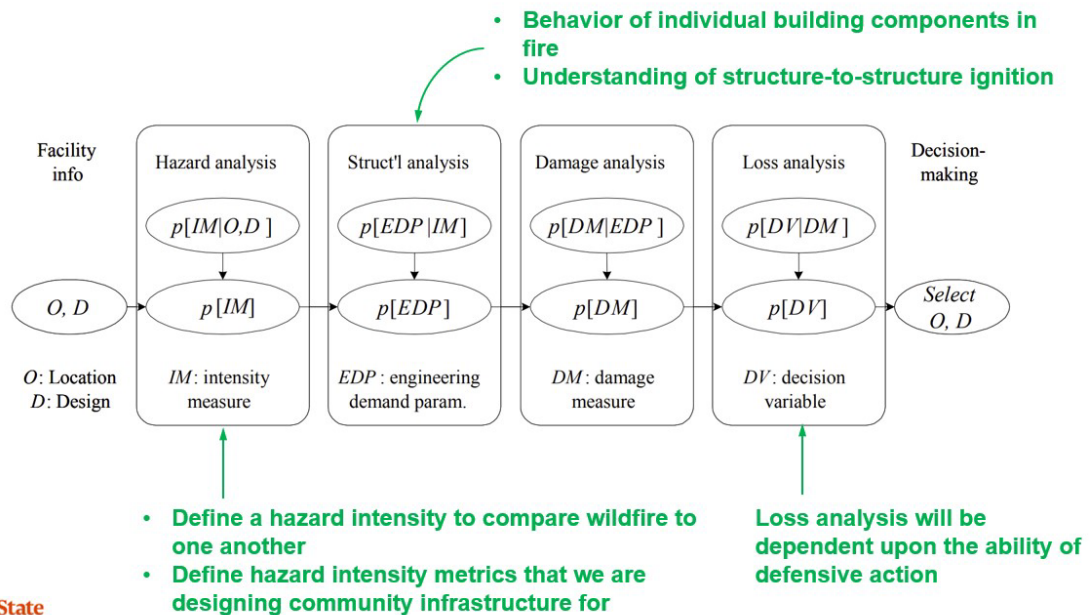


In **moderate-density** neighborhoods where houses are close together, the **houses become the primary mechanism** of spread. Access for defensible action may be limited by reduced defensible space and restricted means of ingress/egress (dependent on other spatial arrangement characteristics).



Fields, R., Fischer, E.C., and Dunn, C.D. "Still standing: A synthesis of local characteristics influencing housing survivability during WUI wildfires," *Under Review*

Performance-based design





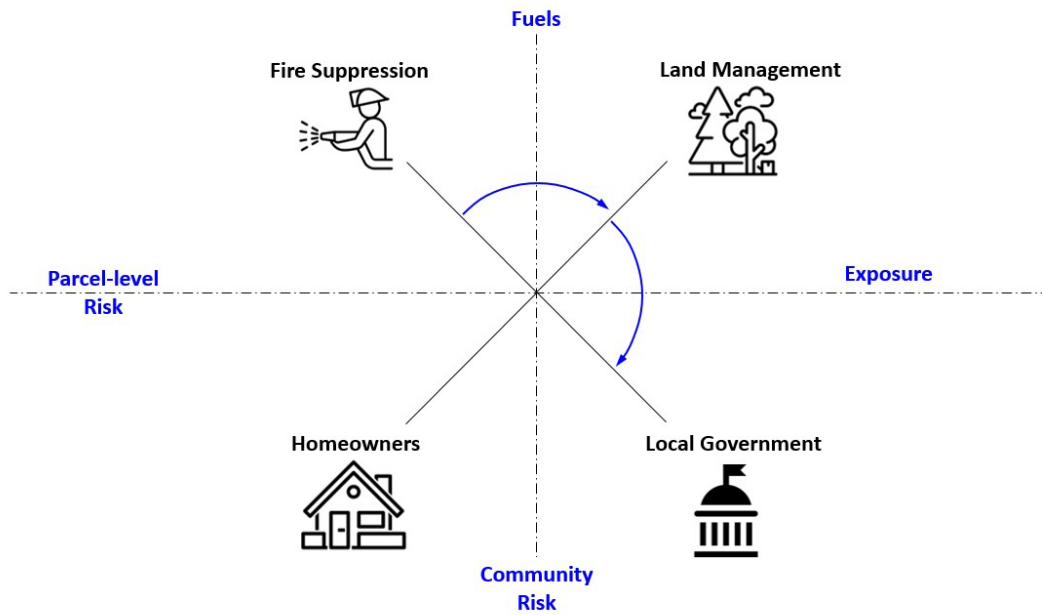
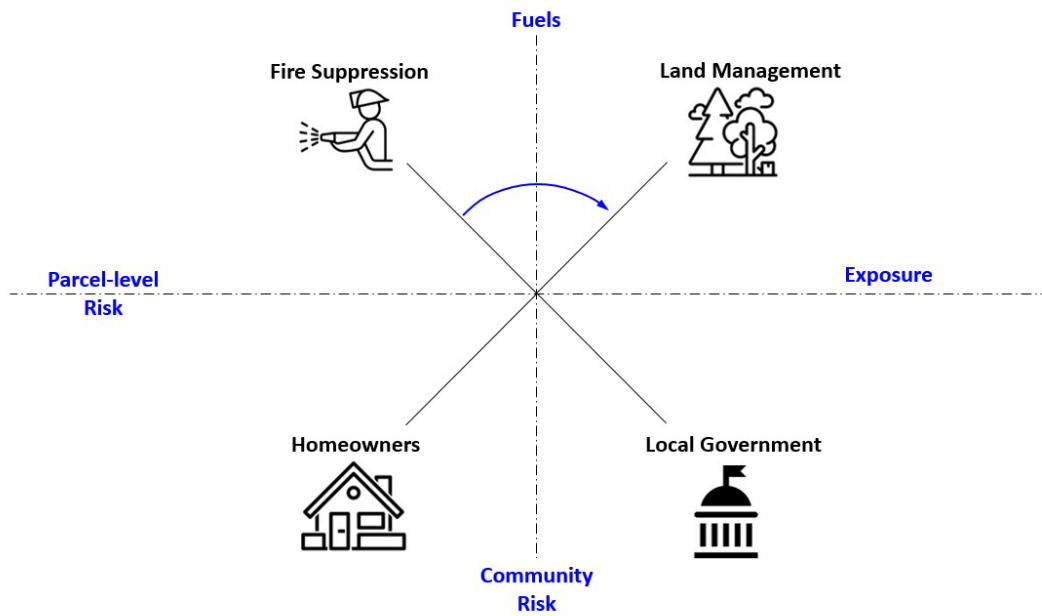
1961 Bel-Air Fire. Los Angeles, CA. (source: <https://www.latimes.com/visuals/photography/la-me-fw-archives-the-1961-bel-air-brush-fire-20170419-story.html>)

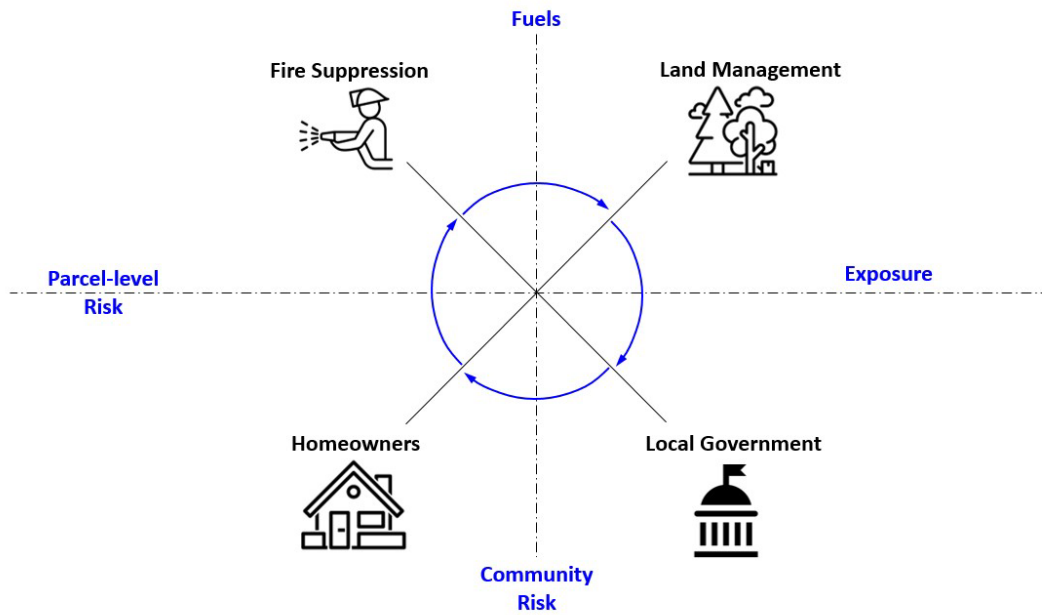
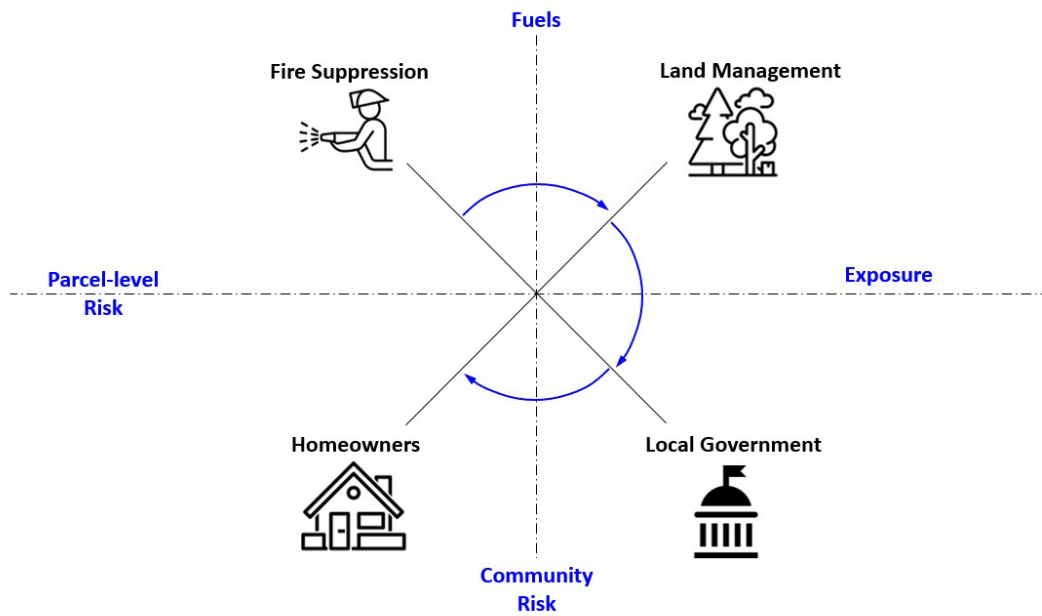
Fire Suppression

Land Management

Homeowners

Local Government





Performance-based design

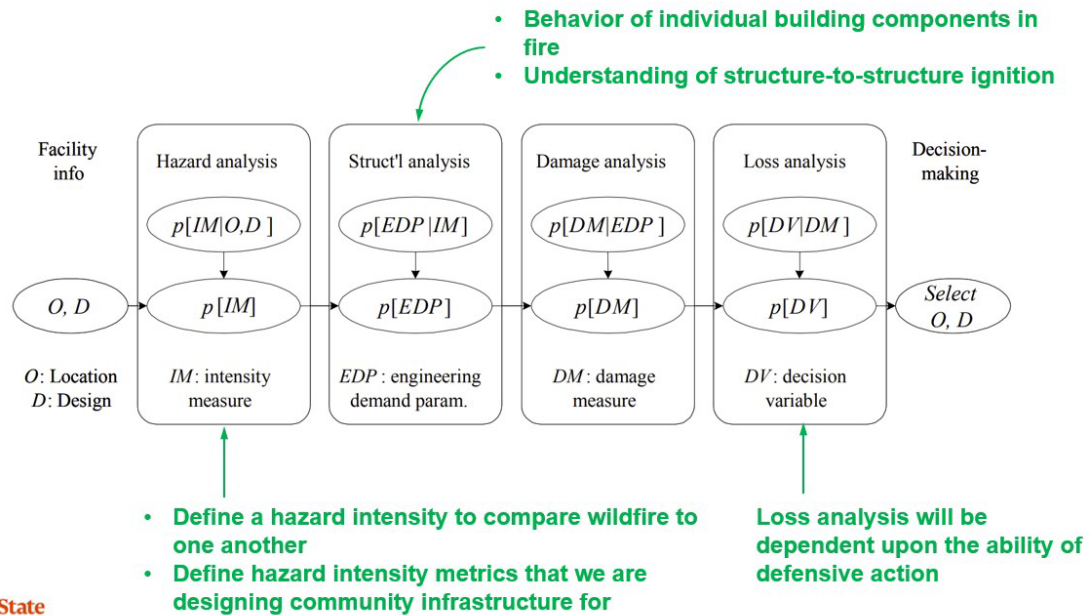
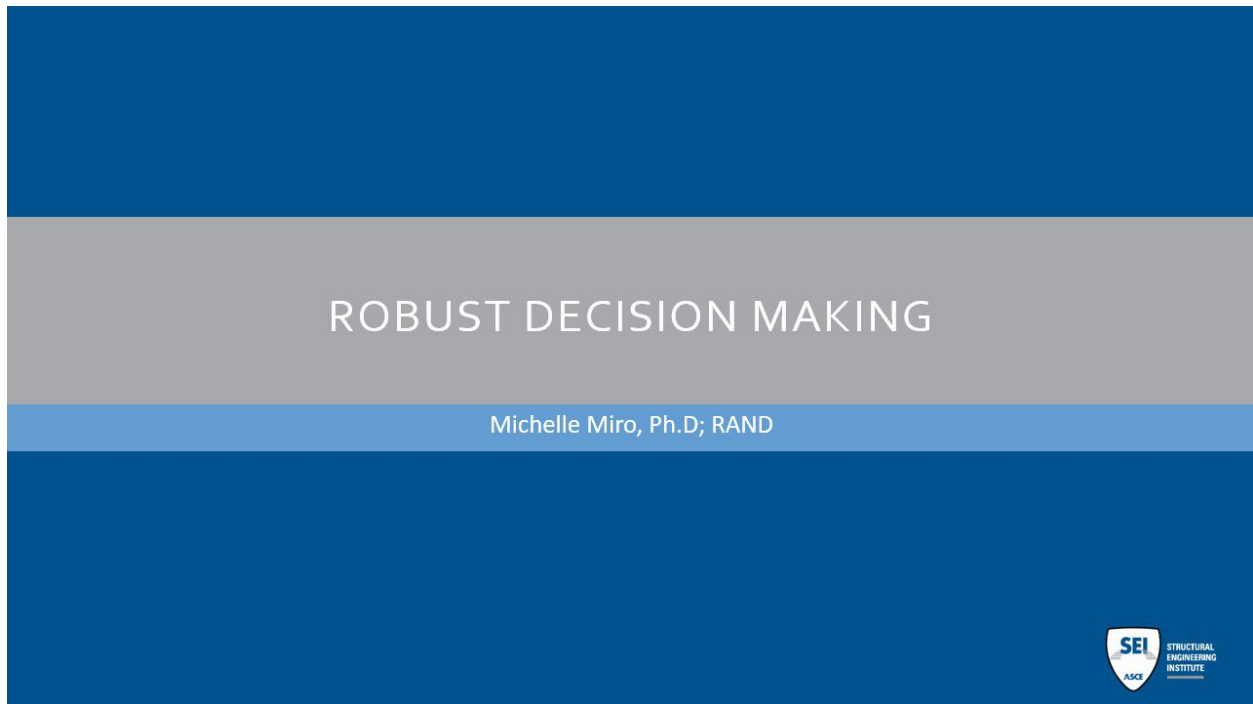


Photo information: 2025 Palisades Fire. Photo credit: Erica Fischer

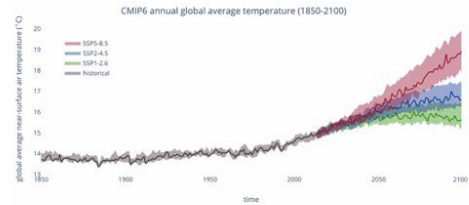
Thank you!
Contact: erica.fischer@oregonstate.edu

B.2.1.4. Synergistic Efforts: Robust Decision Making; Michelle Miro



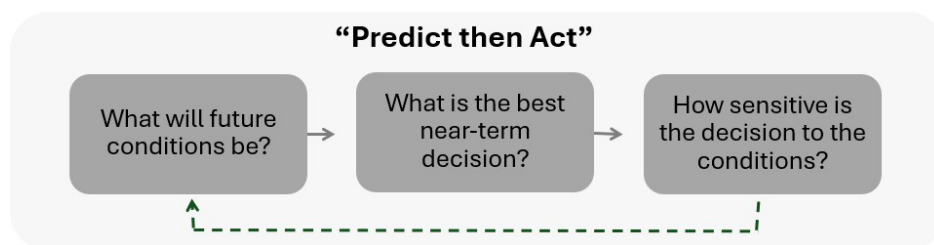
Engineers and planners confront many types of uncertainty

- Climate change
- Economic and development patterns
- Political and regulatory shifts
- Societal trends and responses
- Technological progress



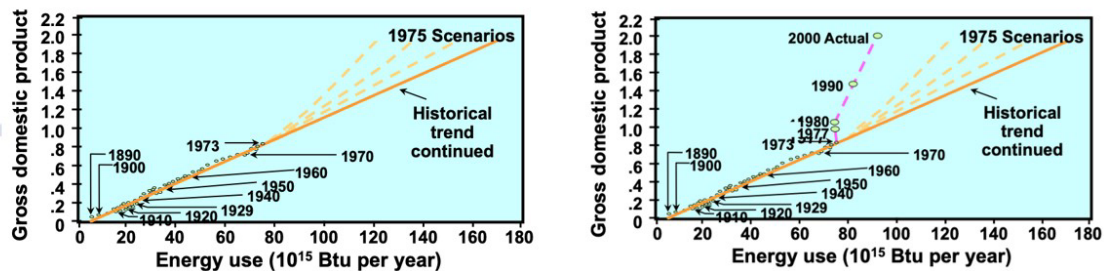
Copernicus Climate Change Service (2021), H20 Innovation (2025)

Traditional planning and design approaches work well when uncertainty is limited



Traditional planning under conditions of high uncertainty may overlook important risks

In the early 1970s forecasters made projections of U.S energy use based on a century of data.

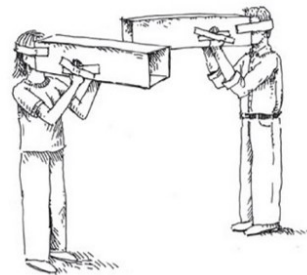


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When uncertainties are deep, Predict then Act methods can break down

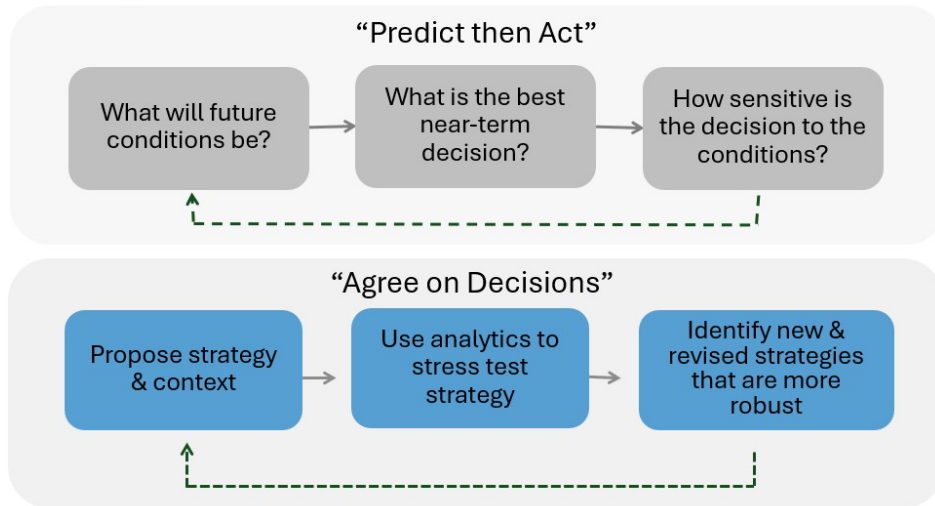
Under conditions of deep uncertainty:

- Uncertainties are often **underestimated**
- Competing analyses can contribute to **gridlock**
- Misplaced concreteness can blind decision makers to **surprise**



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Under deeply uncertain conditions, can run the analysis backwards

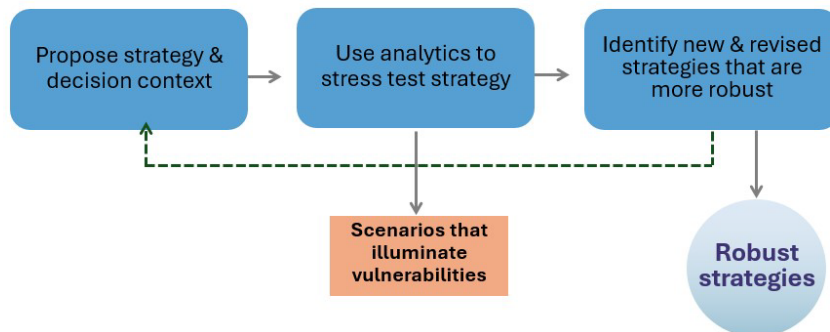


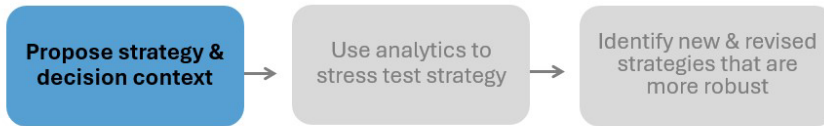
Kalra, N., S. Hallegatte, R. Lempert, C. Brown, A. Fozzard, S. Gill and A. Shah (2014). *Agreeing on Robust Decisions: A New Process for Decision Making Under Deep Uncertainty*. WPS-6906, World Bank.

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Robust Decision Making (RDM) is a quantitative DMDU method

RDM is an iterative analytic process, often used in engagements with stakeholders, designed to support decision making under deep uncertainty



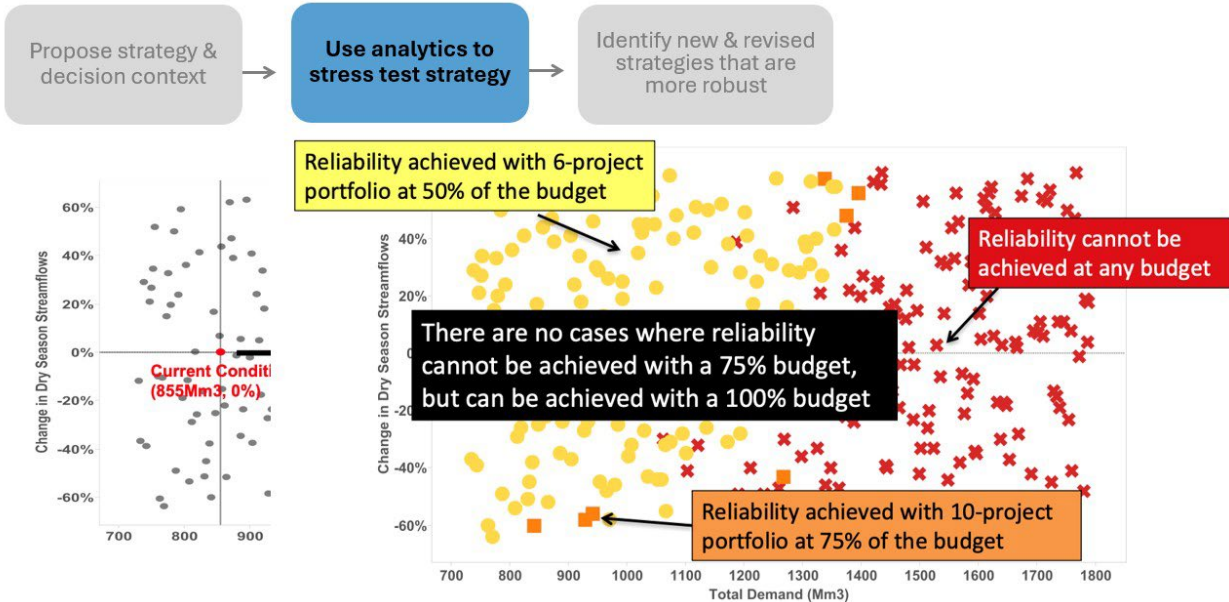


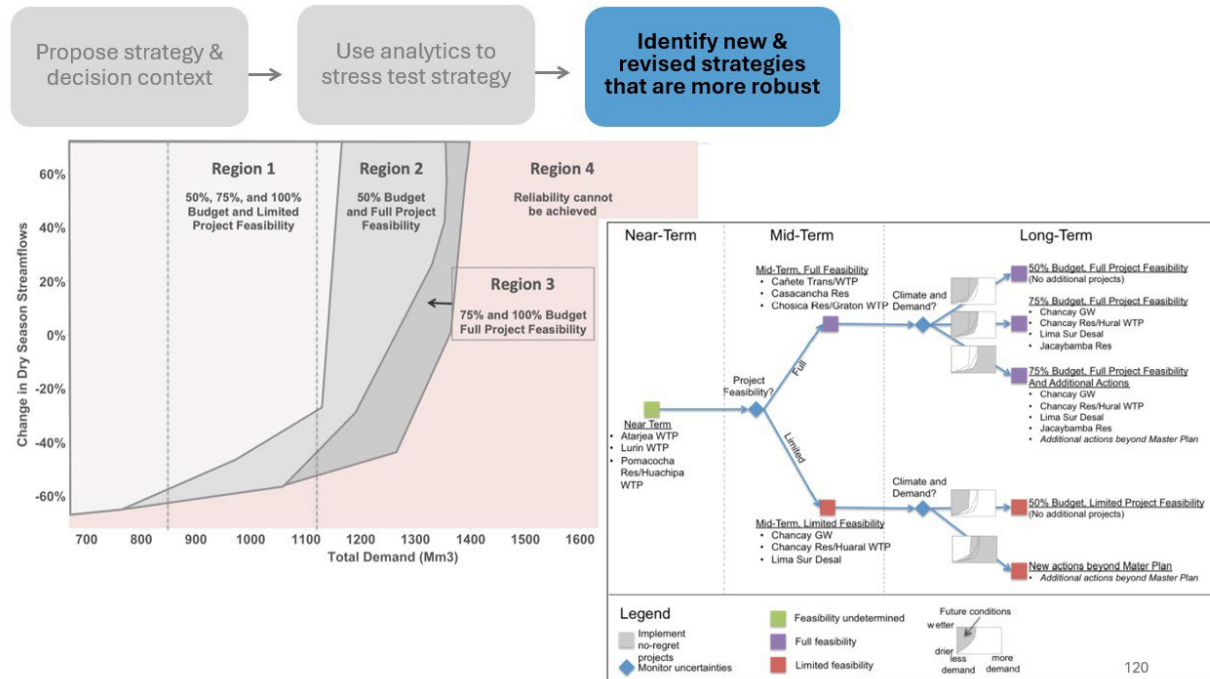
"Future droughts could lead to cuts in my surface water allocations. I would need to pump more groundwater, but this could be really expensive, especially if my neighbors do the same and the groundwater levels go down."

Representation of this quote in the XLRM Matrix

X: Uncertainties	L: Levers (Management Strategies)
- Climate conditions - Water demand	- Updated irrigation infrastructure - Expanded groundwater pumping capacity
R: Relationships (Models)	M: Measures of Performance
- Surface water model - Groundwater model	- Surface water availability - Costs

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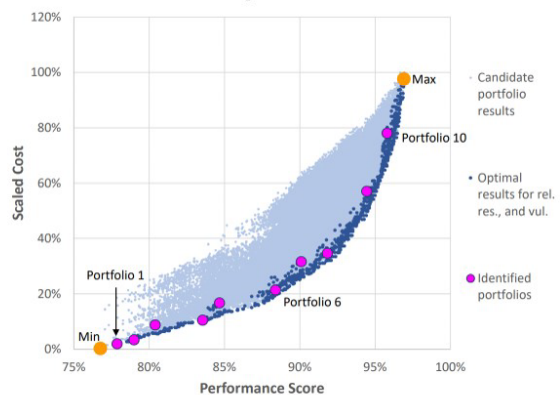




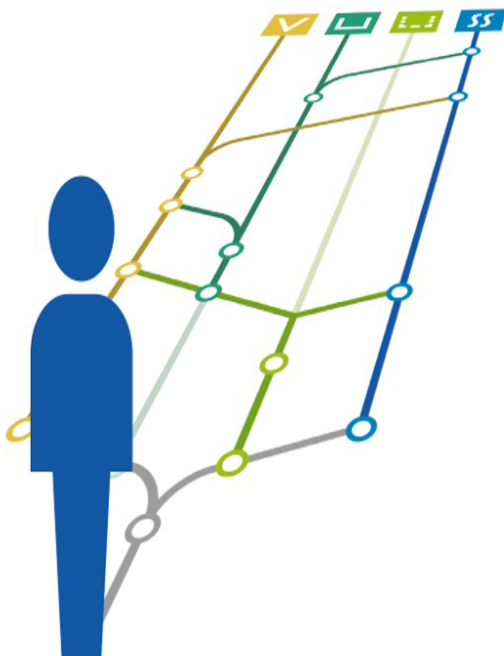
RDM can help answer key questions about infrastructure design

- How do different design modifications perform against uncertainty?
 - Safety/design margins
 - Spatial/functional configurations (e.g., distributed, centralized)
 - Modular design
 - Fail gracefully, recover quickly
 - Enhanced capacity
 - Alternative location
 - Etc.
- What is the system-level robustness to various design modifications?
- How do we balance robustness vs. cost or other tradeoffs?

