MARYLAND COMMISSION ON CLIMATE CHANGE
Scientific and Technical Working Group Meeting
February 17, 2023

Climate-Resilient Infrastructure for a Climate-Ready Nation

Making the Nation’s Infrastructure Climate Resilient

ASCE and NOAA Working Together

Bilal M. Ayyub, PhD, PE, Dist.M.ASCE, Professor and Director
Center for Technology and Systems Management
Department of Civil & Environmental Engineering
A. JAMES CLARK
SCHOOL OF ENGINEERING

Outline:
- NOAA and ASCE priorities and objectives
- ASCE-NOAA summit
- Conveners, advisors and participants
- ASCE-NOAA MOU
- NOAA and ASCE information
- Summit program
- Climate-resilient infrastructure

Priorities and Objectives

Dr. Richard Spinrad (NOAA Administrator) and Dr. Jean-Louis Briaud (2021 ASCE President) meeting on September 14, 2021

NOAA Priorities
- Development of “a full portfolio of environmental products and services in the context of our changing climate, and in coordination and cooperation with NOAA’s sister agencies, …, and ensuring these products and services are more accessible to underserved communities”
  Dr. Richard Spinrad, NOAA Administrator
  June 17, 2021

ASCE Priorities
- Supporting efforts to update ASCE content to reflect projected climate
- Partnering with key stakeholders related to climate and engineering practice
- Supporting ASCE strategic plan goal of having infrastructure and built environment to be safe, resilient, and sustainable

ASCE-NOAA collaboration objectives
- Recommend to NOAA the weather, climate, and coastal ocean information needed by civil engineering practitioners to design and operate infrastructure
- Prioritize NOAA information needed by civil engineers and to develop consensus guidance for practice on how best be provided
- Identify gaps related to climate services to help NOAA with future pursuits and undertakings

Leaders, Planning Committees and Advisors

Presiding

Maria Lehman, P.E., ENV SP, F.ASCE, 2023 ASCE President

Richard Spinrad, Ph.D., CMarSci, NOAA Administrator

Summit Chair

Bilal Ayyub, Ph.D., P.E., Dist.M.ASCE
University of Maryland (UMD), College Park

Planning Committee

Bilal Ayyub, Ph.D., P.E., Dist.M.ASCE, UMD
Edward Clark, NOAA
Benjamin DeAngelo, NOAA
Erica Dintaman, NOAA
David Easterling, Ph.D., NOAA
Erika Haldi, ASCE
Debbie Lee, F.ASCE, NOAA
Mark Osler, NOAA
Brian Parsons, ENV SP, ASCE
Dan Walker, Ph.D., A.M.ASCE, UMD

Includes members of the **ASCE-NOAA Task Force on Climate Resilience in Engineering Practice**

Advisory Committee

Ko Barrett, NOAA Senior Advisor for Climate
Paul Boulos, NAE, Corp Executive, ASCE
Gerry Galloway, Dist.M.ASCE, NAE, UMD
Alice Hill, Council on Foreign Relations
Kimberly Jones, Ph.D., Howard University
Ed Kerns, Ph.D., First Street Foundation
Norma Jean Mattei, Ph.D., P.E. F.ASCE, National Infrastructure Advisory Council, 2017 ASCE President, University of New Orleans
Thomas O'Rourke, Dist.M.ASCE, NAE, Cornell University

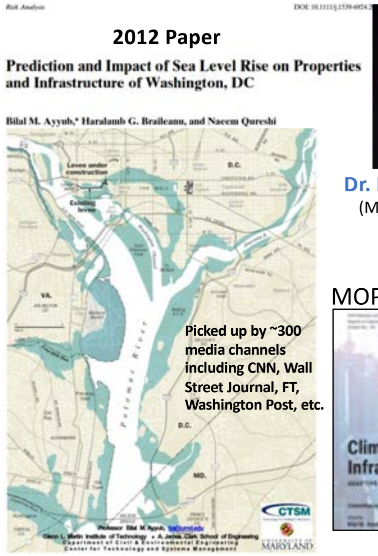
About eighty participants (in person) and others (virtual)

National focus (with some international coverage)

ASCE, NOAA, NIST, FEMA, DoD, EPA, Army Corps, etc., White House, industry, regional planners, academia

NOAA representation: Climate Science and Services
- Weather and climate information providers
- Program managers
- Scientists, researchers
- Data managers
- Operational modelers

ASCE representation: Infrastructure planning and design
- Standard and manual of practice developers
- Domain specialists (institutes and committees)
- Practitioners and researchers



Risk Analysis DOI: 10.1111/j.1539-6924.2

2012 Paper

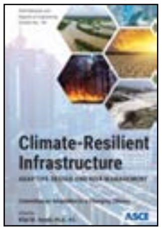
Prediction and Impact of Sea Level Rise on Properties and Infrastructure of Washington, DC

Bilal M. Ayyub,* Haralamb G. Braileanu, and Naeem Qureshi

Picked up by ~300 media channels including CNN, Wall Street Journal, FT, Washington Post, etc.

Dr. Dick Wright
(May 17, 1932 to May 31, 2019)

MOP 140 2018



Professor Ted S. Vinson
Dr. Dan Walker

ASCE Committee on Adaptation to a Changing Climate (founded in 2012)

Professor Michael Kearney **(2012 workshop, impacts on DC)**

News Releases 2021

NOAA, University of Maryland, ASCE to Advance Climate-Smart Construction

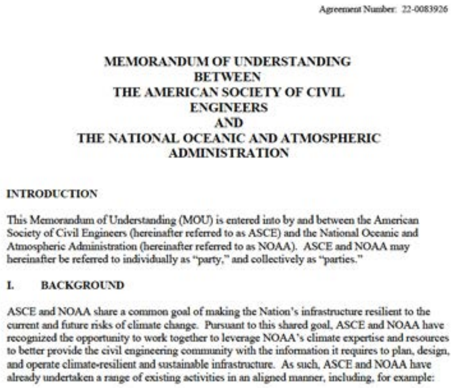
11/3/2021 0

Cooperative Agreement

ASCE-NOAA Memorandum of Understanding

Memorandum of Understanding (MOU)

- Designed to identify opportunities for collaboration and articulate actions to achieve common goals, including to:
  - Improve cooperation in developing and delivering climate information and services required by civil engineering and allied professionals, to design, build, operate and maintain climate resilient infrastructure
  - Facilitate ASCE's efforts to update its published and educational and content to reflect the best available climate information



Agreement Number: 22-0083926

MEMORANDUM OF UNDERSTANDING
BETWEEN
THE AMERICAN SOCIETY OF CIVIL ENGINEERS
AND
THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

INTRODUCTION

This Memorandum of Understanding (MOU) is entered into by and between the American Society of Civil Engineers (hereinafter referred to as ASCE) and the National Oceanic and Atmospheric Administration (hereinafter referred to as NOAA). ASCE and NOAA may hereinafter be referred to individually as "party," and collectively as "parties."

