SYSTEMS OF SYSTEMS PERSPECTIVES ON CRITICAL INFRASTRUCTURE MANAGEMENT IN RESPONSE TO CLIMATE CHANGE AND SEA LEVEL RISE

Edited by Yacov Y. Haimes and
Eugene Z. Stakhiv

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PREFACE

Since 1980, the U.S. has experienced 151 weather disasters with damages exceeding one billion dollars each. With changing climate and development patterns and the severity and frequency of extreme weather events increasing, the United States must address the vulnerability of its complex critical infrastructure, which is largely a fragmented system of systems. The nation's critical infrastructure provides the essential services that underpin the American way of life. A vast array of interdependent infrastructure and information technology networks, services, and resources enable communication, facilitate travel, power our homes and businesses, underpin our economy, and support essential government services. The aging or deteriorating condition of significant parts of these systems both weakens our resilience and negatively affects our nation's security and prosperity. Adaptation and adjustment to natural and human systems in response to actual or expected climate change will require a risk management strategy to protect vulnerable infrastructures and communities.

The complex and variable uncertainties associated with climate change, coupled with sea level rise, will exacerbate the failures of these complex, tightly coupled infrastructure systems. Complex systems are commonly composed of myriad subsystems, which in their essence constitute *systems of systems (*SoS*)*. Each SoS is characterized by a hierarchy of interacting networks and components, with multiple functions, operations, efficiencies, and cost of use. SoS are specific configurations of coupled systems and subsystems with shared states, and usually shared stakeholders, decisions, and objectives. Modeling such systems and their management requires non-conventional approaches.

This workshop was designed to improve our understanding of the intra- and interdependencies and interconnections within and among SoS, both infrastructure systems and their respective management systems that are affected by sea level rise and increased climate variability. The interdependency of the systems makes them more vulnerable to natural and human-caused disruptive events such as sea level rise, and thus introduce challenges for their protection. The framework for addressing the risk of climate change necessarily involves the entities tasked with implementing the workshop's policy recommendations and their federal leadership partners. The Federal Emergency Management Agency, the Department of Homeland Security, the National Oceanic and Atmospheric Administration, the United States Army Corps of Engineers (USACE) and state governments actively engaged the public (federal and state) to solicit input and knowledge regarding infrastructure risk as well as the of review and support for the recommendations for infrastructure adaptation. The public cohort involved with the workshop collaborated with scientists, practicing engineers, and academics who were studying resilience and vulnerability in the context of risk-based systems engineering. Our collaboration developed a practical, hierarchically linked risk management framework to effectively limit and proactively manage the myriad sources of risk associated with climate change adaptation strategies for critical infrastructure.

1. Goals and Objectives of the Workshop

This workshop examined and assessed the well-documented sources of risk and uncertainty associated with climate change and sea-level rise and incorporated a multiagency, interactive infrastructure leading to a comprehensive approach to federal agency infrastructure planning for coastal urban areas. The workshop's three primary objectives were to (i) provide a coherent and systematic hierarchical risk management framework to help assess the projected world-wide catastrophic impact of climate change on sea level rise, and the projected consequences on coastal infrastructures and communities, (ii) provide a methodology for the nation's leading scientists and engineers to collaborate, and to ultimately partner with private and public professionals responsible for managing and increasing the nation's adaptive capacity to respond to the challenge of climate change, and (iii) document the synthesis of diverse approaches and mechanisms for adaptation of risk management strategies under uncertainty, and widely disseminate the proceedings of the workshop in order to increase its impact on the formulation of public policy that addresses scientific, engineering, public health, and safety issues, and the importance of collaboration among all levels of government and the private sector.

Workshop participants collaborated to develop the building blocks of a hierarchical risk management framework that can cut through the 'Gordian Knot' of segmented and limited jurisdictional mandates to effectively respond to uncertainties in planning for, management of, and adaptation of risk management strategies to critical infrastructure. The framework resulted in a three tier integrated, hierarchical decision-making framework: (i) processes for agency implementation of climate adaptation guidelines, (ii) programmatic policies, evaluation principles, and decision criteria, and, (iii) project level design, planning, operating rules, and decision criteria.

2. Workshop Overview

The Workshop was held on March 6 – 9, 2016, in Rice Hall, at the University of Virginia. The format included various presentations, two plenary sessions by interdisciplinary science practitioners, one small group roundtable discussion session on the federal perspective on critical infrastructure, and five full group discussion sessions (see Workshop Program).

There were 47 participants in the workshop including representatives of a broad range of disciplines, such as engineering, economics, sciences, and public policy (see Workshop Participants). The participants shared their expertise and interest in critical infrastructure management in response to future climate challenges. Although a majority of the attendees were public engineers and academics from institutions across the United States, faculty and researchers at institutes were also in attendance. The workshop participants comprised a group of scholars who were diverse in training, career age, gender, and racial and national background.