Portfolio tradeoff analysis



B.2.1.5. Synergistic Efforts: Dynamic Adaptive Policy Pathways; Kathryn Roscoe



Dynamic Adaptive Pathways Planning

Decision-making under uncertainty: An application in Miami-Dade County

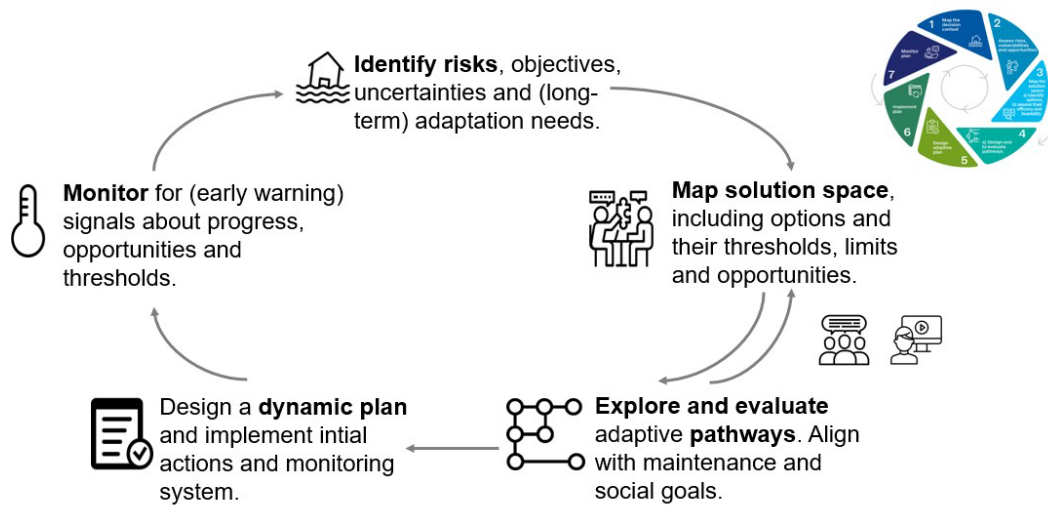
Dr. Kathryn Roscoe, Dr. Marjolijn Haasnoot
October 29, 2025 | SEI NIST Workshop

Deltares

Preparing for an uncertain future



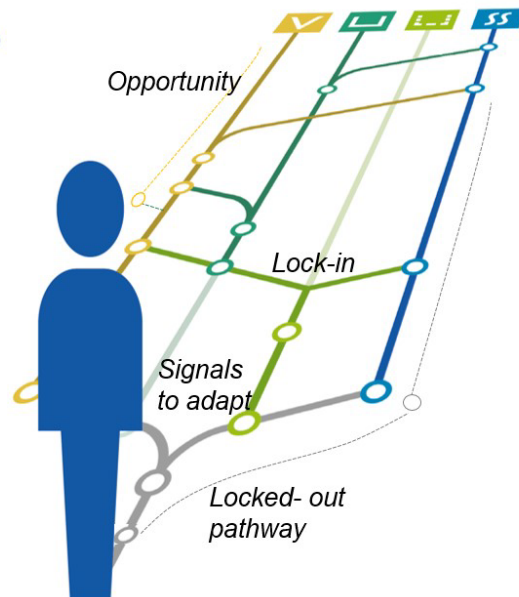
Dynamic Adaptive Pathways Planning (DAPP)



Haasnoot et al. 2013/2019, IPCC SROCC 2019

Exploring adaptation pathways

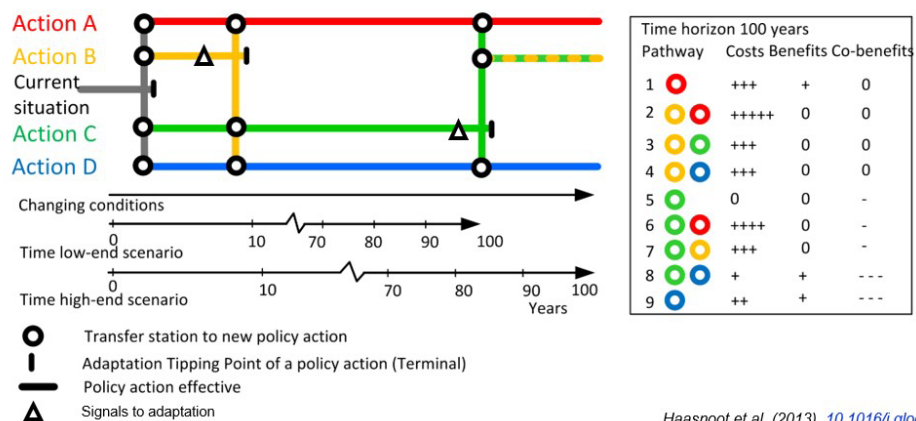
- Break adaptation into manageable steps. Link short-term to long-term.
- Avoid maladaptation
- Adjust depending on how the future unfolds
- Every decision a meaningful step towards the long-term.



Haasnoot et al 2013, 2019, Lawrence et al 2017, 2018, Kwakkel 2016

Adaptation Pathways

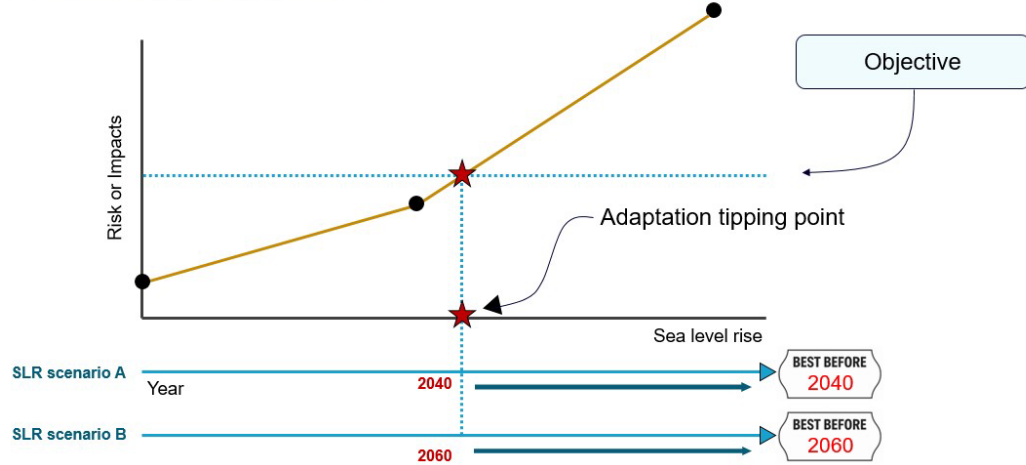
- Maps show different possible sequences of decisions to achieve objectives
- Scorecard helps to evaluate the pathways and decisions



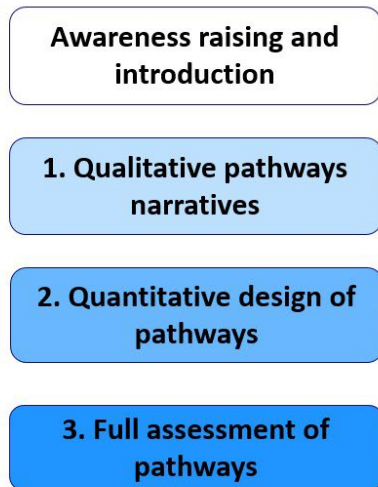
Haasnoot et al. (2013). [10.1016/j.gloenvcha.2012.12.006](https://doi.org/10.1016/j.gloenvcha.2012.12.006)

Deltares

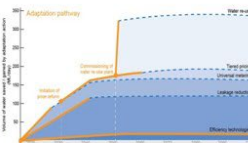
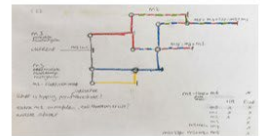
Adaptation tipping points



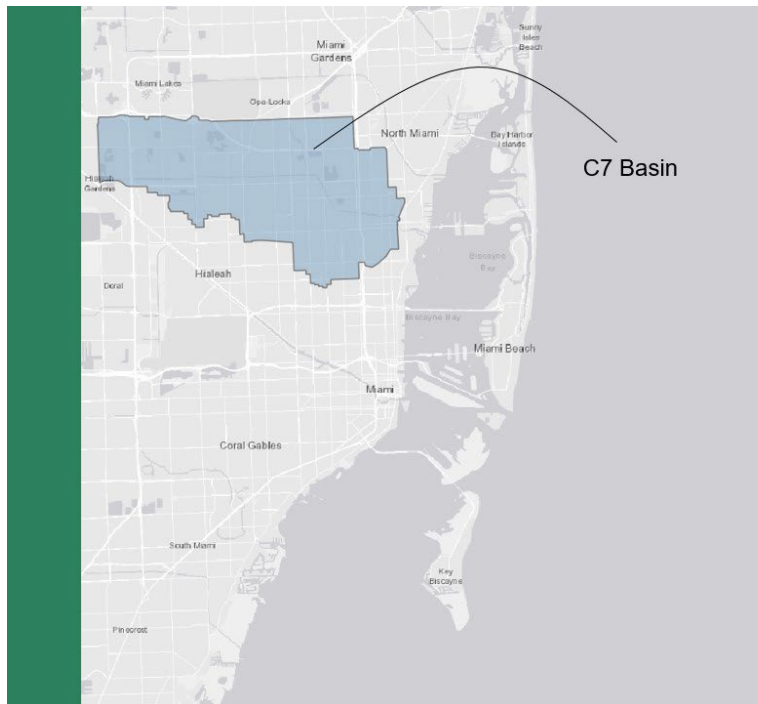
Staged approach to pathways



<http://deltagame.deltares.nl>

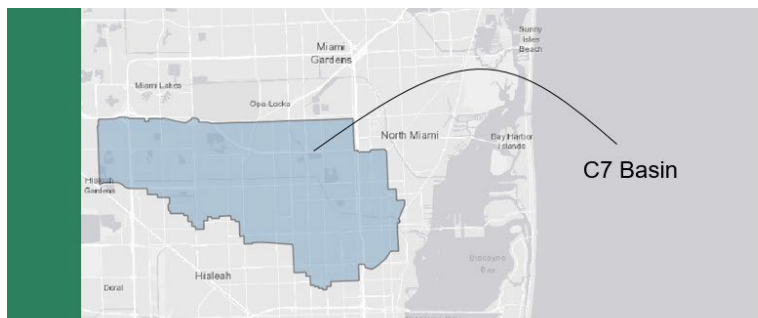


<http://pathways.deltares.nl>
pathways generator **Deltares**

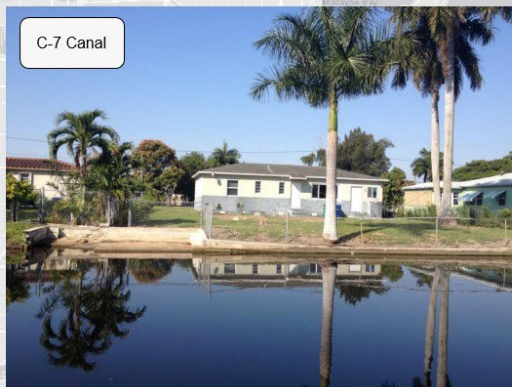


An application in Miami-Dade County

Deltares



An application in Miami-Dade County



Deltares

Exploring the solution space: potential measures and pathways



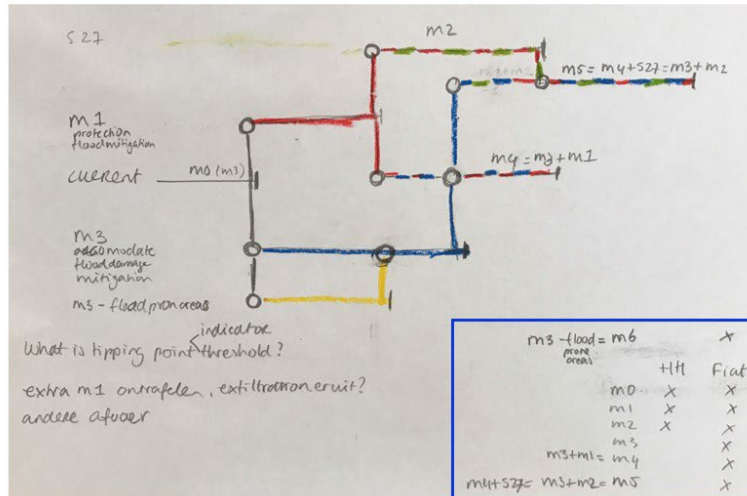
Deltares

Grouping measures into portfolios

- No action (M0)
- Local flood mitigation: flood walls, exfiltration trenches, flap gates, and local pumps (M1)
- Regional flood mitigation: pumps at coastal outlet (small & large pumps) (M2)
- Land-use mitigation: raise roads and buildings to 6, 7 or 8 feet elevation (M3)



Qualitative pathway building



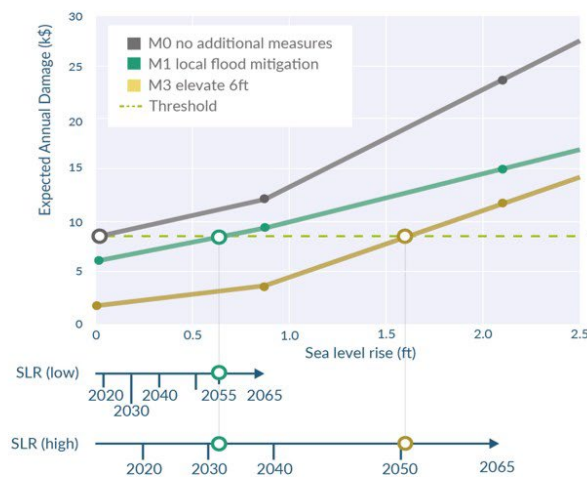
1. Qualitative pathways narratives

2. Quantitative design of pathways

3. Full assessment of pathways

Deltares

Tipping point analysis



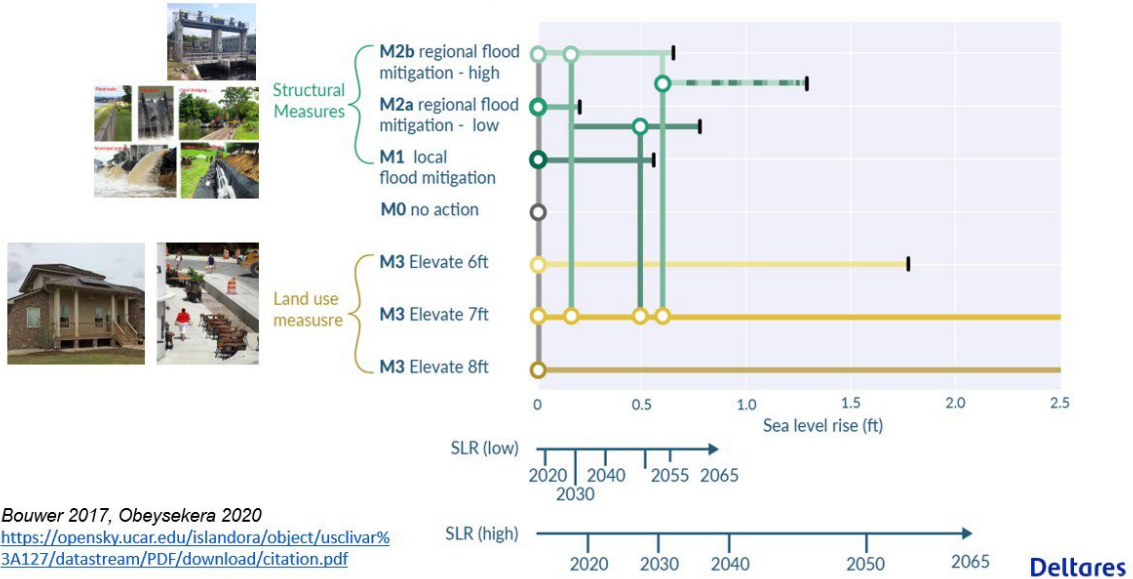
Objective:
Risk should not exceed current levels

Threshold = current EAD

Deltares

Pathways and lessons

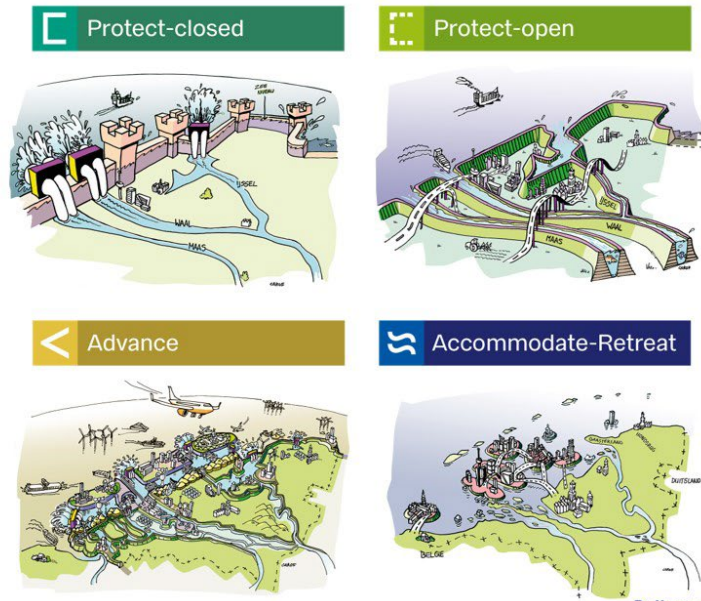
- Structural measures can buy some time
- Land use measures are needed in the end



Preparing for Sea Level Rise in the Netherlands

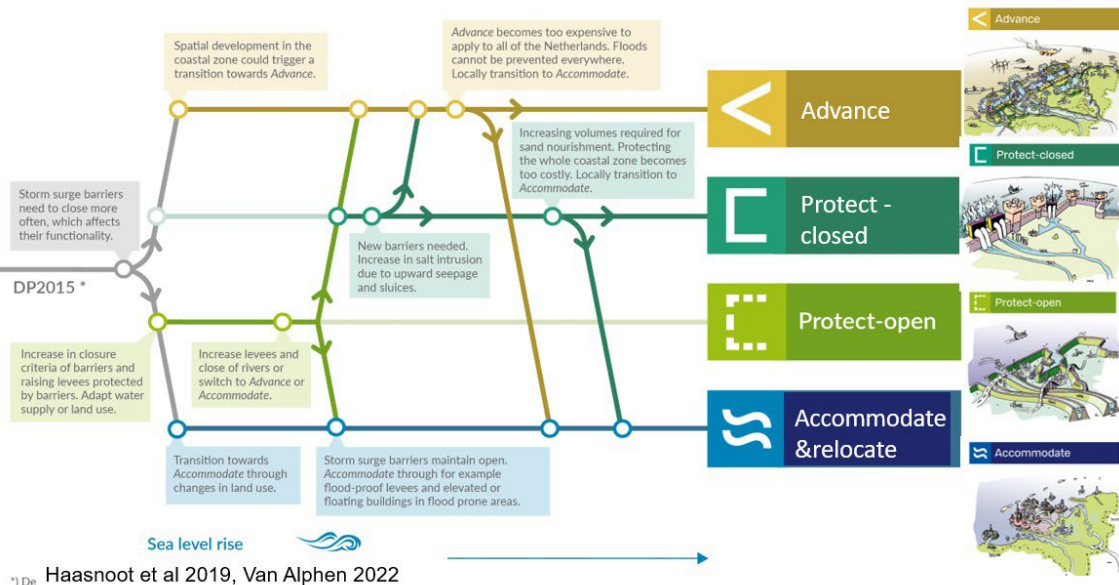


Adaptation strategies



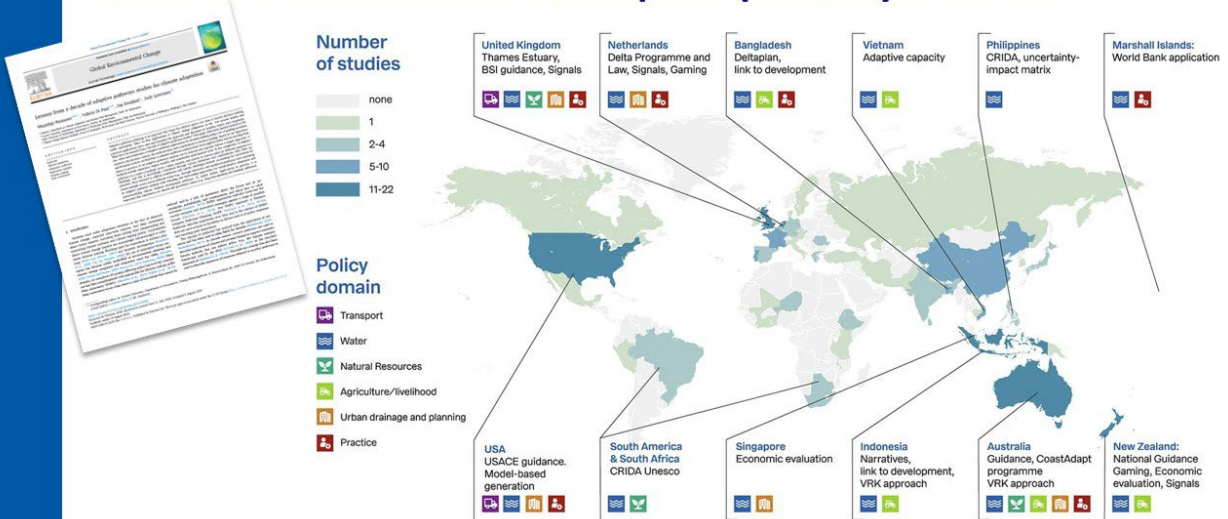
Deltares
Haasnoot et al 2019, Van Alphen 2022

Adaptation pathways and pivotal decisions to sea level rise





Lessons from a decade of adaptive pathways studies



<https://doi.org/10.1016/j.gloenvcha.2024.102907> Deltares

Lessons from a decade of adaptive pathways studies (a selection)

- A pathways approach is useful but not always needed
- It takes time to think differently
- A staged approach helps deal with complexity
- Institutional context can enable (or hinder) the implementation of pathways

<https://www.deltares.nl/en/software-and-data/products/floodadapt>



A staged approach can help

<http://deltagame.deltares.nl>



It takes time to think differently

Deltares

Q&A DISCUSSION

10:45-11:00am

Moderator: Jayantha Obeysekera



PHOTO & BREAK

11:00 – 11:15 am



CASE STUDIES

11:15 am – 12:30 pm



PRESENTATIONS

- **Charlestown Bus Facility Shoreline Stabilization;**
Paul Schuman, Ph.D., P.E.; SGH [15 mins.]
- **Honolulu Flexible Adaptation Pathways;**
Jack Hogan, P.E.; Arup [15 mins.]
- **Resilience Planning with Salt Lake City;**
Milad Roohi, Ph.D.; University of Nebraska [15 mins.]
- **A Comparison of Robust Decision Making Approaches for Community vs Asset-Based Projects;** Ariane Laxo; HGA [15 mins.]
- **Q&A Discussion;** Moderator: Jayantha Obeysekera [15 mins.]



B.2.1.6. Case Studies: Charlestown Bus Facility Shoreline Stabilization; Paul Schuman

CHARLESTOWN BUS FACILITY SHORELINE STABILIZATION

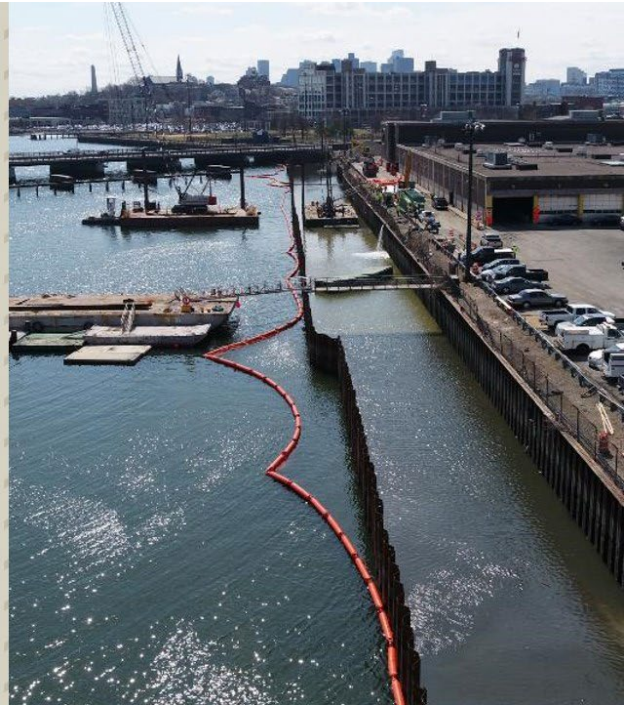
Paul Schuman, Ph.D., P.E.; SGH



**SEI/NIST FORWARD LOOKING CODES
AND STANDARDS WORKSHOP
ADAPTATION AND RESILIENCE**

**CHARLESTOWN BUS FACILITY
SHORELINE STABILIZATION
ADAPTIVE DESIGN APPROACH FOR
IMPROVING RESILIENCE**

**PAUL SCHUMAN
SIMPSON GUMPERTZ AND HEGER (SGH)**



OUTLINE

- Project Overview
- Resiliency Approach
 - Protection
 - Adaptation
 - Recovery



PROJECT OVERVIEW

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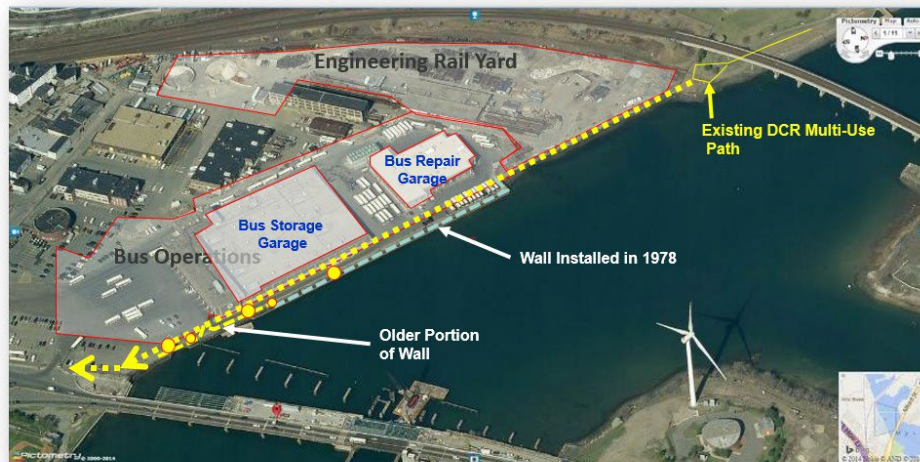
LARGE MULTI-DISCIPLINARY PROJECT TEAM



	Project Team	Status	Project Role
State Agencies	Massachusetts Bay Transportation Authority (MBTA)	Owner of Site	Primary stake holder for bus operations and laydown areas.
	Department of Conservation and Recreation (DCR)	Easement for Bike Path	Primary stake holder for bike path construction
Design	Simpson Gumpertz & Heger Inc. (SGH)	Prime Consultant	Project lead, overall planning for the project, structural and geotechnical design, and pavement evaluation
	Epsilon Associates, Inc. (Epsilon)	Sub-Consultant	Wetlands & Waterways Permitting
	C&C Consulting Engineers, LLC (C&C)	Sub-Consultant	Civil/site and drainage design and field survey
	Chester Engineering (Chester)	Sub-Consultant	Bioengineering for bank stabilization and hydrology study
	Hager GeoScience (Hager)	Sub-Consultant	Geophysical seismic site characterization
	RW Sullivan Engineering (RW)	Sub-Consultant	Site electrical design
	VJ Associates (VJ)	Sub-Consultant	Cost estimating and scheduling
	CDW Consultants (CDW)	Sub-Consultant	Environmental design and LSP
	McMahon	Sub-Consultant	Traffic circulation design
	Appledore Marine	Sub-Consultant	Marine/diver Inspections
	Woods Hole Group	Sub-Consultant	Flood Study
Construction	Middlesex Corporation	General Contractor	Overall Project Oversight for Construction
	Treviocos	Jet Grouting Sub-Contractor	Jet Grouting Construction

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PROJECT SITE

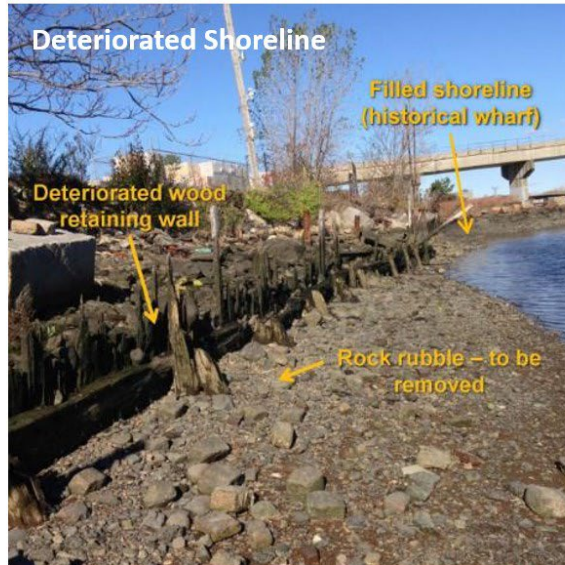
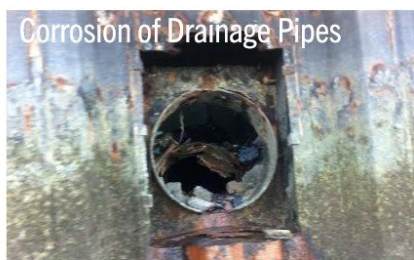
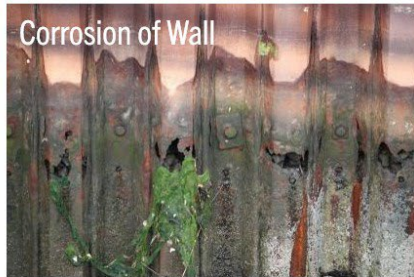


- Larger Areas of Soil Erosion Through Corroded Outfall Pipes
- Smaller Areas of Soil Erosion Through Corroded Sheet Piles

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INITIAL SITE ISSUES

SGH



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FAILING OUTFALL DRAINAGE STRUCTURES

SGH



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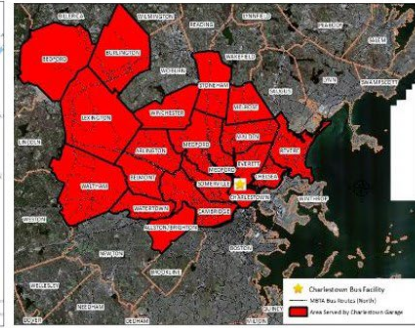
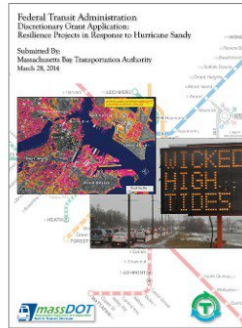
PROJECT FOCUS