I. BACKGROUND

ASCE and NOAA share a common goal of making the Nation's infrastructure resilient to the current and future risks of climate change. Pursuant to this shared goal, ASCE and NOAA have recognized the opportunity to work together to leverage NOAA's climate expertise and resources to better provide the civil engineering community with the information it requires to plan, design, and operate climate-resilient and sustainable infrastructure. As such, ASCE and NOAA have already undertaken a range of existing activities in an aligned manner, including, for example:

MOU signed on Feb 1, 2023

ASCE-NOAA Summit Feb 2, 2023

NOAA Priorities

(over 12,000 employees)

To help the nation prosper, NOAA is pursuing three overarching priorities detailed in the NOAA Strategic Plan 2022-2026:

Building a Climate Ready Nation by establishing NOAA as the primary federal authoritative provider of climate information and services in the whole-of-government response to tackling the climate crisis

Integrating equity into core operations

Promoting economic development while maintaining environmental stewardship with a focus on advancing the New Blue Economy

NOAA Information: Breadth, Depth and Credibility

Local

- Snowfall Impact Index – FEMA, disaster response
- Heating & Cooling Degree Days – Energy Sector
- Temperature & Precipitation Outlooks – Agriculture
- Billion $ Disasters, Climate Extremes Index – Insurance

Regional

- Hurricane Tracks – Emergency Planners
- Space Weather – Aviation Industry
- Drought Outlook – Agriculture
- Climate Normals – Construction, Infrastructure, Agriculture

National & Global

- Drought Monitor – Agriculture
- Global and U.S. Climate Summaries – Numerous Sectors
- Annual State of the Climate Reports – Scientists
- IPCC & National Climate Assessments – Gov't Policymakers

Source: Dr. Sarah Kapnick, NOAA Chief Scientist (2023 presentation to the National Academies

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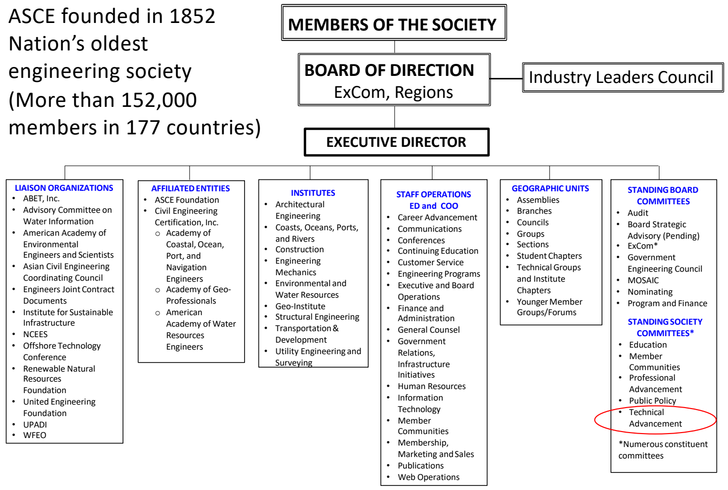
ASCE Introduced

ASCE founded in 1852
Nation's oldest engineering society
(More than 152,000 members in 177 countries)



MEMBERS OF THE SOCIETY

BOARD OF DIRECTION
ExCom, Regions

Industry Leaders Council

EXECUTIVE DIRECTOR

LIAISON ORGANIZATIONS
- ABET, Inc.
- Advisory Committee on Water Information
- American Academy of Environmental Engineers and Scientists
- Asian Civil Engineering Coordinating Council
- Engineers Joint Contract Documents
- Institute for Sustainable Infrastructure
- NCEES
- Offshore Technology Conference
- Renewable Natural Resources Foundation
- United Engineering Foundation
- UPADI
- WFEO

AFFILIATED ENTITIES
- ASCE Foundation
- Civil Engineering Certification, Inc.
  - Academy of Coastal, Ocean, Port, and Navigation Engineers
  - Academy of Geo-Professionals
  - American Academy of Water Resources Engineers

INSTITUTES
- Architectural Engineering
- Coasts, Oceans, Ports, and Rivers
- Construction
- Engineering Mechanics
- Environmental and Water Resources
- Geo-Institute
- Structural Engineering
- Transportation & Development
- Utility Engineering and Surveying

STAFF OPERATIONS
ED and COO
- Career Advancement
- Communications
- Conferences
- Continuing Education
- Customer Service
- Engineering Programs
- Executive and Board Operations
- Finance and Administration
- General Counsel
- Government Relations, Infrastructure Initiatives
- Human Resources
- Information Technology
- Member Communities
- Membership, Marketing and Sales
- Publications
- Web Operations

GEOGRAPHIC UNITS
- Assemblies
- Branches
- Councils
- Groups
- Sections
- Student Chapters
- Technical Groups and Institute Chapters
- Younger Member Groups/Forums

STANDING BOARD COMMITTEES
- Audit
- Board Strategic Advisory (Pending)
- ExCom*
- Government Engineering Council
- MOSAIC
- Nominating
- Program and Finance

STANDING SOCIETY COMMITTEES*
- Education
- Member Communities
- Professional Advancement
- Public Policy
- Technical Advancement

*Numerous constituent committees

CTA includes sustainability, climate, resilience, cold region, forensic, computing, aerospace, energy, codes and standards, etc units.

CTA Units

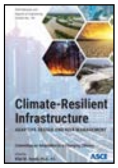
- Changing Climate
- Infrastructure Resilience
- Sustainability
- Cold Regions
- Codes & Standards
- Energy Engineering
- Forensic
- Computing
- Aerospace

ASCE Introduced

- **Publications**
  - Codes and standards (70)
  - Journals (35)
  - Manuals of practice (MOP) (45)
  - Technical reports (hundreds)
  - CE Magazine
  - Information e-delivery

2020

2018



Example ASCE Standard:
Minimum Design Loads and
Associated Criteria for Buildings and
Other Structures, ASCE/SEI 7-22
Year

ASCE 7 Hazard Tool

SEI Structural Engineering Institute

- **Other selected services**
  - Conferences, education and accreditation
  - America's Infrastructure Report Card
  - Advocacy (government relations)
  - ASCE Policy statements
  - Awards
  - Leadership
  - Code of ethics
  - ASCE Foundation

Selected Technical Activities and Timeline

ASCE-NOAA Task Force Workshops

Leveraging Earth System Science and Modeling to Inform Civil Engineering Design:
Workshop I – Temperature and Rainfall (September 9 and 23, 2022)
Workshop II –Extreme Winds and Coastal Hazards (October 21 and 28, 2022)

SEI led workshop Future Environmental Conditions/Climate Change Impacts Workshop (ASCE HQ, Reston, VA)

GI led GEO Congress, (Charlotte NC)

EWRI led 2022 World Environmental and Water Resources Congress, (Atlanta, GA)

COPRI led PORTS '22, (Honolulu, HI)

13 Mar. 2022

31 May 2022

31 July 2022

2 Feb.

ASCE INSPIRE, Nov 16-18 2023 Conference, Arlington, VA

10 Mar. 2022

20 Mar. 2022

5 June 2022

18 Sep. 2022

Stormwater Conference (Wilmington, NC) – **EWRI Listening Session** – Learn what the needs/issues are from the "front-line community."