Following an overview of the workshop program and introduction of the participants, the first plenary speaker, Jim Hall, discussed key infrastructure failures in the United Kingdom and stressed the importance of monitoring the progress of adaptation. Professor Soroosh Sorooshian, Director for the Center for Hydrometeorology and Remote Sensing at the University of California-Irvine, emphasized that predicting future hydro-climate variables remains a major challenge concluding, "factoring in resiliency in water resources systems design and planning is still the safest approach." Also, precipitation measurement utilizing high-resolution observations for accurate calibration and modeling to capture extremes is key.

The five workshop sessions were organized to align the concerns of public and private stakeholders, their priorities, and their responsibilities for critical infrastructure protection. Participants presented their perspectives based on their roles in and response to two highly significant climate events - Hurricane Katrina and Superstorm Sandy. The presentations provided stakeholder perspectives on managing critical infrastructure under climate uncertainty, which initiated an important discussion on how best to prepare for future challenges. All participants concurred with the importance of community resilience in the face of climate change. Improved risk management is a shared responsibility; these complex Systems of Systems require further research by experts and policymakers to define key stakeholder groups, their interactions, and other factors affecting decision-making in order to best assess risk and identify collaborative solutions.

3. Intellectual Merits

The workshop participants examined natural disaster prevention strategies, efficacy of recovery mechanisms, design vulnerabilities, unanticipated risks, system resilience and robustness attributes of two large metropolitan area systems that failed under the impact of extreme meteorological events: New Orleans with Hurricane Katrina and the New York metropolitan area with Superstorm Sandy.

Charles Perrow's seminal work in "Normal Accidents: Living With High Risk Technologies" (1999) exemplified the problematic response and recovery to such rare and extreme climate events, finding that:

- high-risk systems have characteristics that make failures inevitable – almost "normal"
- systems with multiple complex components ('*interactive complexity*') are likely to fail from unanticipated combinations of failures
- '*tightly coupled*" systems are those that have high interactive complexity and operate/move very fast – time-dependent-reducing reaction time to detect failures
- *'system accidents'* are rare, but usually catastrophic
- organizational and technological fixes usually exacerbate complexity
- 'Katrina' and Superstorm Sandy are examples of *system failure*: both the New Orleans Hurricane Protection System (HPS), and the New York metro area evacuation plan are tightly coupled systems with a high degree of complexity. In addition, the HPS may have provided a false sense of security.

Tightly coupled systems, such as New Orleans and the New York metro area were subjected to natural disasters that exceeded the design limits of the each existing system. Each system's particular failure characteristics served as excellent launching points for an examination of how to best achieve system reliability, resilience, and robustness. It also what raised the need for additional research and development (R&D) questions with respect to issues of protection of coastal shoreline infrastructure and the uncertainties of sea level rise. The existing national R&D strategy to deal with these issues, the "National

Critical Infrastructure Security and Resilience Research and Development Plan" (CISR) was used as the template to define specific R&D initiatives related to the two systems under review. The critical water resources infrastructure benefits from the most mature, well-developed infrastructure planning and management system in the field. The technical, technological, and analytical aspects are well understood among academic and practitioner communities, such that the workshop was able to focus on a single barrier—integration of the socio-political decision making systems of the stakeholders, namely scientists, engineers, and policy makers.

The key points are listed below.

- Given the nature of our society, and the governance systems under the federal system of states, it is difficult to plan, design and manage a perfectly integrated system – even of well-identified core critical infrastructures.

- The numerous stakeholders (federal, state, local entities and non-governmental interest groups) with input in planning, decision making, regulation, and engineering design make it very difficult, if not impossible, to design a robust and resilient system that can withstand unforeseen events.

- The federal government has long attempted to better coordinate these various sectors and interests, but society is becoming more complex, with greater demands for sustainability and environmental quality that fragments decision making. Uncertainties associated with climate change are more extreme and confounding, requiring flexibility in strategic planning.

- Analytical aspects of robust decision making are well understood and have been applied successfully in the abstract. While water resources and coastal infrastructure analysis is well understood, collaboration among local and state stakeholders to collect the technical data and integrate it with political decision making at the city council, state legislature and Congressional levels is deficient.

- The distinction in the two case studies of New Orleans versus the New York metro area is one of control. The New Orleans system has been under the planning, design and strict operational control of the USACE for over a century. Thus, it has undergone a pattern of consistent updating and upgrading of models, construction technologies and new data and information under a single stakeholder. It is easier to upgrade a system, if the planning and engineering is conducted by a single integrative body, as demonstrated by the response to Hurricane Katrina, in contrast to the disorganized response to Superstorm Sandy.

- The New York metro area coastal protection system is a system in name only. This multistate jurisdiction defines its own needs and requirements. With the exception of New Jersey's coastal protection system, which was largely planned and designed by the USACE, there is no coherence or strategic plan governing the system.

- The National critical infrastructure R&D strategy offers a good summary of all the basic requirements for requisite R&D. It does not effectively differentiate between the various subcomponents of critical infrastructure, and their particular R&D needs – especially in the relatively mature field of water resources infrastructure.