- Shoreline Stabilization
- **Flood Protection & Resiliency**
- Drainage Structure Repair/Replacement
- Storm Water Improvements
- Maintain Operational Use and Efficiency
- Improve Regulatory Compliance for Material Storage
- Provide Space for DCR Easement

Charlestown Bus Maintenance Facility

- Largest Bus Facility of the 9 MBTA Facilities
- Houses 231 Buses
- Services 39 Weekday Bus Routes
- 18 Communities
- 99,000 Riders a Day (29% of the MBTA's Bus Passengers)
- **\$17,855,258** to Rebuild the Charlestown Seawall to Protect the Maintenance Facility



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BEFORE

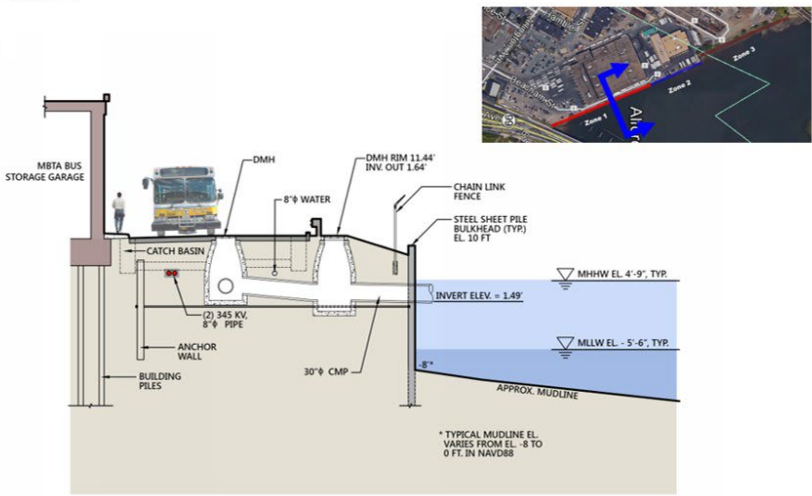
157

AFTER



345 KV Lines

SGH

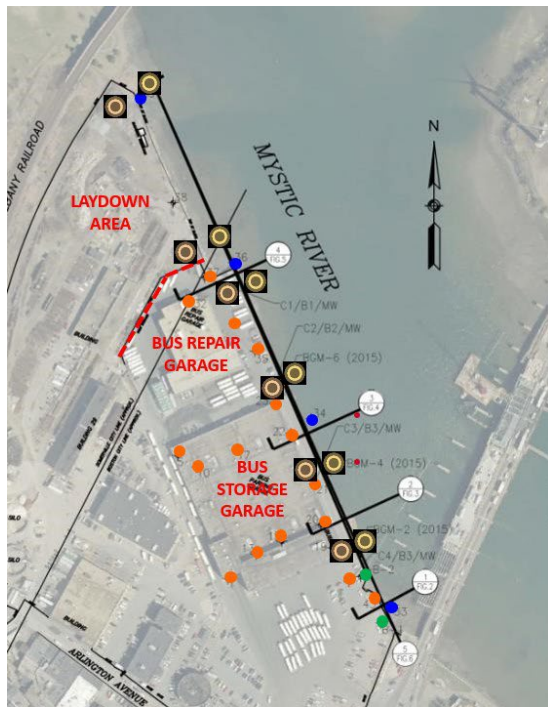


EXISTING CONDITIONS SECTION @ BUS STORAGE GARAGE (TYP.)
ALFORD STREET MBTA BUS STORAGE GARAGE SCALE: NTS

11/20/2018

DRAFT

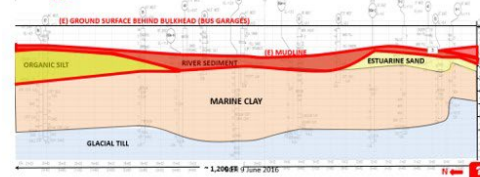
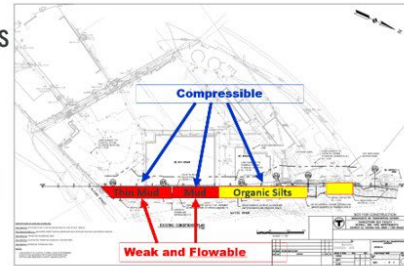
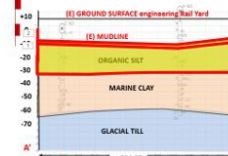
159



GEOTECHNICAL

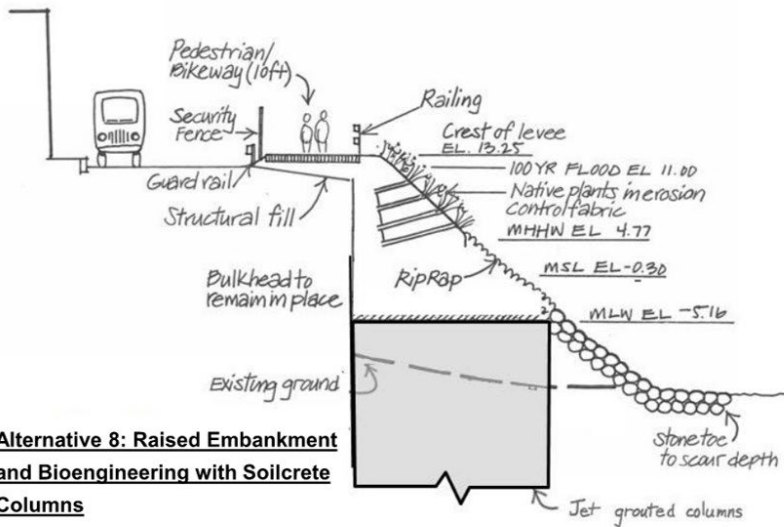
SGH

- 1978 MARINE SOIL TEST BORINGS
- 1978 LAND SOIL TEST BORINGS
- 2011 LAND SOIL TEST BORINGS (JACOBS)
- 2015 SGH PROPOSED MARINE SOIL TEST BORINGS
- 2015 SGH PROPOSED LAND SOIL TEST BORINGS

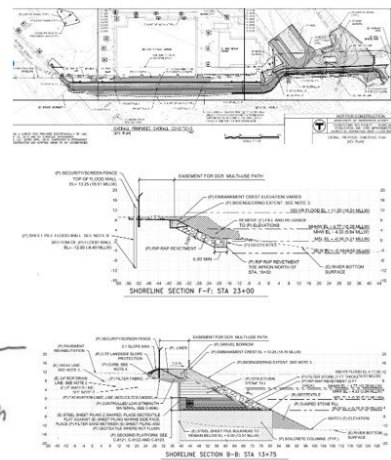


SHORELINE REMEDIATION CONCEPT SELECTED

SGH



Alternative 8: Raised Embankment and Bioengineering with Soilcrete Columns





- Flood Protection/Prevention
 - Preventing Wall Failure
 - Providing Flood Protection
 - How high?
 - Is overtopping the only flood risk?
- Flood Recovery
 - How quickly can the MBTA resume operations?
- Snow
- Understand what is important to Owner!
 - Bus Operations and Maintenance after storms.
 - Flooding of Rail Yard not as problematic for MBTA.
 - DCR not as concerned with bike path being inundated.

SHORELINE NEEDS

SGH

- Prevent Erosion
- Stabilize (E) Wall



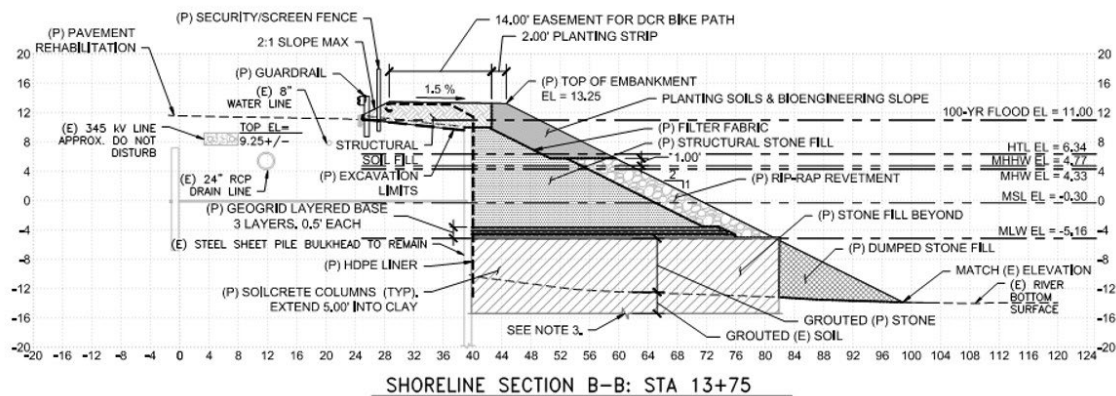
Charlestown Bus Facility - Shoreline Stabilization and Yard Improvements Project
Figure 5
Photo of Existing Conditions - Shoreline Areas D through F

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BUS OPERATIONS SHORELINE NEW EMBANKMENT TO STABILIZE WALL NEW EMBANKMENT TO INCREASE FLOOD PROTECTION

SGH

Flood Protection Elevation 13 ft for MBTA and DCR

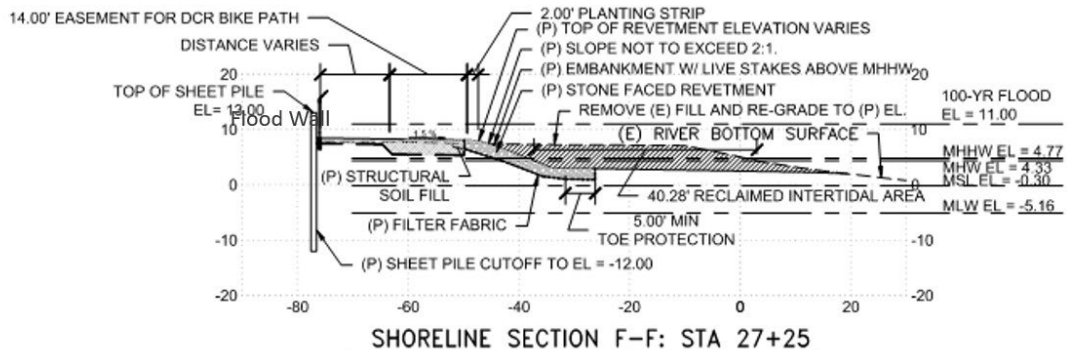


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ENGINEERING RAIL YARD STABILIZE (E) SHORELINE WITH REVETMENT (N) FLOOD WALL INCREASES FLOOD PROTECTION

SGH

Flood Protection Elevation 13 ft for MBTA
Flood Protection Elevation 8-10 ft for DCR



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FLOOD PROTECTION HEIGHT_PROJECT NARRATIVE LANGUAGE

SGH

G. → Technical Capacity: ¶

¶

MBTA staff participated in the mandatory on-line training that FTA offered on Hazard

¶

Consistent with the goals of the grant offering, the MBTA certifies that the project will be designed and built to be resilient to the best available FEMA flood hazard information as of February 1, 2014, plus one foot, as defined in the FTA's Notice of Funding Availability issued December 26, 2013. ¶

e capacity to implement the project and the MBTA staff's capability will be supplemented design and construction management services of er contract for a specific project. Alternatively, e of an on-call consultant and the construction

expertise of an experienced construction firm. The MBTA is an experienced Federal grantee and has the systems and internal controls needed in place to separately track and report on funding under this grant. ¶

¶

Consistent with the goals of the grant offering, the MBTA certifies that the project will be designed and built to be resilient to the best available FEMA flood hazard information as of February 1, 2014, plus one foot, as defined in the FTA's Notice of Funding Availability issued December 26, 2013. ¶

Federal Transit Administration
Discretionary Grant Application:
Resilience Projects in Response to Hurricane Sandy

Submitted By:
Massachusetts Bay Transportation Authority
March 28, 2014

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Woods Hole Data

Recurrence Intervals and Probabilities of Occurrences

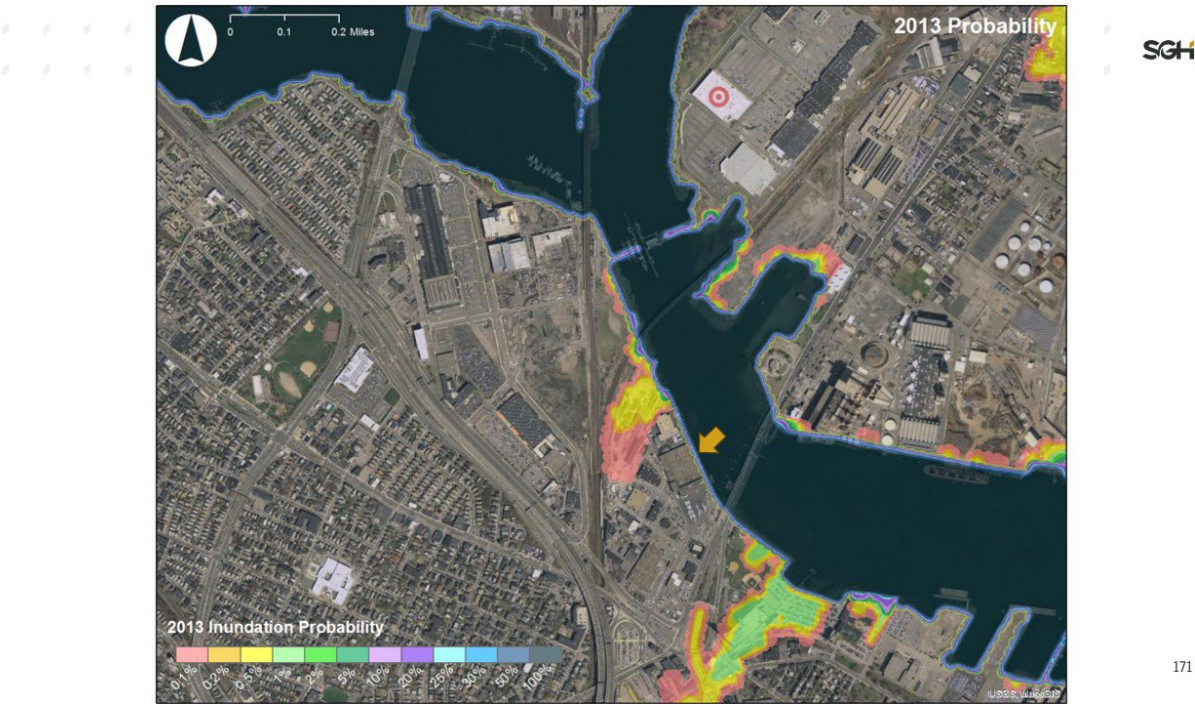
ARI (years)	Probability of occurrence in any given year	Percent chance of occurrence in any given year
1000	1 in 1000	0.1%
500	1 in 500	0.2%
100	1 in 100	1%
50	1 in 50	2%
20	1 in 20	5%
10	1 in 10	10%
5	1 in 5	20%
2	1 in 2	50%
1	1 in 1	100%



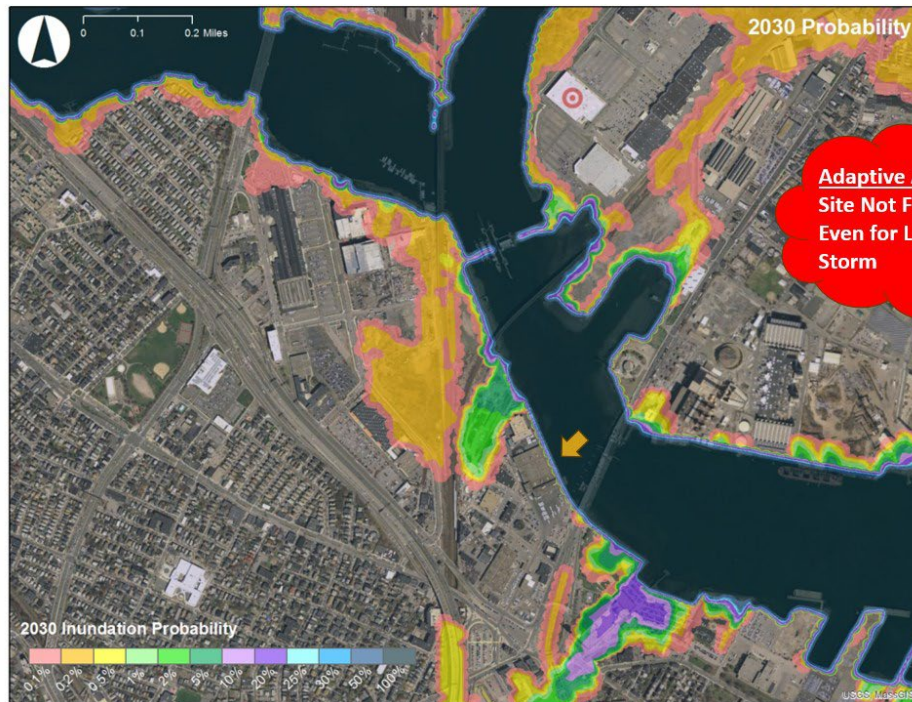
Mystic River Projections

Exceedance Probability	2013	2030	2070
	Water Surface Elevation (ft-NAVD88)	Water Surface Elevation (ft-NAVD88)	Water Surface Elevation (ft-NAVD88)
0.1	9.9	10.8	14.1
0.2	9.8	10.7	14.0
0.5	9.1	10.1	13.5
1	8.7	9.9	12.8
2	8.6	9.8	12.2
5	8	9.5	11.5
10	7.6	9.0	11.0

170

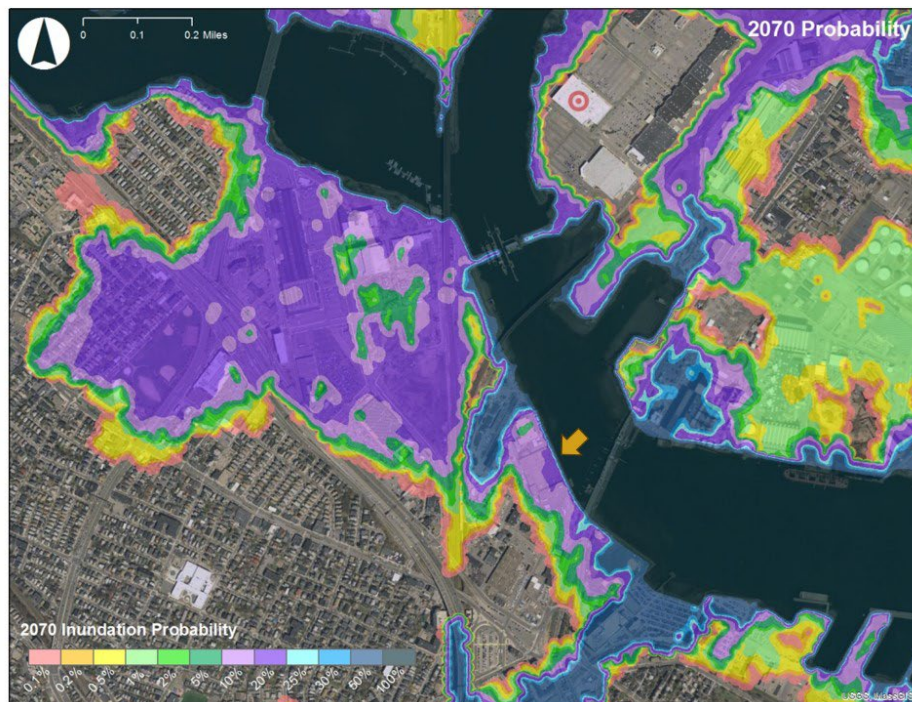


171



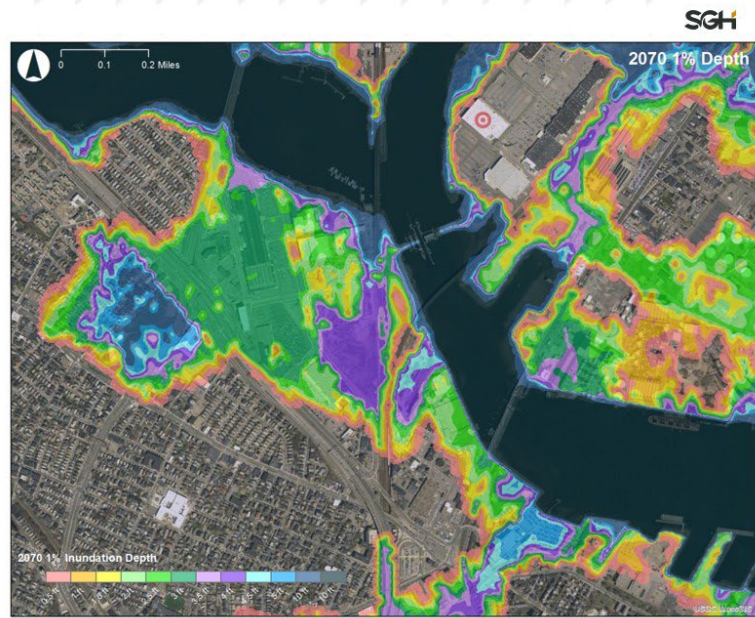
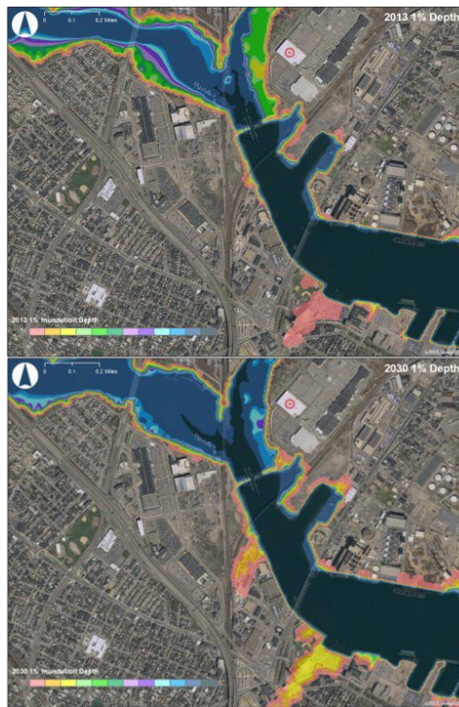
SGH

172



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Figure 3. 2070 flood probabilities in the vicinity of the Charlestown MBTA Bus Depot with proposed resiliency design in place.

Adaptive Approach
Future Levee or
Floodwall on Land



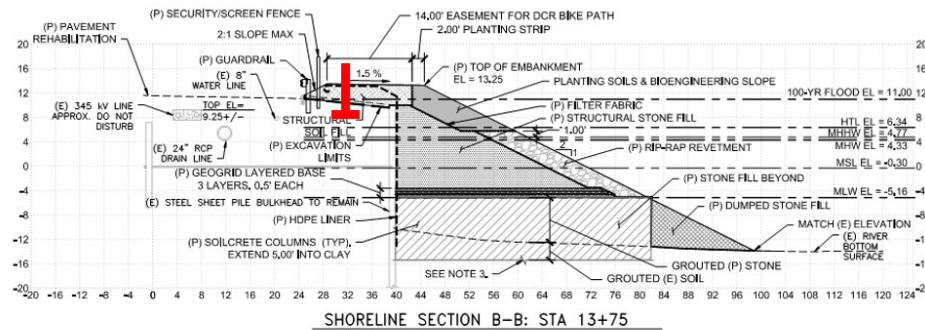
Figure 4. 2070 flood probabilities in the vicinity of the Charlestown MBTA Bus Depot with proposed resiliency design, including additional flood wall along Alford Street, in place.

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INCREASING FLOOD PROTECTION IN FUTURE

SGH

- Flood Protection is EL. 13.00'
 - 2 ft Above 100 Year Flood
- Design accommodated for addition of concrete flood wall on top of the embankment in the future.
 - If built as part of the project, repairs/replacement would be likely before needed.

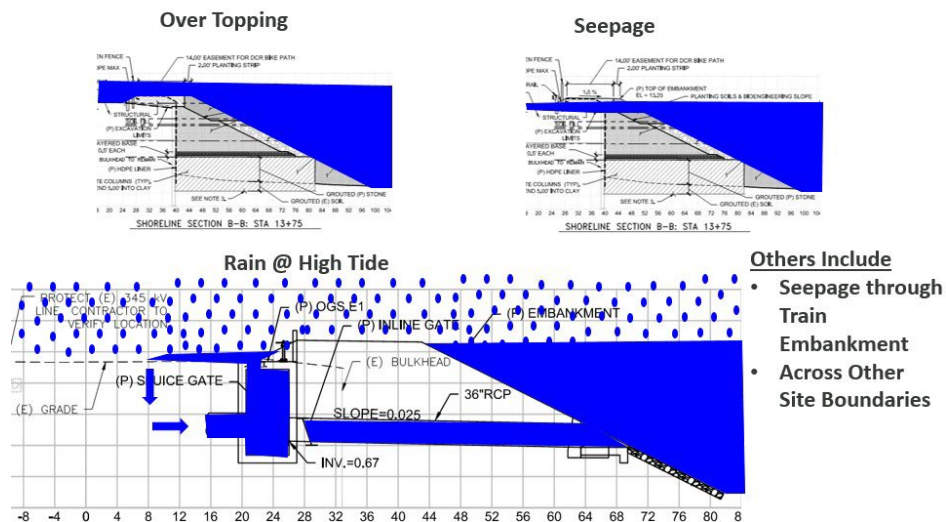


**Adaptive Approach
Accommodate Concrete
Flood Wall in Future**

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WAYS WATER CAN ENTER SITE

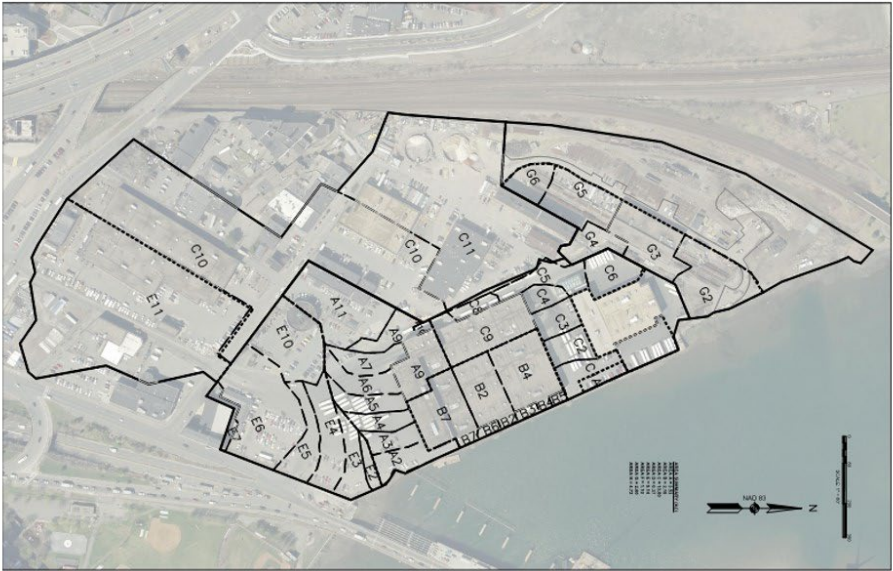
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SUB-CATCHMENT BREAKDOWN

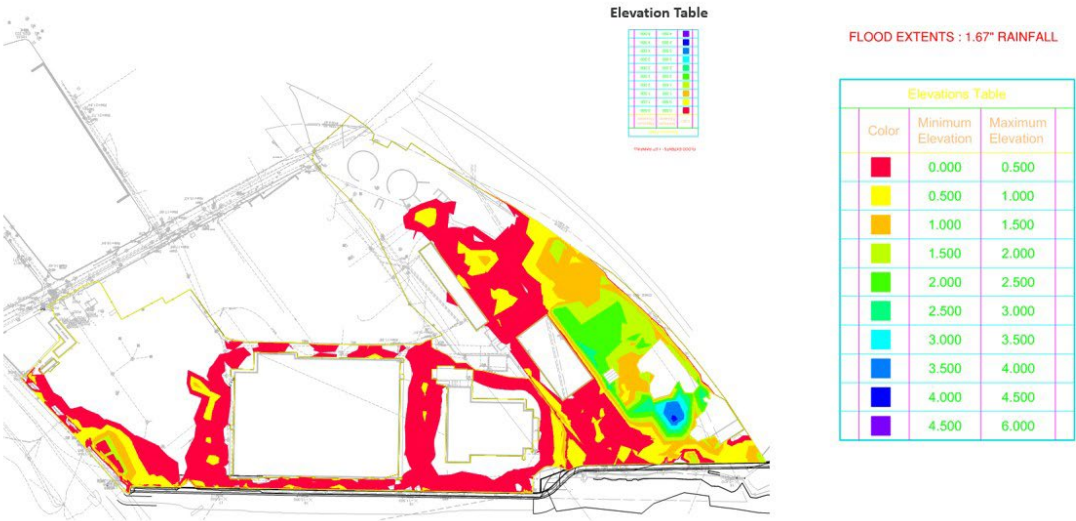
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BATHTUB ANALYSIS
1.67 IN. RAINFALL

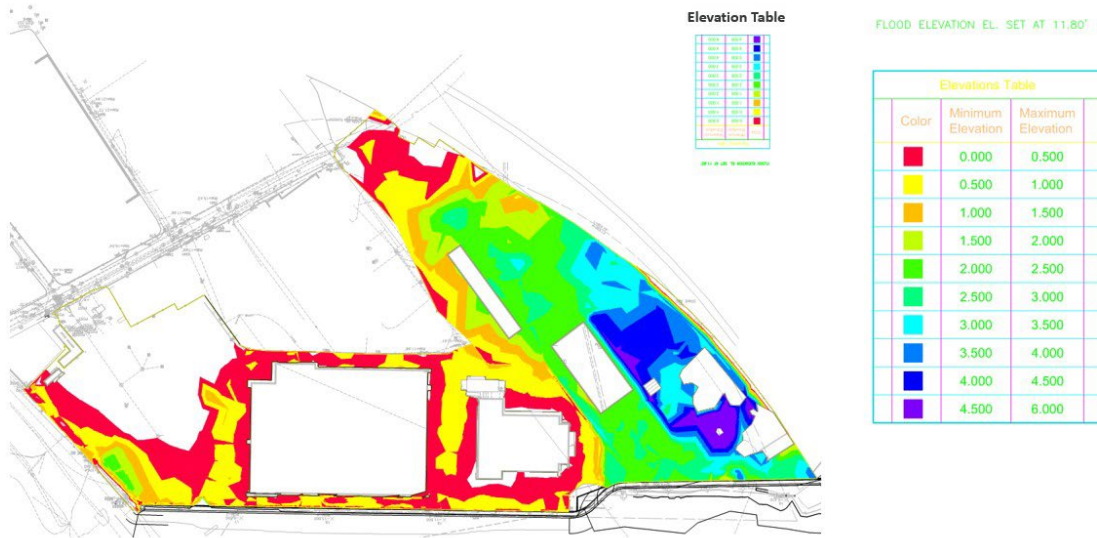
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BATHTUB ANALYSIS 1.8' RAIN FALL

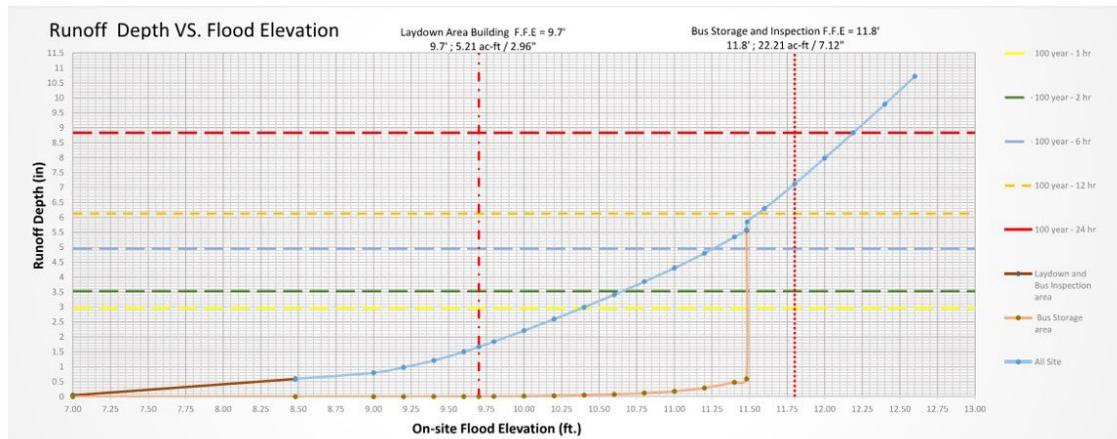
SGH



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RUNOFF DEPTH VS. FLOOD ELEVATION

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There is not a lot of time for a flood to occur due to rain since the tide cycle is consistent and has a 10 ft swing in Boston.