T&DI hosts ICTD (Seattle, WA)

UESI Pipelines Conference – (Indianapolis, IN)

2023 Summit
Making the Nation's Infrastructure Climate Resilient: NOAA and ASCE Working Together
(ASCE HQ, Reston, VA)

SEI workshop September 2022, Reston, VA

ASCE-NOAA Leadership Summit on Climate-Ready Infrastructure

February 2, 2023
ASCE Headquarters, Reston, VA

8:00am Breakfast & Registration

8:30-9:15am Welcome, MOU and Introductions

- Welcome and Background: Crosswalk – NOAA and ASCE strategic plans
- NOAA Administrator: remarks on MOU
- ASCE Executive Director: remarks and introduction
- ASCE President: remarks on MOU

9:15-10:30am Panel 1: Climate Resilience in Engineering Practice: Progress and Way Forward

- Key climate hazards workshops
- Information needs, sources, access, and processes

10:30-11:00am Networking Break

11:00-12:15pm Panel 2: Climate Resilience in Engineering Practice: Broader Perspectives

- Broader perspectives on impacts and risks of climate hazards

12:15-1:45pm Lunch (Luncheon Speaker)

- Climate Change: The Engineers Dilemma

1:45-3:00pm Panel 3: Designing for Equity in Climate-Ready Infrastructure

- Case studies: economics, climate, infrastructure, environmental justice

3:00-3:30pm Summary and Closure

- Summary by co-chairs
- Closing remarks, next steps and adjournment

3:00-3:30pm Summary and Closure

3:00-3:30pm Summary and Closure

- Summary by co-chairs and Q/A (25min)
- Closing remarks (5 minutes)

Moderator:

Bilal M. Ayyub, Ph.D., P.E., Dist.M.ASCE, University of Maryland

Benjamin J. DeAngelo, NOAA, Deputy Director, Climate Program Office, Principal Representative to the U.S. Global Change Research Program

Summary by panel co-chairs

Panel 1: Dan Walker and Benjamin DeAngelo

Panel 2: Debbie Lee and Thomas O'Rourke

Panel 3: Kimberly Jones and Vankita Brown

Closing Remarks:

Norma Jean Mattei, Ph.D., P.E., F.SEI, F.ASCE, National Infrastructure Advisory Council, 2017 ASCE President, University of New Orleans

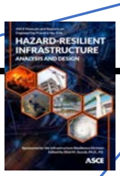
Climate adaptation, energy issues, and sustainable, resilient infrastructure

NOAA-funded projects from the Climate Modeling, Analysis, Predictions, and Projections Program (MAPP)
Consider participating in the ASCE INSPIRE 2023 Conference
Learn more at https://inspire.asce.org/

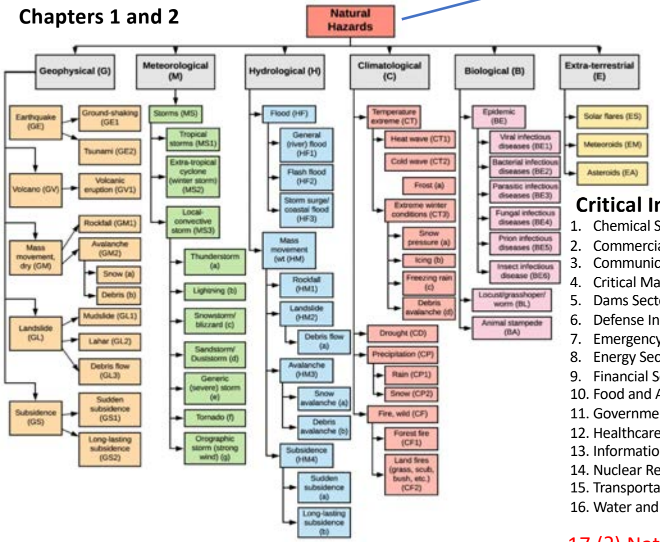
POC Bilal M. Ayyub ba@umd.edu

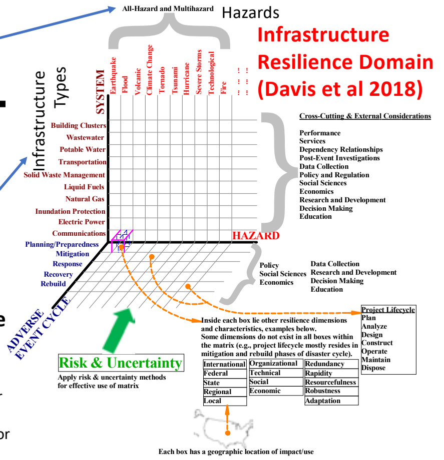
Hazard-Resilient Infrastructure:

Manual of Practice on Analysis and Design (Number 144)



Chapters 1 and 2





Apply risk & uncertainty methods for effective use of matrix

Inside each box lie other resilience dimensions and characteristics, examples below. Some dimensions do not exist in all boxes within the matrix (e.g., project lifecycle mostly resides in mitigation and rebuild phases of disaster cycle).

Each box has a geographic location of impact/use

Infrastructure Resilience Domain (Davis et al 2018)

Critical Infrastructure

1. Chemical Sector
2. Commercial Facilities Sector
3. Communications Sector
4. Critical Manufacturing Sector
5. Dams Sector
6. Defense Industrial Base Sector
7. Emergency Services Sector
8. Energy Sector
9. Financial Services Sector
10. Food and Agriculture Sector
11. Government Facilities Sector
12. Healthcare and Public Health Sector
13. Information Technology Sector
14. Nuclear Reactors, Materials, and Waste Sector
15. Transportation Systems Sector
16. Water and Wastewater Systems Sector

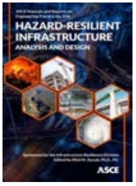
17 (?) Natural and Nature-based Infrastructure

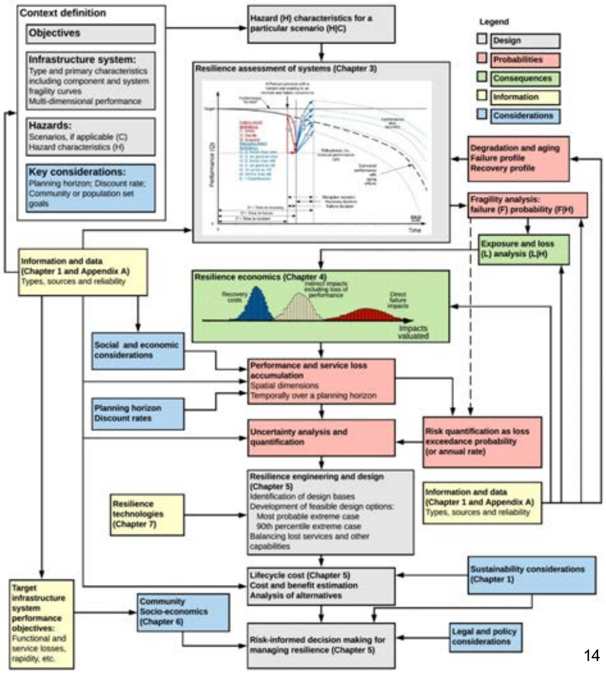
Technologies needed for integration

Hazard-Resilient Infrastructure: Analysis and Design

Methodology (Chapter 2)

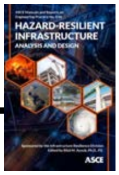
- Context definition
- Hazard identification and characterization
- Failure probability and fragility estimation
- Resilience assessment
- Exposure and loss analysis
- Economic valuation and loss accumulation
- Risk quantification: loss exceedance rates
- Extremes and uncertainty analysis
- Resilience engineering and design
- Lifecycle analysis
- Risk management
- Community socio-economics





Hazard-Resilient Infrastructure:
Analysis and Design

Outline and Structure

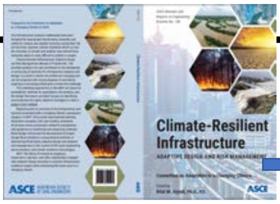


- Chapter 1. Introduction
  - Sets the context
  - Articulates the needs
  - Provides objective and scope statements
  - Describes hazards
  - Defines users and uses of the manual
- Chapter 2. Methodology **(Framework)**
  - Provides an overall framework and the steps necessary for assessing infrastructure resilience
- Chapter 3. Resilience Assessment
  - Introduces methods for resilience assessment of infrastructure systems and networks based on their performances
- Chapter 4. Resilience Economics and Risk Management
  - Introducing fundamentals such as planning horizon, discount rates, cost estimation, loss accumulation
  - Discusses approaches for risk management including evaluating investments
  - Establishes links to optimization and lifecycle considerations
- Chapter 5. Designing for Resilience
  - Provides design philosophies
  - Discusses considerations and provides approaches

Hazard-Resilient Infrastructure:
Analysis and Design

Outline and Structure

2018



- Chapter 6. Community Socio-economics
  - Factors, benefits and metrics
- Chapter 7. Emerging Resilience-Enabling Technologies
  - New and existing infrastructure
- Appendix A. Terminology
  - Terminology and definitions as used in the manual of practice

Technologies needed for resilience and integration

2021

Definition: Technology
- Application of scientific knowledge for practical purposes, e.g., resilience
- Skills, methods, and processes used to achieve goals, e.g., resilience
- To produce goods or services
  - Products: physical (materials, sensors, robots, etc.), cyber (software, databases, blockchain, crypto-technologies, etc.) , processes/methods for intelligent decision (MOP, standards, etc.)

Resilience Quantification

Chapter 2 and 3

Technologies needed for all stages and beyond

Ductility	Redundancy	Robustness	Rapidity	Resourcefulness	Adaptability	Efficiency

Resilience Definitions

Ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions

Persistence of its functions and performances under uncertainty in the face of disturbances

Ayyub, B. M., "Systems Resilience for Multi-Hazard Environments: Definition, Metrics and Valuation for Decision Making," Risk Analysis J., 34(2), DOI: 10.1111/risa.12093, 2014.

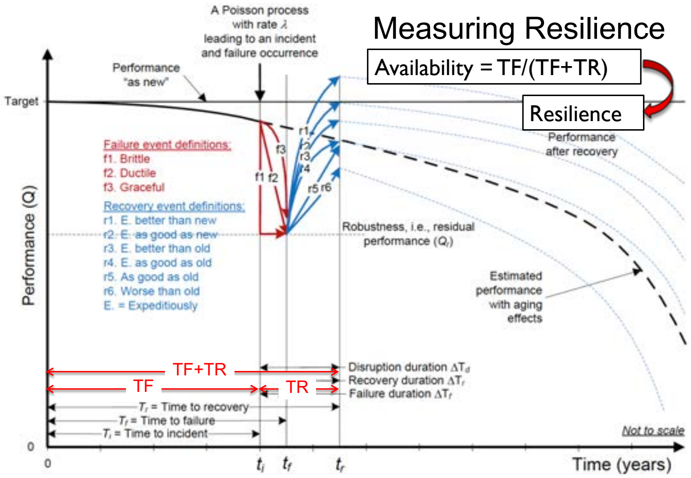
Wang, C., and Ayyub, B. M., "Time-Dependent Resilience of Repairable Structures …," ASCE-ASME J. Part A, DOI: 10.1061/AJRUA6.0001246, 2022.

Time-Dependent Reliability ($R(t)=1-F(t))=P(T\geq t)$)

$$R(t)=\int_{s=0}^{\infty}\exp\left[-\lambda t\left(1-\frac{1}{t}\int_{\tau=0}^{\tau=t}P(c(\tau)s>L)d\tau\right)\right]f_{S_0}(s)ds$$

Load rate λ

Strength (S) aging $c(t)$



$$\text{Resilience}(R_e)=\frac{T_i+F\Delta T_f+R\Delta T_r}{T_i+\Delta T_f+\Delta T_r}$$

$R_e \geq 0$

$$\text{Failure}(F)=\frac{\int_{t_i}^{t_f}fdt}{\int_{t_i}^{t_f}Qdt}$$

$$\text{Recovery}(R)=\frac{\int_{t_f}^{t_r}rdt}{\int_{t_f}^{t_r}Qdt}$$

Measuring Performance (aggregated vs. integrated)

Chapter 2 and 3

Examples

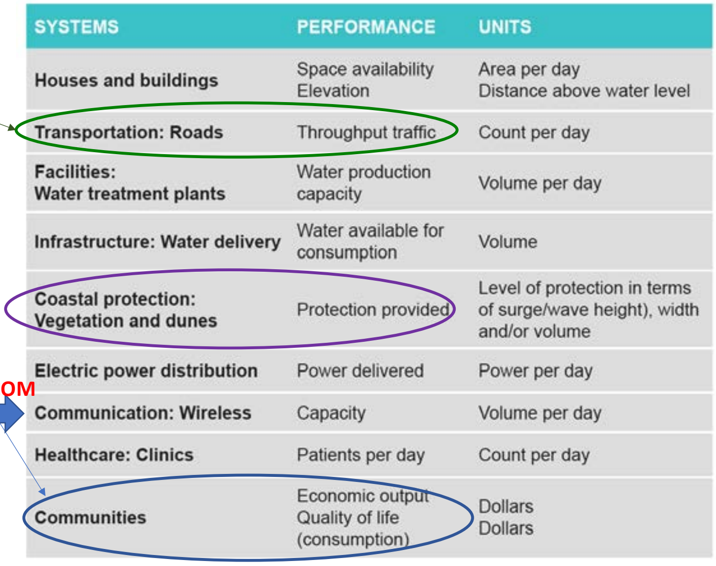
- Transportation: **Roads**
- Network topology: efficiency
- Community **wellbeing**

Multi-dimensional Performance: water distribution

- Fire hydrants: volume and pressure
- User consumption: volume and quality
- Delivery: reliability

Credit: Dr. C. Davis

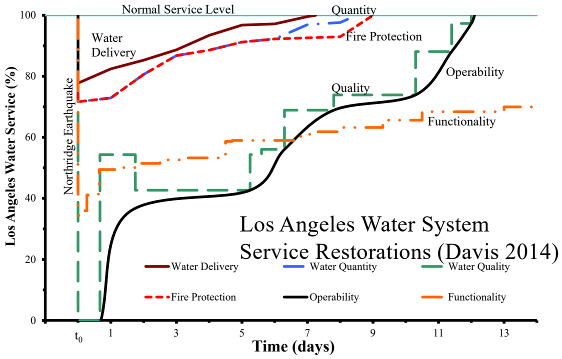
USSTRATCOM NC3



SYSTEMS	PERFORMANCE	UNITS
Houses and buildings	Space availability Elevation	Area per day Distance above water level
Transportation: Roads	Throughput traffic	Count per day
Facilities: Water treatment plants	Water production capacity	Volume per day
Infrastructure: Water delivery	Water available for consumption	Volume
Coastal protection: Vegetation and dunes	Protection provided	Level of protection in terms of surge/wave height), width and/or volume
Electric power distribution	Power delivered	Power per day
Communication: Wireless	Capacity	Volume per day
Healthcare: Clinics	Patients per day	Count per day
Communities	Economic output Quality of life (consumption)	Dollars Dollars