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SNOW

183



184



SGH



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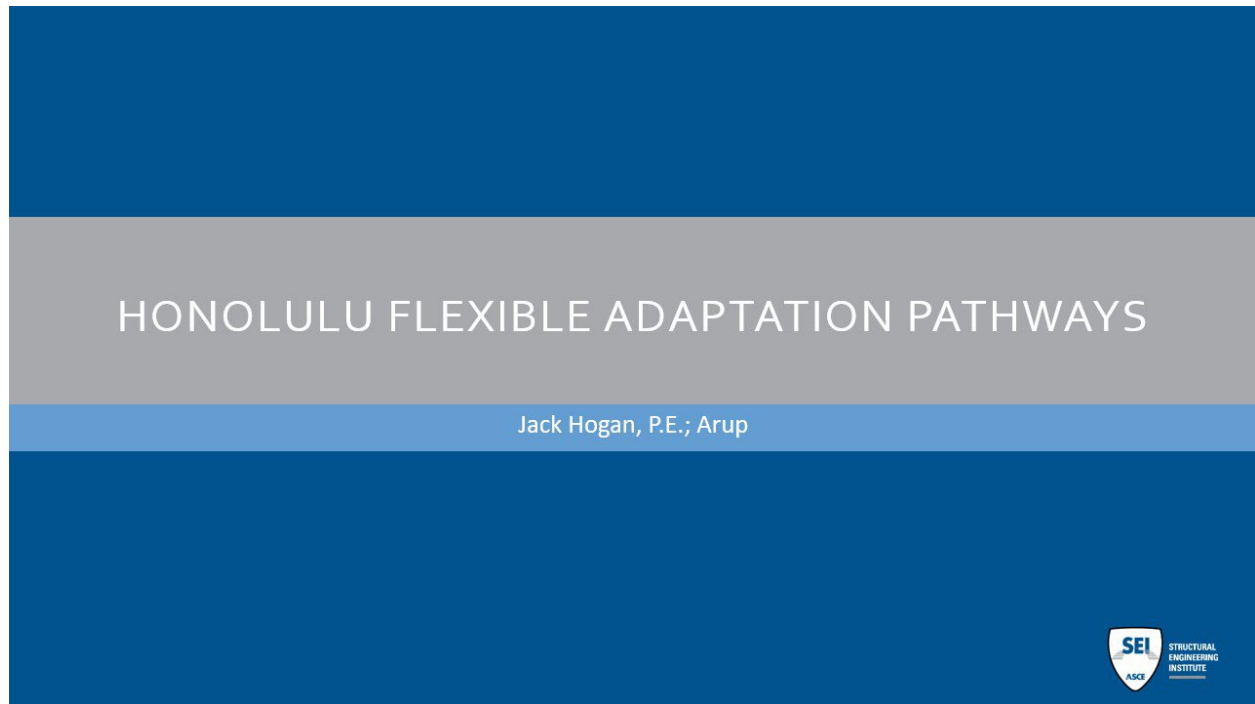


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B.2.1.7. Case Studies: Honolulu Flexible Adaptation Pathways; Jack Hogan



Flexible Adaptation Pathways

An approach for Sea Level Rise and Flood Infrastructure

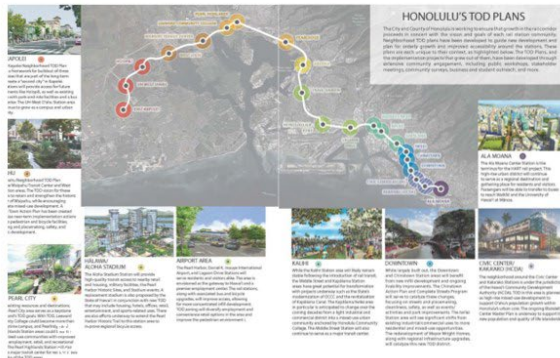
Project Snapshot Honolulu, Hawaii

Jack Hogan, PE
Jack-W.Hogan@arup.com



ARUP

Infrastructure Needs Assessment – Future (Proposed)

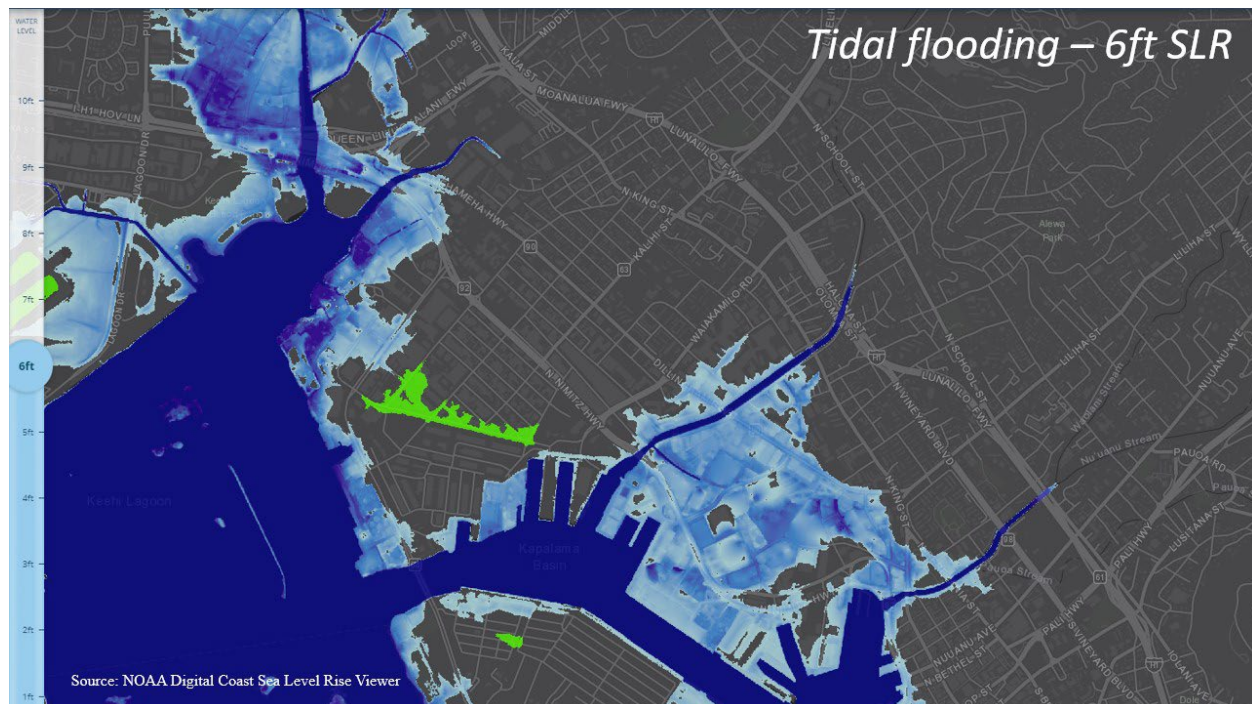


(Proposed) Large scale flood infrastructure needs considered for TOD areas

(Proposed) Flexible Adaptation Pathways applicable to infrastructure evaluation and planning

Infrastructure	Plans Outlined	Costs Estimated
Sewage	☒	☒
Water	☒	☒
Drainage	☒	☒
Storm water quality	☒	☒
Intersections and roadways	☒	☒
Storm flooding	☐	☐
Coastal flooding	☐	☐

ARUP



Challenge

- Large scale infrastructure is *capital-intensive* and *long-lived*
- *Uncertainty* in how the future may unfold due *climate* and *socio-economic* conditions



ARUP

Response – Infrastructure Planning – Static Approach

- Static ‘optimal’ plan using a single ‘most likely’ future
- Static ‘robust’ plan that will produce acceptable outcomes in most plausible future worlds

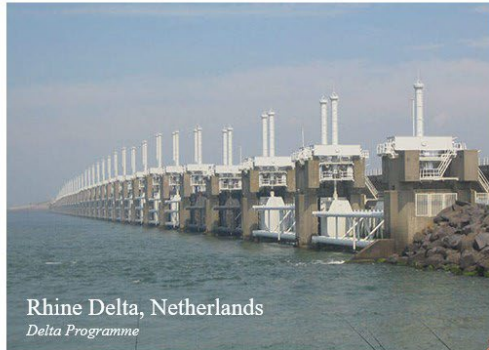


(Dessai and Hulme, 2007; Dessai and Van der Sluijs, 2007; Hallegatte et al., 2012).

ARUP

Response – Infrastructure Planning – Dynamic Approach

- Dynamic adaptive plans contain a strategic vision of the future, commit to short-term actions, and establish a framework to guide future actions



(Albrechts, 2004; de Neufville and Odoni, 2003; Haasnoot et al., 2011; Hallegatte, 2009; Hallegatte et al., 2012; Ranger et al., 2010; Schwartz and Trigeorgis, 2004; Swanson et al., 2010).

ARUP

Flexible Adaptation Pathways – Concepts

- Real options – infrastructure options that are fitted with flexibility to adapt to future changes, rather than for a specific design scenario
- Potential lock-ins – when an option leads to a failure to adjust adequately to a changed environment; path-dependency of investment decisions can lead to stranded assets if conditions change
- No regrets options – options which achieve positive outcomes under all plausible projections of climate change
- Trigger and Tipping points - a trigger indicates when a decision is needed for a forthcoming action; tipping point is the point at which a particular action is no longer adequate for meeting objectives
- Flexible adaptation pathway map – path of actions that result in least regrets and achieves overall objectives

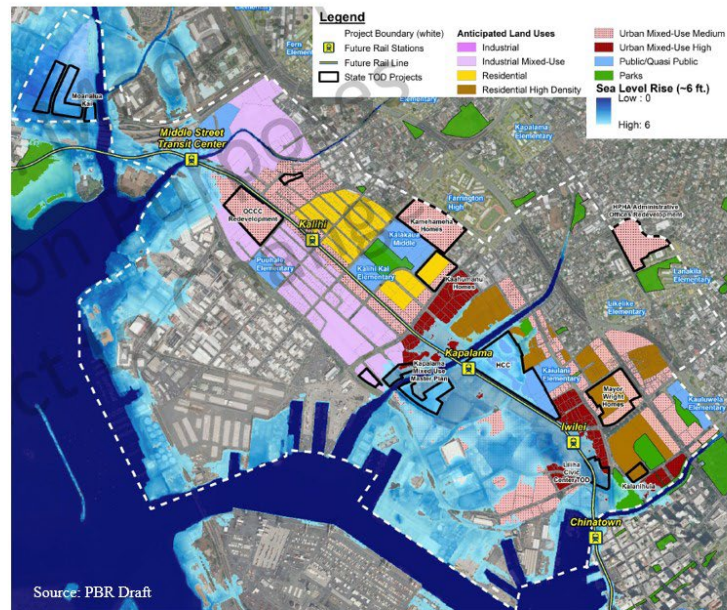


(Haasnoot et al. / Global Environmental Change 23 (2013) 485–498)

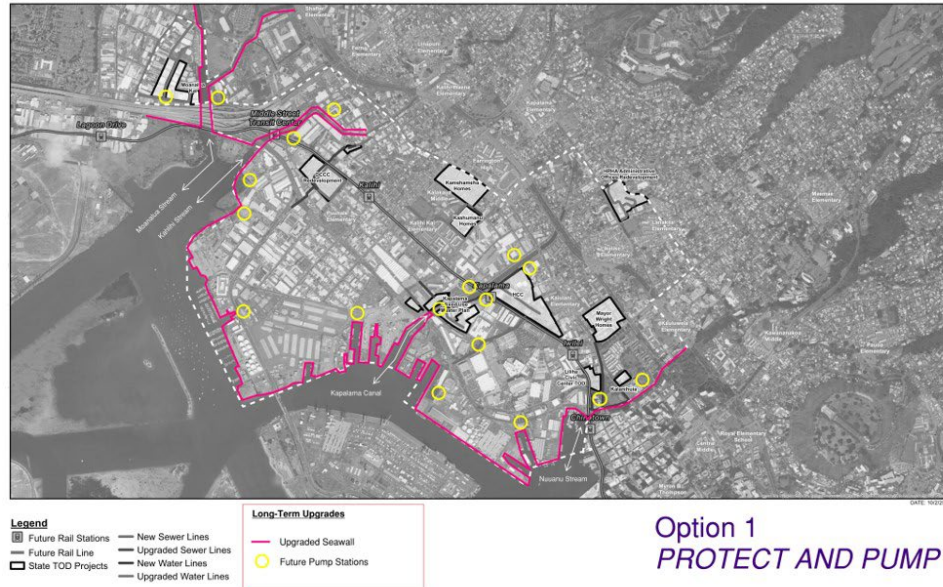
ARUP

Iwilei-Kapalama

Objective: Ensure adequate infrastructure capacity and *flood protection* for TOD area investments *through 2100*

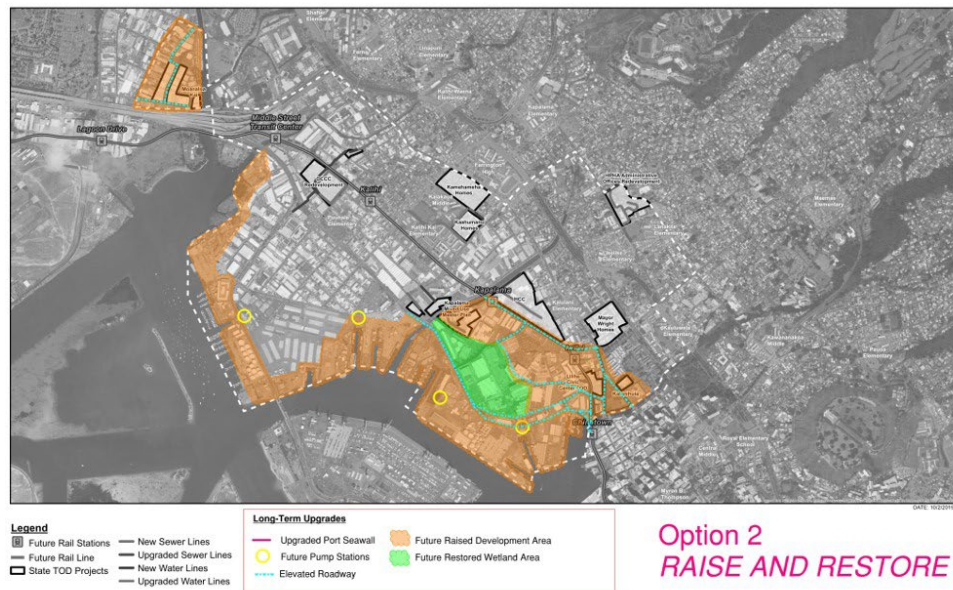


ARUP



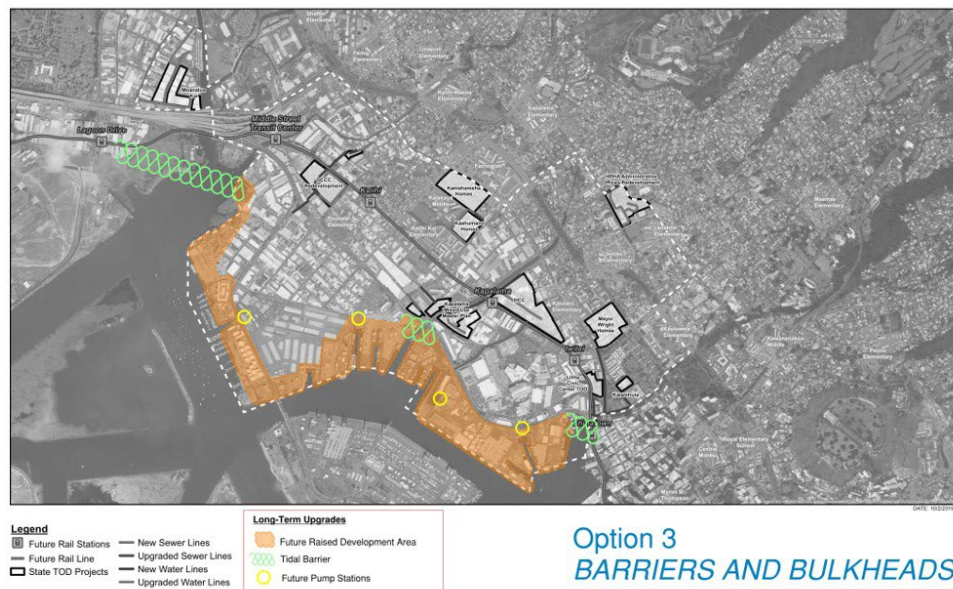
Hypothetical infrastructure concept – for demonstration purposes only

ARUP



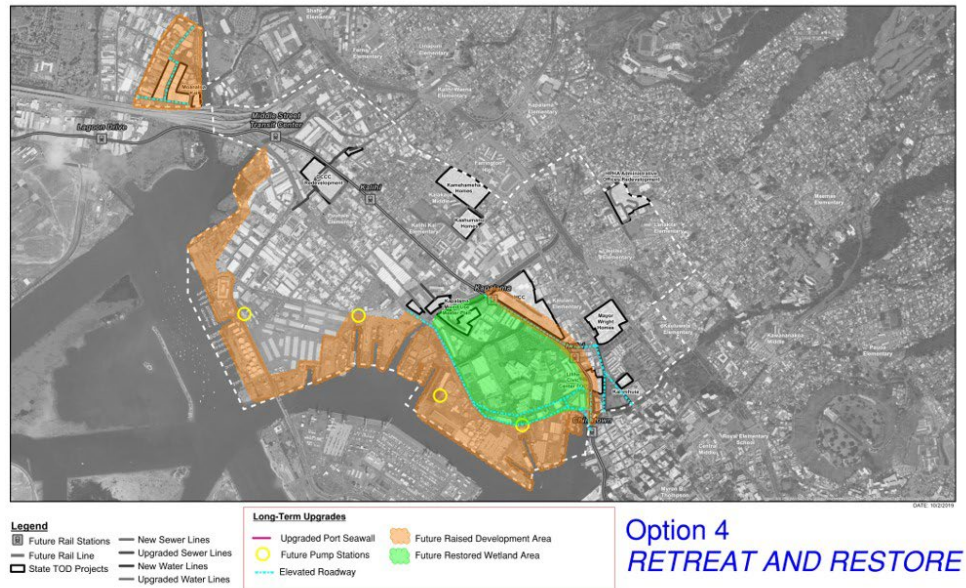
Hypothetical infrastructure concept – for demonstration purposes only

ARUP



Hypothetical infrastructure concept – for demonstration purposes only

ARUP

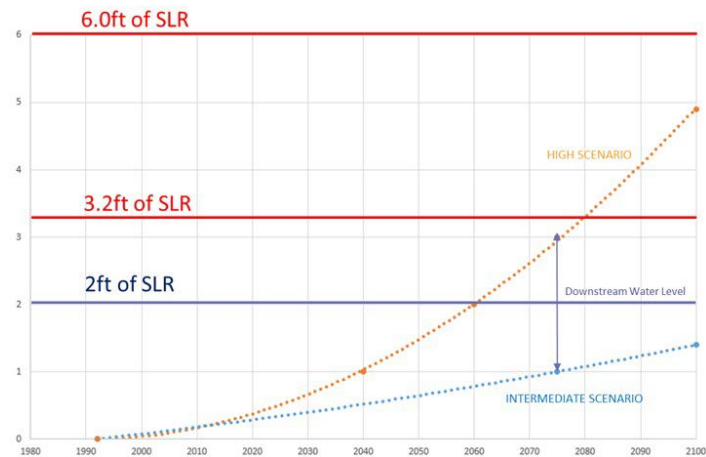


Hypothetical infrastructure concept – for demonstration purposes only

ARUP

Uncertainty – When and How Much?

Accumulated Sea Level Rise (feet) at Kapalama Canal



ARUP

Flexible Adaptation Pathways – Objective and Options

Option 1
(Protect and Pump)

Option 2
(Raise and Restore)

No Action

Option 3
(Barriers and Bulkheads)

Option 4
(Retreat and Restore)

Objective: Ensure adequate infrastructure capacity and *flood protection* for TOD area investments through 2100

ARUP

Flexible Adaptation Pathways - Triggers, Timing, and Thresholds

Option 1
(Protect and Pump)

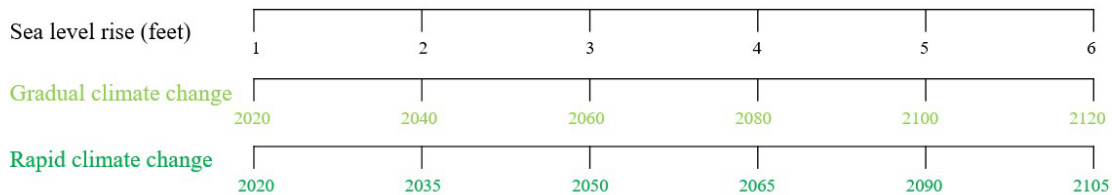
Option 2
(Raise and Restore)

No Action

Option 3
(Barriers and Bulkheads)

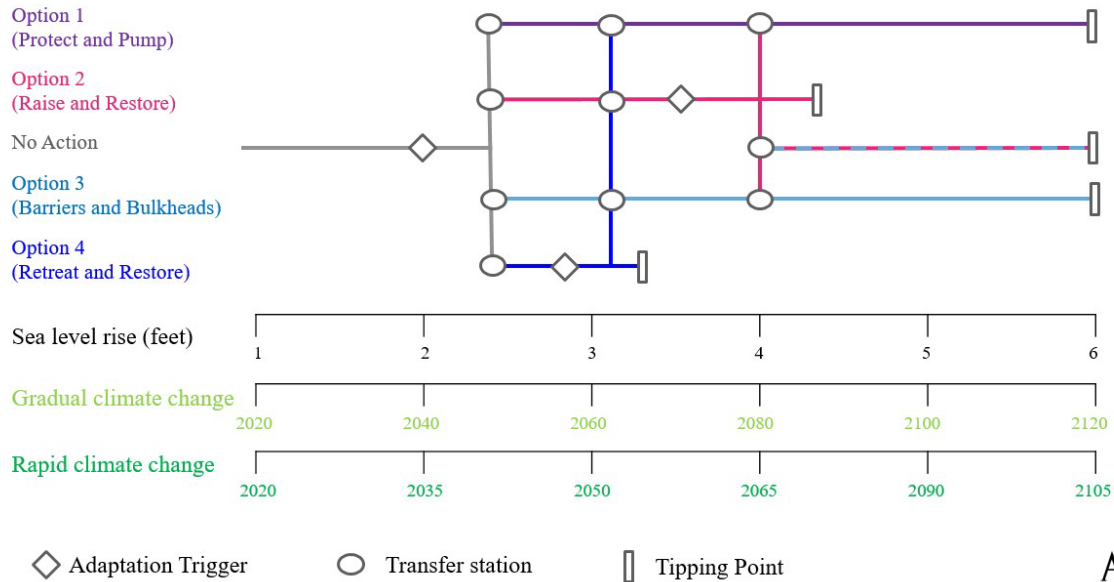
Option 4
(Retreat and Restore)

Objective: Ensure adequate infrastructure capacity and *flood protection* for TOD area investments through 2100

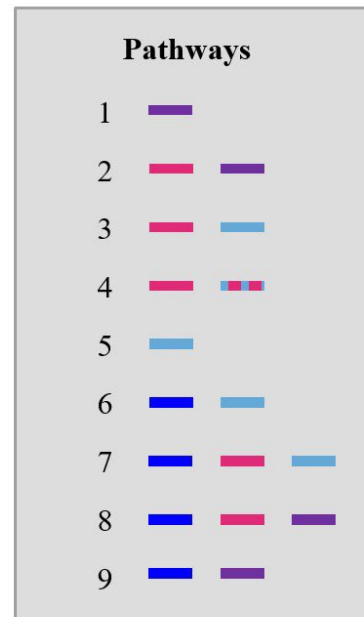
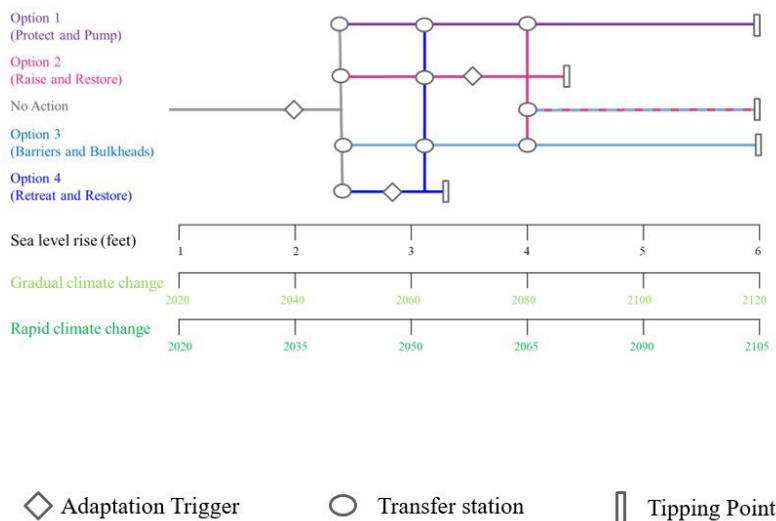


ARUP

Flexible Adaptation Pathway - Map



Flexible Adaptation Pathways

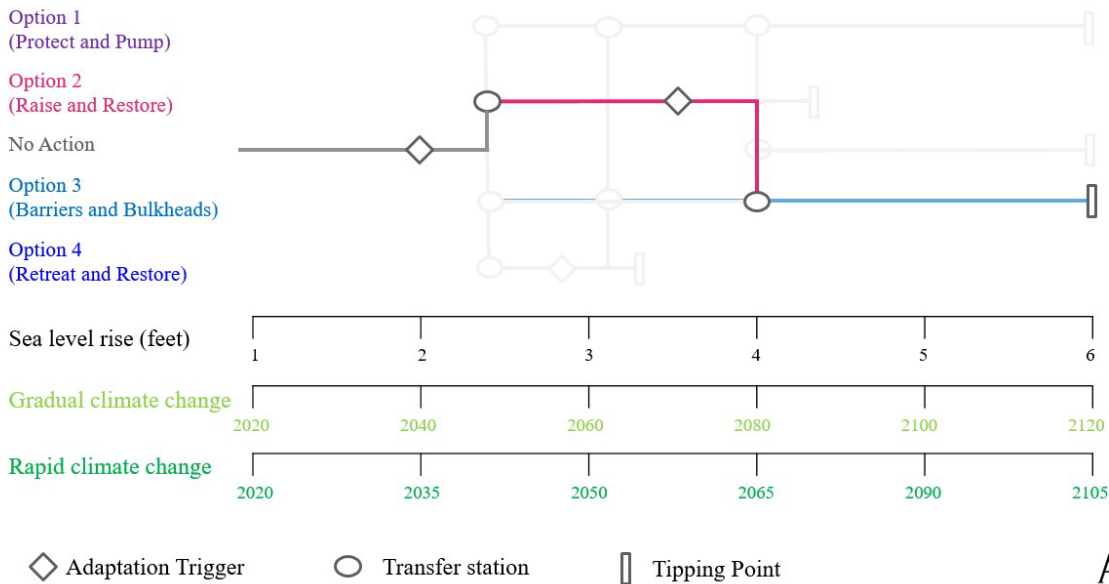


Flexible Adaptation Pathways - Selection

Pathways	Costs	Benefits	Net Present Value
1 	----	+++	\$
2  	-----	++++	\$\$\$
3  	---	+++++	\$\$\$\$\$
4   	----	+++++	\$\$\$\$
5 	---	+++	\$
6  	----	++	\$\$\$
7   	-----	+++	\$\$
8   	-----	++++	\$
9  	-----	++	\$

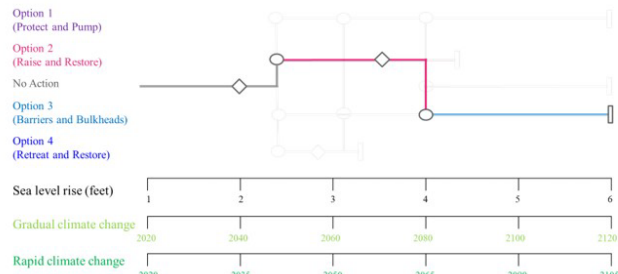
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Flexible Adaptation Pathway – Hypothetical



ARUP

Flexible Adaptation Pathway

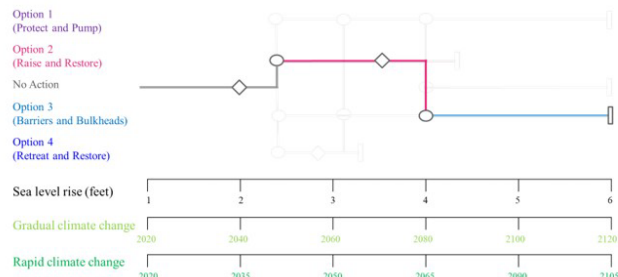


Core Findings (Hypothetical)

- Port and waterfront parcels require protection in all scenarios (no-regrets solution)
- Raising parcels is ineffective as a standalone solution (eventual transfer essential)
- Implementing seawalls or tide barriers too early could be economically inefficient
- Restoration combined with protection leads to co-benefits and high NPV
- Upfront costs of hard infrastructure can be deferred but only temporarily
- Early commitment to protection or retreat focused options promote path-dependence

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Flexible Adaptation Pathway



Trigger	Action (Hypothetical)
SLR 1ft 2020-2030	• Initiate comprehensive flexible adaptation pathways study
SLR 2ft 2030-2040	• Raise all waterfront parcels • Restore lower Iwilei wetland
SLR 3ft 2040-2060	• Install pump stations
SLR 4ft 2060-2080	• Construct tidal barriers • Reinforce waterfront bulkheads
SLR 5ft 2070-2100	• Monitoring
SLR 6ft 2080-2120	• Evaluate future plans

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Flexible Adaptation Pathways - Benefits

- Providing flexibility to adapt infrastructure planning to uncertain climate change outcomes
- Avoiding lock-in decisions and identifies near-term ‘no regret’ options
- Clearly outlining future decision (trigger) points for investment
- Presenting approachable framework for cost-benefit analysis
- Mapping out achievable pathways towards successful future outcomes

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Flexible Adaptation Pathways

An approach for Sea Level Rise and Flood Infrastructure

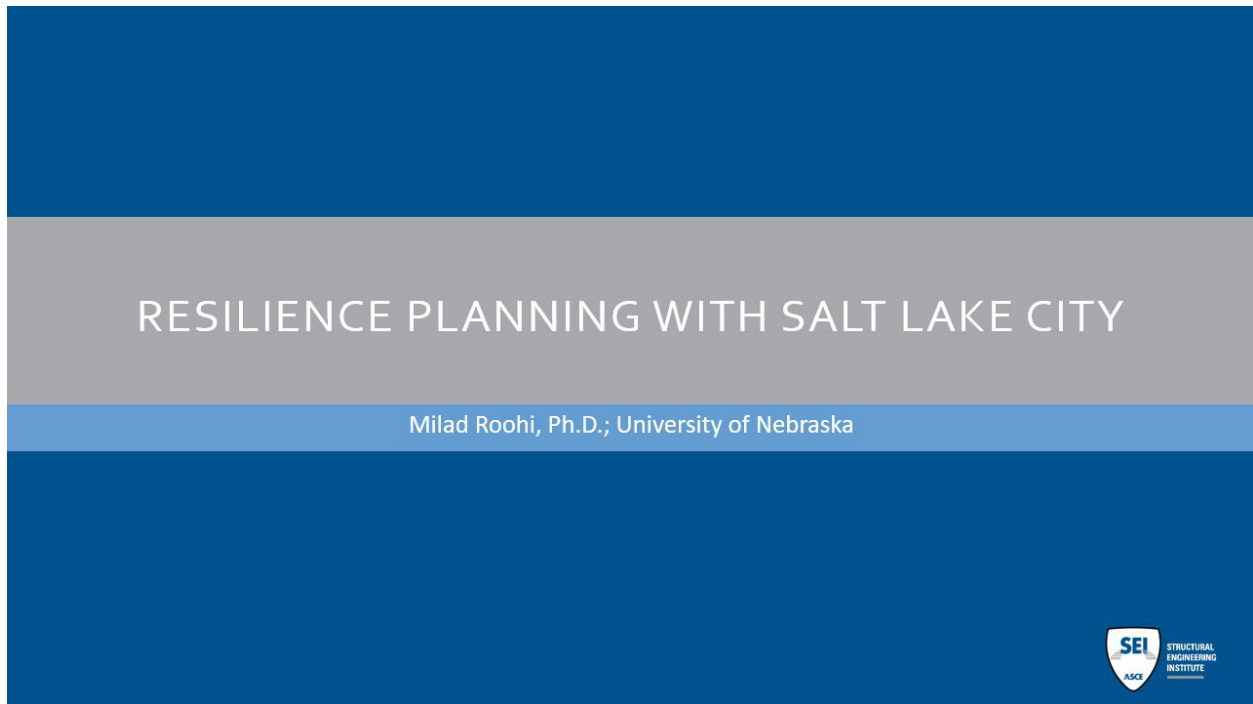
Project Snapshot Honolulu, Hawaii

Jack Hogan, PE
Jack-W.Hogan@arup.com



ARUP

B.2.1.8. Case Studies: Resilience Planning with Salt Lake City; Milad Roohi



SEI/NIST Forward Looking Codes and Standards:
Adaptation and Resilience Workshop
Oct 29-30, 2025

Resilience Planning with Salt Lake City

Milad Roohi, Ph.D.
Assistant Professor,
Director of Smart Resilient Infrastructure and Urban Systems (SiRIUS) Lab
Durham School of Architectural Engineering and Construction
University of Nebraska-Lincoln,

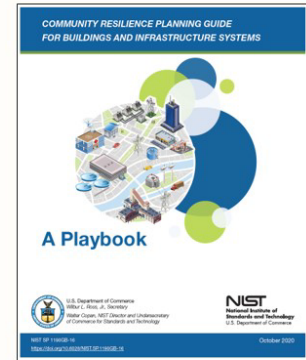


NIST CENTER FOR RISK-BASED COMMUNITY RESILIENCE PLANNING



Infrastructure and Community Resilience Planning
A Co-creation Process Bridging Science, Systems, and Stakeholders

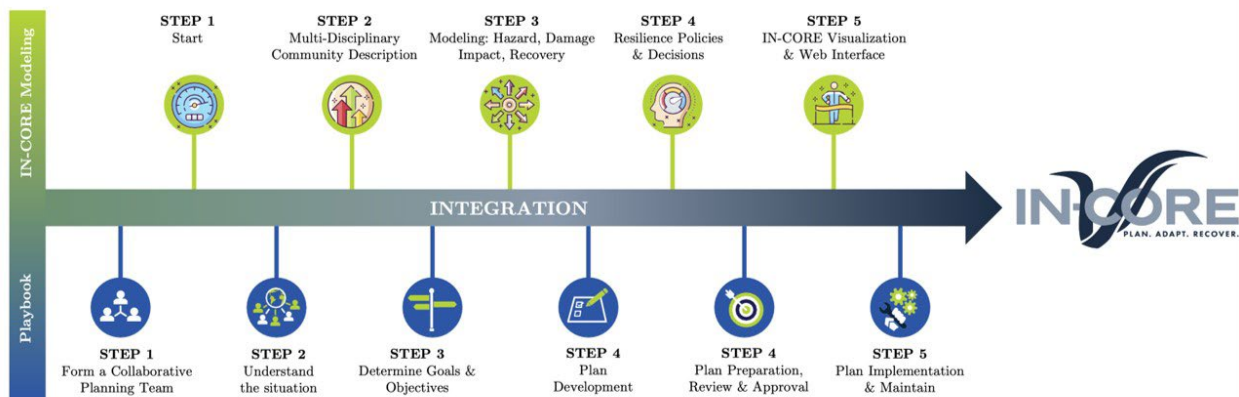
- ❑ Resilience is no longer a **top-down engineering challenge**.
- ❑ Today, it's a **multi-directional process** grounded in **co-creation**; where engineers, planners, policymakers, and communities collaboratively shape solutions tailored to local contexts.



NIST's six-step Community Resilience Planning Guide was a milestone in this shift. Developed with input from over 250 stakeholders, it reframed resilience as a shared process:

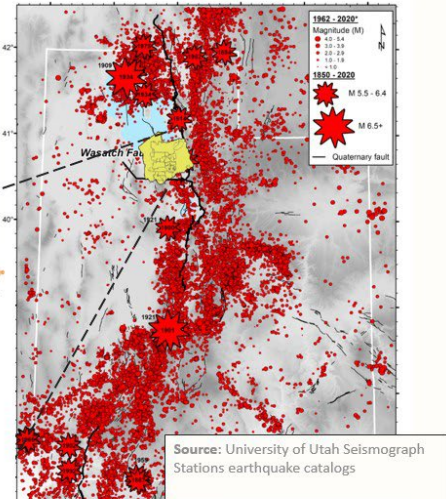
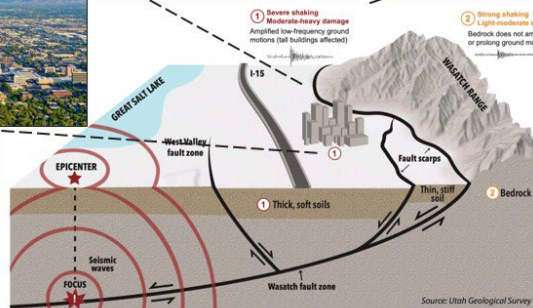
- ❑ Cross-sector planning teams form the foundation
- ❑ Community priorities guide performance goals
- ❑ Technical tools support-but don't dictate-decisions

Integrating the Playbook and IN-CORE



Salt Lake County (SLC), Utah

Population of 1.18 million (2020 US Census) and **284,000 buildings**. SLC is located along the **Wasatch Fault**, Utah's most active fault, and extends about 240 miles from southern Idaho to central UT.



Earthquakes in the Utah region 1850–2020.
Starbursts show mainshock earthquakes



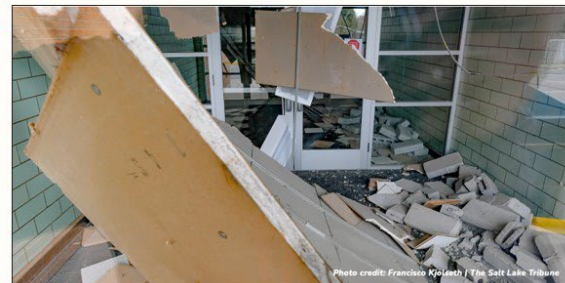
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Unreinforced Masonry Buildings (URMs)

URMs are Utah's most vulnerable buildings

- ☐ URMs are constructed without reinforcing steel, primarily using brick or block
- ☐ They pose a significant earthquake risk and are the primary source of deaths and injuries during major earthquakes
- ☐ While Utah's adopted codes have not allowed URM construction since 1976, **over 140,000 URMs still exist in Utah, making up 20% of occupied buildings!**

West Lake Junior High School suffered extensive damage during the Magna 5.7 earthquake of 2020. If remote learning due to the COVID-19 pandemic had not kept students home, it's likely that this damage would have caused injuries or even death.



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Seismic Risk Reduction and Mitigation Efforts

- ❑ "Fix the Bricks" program (SLC's Emergency Management Team)
- ❑ Utah is conducting a statewide inventory of URM construction in public K-12 schools.
- ❑ Initial findings indicate that approximately 130 school campuses in Utah have URM.
- ❑ Around 76,000 Utah children attend these schools with URM, posing potential earthquake risks.



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Seismic Mitigation for Achieving Community Resilience Goals

Objective: develop a multidisciplinary approach for developing mitigation policies to align individual structural retrofits with broader community resilience goals.

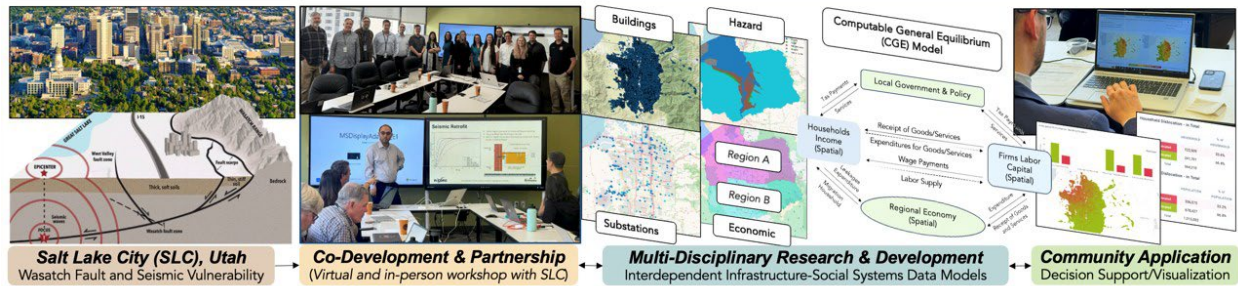


- ❑ Upgrading buildings that are not compliant with building codes is crucial to ensure a quick post-event recovery to social and economic systems



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Co-Creation Process with SLC



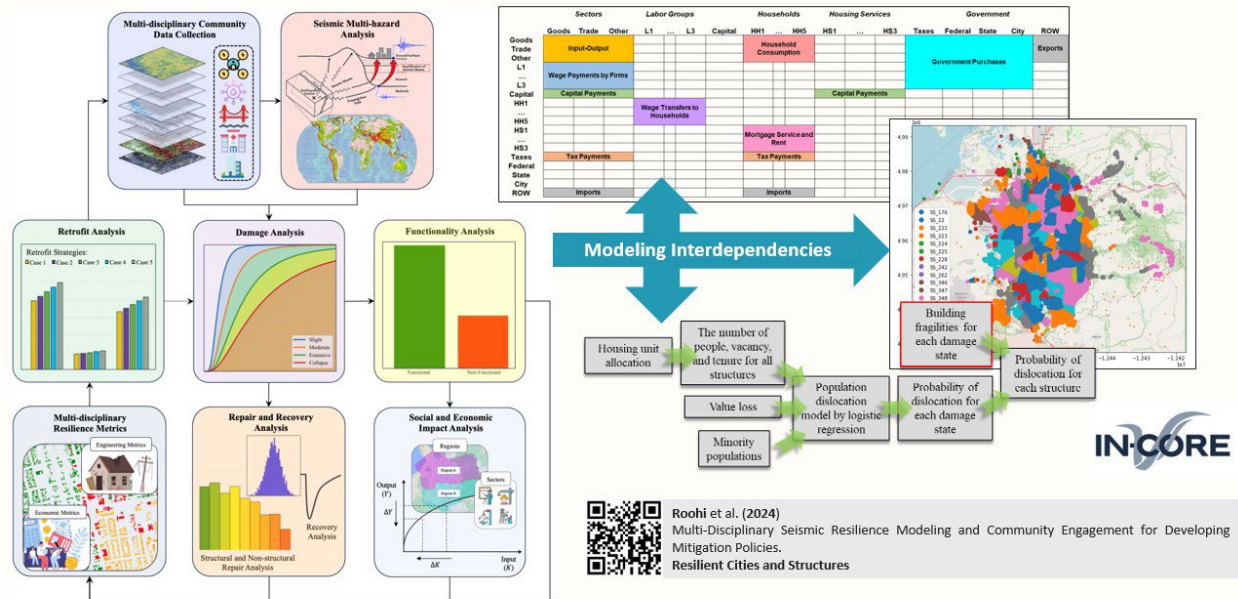
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SLC Workshops



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Method of Approach for Community Resilience Modeling



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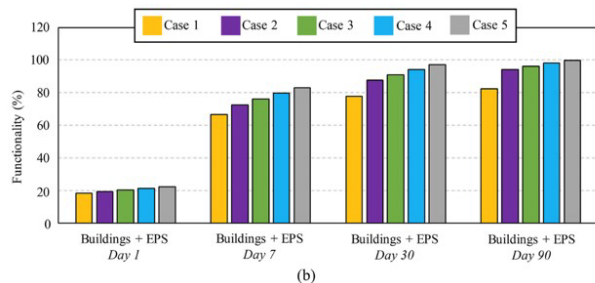
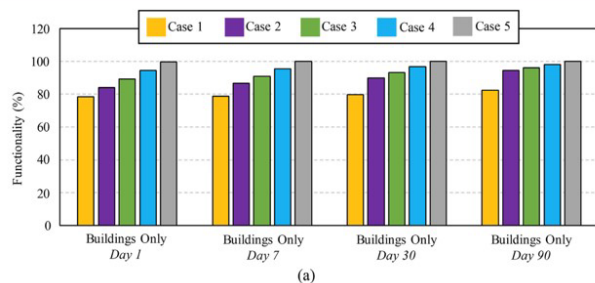
Seismic Retrofit and Functional Recovery Metrics

We considered Wood or Metal Deck Diaphragms Retrofit and the retrofit costs in estimated using the FEMA BCA Tool (version 6.0)

Case 1 is the baseline and **Cases 2, 3, 4, and 5** are the cases that have 25%, 50%, 75%, and 100%, respectively, of the URM buildings



Sediek, Roohi, van de Lindt (2024)
A Decision Support Methodology for Seismic Design Requirements of Buildings to Achieve Community-Level Resilience Metrics
ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering



222

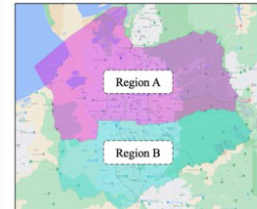
Employment Impact Metrics

Case Analysis	Region	Base Value	Employment Impact				
			Case 1	Case 2	Case 3	Case 4	Case 5
$M_w 7.1$	A	488,950	-13,115	-11,962	-10,795	-9674	-8575
	B	229,468	-2.68 %	-2.45 %	-2.21 %	-1.98 %	-1.75 %
$M_w 6.5$	A	488,950	-5396	-4998	-4600	-4209	-3825
	B	229,468	-2.35 %	-2.18 %	-2.00 %	-1.83 %	-1.67 %
$M_w 6.5$	A	488,950	-8028	-7093	-6172	-5246	-4369
	B	229,468	-1.64 %	-1.45 %	-1.26 %	-1.07 %	-0.89 %
$M_w 6.5$	A	488,950	-3113	-2790	-2464	-2153	-1845
	B	229,468	-1.36 %	-1.22 %	-1.07 %	-0.94 %	-0.80 %

Case 1 is the baseline and **Cases 2, 3, 4, and 5** are the cases that have 25%, 50%, 75%, and 100%, respectively, of the URM buildings

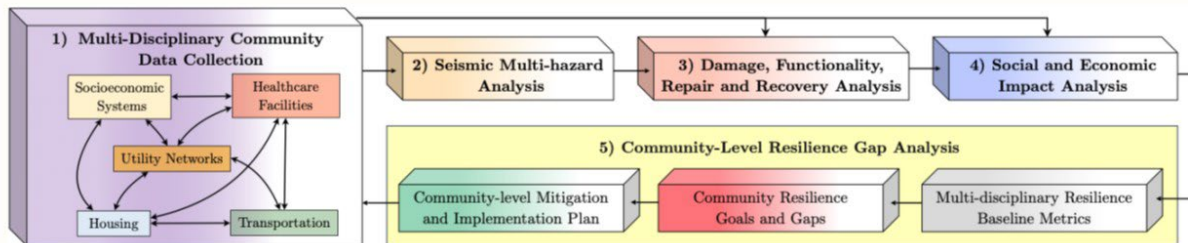


Roohi et al. (2024),
Multi-Disciplinary Seismic Resilience Modeling and Community Engagement for Developing Mitigation Policies.
Resilient Cities and Structures



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Decision-Support Framework

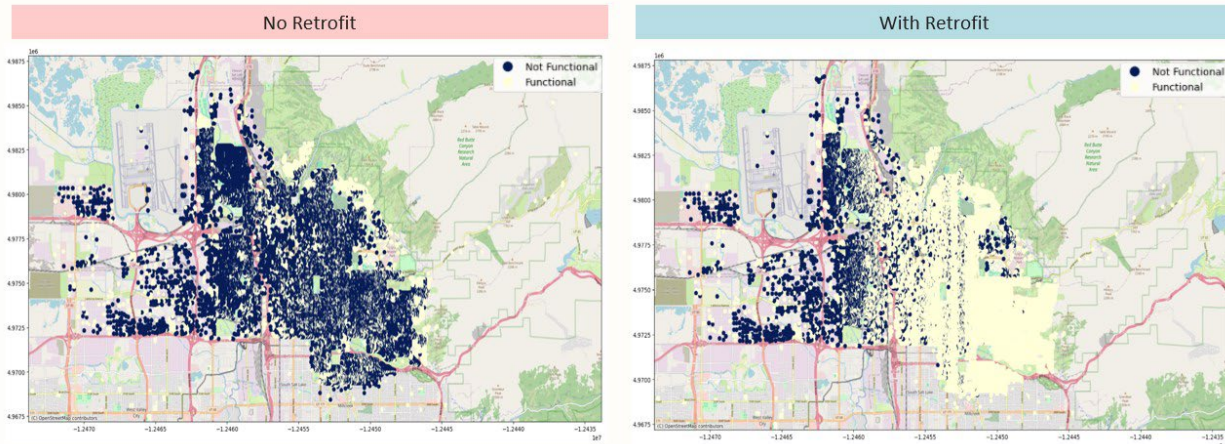


Roohi et al. (2024), Multi-Disciplinary Seismic Resilience Modeling and Community Engagement for Developing Mitigation Policies. Resilient Cities and Structures

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Sample Simulation Results for Salt Lake City Building Functionality

1 billion \$ Budget – M_w 7.1 EQ



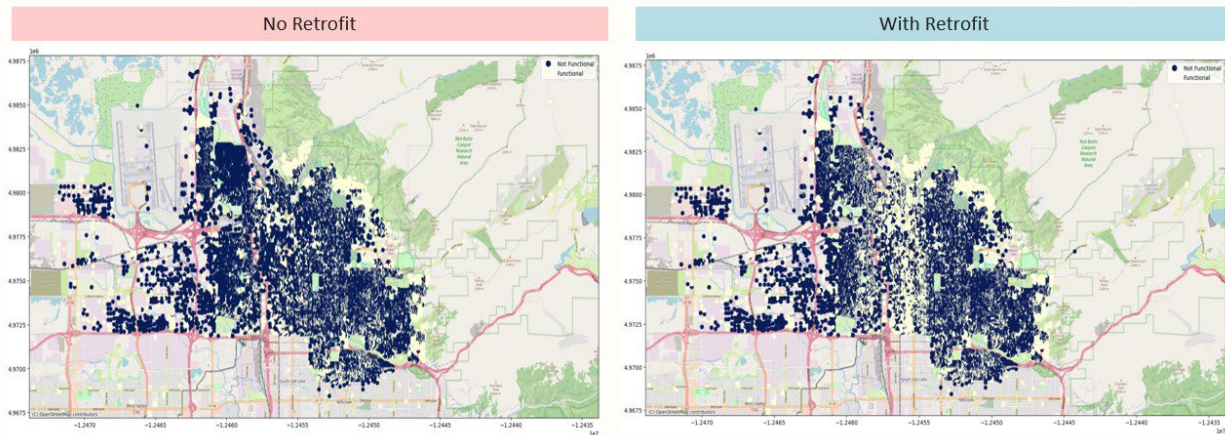
Sediek, Roohi, van de Lindt (2024). A Decision Support Methodology for Seismic Design Requirements of Buildings to Achieve Community-Level Resilience Metrics. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering.



225

Sample Simulation Results for Salt Lake City Building Functionality

300 million \$ Budget – M_w 7.1 EQ



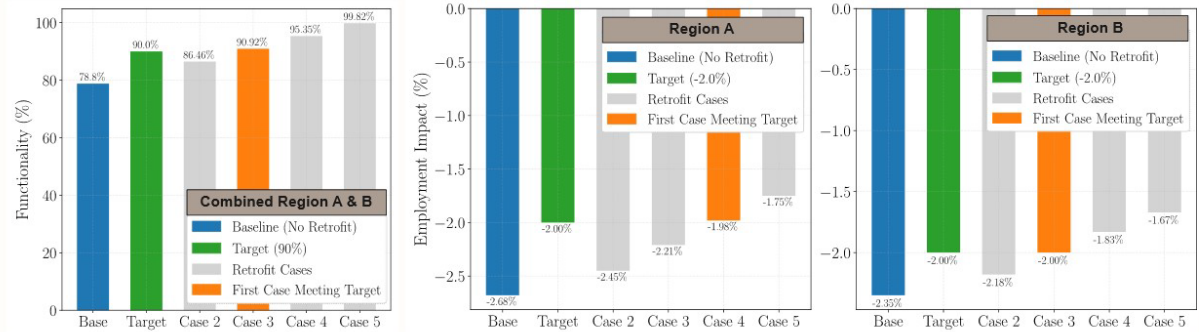
Sediek, Roohi, van de Lindt (2024). A Decision Support Methodology for Seismic Design Requirements of Buildings to Achieve Community-Level Resilience Metrics. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering.



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Resilience Gap Analysis

EQ	Metrics	Region	Baseline (Case 1)	Target	Gap
Mw 7.1	Buildings Functional (7-day recovery)	Combined	78.00%	90.00%	12.40%
	Employment	A	-2.68% (-13,115 jobs)	< -2.0%	+0.68% (+3,336 jobs)
		B	-2.35% (-5,396 jobs)	< -2.0%	+0.35% (+1,199 jobs)

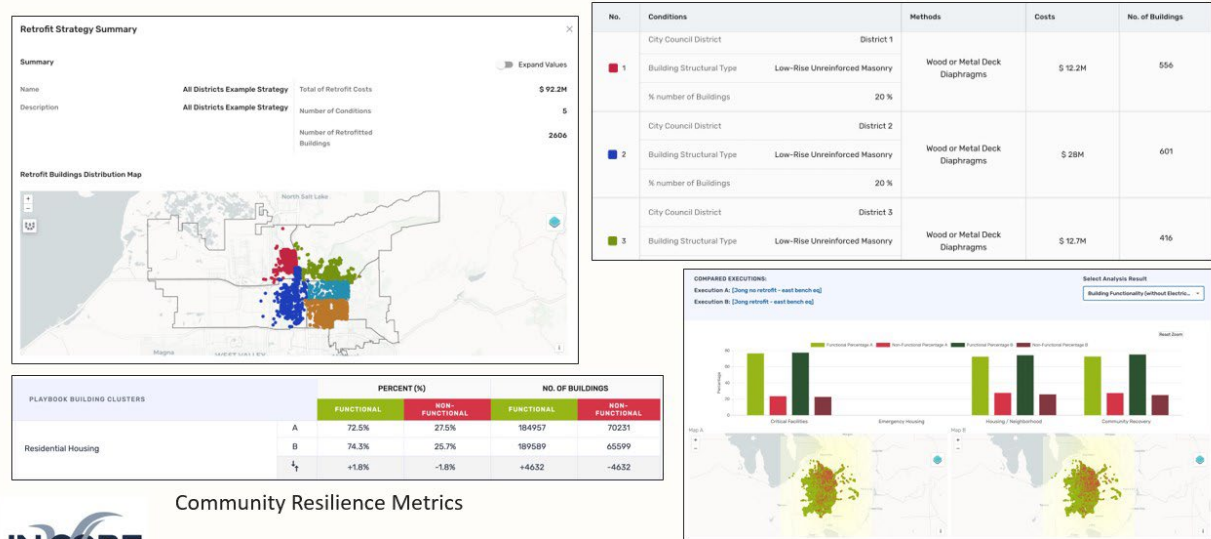


Roohi et al. (2024). Multi-Disciplinary Seismic Resilience Modeling and Community Engagement for Developing Mitigation Policies
Resilient Cities and Structures

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SLC Community Application

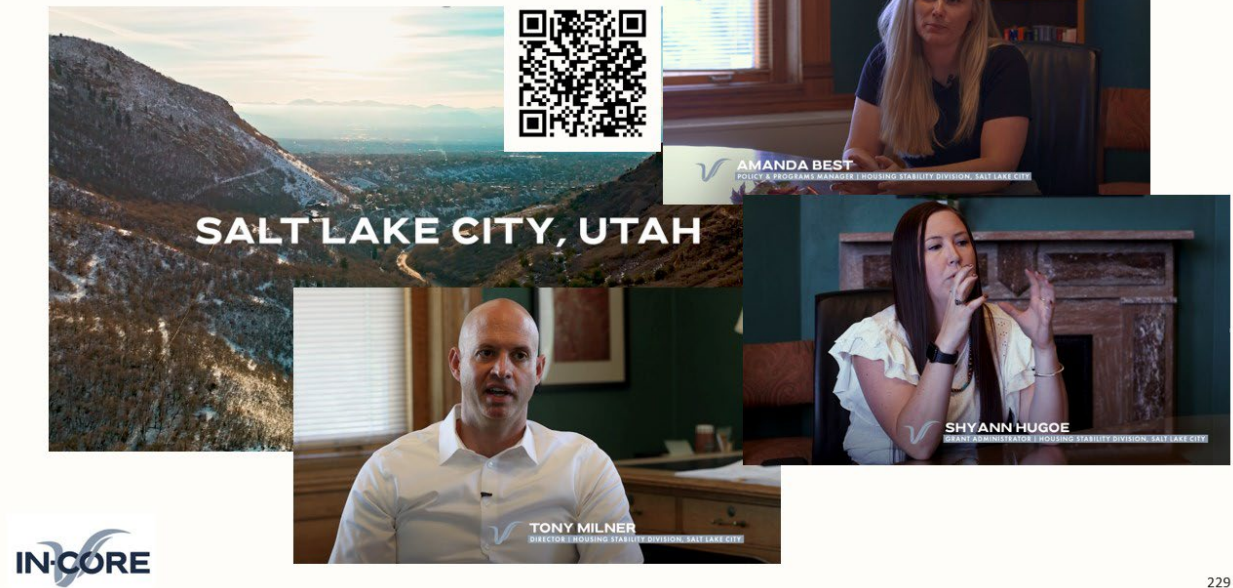
Retrofit Strategy Builder



Community Resilience Metrics

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SLC Testimony



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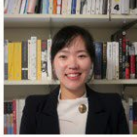
Summary and Conclusions

- ❑ Enhancing resilience requires **more than traditional approaches**. By **combining emerging algorithms with community data and insight, adaptive frameworks** can be developed to **reflect the unique needs, risks, and strengths of each community**.
- ❑ This research and partnership represents **a step forward in resilience science and practice**, emphasizing the importance of data-driven insights coupled with local knowledge and community engagement.
- ❑ This will help **US communities minimize service interruptions, optimize mitigation, response, and recovery strategies**.