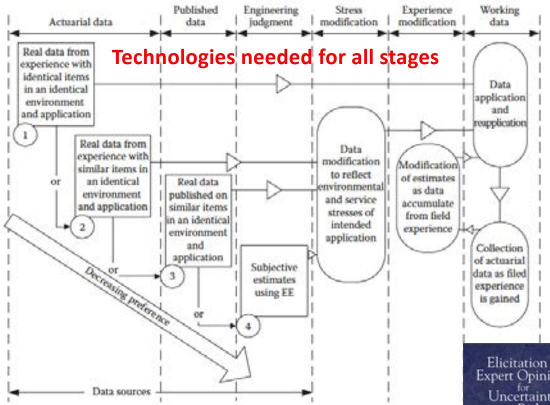
Multi-dimensional Performance and Data Needs

Chapter 2 and 3

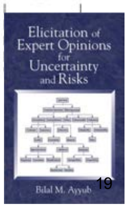


Los Angeles Water System Service Restorations (Davis 2014)

Data needs, sources and uncertainty



Technologies needed for all stages

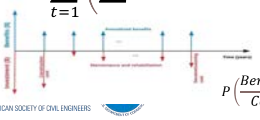


Loss accumulation models (Chapter 4)

$$L = \sum_{t=1}^{T}\left(\sum P(E)P(H|E)P(F|H)(L|F)\mathrm{e}^{-\mathrm{it}}\right)$$

where:

L	Loss (L) accumulated over the planning horizon represented by the time period T
$P(E)$	Probability of an event (E) or related scenario at time t
$P(H\|\mathrm{E})$	Annual probability of a hazard (H) under the conditions defined by E
$P(F\|H)$	Probability of a failure (F) upon the occurrence of H
$L\|F$	Loss (L) upon the occurrence of F
i	Annual discount rate



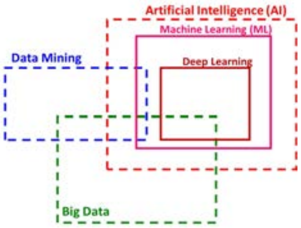
$$P\left(\frac{Benefit}{Cost} \geq 1\right) = P(Cost - Benefit \leq 0)$$

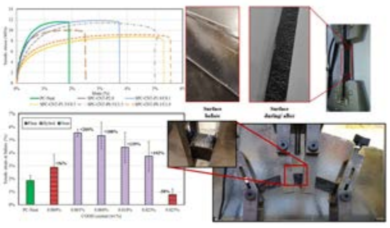
AMERICAN SOCIETY OF CIVIL ENGINEERS

Chapter 7

Technologies for Hazard-Resilient Infrastructure

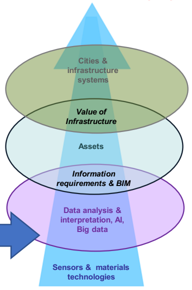
Gartner Hype Cycle for emerging technologies





A Bigger Picture….

The Value of emerging technology needs to be evaluated.



Large-scale implementation roadmap of emerging technologies for resilient infrastructure

CITY-SCALE SYSTEM OF SYSTEMS
- *What economic value does our infrastructure create?*
- *How does our infrastructure best serve our communities?*
- *What form should our infrastructure take?*

LIFETIME VALUE OF INFRASTRUCTURE
- *How do we operate, manage & maintain our assets to deliver best whole life value?*
- *How do we futureproof our assets against changing requirements & against shocks?*
- *What decisions? what information?*

DATA ANALYSIS AND INTERPRETATION IN REALTIME
- *How do we best design, construct & monitor our structures to deliver the performance we need?*
- *What data do we need to do this, & how do we interpret it?*
- *Data cleansing and reliability concerns.*
- *How can AI, big data and deep learning help in complex data analysis?*

EMERGING MATERIALS
- *What are the necessary materials criteria for improved structural resilience?*
- *What is the necessary level of maturity/readiness of an emerging material to proceed to field application?*
- *Materials standards and specifications.*

ROBUST SENSOR SYSTEMS
- *What sensors do we need?*
- *How can we make them robust?*
- *Reliable, robust systems for data collection*
- *Standards to enable interoperability*

ASCE
AMERICAN SOCIETY OF CIVIL ENGINEERS

Resilience Quantification

Chapter 2 and 3

Technologies needed for all stages and beyond

Ductility	Redundancy	Robustness	Rapidity	Resourcefulness	Adaptability	Efficiency

***Components* of Infrastructure Resilience, Four Rs!**

Measurement science
Quantification in kind and in uncertainty for economic valuation and tradeoff analysis

Resilience

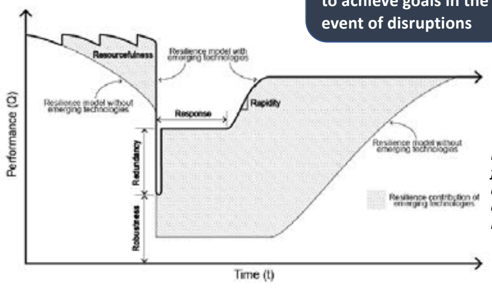
Resourcefulness
Capacity to mobilize and apply material and human resources to achieve goals in the event of disruptions

Robustness
Ability of elements and systems to withstand a given level of stress or demand without suffering degradation or loss of function

Redundancy
Availability of substitutable elements or systems that can be activated upon the occurrence of multi-hazard scenario

Rapidity
Capacity to meet priorities and achieve goals in a timely manner to contain losses

Bruneau, M., Chang, S. E., Eguchi, R. T., et al. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. Earthquake Spectra, 19(4):733–752.



Hubbard et al. 2020 "A framework for evaluating emerging technologies contributions to system resilience"

Taha, M.R., Ayyub, B.M., Soga, K., Daghash, S., Murcia, D.H., Moreu, F., Soliman, E., 2021, "Emerging Technologies for Resilient Infrastructure: A Conspectus and Roadmap," State-of-the-Art, ASCE-ASME J.