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Acknowledgement

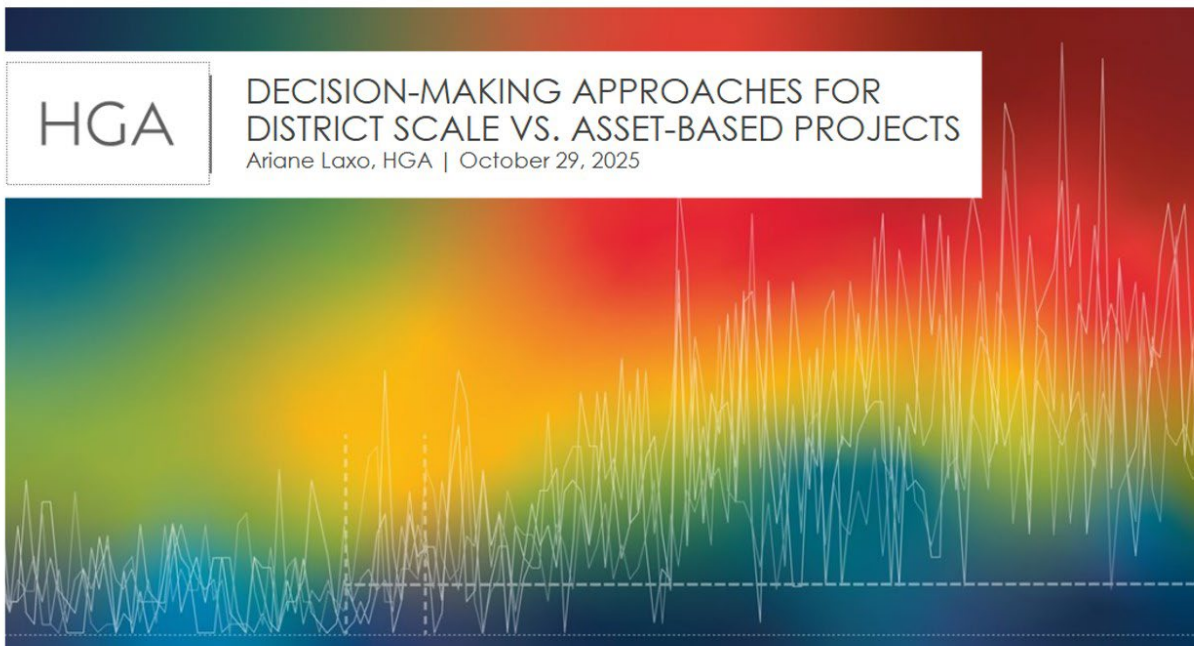
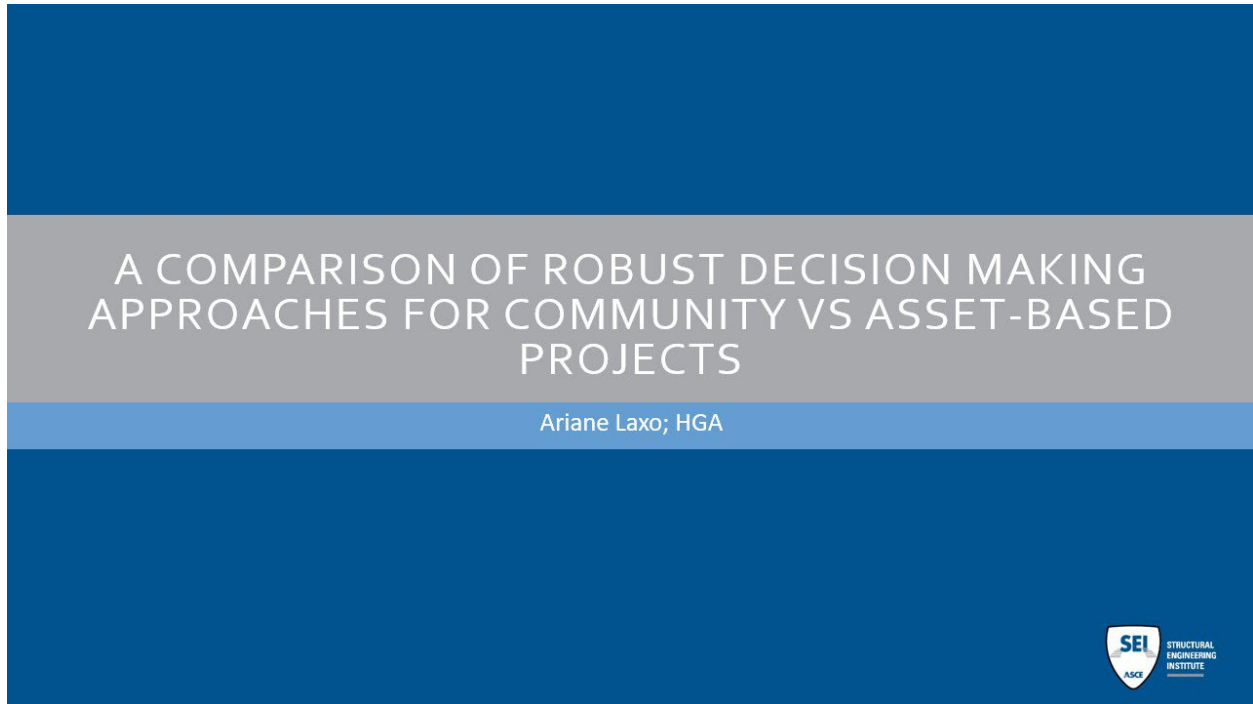
Engineering	CSU	UNL	Cairo University	Computer Science	NCSA UIUC	NCSA UIUC	NCSA UIUC
							
	Dr. John van de Lindt	Saeid Ghasemi	Dr. Omar A. Sediek		Dr. Jong Lee	Chris Navarro	Chen Wang
Economic Science	CSU	CSU	CSU	Urban Planning	SBU	FAU	Social Science
							
	Dr. Hwayoung Jeon	Dr. Martin Shields	Dr. Harvey Cutler		Dr. Sara Hamideh	Dr. Melina Matos	Dr. N. Rosenheim



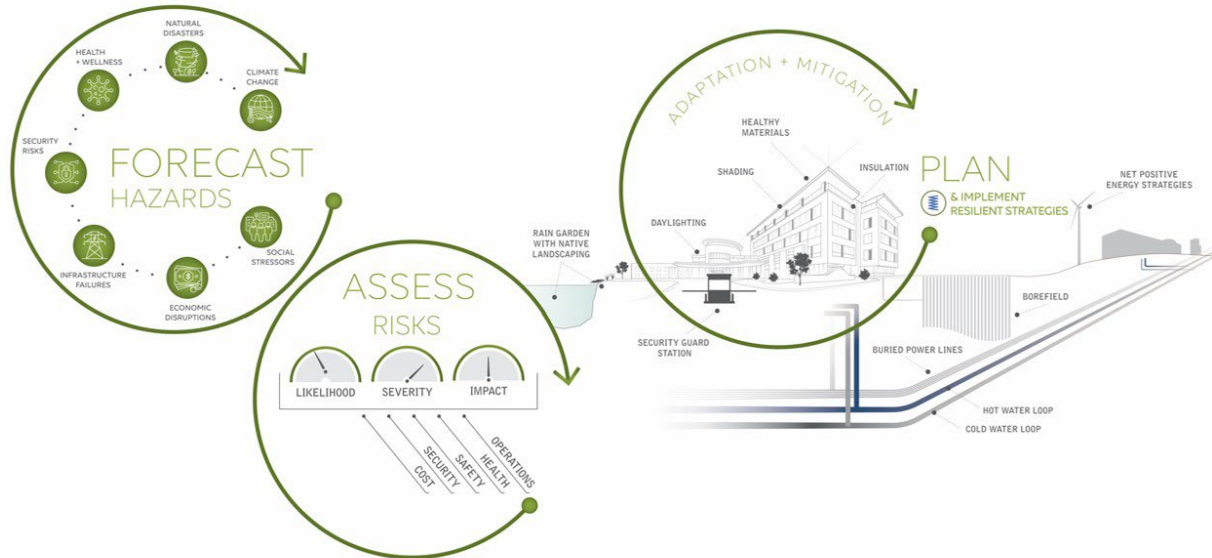


NATIONAL INSTITUTE OF
STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

B.2.1.9. Case Studies: A Comparison of Robust Decision Making Approaches for Community vs Asset-Based Projects; Ariane Laxo

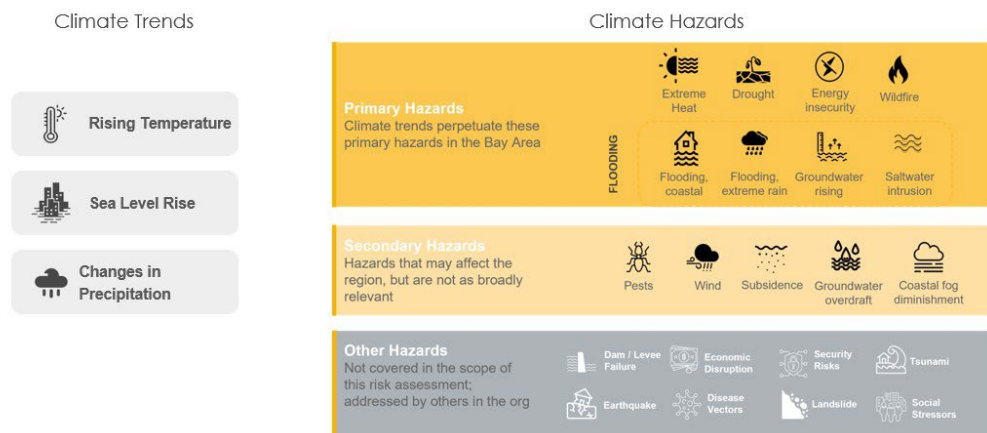


Planning for Resilience



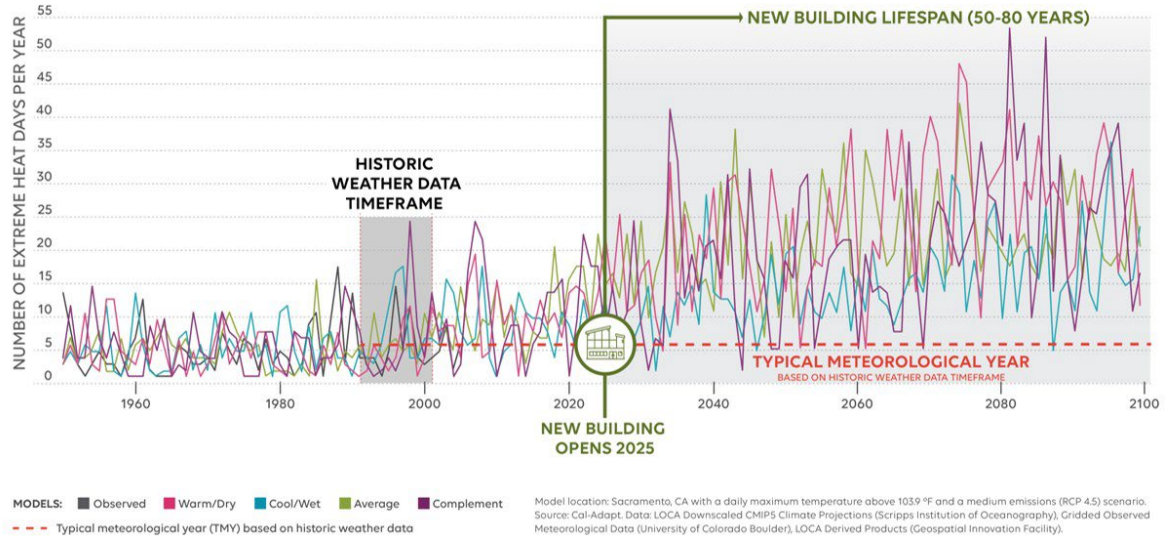
Forecast: All Hazards Approach

Bay Area Example

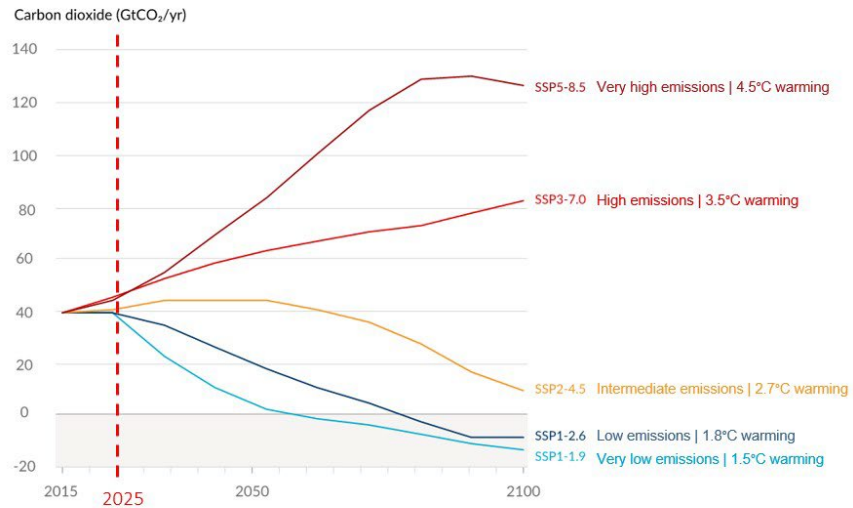


Graphic by: HGA

Standard Practice: Historical Weather



Evaluate Multiple Scenarios



Source: 2021 IPCC AR6 Summary for Policy Makers

Scenario Planning

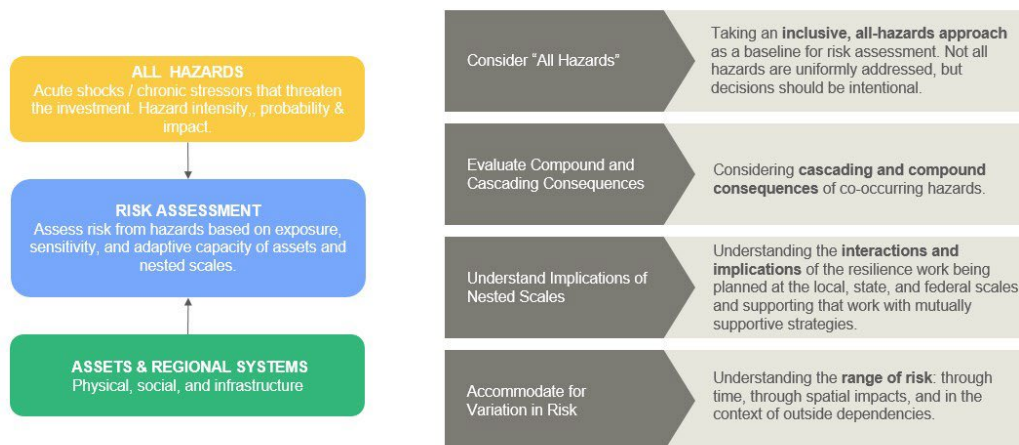
Scenario planning constructs scenarios as *descriptions of possible alternative futures* and/or the causal events and trajectories that can lead to different future states. These scenarios are often presented in the form of narratives or storylines and are not predictions of what the future will look like, but *plausible representations* of possible futures based on drivers of change.

Silvia Serrao-Neumann et al., 2019

Scenario planning for climate change adaptation for natural resource management

Assess: Risk Assessment

Guiding Principles



Assess: Risk Assessment

Consider the range of likely impacts

Human	Human physical and mental health may be negatively affected. Health impacts may lead to a reduction in productivity, increases in remote work, and more employee sick days.
Program	Indoor and outdoor programming may be paused indefinitely or need to be relocated to new spaces. Programs may also have less capacity, less efficiency, and less participation.
Operations	District and building operations may be paused indefinitely or have less efficiency and capacity.
Physical Assets	Buildings and infrastructure may have mild to severe damage. Materials and systems may have shorter lifespans and/or worse performance.

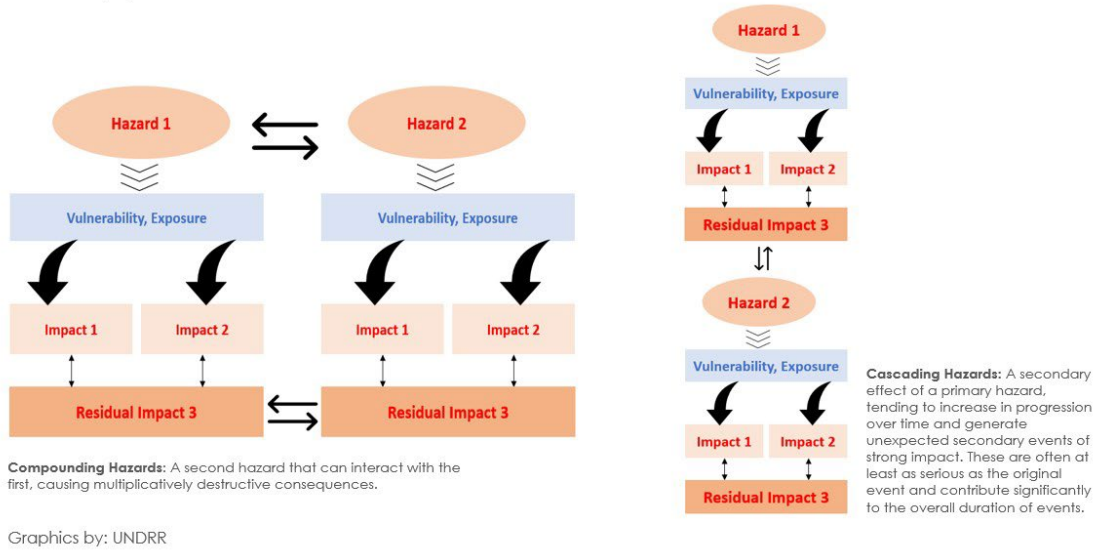
Assess: Risk Assessment

Begin with the most vulnerable communities

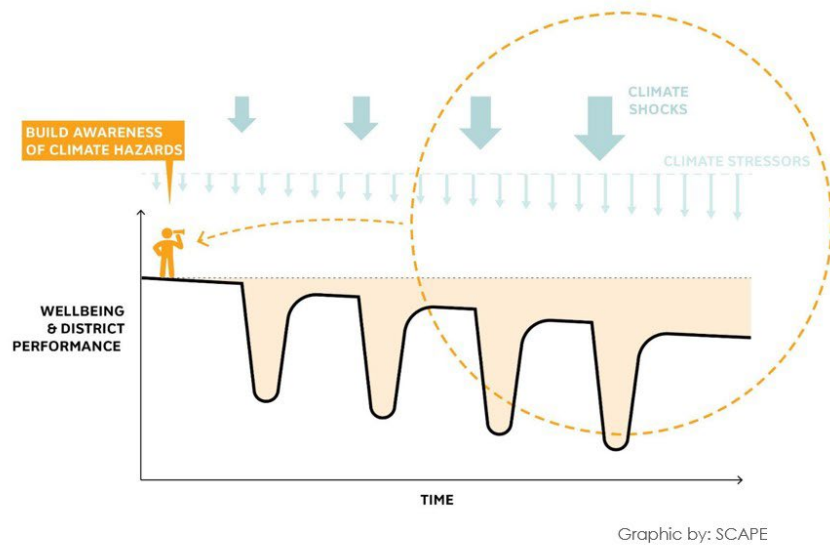


Assess: Risk Assessment

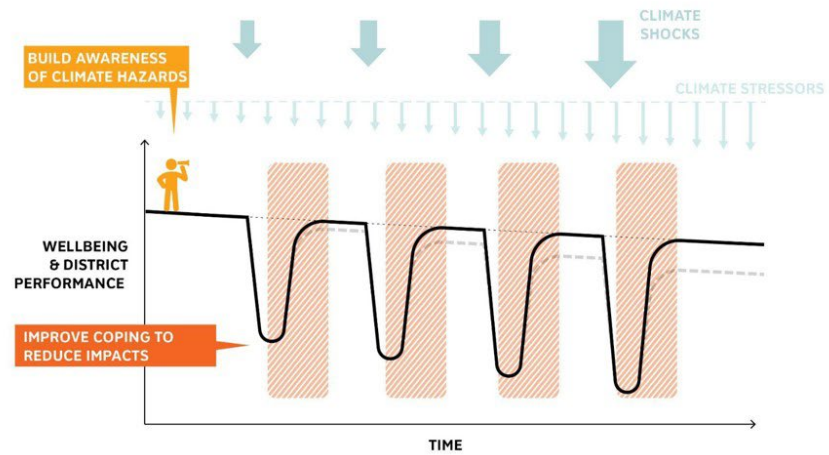
Disasters multiply and cascade risks



Plan: Build Awareness

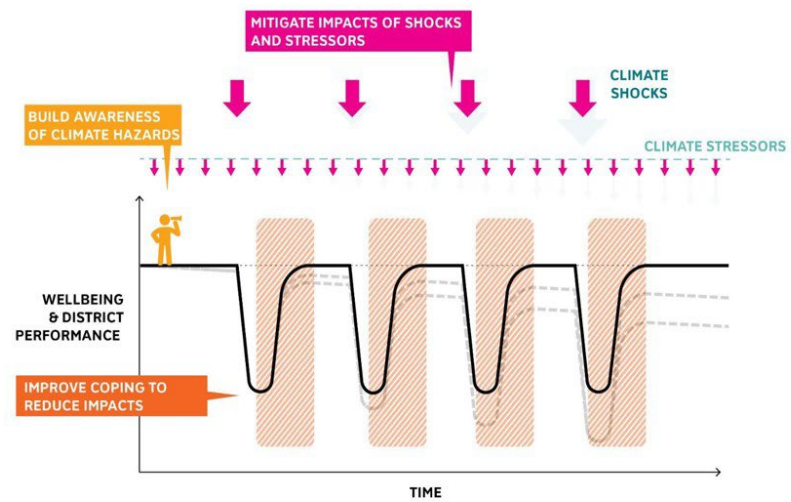


Plan: Improve Coping Capacities



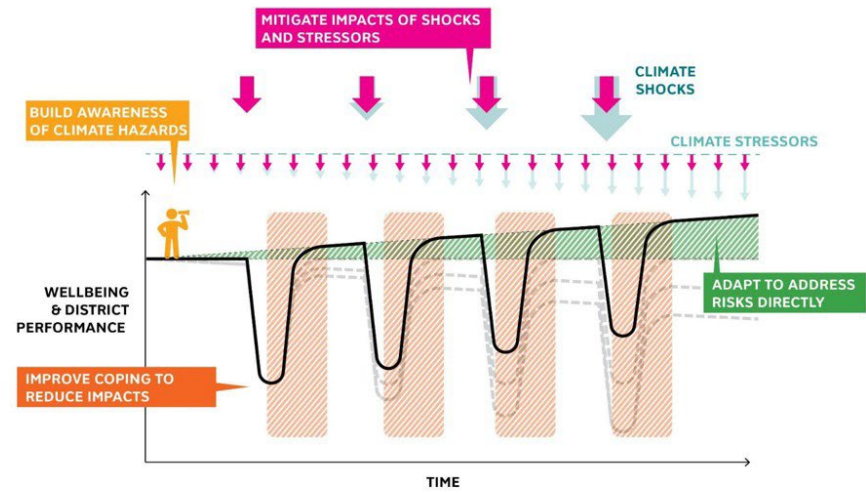
Graphic by: SCAPE

Plan: Mitigate Impacts



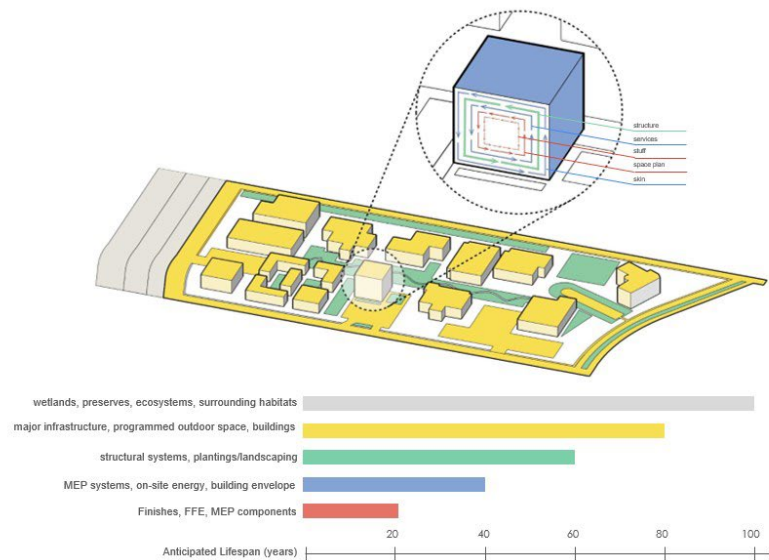
Graphic by: SCAPE

Plan: Adapt to Risks



Graphic by: SCAPE

Timescale & System Lifespan



Resilience Across Scales: California



Graphic by: HGA

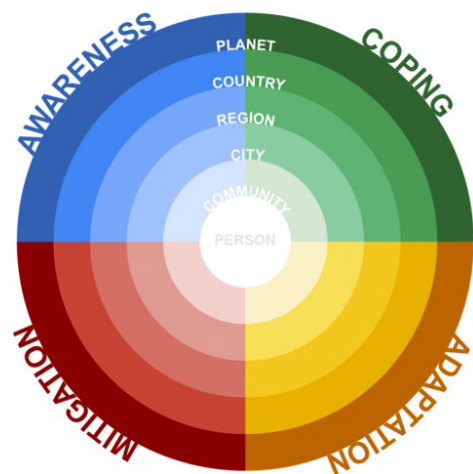
Resilience Across Scales

Awareness: engage stakeholders and establish ongoing assessments to raise understanding of climate and other hazards, laying the groundwork for informed decision-making.

Coping: provide immediate resources and strategies to individuals and organizations to manage current exposures and sensitivities to climate risks.

Impact mitigation: reduce near- and mid-term impacts of escalating hazards by intercepting risks through targeted interventions based on present vulnerabilities.

Adaptation: adjust built environments and infrastructure, behaviors, policies, and financial systems to prepare for and respond to evolving climate threats through long-term adaptation pathways.



Graphic by: Climate Adaptation Partners and HGA

[Tools](#)
[Data](#)
[Help](#)
[Blog](#)
[Events](#)
[About](#)

Explore and analyze climate data from California's Climate Change Assessments

Cal-Adapt provides the public, researchers, government agencies and industry stakeholders with essential data & tools for climate adaptation planning, building resiliency, and fostering community engagement.

Cal-Adapt is evolving!

Learn about the Cal-Adapt enterprise and our mission to support California's climate change initiatives and preview our future plans.

[READ MORE](#)

Looking for climate data for California's Fifth Climate Change Assessment? Visit the [blog post on accessing next generation climate data](#)

Explore interactive maps and charts

Visualize and download **downscaled CMIP5 climate data** and other datasets developed for California's [Fourth Climate Change Assessment](#). Read our [Get Started](#) guide to learn more about working with climate data.

Designed for a **broad range of users**.

Local Climate Change Snapshot Tool

Quickly view a variety of climate data for a city, county, or other place.

Explore all Climate Tools

Explore data on temperature, precipitation, snowpack, wildfire, and more.

Download Data

Download Fourth Assessment climate data in NetCDF, GeoTIFF and CSV formats.

Latest on Cal-Adapt Blog

[Empowering Climate Resilience at the California Adaptation Forum 2023](#)

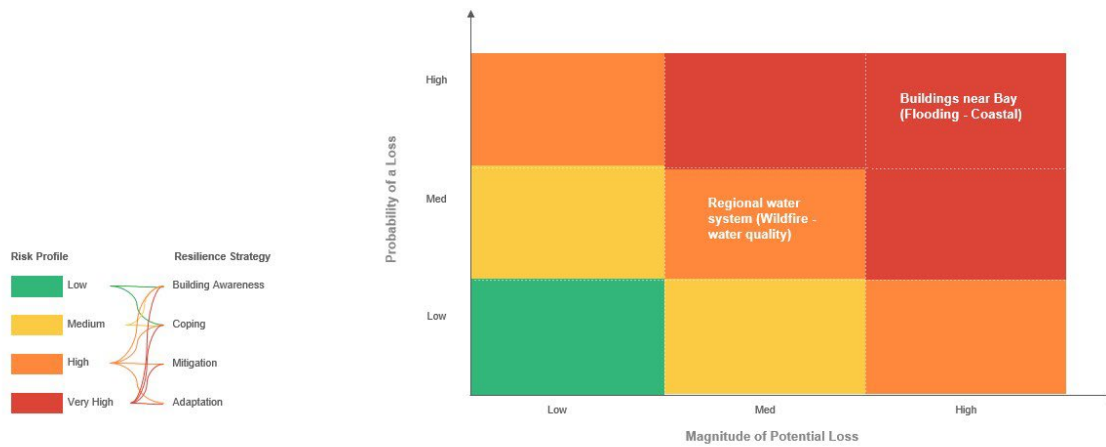
After two great sessions at the California Adaptation Forum in Pomona at the end of July, attendees at both of our Forum sessions had the chance to use Analytics Engine tools for the months of August and September.

[SEE ALL POSTS](#)

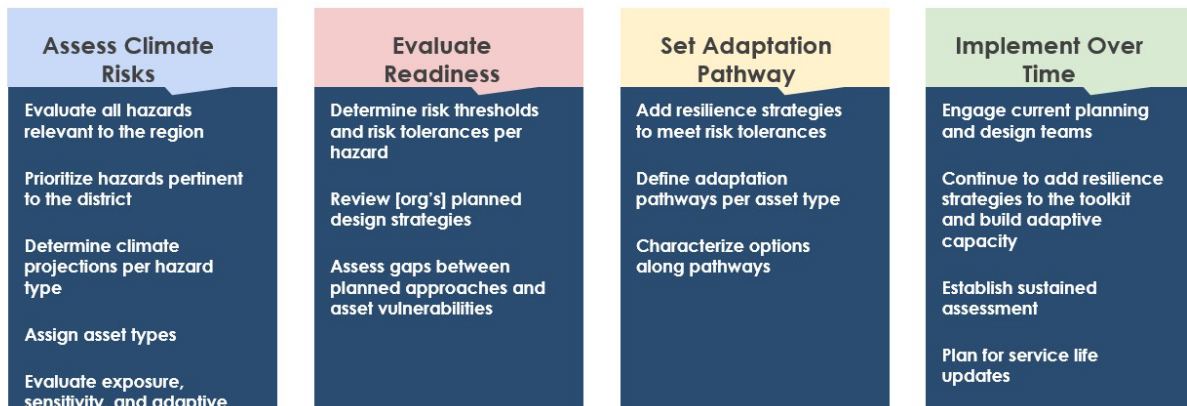
RISK TOLERANCE EXAMPLES

	Extreme Heat	Flooding	Drought	Wildfire	Energy Insecurity
People	No net increase in heat health events by managing exposure and readiness for coping with system failure.	No net increase in flood-related health events	No net increase in water demand beyond project targets	No net increase in smoke-related, or fire-related injury. No net loss of working hours during wildfire season.	No negative health impacts; No interruption to work
Buildings	No net increase in heat health events by managing exposure and readiness for coping with system failure.	No net occupancy loss of residential or workplace buildings. Sustained access/emergency egress.	Sustained access to potable water and flushing toilets during shelter in place events; no subsidence-driven losses; Maintenance of indoor air quality during high dust events	No net increase in smoke-related injury. No net loss of working hours during wildfire season.	No net loss in residential building functionality; Accessibility to cooling centers; Targeted drawdown on office functions to redirect resources toward residential buildings
Open Space	Heat management channeling	No net occupancy loss of residential or workplace buildings. Sustained access/emergency egress.	Sustained access to potable water and flushing toilets during shelter in place events; no subsidence-driven losses; Maintenance of indoor air quality during high dust events	Play, community gathering) and a plan to activate when outdoor environments are not safely occupiable due to smoke. Districts must manage ecosystems for wildfire readiness and recovery.	Targeted drawdown on office functions to redirect resources toward residential buildings
District Infrastructure	System readiness, in concert with passive strategies, for increased demand load	Demonstrable graduated flood response in alignment with flooding thresholds		Districts must have demonstrable capacity to manage smoke impacts on district infrastructure.	
Regional/ Municipal Systems	Preparation for city/municipal failures	Preparation for municipal failure and need to self-manage district resources for passive habitability and ongoing operations	Recognizing growing public water shortages, consider extent to which districts can be independent of municipal water systems	Districts must have backup resources for those services provided by the municipalities (water, power) that may be purposefully taken offline as part of preemptive measures or may lose capacity during redirection efforts for wildfire responses.	Districts must have ability to operate district infrastructure without reliance on municipal services for a designated period of time

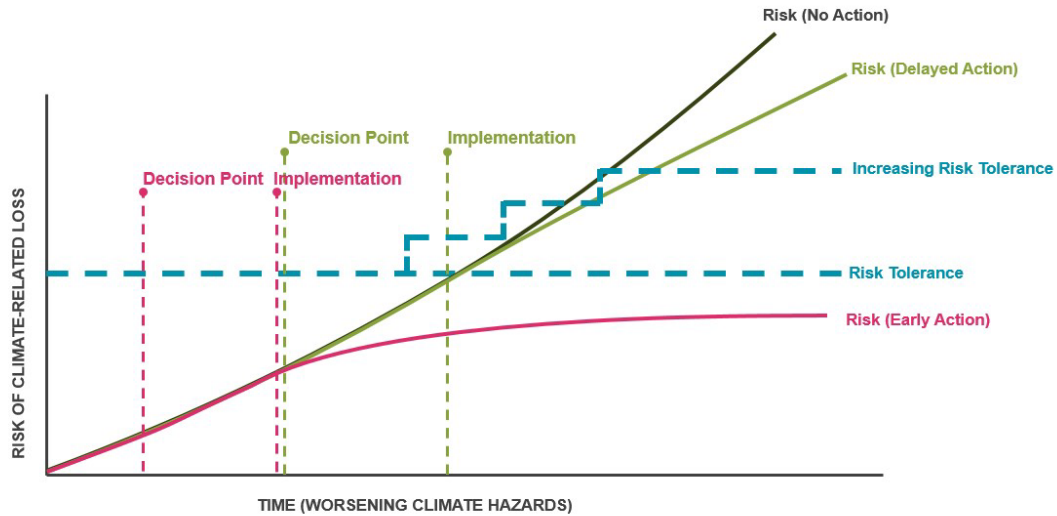
Risk Profile: Prioritizing action



Building Adaptation Pathways



Adaptation Pathways & Critical Decision Points



Example Adaptation Pathways

CODE pathway	Design guidelines Pathway	Sustainability goals Pathway	New Development Adaptation Pathway	Full Portfolio Adaptation Pathway
Meet existing code requirements	Meet current design guidelines	Meet sustainability goals; improve existing development risk awareness	Improve <u>new developments</u> to respond to climate hazards; increase engagement to build awareness and coping for risks	Improve new developments <u>and existing portfolio</u> to respond to climate hazards; increase engagement to build awareness and coping for risks

Open Space

Plant Stormwater Tolerant Species

DEFEND

Strategy Description:

Plant species characteristics are important in effective flood resilience strategies. Plant design should tend toward stormwater resistant species in areas at risk of flooding. These species will help reduce damage by encouraging the growth of root systems which stabilize banks and prevent erosion.

Performance Metrics:

- # STORMWATER TOLERANT PLANT SPECIES
- AREA COVERED BY STORMWATER TOLERANT PLANT SPECIES

Case Studies:

- [PLANTS FOR SWALES \(MINNESOTA STORMWATER MANUAL\)](#)
- [GEORGIA STORMWATER MANAGEMENT MANUAL](#)

Hazards Addressed:



Image Source: <http://www.3riverswetweather.org/>

Buildings

Dormant Buildings

ACCOMMODATE | RELOCATE

Strategy Description:

During hazard events buildings can be assigned to shut off or become dormant. This will allow for energy savings when there is an energy insecurity event. Buildings can be partially or fully dormant, and some active buildings may be assigned an altered program to accommodate for occupant needs. The system energy saved from the dormant buildings will allow for the preservation of cool buildings and program function during hazard events.

Performance Metrics:

- # OF DORMANT OR PARTIALLY DORMANT BUILDINGS
- # OF BUILDINGS WITH ALTERED PROGRAM

Case Studies:

- [BUILDING AMERICA SOLUTIONS CENTER DESIGN FOR EXTREME HEAT GUIDE](#)

Hazards Addressed:

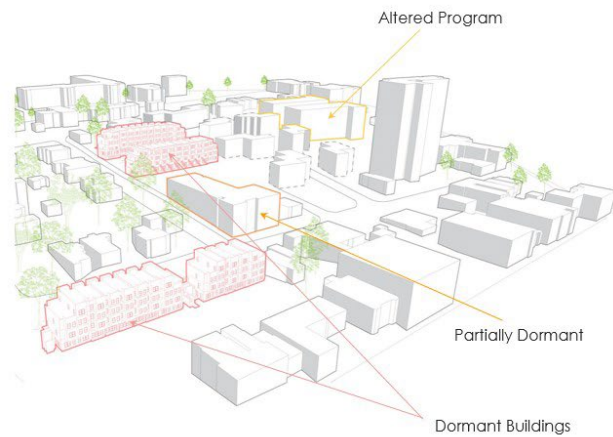


Image Source: <https://www.maparchitects.com/cottage-gardens-redevelopment>



**Climate Resilience Design Standards Tool**
ResilientMass Action Team



Project Search

Project Name

cell signaling

Advanced Query



Clear Search Search

1 Result:

New Project

Cell Signaling Technology
PrivateOffice

Created By: ArianeLavo
Towns: Manchester

Project #23914
Assets: 1

Cell Signaling Technology
Project Number: 23914 [\(Link\)](#)
Project Status: Not Scored

Tool Reporting Workflow

Hello, ArianeLavo 
[Terms of Use](#)
[Delete Project](#)

START HERE

LOCATE PROJECT
Project Located

PROJECT INPUTS
Missing Information

PROJECT OUTPUT

Overall Project Scores Output

The Ecosystem Service Benefits Score and Preliminary Climate Hazard Exposure Ratings presented below are assigned to the overall project, while the Preliminary Climate Risk Ratings and Climate Resilience Design Standards are asset-specific. The Scores and Standards are based on the questions previously answered and the location of the overall project. This information can be used to think critically about site suitability, regional resilience efforts, and adaptive site design for long-term climate resilience.

Environmental Justice

In Massachusetts, an Environmental Justice (EJ) neighborhood (census block group) is defined as meeting one or more criteria linked to the size of a census block group's minority populations, median household income, and language isolation. EJ neighborhoods typically include climate vulnerable populations, who

Does this project fall within mapped Environmental Justice neighborhoods?

No

Ecosystem Benefits

The purpose of this output is to provide an overall indication of the Ecosystem Service Benefits (ESB) provided by a project, through protection of natural resources and implementation of nature-based solutions. Natural systems and ecosystem services provide great economic value and social benefit, often untapped in non-resilient

Ecosystem Benefits Scores

High

Preliminary Climate Hazard Exposure Score

The purpose of the Exposure Score output is to provide a preliminary assessment of whether the overall project site and subsequent assets are exposed to impacts of natural hazard events and/or future impacts of climate change. For each climate parameter, the Tool will calculate one of the following exposure ratings: Not Exposed, Low Exposure, Moderate Exposure, or High Exposure. Click on the question mark to identify why your project location is

 Sea Level Rise/Storm Surge

 Extreme Precipitation

 Extreme Heat

Target Planning Horizon: 2070 ?

Return Period: 50-yr (2%) ?

Design Criteria Applicable for Phase I Building

✓ Projected Total Precipitation Depth & Peak Intensity for 24-hr Design Storms

Definition

Projected Total Precipitation Depth Values and Peak Intensity Methodology

How Total Precipitation Depth may inform Planning

How Total Precipitation Depth may inform Early Design

How Total Precipitation Depth may inform Project Evaluation

Limitations for Projected Total Precipitation Depth & Peak Intensity, Standards, and Guidance

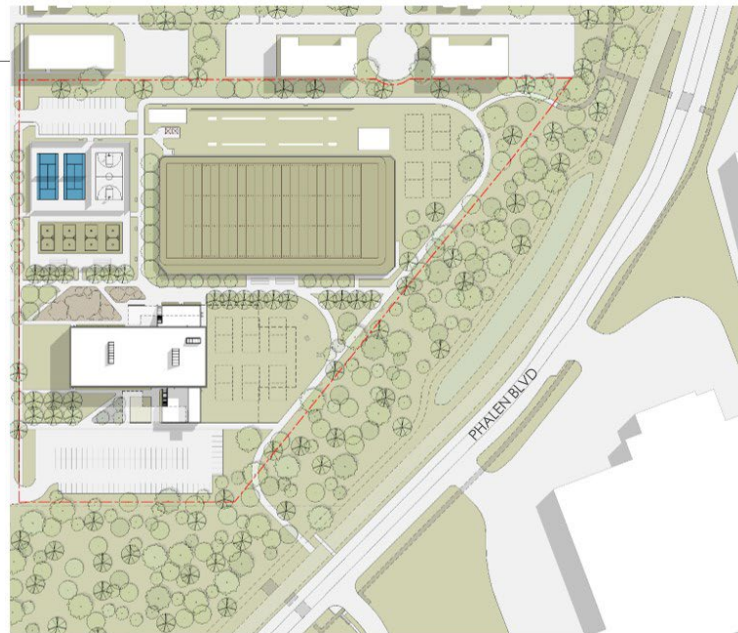
Design Criteria Not Applicable for Phase I Building

✗ Projected Riverine Peak Discharge & Peak Flood Elevation

Co-benefits of sustainability & resilience



Community Center
City of St Paul, MN



Resilience Hub

Operating modes:
1. Normal (99.9%)
2. Outage

RESILIENCE HUBS

RESILIENCE HUBS use a physical space - a building and its surrounding infrastructure - to meet numerous goals, both physical and social. Resilience hubs are an opportunity to efficiently improve emergency management, reduce climate pollution and enhance community resilience. These spaces also provide opportunities for communities to become more self-determining, socially connected, and successful in the long-term. This document outlines initial thinking about essential elements of a Resilience Hub and how to begin planning for Hub development.



Resilience Hubs are community-serving facilities augmented to support residents, coordinate communication, distribute resources, and reduce carbon pollution while enhancing quality of life. Hubs can meet a myriad of physical and social goals by utilizing a trusted physical space such as a community center, recreation facility, or multi-family housing building as well as the surrounding infrastructure such as a vacant lot, community park, or local business. They provide an opportunity to effectively work at the nexus of community resilience, emergency management, climate change mitigation, and social equity while also providing opportunities for communities to become more self-determining, socially connected, and successful before, during, and after disruptions.

Resilience Hubs serve communities in three operating conditions: Normal (>99% of the time), Disruption and Recovery. To serve as a Resilience Hub, a community-serving facility will generally

require a series of upgrades to ensure that the facility meets the daily needs identified by community members while also being able to provide critical services in the event of a disruption, often including:

- Access to electricity, heating and cooling
- Food, tools, resources, and sometimes shelter
- Water
- Information, communication infrastructure, and a trusted set of "Hub managers" to streamline information sharing
- Logistical coordination with partner groups that provide aid and post-disruption support
- Access to basic health and medical supplies

Community facilities typically require enhancements and upgrades that improve their capacity to provide service in all three operating conditions (everyday, disruption, and recovery). Upgrades can range in complexity and cost. Some may be as simple

as provisioning additional materials, whereas others may be as sophisticated as installing hybrid resilience power solutions. Upgrades typically fall into five main categories:

While upgrades and services carry additional capital and operating expense for the facility, these investments can generate financial, sustainability, and social returns not only for the facility, but also for the surrounding community.



Resilient Programming and Services

Offering additional services and programs that build relationships, promote community preparedness, and improve residents' health and well-being.



Resilient Structure

Strengthening the resilience of the facility to ensure that it meets operational goals in all conditions.



Resilient Power

Ensuring reliable backup power to the facility during a hazard while also improving the cost-effectiveness and sustainability of operations in all three operating modes.



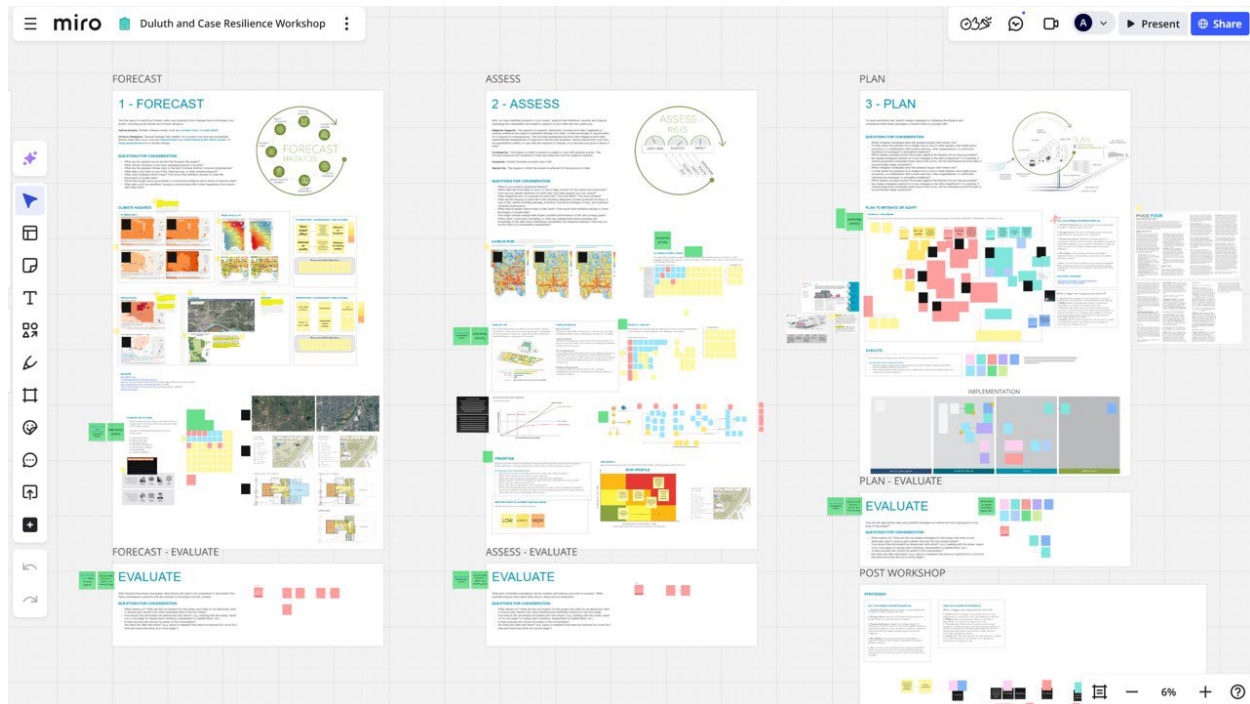
Resilient Communications

Ensuring the ability to communicate within and outside the services area during disruptions and throughout recovery.



Resilient Operations

Ensuring personnel and processes are in place to operate the facility in all conditions.



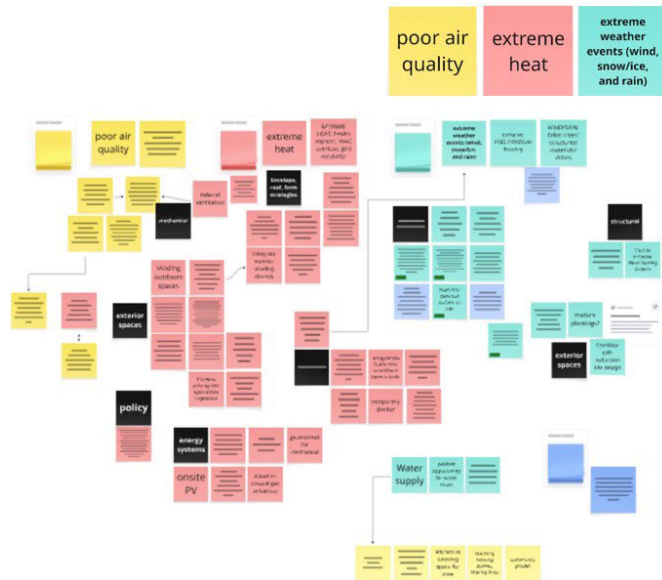
Impact on Vulnerable Populations

HAZARD	VULNERABLE POPULATIONS	IMPACTS
 Heavy Rain Events	- Older adults, especially those living alone and/or have low-incomes - Residents with limited English proficiency - Residents with mobility limitations (access to transportation, ambulatory difficulties) - Residents who lack property, rental, or homeowner insurance (typically low-income)	- Drowning or injury - Mold or waterborne disease - Economic loss - Property damage - Travel limitations
 Extreme Weather Events	- Older adults, especially those living alone and/or have low-incomes - Residents with limited English proficiency - Residents with mobility limitations (access to transportation, ambulatory difficulties) - Residents who lack property, rental, or homeowner insurance (typically low-income) - Homeless and those in unstable housing	- Property damage - Injury or death - Travel limitations
 Poor Air Quality Days	- Older adults, especially those living alone and/or have low-incomes - Younger children - Residents with respiratory illnesses - Those who work outside - Residents living near high-volume traffic corridors (interstates, arterial roads)	- Asthma attacks - Severe allergies - Cardiovascular health
 Extreme Heat	- Older adults, especially those living alone and/or have low-incomes - Younger children - Residents with respiratory illnesses - Those who work outside - Low-income residents with no or limited access to air conditioning - Homeless and those in unstable housing	- Heat stress - Heat stroke - Cardiovascular health - Dehydration

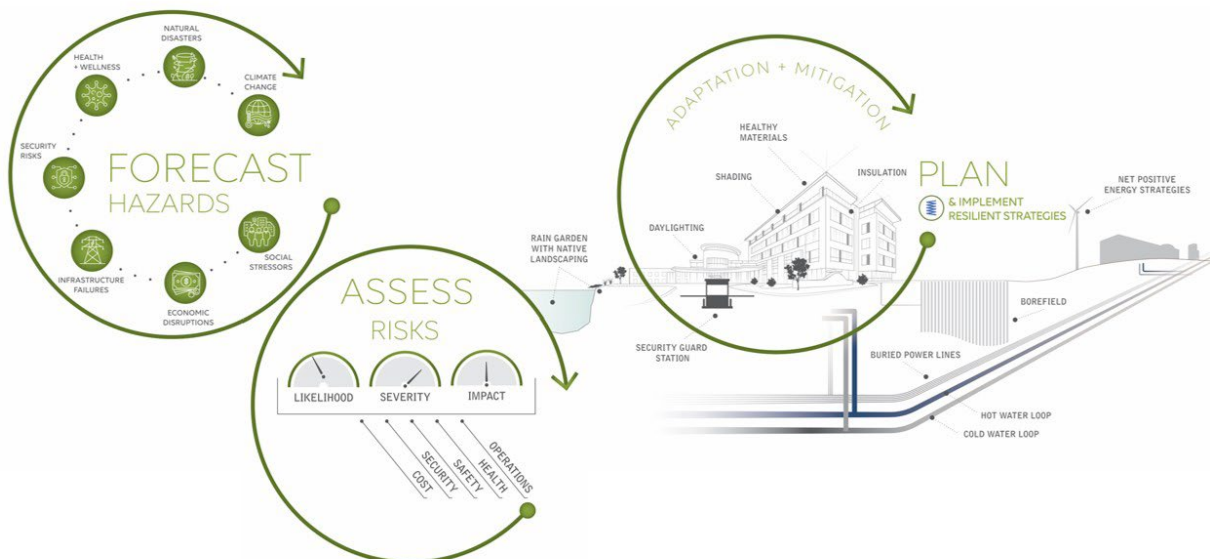
Schematic Design Progress

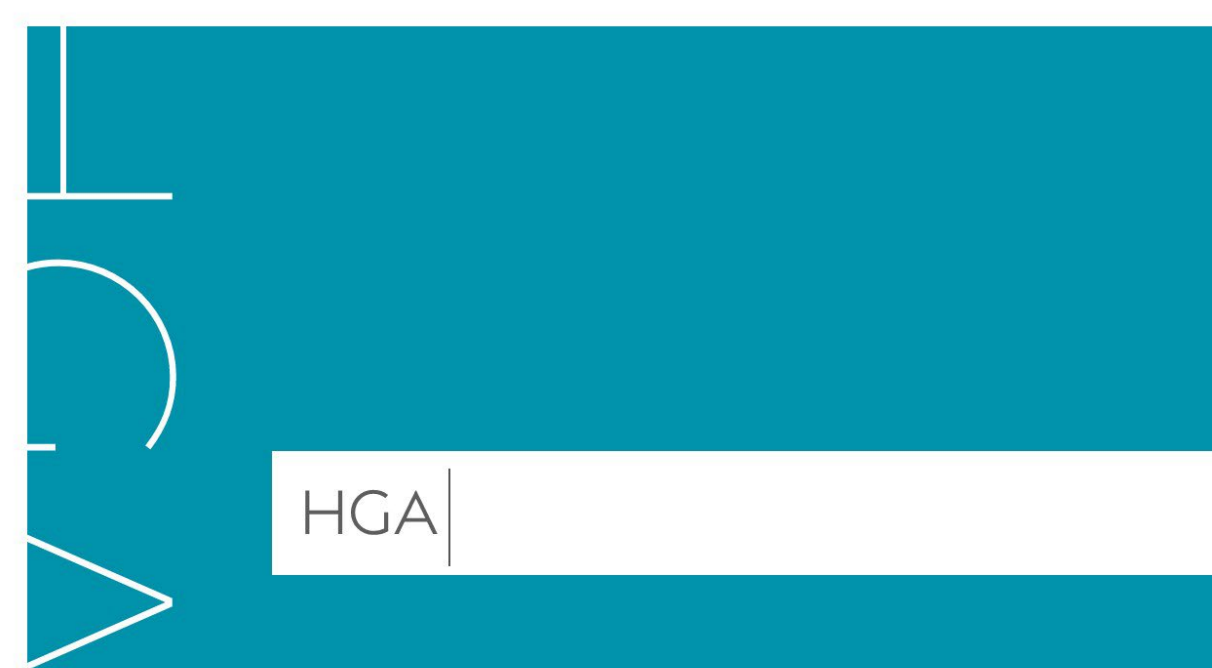
Evaluating design concepts based on:

1. Adaptive Capacity
2. Design Impact
3. Community Impact
4. Feasibility
5. Cost



Planning for Resilience





Q&A DISCUSSION

12:15 – 12:30pm

Moderator: Jayantha Obeysekera

The logo for the Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE). It features a shield-shaped emblem with "SEI" and "ASCE" inside, and the text "STRUCTURAL ENGINEERING INSTITUTE" to the right.

LUNCH

12:30 – 1:00 pm

CONCLUSION of ZOOM Broadcast

Virtual attendees – PLEASE switch to next Teams meeting



PLENARY DISCUSSION

1:00 pm – 2:00 pm



B.2.2. Plenary: Reality on the Ground

PLENARY: NEXT GENERATION GOALS FOR ADAPTATION AND RESILIENCE

Next Generation Goals for Adaptation and Resilience – [50 mins.]; ALL

• Moderators: Jayantha Obeysekera, Terri McAllister

Plenary Panel Discussion – Reality on the Ground: If I had a magic wand...

Barriers to decision making, challenges to innovative solutions, risk-reward sharing, community vs individual development goals and incentives

Speakers

- Rogelio Madan, Resilience Officer, Planning Department, Miami Beach [15 mins]
- Jennifer Jurado, Ph.D., Chief Resilience Officer, Broward County, Florida [15 mins]

Discussion to prepare for breakouts



CITY OF
MIAMI BEACH

**Rogelio A. Madan, AICP,
Development & Resilience
Officer
Miami Beach Planning
Department**

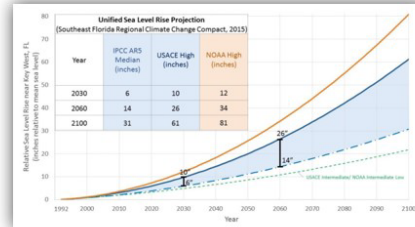


MIAMI BEACH
RISING
ABOVE

Adaptation Action Areas (AAA)

Miami Beach Comprehensive Plan

- **Future Land Use Element**
 - Encourage the use of landscaping techniques that enhance stormwater management
 - Modify the level of service for storm sewer capacity to be consistent with the City's Storm Water Master Plan.
- **Infrastructure Element**
 - Require that the Land Development Regulations include a freeboard requirement that requires the raising of ground floors in new construction to reduce losses due to flooding.
 - Modify the level of service for the drainage facilities design storm standard – Utilize Stormwater Master Plan.
- **Conservation/Coastal Zone Management Element**
 - Encourage the use of highly water-absorbent native and Florida friendly plants.
 - Designate the City of Miami Beach as an AAA pursuant to section 163.3177(6)(g)(10), Florida Statutes and establish resiliency strategies.
 - Sets basis for measuring Sea Level Rise – Southeast Florida Regional Climate Action Plan.



The City has adopted the NOAA Intermediate-High sea level rise projection as the basis for determining the sea level boundary conditions for use in design and planning of stormwater infrastructure improvements for the City through the 2060 planning horizon (boundary condition elevation = 2.70 ft. NAVD) to be used in conjunction with the 10-year recurrence interval, 24-hour duration design storm event as the acceptable drainage level of service for the City. The total Design Storm rainfall event is 8.75-inches which is derived by multiplying the SFWMD published value of 7.00-inches for the Miami Beach area multiplied by a factor of safety of 1.25.