Recovery Profile: Bridge Failure

August 1, 2007

Technology: Seismic structural fuses

Fatigue failure

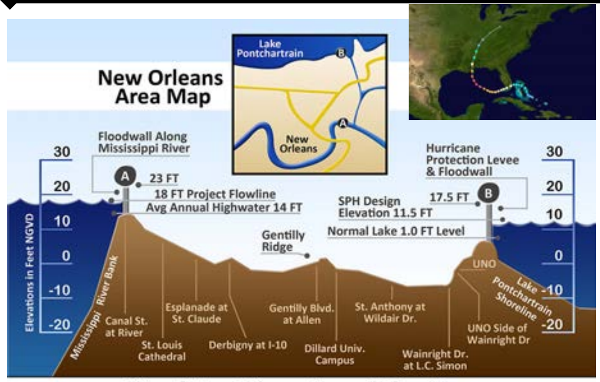
After

Eight lane (Interstate 35 W crossing the Mississippi River in Minneapolis)
Steel truss arch bridge collapsed during rush hour
Deaths = 13, Injuries = 145, Average daily traffic = 140,000 vehicles
Replacement bridge fast-tracked opened on September 18, 2008

Single-step recovery
Recovery time:
About one year
Bridge robustness:
0%
Recovery profile:
A single-step recovery profile

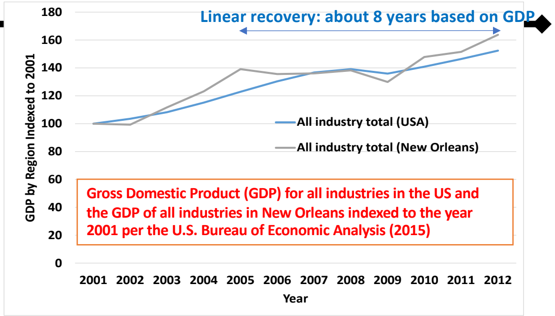
Recovery Profile: New Orleans and Hurricane Katrina,

August 23–31, 2005



City of New Orleans Ground Elevations

From Canal St. at the Mississippi River to the Lakefront at U.N.O.



Most destructive natural disaster in American history, 90,000 mi^2 (233,000 km^2) of land impacted, an area the size of the United Kingdom

- Total direct damage $108 billion (2005 US$)
- Direct and indirect fatalities 1,833
- Insurance claims fulfilled of $41.1 billion (private) and $16.1 billion (public)
- Post-Katrina protections of $120.5 billion on the Gulf Region

- Challenges in characterizing recovery
  - Multidimensionality
  - Transfers to other regions
  - Disruptions during recovery
- Population growth has not kept up with the GDP growth
  - Perhaps attributable to changes in the composition of the industries, population skill levels, and incomes

---

Network Resilience: Technology

- Tunnels
  - – Performance
  - – Quantification of resilience
  - – Enhancement of resilience
- Metro systems
  - – Network definition
  - – Interconnectedness and network vulnerability
  - – Network resilience
  - – Enhancement strategies
- Hazards
  - – Water (surge and wave) level rise
  - – Flooding of stations

Shanghai

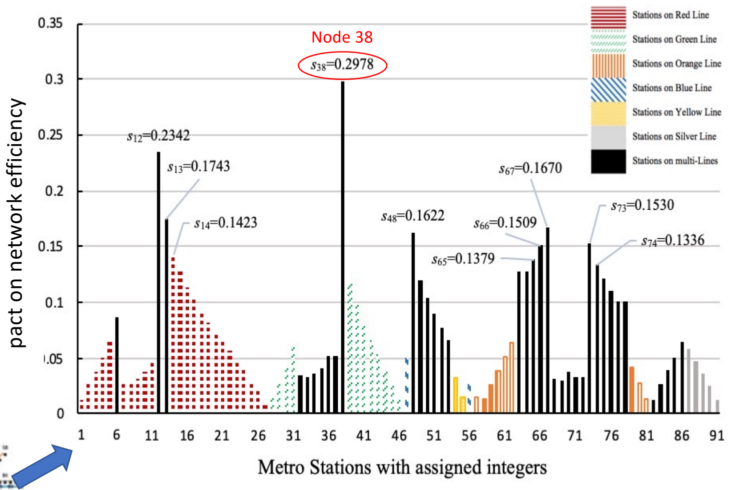
Zhang, F., Du, F., Huang, H., Zhang, D., Ayyub, B. M., and Beer, M., 2018. “Resiliency Assessment of Urban Rail Transit Networks: Shanghai Metro as an Example,” Safety Science, Elsevier, Volume 106, July 2018, Pages 230–243, https://doi.org/10.1016/j.ssci.2018.03.023.

Saadat, Y., Ayyub, B. M., Zhang, Y. J., Zhang, D. M., and Huang, H. W. 2019. “Resilience of Metrorail Networks: Quantification with Washington D.C. as a Case Study,” ASCE-ASME J. Risk Uncertainty Eng. Syst., Part B: Civ. Eng., doi:10.1115/1.4044038

Washington DC

Washington D.C. Metro

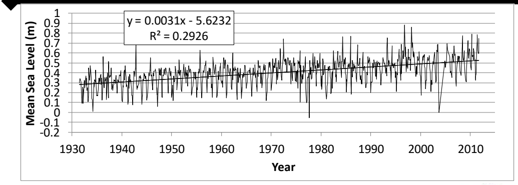
Vulnerability of Washington D.C. Metro network subjected to node loss

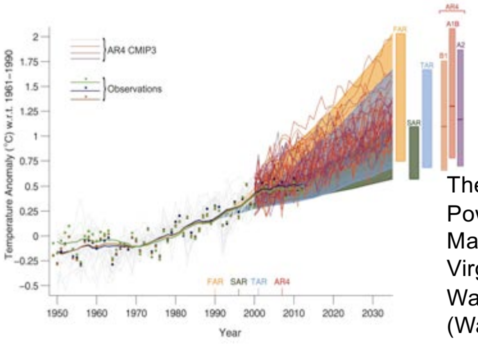


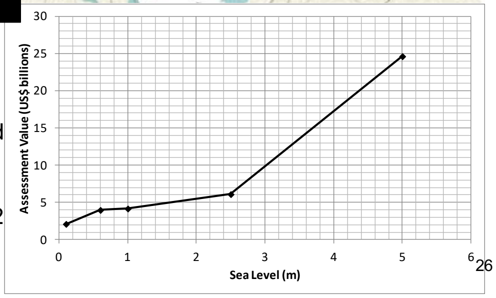
Saadat, Y., Ayyub, B. M., Zhang, Y. J., Zhang, D. M., and Huang, H. W. 2019. "Resilience of Metrorail Networks: Quantification with Washington D.C. as a Case Study," ASCE-ASME J. Risk Uncertainty Eng. Syst., Part B: Civ. Eng., doi:10.1115/1.4044038

Impacts of Water Level Rise on Washington DC

Ayyub, B. M., Braileanu, H. G., and Qureshi, N., 2012, "Prediction and Impact of Sea Level Rise on Properties and Infrastructure of Washington, DC," Risk Analysis Journal, Society for Risk Analysis, online 2011 Oct 28, 1-18. doi: 10.1111/j.1539-6924.2011.01710.x. Picked up by ~300 media channels including CNN, Wall Street Journal, Washington Post, etc.