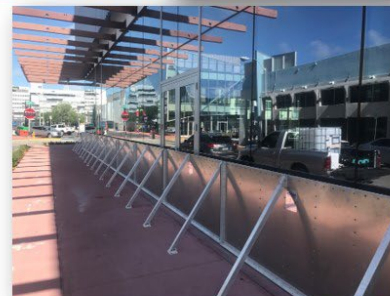
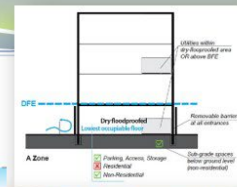
Sea Level Rise Projections (NGVD)				
	Low Prj.	High Prj.	Low Prj.	High Prj.
	Mean Sea Level		Mean High Water	
1992	0.60	0.60	1.81	1.81
2030	1.10	1.43	2.31	2.64
2060	1.77	2.77	2.98	3.98
2100	3.18	5.68	4.39	6.89

Sea Level Rise Projections (NAVD)				
	Low Prj.	High Prj.	Low Prj.	High Prj.
	Mean Sea Level		Mean High Water	
1992	-0.96	-0.96	0.25	0.25
2030	-0.46	-0.13	0.75	1.08
2060	0.21	1.21	1.42	2.42
2100	1.62	4.12	2.83	5.33

FREEBOARD ORDINANCE

Chapter 54 of City Code

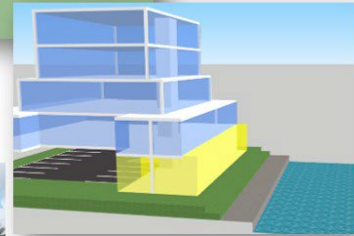
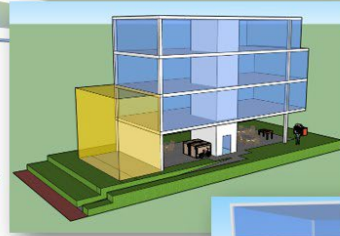
- Minimum Base Flood Elevation (BFE):
 - 8.0 ft. NGVD (6.44 ft. NAVD)
- City of Miami Beach Freeboard:
 - Minimum 1 ft.
 - Maximum 5 ft.
- Future Adjusted Grade:
 - Midpoint elevation between future grade (sidewalk elevation) and the minimum required flood elevation.
- New Residential Construction
 - Finished floor must be above BFE + minimum Freeboard.
 - Garages constructed no lower than future Adjusted Grade and must have sufficient height to accommodate being raised in the future.
- New Nonresidential Construction
 - Lowest floor, electric, and mechanical equipment must be located above BFE + minimum Freeboard.
 - Alternatively in A-zones, watertight floodproofing may be used, WITH up to the level of the Freeboard.
- Seawall Elevation:
 - Built to accommodate a height of 7.26 ft. NGVD (5.7 ft. NAVD)



GRADE ORDINANCE

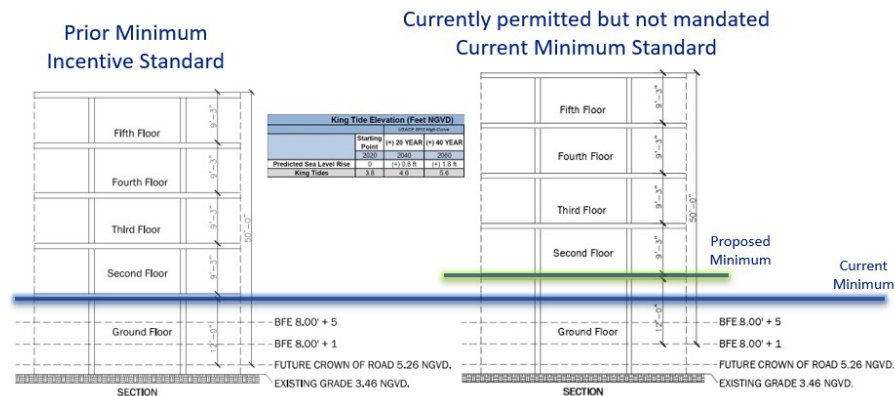
Land Development Regulations:

- Height of Buildings measured from Base Flood Elevation plus Freeboard.
- For commercial properties, height shall be measured from the base flood elevation, plus freeboard
 - Height of the first floor shall be tall enough to allow the first floor to eventually be elevated to BFE + Freeboard, with a future minimum interior height of at least 12 ft. as measured from the height of the future elevated adjacent right-of-way elevation as provided under the city's public works manual.
 - Future Crown of Road: 5.26 NGVD (3.7 NAVD)
- Residential Districts Yard Elevations:
 - Minimum Yard Elevation: 6.56 ft. NGVD (5 ft. NAVD).
 - Maximum Yard Elevation: Greater of 30 inches above grade or Future Adjusted Grade (Adjusted Grade from Future Crown of Road).
 - Does not apply to driveways and walkways.
- Requires stormwater retention and retaining walls



Non-Residential Ground Floor Standards

- Define Base Flood Elevation plus City of Miami Beach Freeboard as the **"DESIGN FLOOD ELEVATION" (DFE)**.
- Require the **"Minimum Height of Non-Residential Ground Floor"** to be 12' above the DFE



New standard leaves 15.4' of headroom if floor is raised to match the 2060 King Tide Elevation. This is an extra 3.74' from the prior standard.

Why not raise floors higher today?

If commercial ground floors are required to be located at BFE + 1-5, there could be negative impacts, especially on small sites :

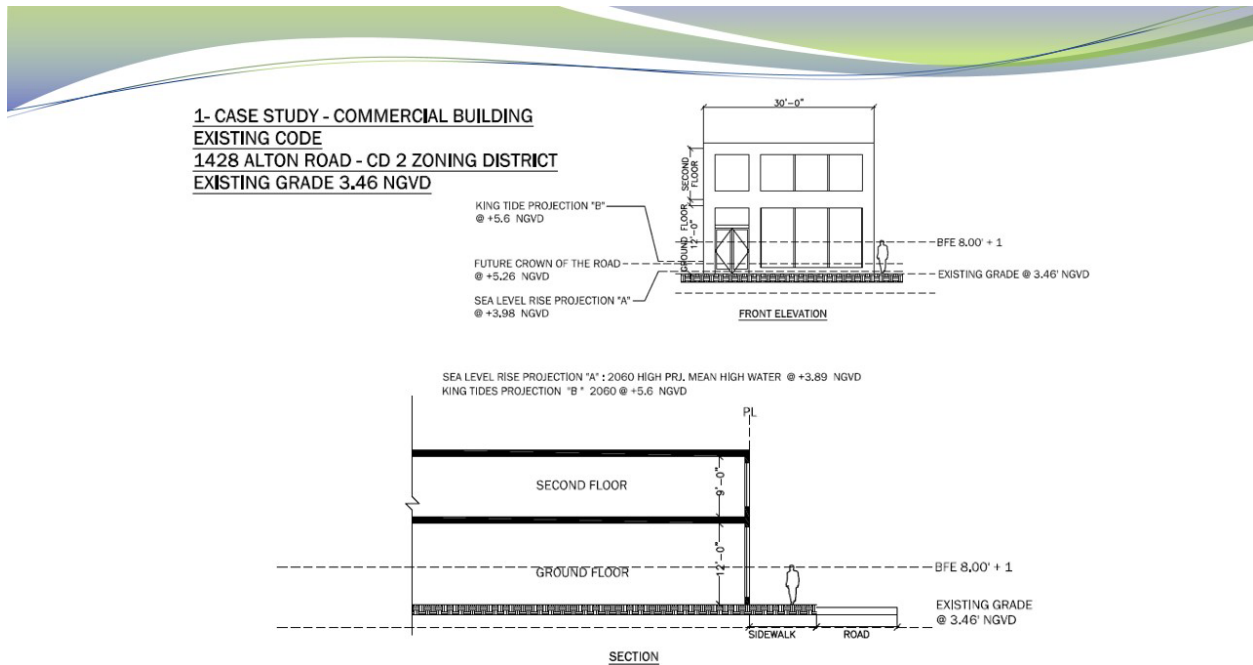
- Undesirable pedestrian experience.
- Undesirable commercial space since large areas are required for transition areas.
- Undesirable commercial space related to transparency and difference of heights between sidewalk and interior space.
- Potential unsafe spaces (lack of eyes on the street).
- Undesirable Architecture (tall knee walls).
- Elevated Construction Cost.
- Can be offset by large transition areas inside the structure or outside by providing greater setbacks; however, many sites do not have the depth, FAR, or historic character to accommodate this.
- Transitions between elevations are more complex.

The most important thing is for buildings to have sufficient height so that they can adapt as necessary. Windows and other façade elements are typically changed every 20 years, raising floors can be considered at those times.

Existing Building Standards

For buildings undergoing a substantial renovation (50% rule):

- **Raised Floor:** Where feasible, the ground floor shall be located at a minimum elevation of one foot (1') above the highest sidewalk elevation adjacent to the frontage.
 - Ramping and stairs from the sidewalk elevation to the ground floor elevation shall occur inside the property and not encroach into the public sidewalk or setback areas.
- **Knee Wall:** Except where there are doors, facades shall have a knee wall with a minimum height of two feet-six inches (2'-6") above the sidewalk elevation.
- **Flood Resistant:** Where feasible, ground floors shall utilize flood damage resistant materials for a minimum of 2' 6" above the floor elevation.
- **Convenient Flood Panels:** Flood panels for doorways shall be permanently located next to all doorways.
- **Waivers:** DRB and HPB can waive requirements, however, alternative flood control measures should be considered.



Short-Frontage Standards

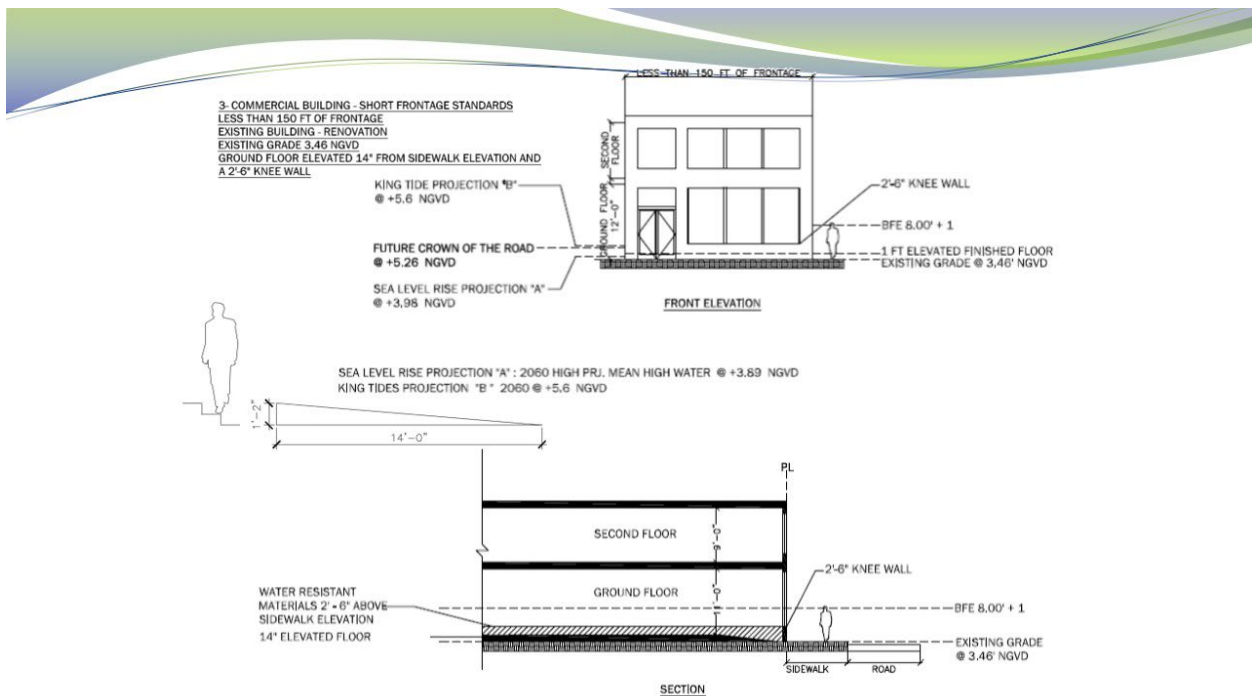
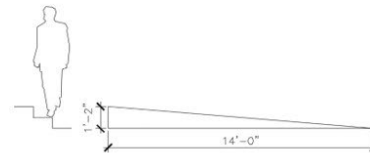
Frontages less than 150' wide

Incorporates Existing Building Standards + the following:

- **Ground Floor Setback:** Minimum ground floor setback of 15' from the back of the curb of the roadway, to provide:
 - 10' wide sidewalk Circulation Zone
 - 5' must be a "Clear Pedestrian Path"
 - 5' wide landscape area
- **Raised Floor:** The ground floor shall be located a minimum of the future crown of road (~5.26 NGVD).
 - Ramping and stairs from the sidewalk elevation can occur in the 5 feet of the setback closest to the building.
 - Steps and ramping cannot interfere with the clear pedestrian path
 - Steps and ramping can only go to an elevation of 14" below the future crown of road.
 - Additional ramping to get to the elevation of the interior floor must occur behind the setback.
- For developments that have multiple frontages and one frontage is greater than 150', the development shall follow the more stringent standards for buildings with long frontages



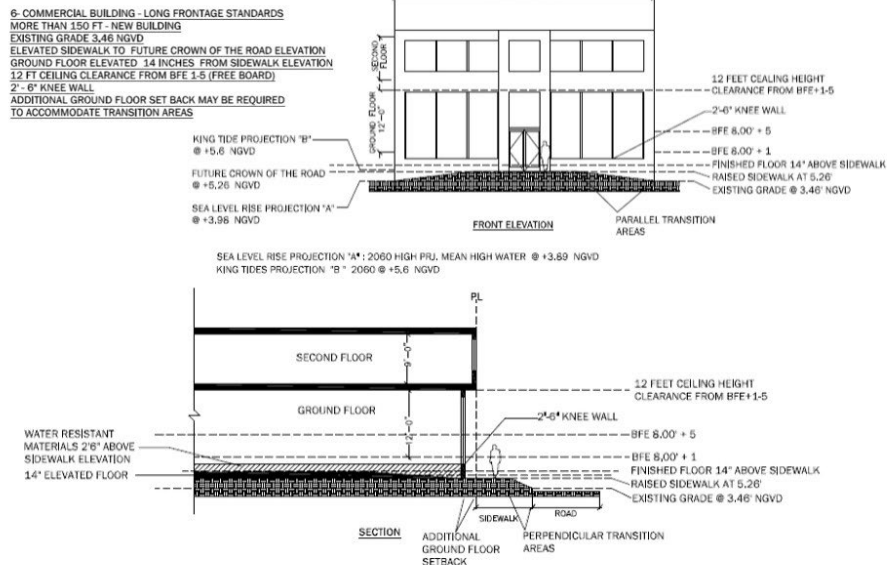
(Harmonization purposes)



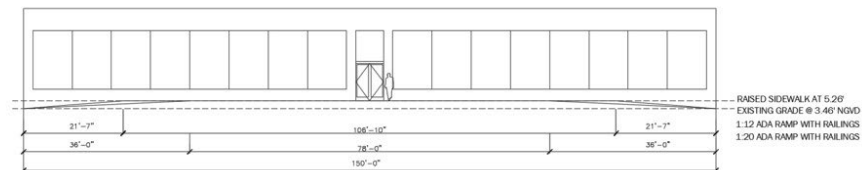
Long-Frontage Standards

Incorporates Short-Frontage Standards + the following:

- **Raised Sidewalk:** With the exception of transition areas, the sidewalk must be raised at a minimum to the future crown of road elevation (5.26' NGVD).
- **Ground Floor Setback:** Minimum ground floor setback of 15' from the back of the curb of the roadway
 - 10' wide sidewalk circulation zone
 - 5' must be a "Clear Pedestrian Path"
 - 5' wide landscape transition area between the raised sidewalk and the lower vehicular roadway.
- **Raised Trees:** Trees be planted in raised planters or stabilized planting areas with a minimum elevation of the future crown of road.
- **Transition Standards:** The use of steps, ramp switchbacks, and handrails be prohibited in parallel transition areas.
- **Access to Parking:** Steps that are no wider than 36 inches should be placed between every two parking spaces where parallel parking exists.
- **Raised Floor:** The ground floor elevations be located a minimum of 14" (2 steps) above the raised sidewalk elevation.
- **Knee Wall:** Except where there are doors, facades shall have a knee wall with a minimum height of two feet-six inches (2'-6") above the raised sidewalk elevation.



EXTERIOR RAMP REQUIREMENTS



Requires architects to consider the placement of doorways in relation to raised sidewalks before the building is designed. *Currently this is an afterthought.*



JENNIFER JURADO, PH.D.

Chief Resilience Officer, Broward County, Florida



PLENARY: NEXT GENERATION GOALS FOR ADAPTATION AND RESILIENCE

Discussion to prepare for breakouts

- LCA
- a



BREAKOUTS - DEVELOP RESEARCH AGENDA FOR ADAPTATION AND RESILIENCE

PURPOSE:

Identify engineering strategies for enhancing resilience to evolving hazards and adaptive capacity of buildings and infrastructure systems under uncertain future conditions, including degradation of materials and performance of the built environment.

Note we are not including Nature Based Solutions for this workshop.

SCOPE:

- *Develop approaches for resilience including adaptive design pathways and robust decision-making under nonstationary conditions, considering both loads and structural capacity.*
- *Identify barriers and opportunities for applying adaptive pathways and resilience strategies in practice. Discuss standards, codes, and decision frameworks to bridge engineering and community resilience needs, and potential solutions.*



PLENARY: BREAKOUTS - DEVELOP RESEARCH AGENDA FOR ADAPTATION AND RESILIENCE

PROMPTS:

- 1) What do you wish you had to advance design practice and building standards for adaptation and resilience?*
- 2) What are the next generation research needs for adaptation and resilience?*
- 3) Prioritize top 5 research needs. (Each written as a sentence.)*

NOTE: Communication is important, but this workshop is not about communication – it is technical roadmap for research/advancement, including social impacts!

GOAL: What do you wish you had?



PLENARY: CHARGE THE BREAKOUTS

SCHEDULE: BREAKOUT SESSIONS 2:15PM – 4:45 PM

2:15pm – 2:30 pm = Breakout Session Introductions
and *Identify Day 2 Reporter*

(THREE TOPICS for approximately 30-45 minutes each)

2:30pm – 3:00pm = *What do you wish you had to advance design
practice and building standards for adaptation and resilience?*

3:00pm – 3:30pm = *What are the next generation research needs for
adaptation and resilience?*

3:30pm – 3:45pm = BREAK

3:45pm – 4:45pm = *Define and Prioritize top 5 research needs.*



Asking for a
VOLUNTEER for
Day 2 Report Outs

GROUP: **NAME** Top 5 NEEDS

Identify the TOP 5 Priority Items and describe each in 1-2 complete sentences.

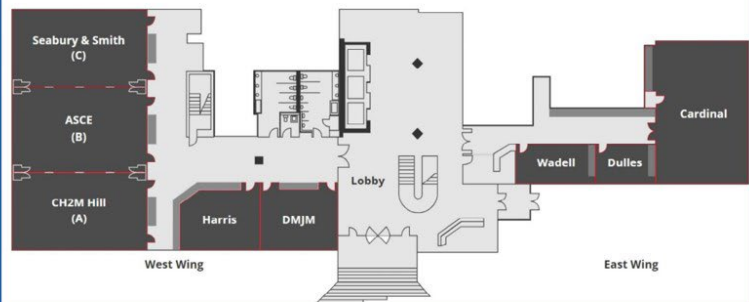
- 1.
- 2.
- 3.
- 4.
- 5.



BREAKOUT GROUPS

Group	Room	Moderator	Note Takers
1 - IN PERSON	CH2MHill	Michel Ghosn	Sihan Li, Jennifer Goupil
2 - IN PERSON	Seabury & Smith	Kevin Borth	Matt Gilbertson, Obey
3 - VIRTUAL	Harris	Joe Barsugli	Elisabeth Gilmore, Jack Hogan
4 - VIRTUAL	DMJM	Mari Tye	Joe Ackroyd

ASCE Conference Center



VIRTUAL PARTICIPANTS: PLEASE stay online, you will be moved to your room now. PLEASE wait to meet your Moderator BEFORE you take your break!!



BREAKOUT SESSIONS

2:15 pm – 4:45 pm



STRUCTURAL
ENGINEERING
INSTITUTE

SUMMARY & ADJOURN

4:45 – 5:00 pm



B.3. Day 2: Overview Presentations

ADAPTATION AND RESILIENCE

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

Oct 29-30, 2025

SEI/NIST Forward Looking Codes and Standards Workshop #4



FORWARD-LOOKING CODES AND STANDARDS: WELCOME

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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. 29-30: Adaptation and resilience** - buildings and infrastructure system assessment, material durability, mitigation, retrofit.



AGENDA

Digital Package

(password: adaptationresilience)

- AGENDA
- Participant List
- Slide Decks

Day 2: Oct 30; 9:00am – 12:00pm Eastern

8:30am-9:00am – NETWORKING CONTINENTAL BREAKFAST PROVIDED

9:00am-9:15am – Welcome

- Purpose and Goals of Day 2

9:15am-11:00am – Report Out

- Breakout Session Report out: [15 mins EACH = 10 mins. + 5 mins Q&A]

15-minute COFFEE BREAK (10:15am)

- Moderated Discussion of Breakout Reports [30 mins.]
Moderator: Jayantha Obeyesekere

11:00am-11:45am – Prioritization

- Prioritization of Research Needs - Survey [15 mins.]
- Discussion of Survey Results [30 mins.]

11:45am-12:00pm – Conclusion

- Summary and Adjourn Day 2

12:30-3:00pm – Workshop Steering Committee Meeting

REPORT OUT & PRIORITIZATION

9:15 am – 11:45 am



B.3.1. Breakout Session Reports

BREAKOUT ₁

In Person



BREAKOUT GROUP 1

MODERATOR: **MICHEL GHOSN**
NOTE TAKER: **JENNIFER GOUPIL**

DAY 2 REPORTER: **Milad Roohi**

ATTENDEES:

1. **Michel Ghosn**
2. **Julie Pietrzak**
3. **Joel Good**
4. **John van de Lindt**
5. **Milad Roohi**
6. **Ann Kosmal**
7. **Jenifer Goupil**

GROUP: 1 Top 5 Research NEEDS

1. **Incentives and Financial Mechanisms**: Investigate how financial, behavioral, and policy-based incentives can effectively motivate infrastructure owners to invest in resilience that aligns with community needs and long-term value.
2. **Decision-Making Tools, Design Guidance, Standards, and Codes**: Create design approaches for adaptation — leading to decision-support tools, design guidance, standards, and codes — that integrate resilience into infrastructure planning across diverse stakeholders.
3. **Design Ready Hazard Data**: Establish standardized, geographically targeted datasets that are consistent with design standards and codes for use in resilience modeling and performance based designs.
4. **Resilience Outcomes Measurement Science**: Identify, quantify, and measure the factors influencing community resilience outcomes, and use measurement science to establish trends and develop evidence-based guidance.
5. **Recovery Data and Models**: Develop, update, and calibrate data and models for incorporating functional recovery of facilities, infrastructure networks, and communities and their interactions into resilience-informed design standards and tools.



BREAKOUT 2

In Person



BREAKOUT GROUP **2**
2:15PM – 2:30PM

MODERATOR: **Kevin Borth**
NOTE TAKERS: **Matt Gilbertson, Jayantha Obeysekera**

DAY 2 REPORTER:
Robin Kemper

ATTENDEES:

1. Kevin Borth
2. Matt Gilbertson
3. Jayantha Obeysekera
4. Robin Kemper
5. Kingsley Lau
6. Ming Liu
7. Seth Thomas
8. David Mizzen
9. Paul Schuman

GROUP: 2 Top 5 NEEDS

Identify the TOP 5 Priority Items and describe each in 1-2 complete sentences.

1. Research to identify and reduce uncertainties to better define future hazard levels for design.
2. Research associated to develop methodologies for adaptive pathway designs including multi-hazards, fragility curves, system degradation and implementation in Performance Based Design.
3. Develop a database of actual building performance (failures and successes) under extreme events including cost-benefit analysis.
4. Develop simplified tools based on common framework and data accessible to define future hazard risks and provide design values to practitioners and building owners for implementation on projects.
5. Extend functional recovery research for current and future hazards for new building design and existing buildings.



BREAKOUT₃

Virtual



BREAKOUT GROUP

2:15PM – 2:30PM

MODERATOR: **Joe Barsugli**
NOTE TAKER: **Elisabeth Gilmore**

DAY 2 REPORTER: **Adam Reeder**

ATTENDEES:

1. Joe Barsugli – climate science
2. Elisabeth Gilmore - adaptation research,
3. Ayse Hortascu - how to get to one standard
4. Adam Reeder - making standards implementable by practitioners (flood/wind)
5. Rahemeen Ahmed – Uncertainty communication to clients. Standardize communication
6. Fabio Biondini - Lifecycle performance/bridges how to incorporate time factor in resilience - deep uncertainty framework + lifecycle
7. Manuel Perotin -- (flood/wind) Advance guidance so it can be implemented/adopted and data supporting this. Also enforcement
8. Erica Fischer – (seismic/wildfire/..) Common language; how to address existing
9. Nasim Uddin (Nat. Hazards Journal). How to know the unknown -- how to make a building adaptive? Smart building to reconfigure itself.
10. Ning Lin – Adaptive strategy – why are specific options chosen -- can it be linked to economic or reliability goals.

GROUP: *Group 3*

Top 5 NEEDS

1. **Improve and standardize the characterization of current and projected hazard levels including metrics and indicators for implementing adaptive strategies over time.** In particular, hazard s not included in available climate projections (such as hail), emerging hazards (such as wildfire), and multiple AEPs including events rarer than 1/500 AEP).
2. **Improve understanding of the how preferences around risk and resilience scale from individual to community and the implications for practical engineering design at the project scale.** Specific needs include designing for multiple risk and resilience preferences, creating scalable solutions from community-led resilience efforts, and consideration of resilience in the full disaster cycle including testing assumptions about community capacity.
3. **Investigate the conditions under which prescriptive or non-prescriptive approaches are preferred their relative benefits and tradeoffs for adaptive building design,** including understanding the risk of locking in obsolete technological solutions, and the ability of prescriptive methods to handle a range of options. As an illustration we mentioned the goal of developing requirements for early warning times or response times for active solutions for different hazards and building types.
4. **Support broad-based research to inform adaptive design for wildfire** including better hazard characterization (common descriptive language, intensity metrics, etc.), and better quantification of demands on structures through real-time structural health monitoring and improved sensor technology.
5. **Improve understanding of the legal, political and policy challenges and barriers to implementation of adaptive strategies over time** and the implications for engineers' liability and standard of care under non-stationarity and deep uncertainty about future conditions. Determine how best to design for adaptive measures when the owner(s), not the engineers, will be responsible in the long term. Are standards and practices formulated so that design professional can be confident in signing and sealing given given uncertainty over project life span.
6. **Understanding the benefits of resilience to improve likelihood of adoption into codes so that it can be incorporated into standard development up front.** Examples discussed include economic analysis, insurability, role of public-private partnerships, and allocation of resources across different elements of resilience (for example, resistance vs. recovery), lifecycle analysis of long-term (inter-generational) resilience.



BREAKOUT 4

Virtual



BREAKOUT GROUP #
2:15PM – 2:30PM

MODERATOR: **Mari Tye**
NOTE TAKER: Sihan Li
DAY 2 REPORTER: **Norma Jean Mattei**

ATTENDEES:

1. Mari Tye
2. Norma Jean Mattei
3. Michele Barbato
4. Roy Lobo
5. Lauren Mudd
6. Zoubir Lounis
7. Abigail Beck
8. Ruohua Guo
9. Ken Kunkel
10. Teng Wu
11. Sihan Li
- 12.
- 13.
- 14.
- 15.

GROUP: *4 Norma Jean Mattei*
Top 5 NEEDS

Identify the TOP 5 Priority Items and describe each in 1-2 complete sentences.

1. Integrate time dependent structural capacity degradation with non-stationary load effect
2. Develop guidance for performance based design where appropriate for hazards such as fire and flood that aren't already addressed, while maintaining flexibility for minimum design code on smaller projects
3. Incorporate risk and resilience metrics in current design frameworks to enable consideration of exposure and vulnerability, and assessment of the economic impacts of failure.
4. Foster multidisciplinary collaboration and integration that includes community driven risks and priorities.
5. Leverage existing hazards and building performance data to inform performance based design, and incorporation better translation of existing research into design practice



COFFEE BREAK

10:15 – 10:30 am



MODERATED DISCUSSION OF BREAKOUT REPORTS

- Moderator: Jayantha Obeysekera [30 mins]



PRIORITIZATION OF RESEARCH NEEDS & DISCUSSION

11:00 – 11:45am



SURVEY RESULTS



DISCUSSION OF SURVEY RESULTS 11:15-11:45 am

Moderator:

Jayantha 'Obey' Obeysekera – Workshop Director

- Review of findings
- Discussion (ALL PARTICIPANTS)



SUMMARY & ADJOURN

11:45 am – 12:00 pm



ASCE/NIST FORWARD LOOKING CODES & STANDARDS WORKSHOPS

FOUR WORKSHOP REPORTS: Published Spring/Q2 2026

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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FINAL SYNTHESIS REPORT: Published Spring/Q2 2026



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

STRUCTURAL
ENGINEERING
INSTITUTE

SUMMARY & ADJOURN

12:00 pm

PLEASE recycle your Name Badges



Appendix C. Workshop Reading Material

Obeysekera, Jayantha, and Sihan Li. "Future Conditions: Decision Making under Deep Uncertainty." Paper submitted to ASCE Convention, 2025.

Obeysekera, Jayantha, Marjolijn Haasnoot, and Robert Lempert. "How Are Decision-Science Methods Helping Design and Implement Coastal Sea-Level Adaptation Projects?" *Variations* 18, no. 3 (Fall 2020). <https://doi.org/10.5065/fp9y-ae42>.

Appendix D. Workshop Participants

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

Joe	Ackroyd	NYC
Rahemeen	Ahmed	Arup
Ahmed	Attar	NRC Canada
Bilal	Ayyub	University of Maryland
Michele	Barbato	University of California,
Joseph	Barsugli	University of Colorado Boulder, NOAA Affiliate
Abigail	Beck	University of Houston
Fabio	Biondini	Polytechnic of Milan, Italy
Kevin	Borth	HGA
Casey	Brown	University of Massachusetts Amherst
Eun J.	Cha	University of Illinois Urbana-Champaign
Chris	Clavin	NIST
William	Coulbourne	Consultant
Lakshmana	Doddipatla	FM
Erica	Fischer	Oregon State
David	Frost	Georgia Institute of Technology
Michel	Ghosn	CUNY
Matt	Gilbertson	Simpson Gumpertz & Heger
Elisabeth	Gilmore	Carleton University
Catalina	Gonzalez	George Mason University
Joel	Good	RWDI
Jennifer	Goupil	ASCE/SEI
Ruohua	Guo	Reliability Equity LLC
Jack	Hogan	Arup
Brenda	Hoppe	HGA
Ayse	Hortascu	ATC
Jennifer	Jurado	Broward County
Robin	Kemper	Zurich
Ann	Kosmal	Kosmal Partnership
Ken	Kunkel	NOAA/NCSU
Kingsley	Lau	Florida International University
Sihan	Li	RWDI
Ning	Lin	Princeton University
Ming	Liu	NAVFAC–EXWC
Roy	Lobo	HCAI
Zoubir	Lounis	National Research Center Canada

Rogelio	Madan	Miami Beach
Norma Jean	Mattei	The University of New Orleans
Kris	May	Pathways Climate Institute
Michelle	Miro	RAND
David	Mizzen	ARA
Lauren	Mudd	ARA
Jayantha	Obeysekera	FIU
Manuel	Perotin	CDM Smith
Julie	Pietrzak	Thornton Tomasetti
Adam	Reeder	CDM Smith
Milad	Roohi	University of Nebraska Lincoln
Kathryn	Roscoe	Deltares
Paul	Schuman	SGH
Seth	Thomas	KPFF
Mari	Tye	Johns Hopkins University
Nasim	Uddin	University of Alabama at Birmingham
John	Van de Lindt	Colorado State University
Teng	Wu	University of Buffalo
Erik	Zuker	HNTB