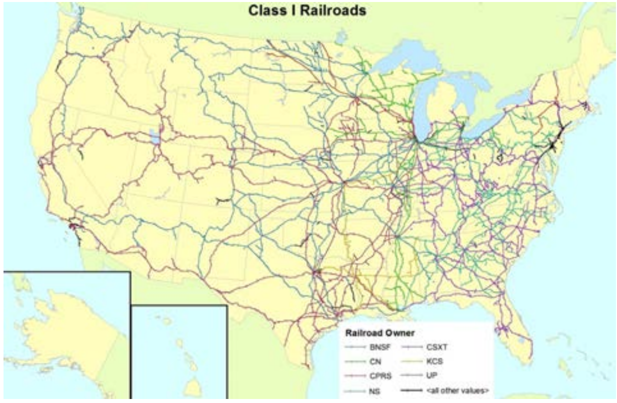




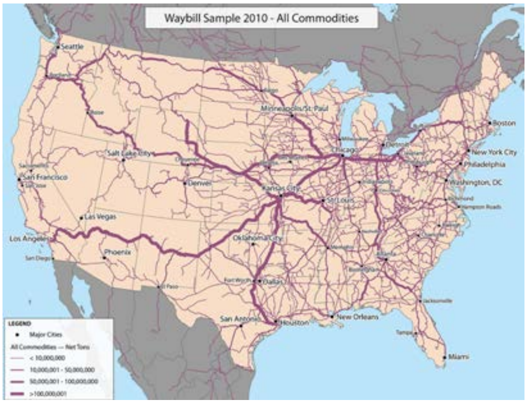
The Impact of a Powerful Hurricane Making Landfall around Virginia Beach, on Washington, DC (Washington Post 2012 based on Results by Ayyub et al. 2012)

Freight Railroad Networks

Class I railroads (seven entities*)



Destination of freight



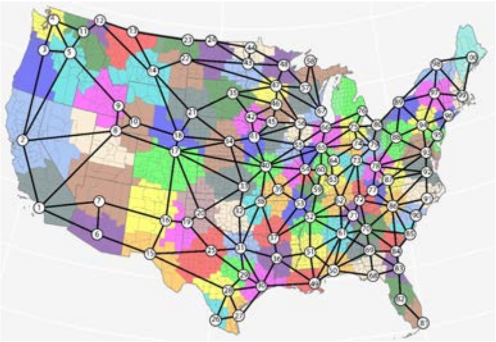
Class I Railroads (2006 Bureau of Transportation Statistics, National Transportation Atlas Database, Rail Network, 1:2,000,000 base scale)

* BNSF Railway, CN Canadian National Railway, CP Canadian Pacific, CSX Transportation, FXE Ferrocarril Mexicano (Ferromex), KCS Kansas City Southern Railway, NS Norfolk Southern, KCSM Kansas City Southern de México, UP Union Pacific Railroad

Aggregate U.S. Railroad Network: Unweighted Network

Aggregate topology and commodity volumes

Aggregate topology and assignment of counties



Class 1 freight railroad:
About 140,000 miles
Waybill data

Unweighted Network Characteristics

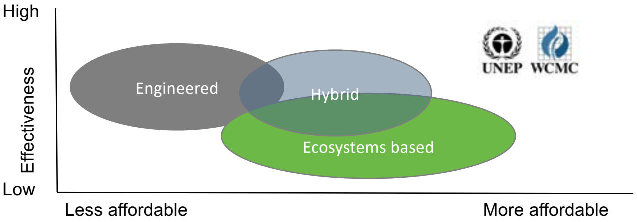
- Number of nodes: 100
- Number of links: 226
- Average node degree: 4.52
- Standard deviation of node degree: 1.599
- Characteristic path length: 5.116
- Network efficiency: 0.2636

- **Topology for HAZMAT**
- **Topology for climate impacts**

Nature-Based and Natural Solutions

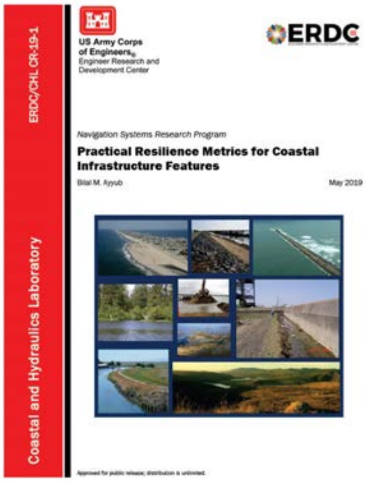
(Chapter 5)

- **Natural Infrastructure**: Strategic use of networks of natural lands, working landscapes, and other open spaces to conserve ecosystem values and functions with benefits to humans (dunes, vegetations, etc.)
- **Nature-Based Solutions:** Use of natural or semi-natural areas or systems to mitigate environmental impacts, increase efficiency or secure ecosystem services (barrier islands, vegetations, etc.)
- **Ecosystem-Based Adaptation:** use of biodiversity and ecosystem services as part of an overall adaptation strategy (related concepts: soft engineering, eco-disaster risk reduction, nature-based defences, green infrastructure)



UNEP WCMC

United Nations Environment World Conservation Monitoring Center


ERDC/CHL CR-19-1

Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

ERDC

Navigation Systems Research Program

Practical Resilience Metrics for Coastal Infrastructure Features

Bilal M. Ayyub

May 2019

Approved for public release; distribution is unlimited.

Performance of Coastal Infrastructure

Natural, nature-based, structural and non-structural

Example: Energy and Industrial Facilities


Beaches and dunes


Marshes


Maritime forests


Man-made barrier island


Mangrove swamps


Tidal mud flats


Levees


Drainage Pumping Station

ecology and environment, inc.

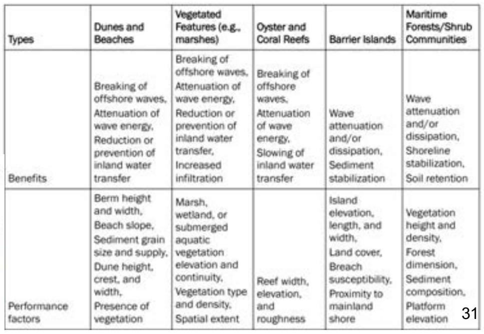
Performances: Natural and Nature-Based Features

Examples

- Dunes and beaches
  - Berm height and width
  - Beach slope
  - Sediment grain size and supply
  - Dune height, crest and width
  - Presence of vegetation
- Vegetated features, e.g., marshes
  - Marsh, wetland or submerged aquatic vegetation
  - Elevation and continuity
  - Vegetation type and density
  - Spatial coverage and health

Quantification: essential for risk management

Resilience: recovery and multiple events



Types	Dunes and Beaches	Vegetated Features (e.g., marshes)	Oyster and Coral Reefs	Barrier Islands	Maritime Forests/Shrub Communities
Benefits	Breaking of offshore waves, Attenuation of wave energy, Reduction or prevention of inland water transfer	Breaking of offshore waves, Attenuation of wave energy, Reduction or prevention of inland water transfer, Increased infiltration	Breaking of offshore waves, Attenuation of wave energy, Slowing of inland water transfer	Wave attenuation and/or dissipation, Sediment stabilization	Wave attenuation and/or dissipation, Shoreline stabilization, Soil retention
Performance factors	Berm height and width, Beach slope, Sediment grain size and supply, Dune height, crest, and width, Presence of vegetation	Marsh, wetland, or submerged aquatic vegetation elevation and continuity, Vegetation type and density, Spatial extent	Reef width, elevation, and roughness	Island elevation, length, and width, Land cover, Breach susceptibility, Proximity to mainland shore	Vegetation height and density, Forest dimension, Sediment composition, Platform elevation

USACE 2013
Ayyub 2019

Strategies to Enhance Resilience

(Chapter 5)

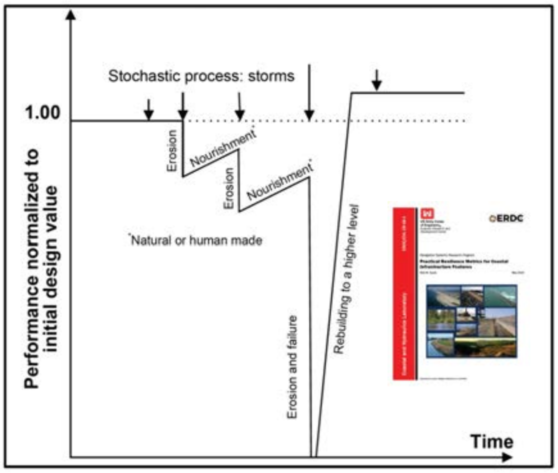
- Hardening systems
  - Land-use/associated policies
  - System designs
  - Technologies, such as using engineered weak-points in systems acting like fuses
- Soft solutions
  - Natural and nature-based infrastructure
  - Insurance and insurance securities
  - Social programs, governmental help for recovery
  - Societal measures, such as private programs

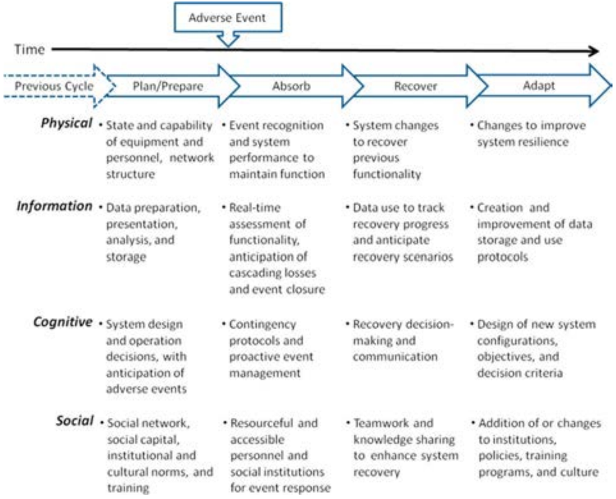
Ayyub, B. M., Pantelous, A., and Shao, J., 2016. “Towards Resilience to Nuclear Accidents: Financing Nuclear Liabilities via Catastrophe Risk Bonds” ASCE-ASME J. Risk Uncertainty Eng. Syst., Part B: Mechanical Eng., DOI: 10.1115/1.4033518.

Technologies: sensors, drones, imaging, etc.

Performances: Natural and Nature-Based Features

Considerations





	Plan/Prepare	Absorb	Recover	Adapt
Physical	State and capability of equipment and personnel, network structure	Event recognition and system performance to maintain function	System changes to recover previous functionality	Changes to improve system resilience
Information	Data preparation, presentation, analysis, and storage	Real-time assessment of functionality, anticipation of cascading losses and event closure	Data use to track recovery progress and anticipate recovery scenarios	Creation and improvement of data storage and use protocols
Cognitive	System design and operation decisions, with anticipation of adverse events	Contingency protocols and proactive event management	Recovery decision-making and communication	Design of new system configurations, objectives, and decision criteria
Social	Social network, social capital, institutional and cultural norms, and training	Resourceful and accessible personnel and social institutions for event response	Teamwork and knowledge sharing to enhance system recovery	Addition of or changes to institutions, policies, training programs, and culture

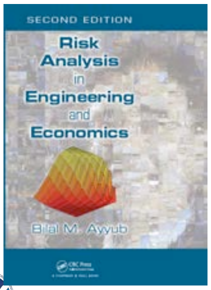
Linkov et al. 2013

Economic Valuation of Resilience **(Chapter 4)**

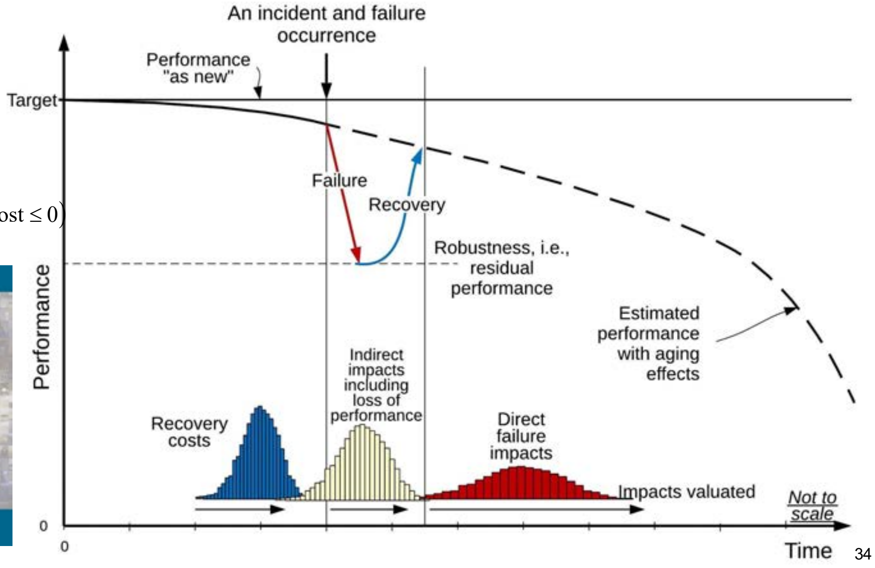
Gilbert, S., and Ayyub, B., 2016. "Models for the Economics of Resilience," ASCE-ASME J. Risk Uncertainty Eng. Syst., Part A: Civil Eng., DOI: 10.1061/AJRUA6.0000867.

Willingness to pay
Decision analysis
Discount rates
Tradeoffs
Cost-benefit analysis

$$P\left(\frac{\text{Benefit}}{\text{Cost}} \ge 1\right) = 1 - P(\text{Benefit} - \text{Cost} \le 0)$$



Data needs



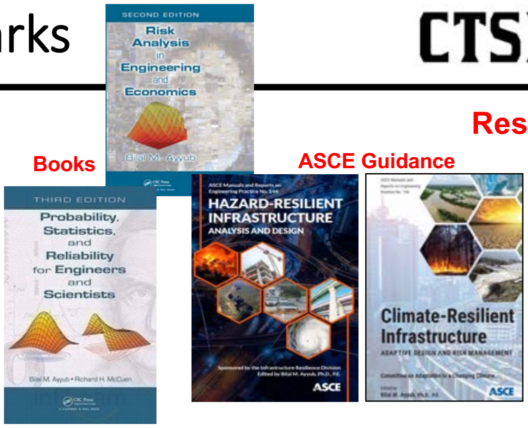
Concluding Remarks

CTSM Center for Technology and Systems Management
Technology for Intelligent Decisions

- **Hazard-resilient infrastructure**: consistency across sectors and hazards
- **Measurement science**: resilience including recovery
- **Technologies** needed for **different phases** and **integration**
- **Systems and networks**
- **Economics** of resilience enhancing strategies

Resources available

Books **ASCE Guidance**



Journals

Call for Papers

ASCE American Society of Civil Engineers

ASME SETTING THE STANDARD

ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems: Part A. Civil Engineering and Part B. Mechanical Engineering
More information https://en.wikipedia.org/wiki/ASCE-ASME_Journal_of_Risk_and_Uncertainty_in_Engineering_Systems

Thank you

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