4. Broader Research and Development Implications

Natural systems play an important part in defining a risk environment. Natural disasters, such as hurricanes, floods, earthquakes, and tornadoes, space weather events, and pandemics pose significant risks to America's critical infrastructure. The country is already experiencing the effects of climate change, such as sea level rise, temperature fluctuations, and changes in precipitation, which increase risk to critical infrastructure systems. Accidents and technological failures, such as dam breaches and chemical spills, have the potential to cause loss of life and significant economic impact. Aging and failing infrastructures can have adverse effects on security, community resilience, and public safety.

Risk versus Vulnerability Management

A key part of the participant discussions was the distinction between risk management and vulnerability management, and whether risk analysis, as a fundamental analytical approach, is relevant to adopting a structured SoS approach. There has been a strong recent trend in natural hazards management toward quantifying risks of various hazards, their consequences, and in evaluating risk reduction options. The relationship between vulnerability and risk is not commutative - *reduced vulnerability always means reduced outcome risk, but reducing the outcome risk does not always reduce vulnerability.* (Sarewitz, et. al, 2003)

As an example, Sarewitz, et al (2003) offer the example of the United States National Flood Insurance Program (NFIP), which was discussed at length by some of the workshop participants. The NFIP is based on the assumption that the risk of a flood at a particular location exceeding a certain level (i.e., the "100-year" flood) can be quantified to allow for actuarially sound risk management practices. Since the NFIP has been in effect, this insurance regime has arguably increased vulnerabilities to flood losses rather than reduced the outcome risk. One main reason for this perverse effect is the assumption of climate stationarity that necessarily underlies the notion of a "100-year" flood. This assumption is fundamentally flawed because climate varies and changes across all time scales. Extrapolating from a finite record of past events to the immediate future does little more than guarantee that risk estimates for floods of particular magnitudes will be wrong. The situation is made worse by the fact that the risk management approach is not only used to manage risk, but also to estimate vulnerability. Based on predicted flood risk, construction zones are delineated. If event risks are underestimated in decision processes, the resulting policies can increase vulnerability and, by extension, the associated risks.

In other words, Sarewitz et al, demonstrate that certain analytical techniques may create conditions equivalent to 'incidental technological hazards' – or something akin to the 'moral hazards' of believing that one is safer than is actually the case. Likewise, for sea level rise and coastal storm mitigation and adaptation actions, there are many policy incentives that focus on vulnerability reduction. These actions and incentives cannot readily be encompassed within a risk-analytic framework since the framework leverages many objectives other than outcome risk reduction. For example, social and equity objectives related to 'environmental justice' concerns, disadvantaged neighborhoods, and ecological concerns.

In general, coastal storm risk management, combined with sea level rise, is primarily about *strategic assessments* of reducing relative vulnerabilities of future events. Employing the principles and tools of risk-benefit cost analysis is appropriate in these instances. The response to Hurricane Katrina was an application of a strategic risk analytic approach that came closest to reflecting a classic SoS approach. On the other hand, because of the fragmented political decision making nature of the New York metropolitan region, the response has been to employ a more fragmented *tactical* flood disaster risk management approach, one that focuses on reducing identified local vulnerabilities, while attempting to fit a series of disconnected local decisions into a loosely conceived risk management 'strategy.'

The Outlines of the Workshop's Proposal to NSF

Our research proposal stems from an adherence to the suggested priorities of the National Critical Infrastructure Security and Resilience Research and Development Plan" (2015), and the clear contrast in approaches between the New Orleans-type SoS response versus that of the NY metro region SoS response. We believe that a comparative analysis of the two natural catastrophes and their different risk management preparatory and post-disaster response paths provides ample insights and 'lessons learned' that are compatible with the CISR R&D objectives:

- Develop the foundational understanding of critical infrastructure systems and systems dynamics
- Develop integrated and scalable risk assessment and management approaches
- Develop integrated and proactive capabilities, technologies, and methods to support secure and resilient infrastructure

We intend to pursue a series of substantive proposals that will explore the relationship between those *strategic* components that are compatible with a risk analytic SoS framework, and those that are more adaptable to a more qualitative vulnerability assessment.

This workshop would not have been possible without the support of the National Science Foundation's (NSF) Division of Civil, Mechanical and Manufacturing Innovations programs on Civil Infrastructure Systems and Critical Resilient Infrastructure Systems and Processes. The support and encouragement of NSF's Program Director, Dr. Elise Miller-Hooks was instrumental in the workshop's success.

Drs. Eugene Z. Stakhiv and David A. Moser of the Institute of Water Resources of the United States Army Corps of Engineers were essential to the planning and execution of the workshop program and its valuable database. The quality of this workshop and its proceedings is attributable to the varied session perspectives and the eminence of its scholars and contributors in the fields of critical infrastructure protection and climate change.

We would also like to thank the organizations endorsing and supporting the workshop. The American Water Resources Association, the American Academy of Water Resources Engineers, the International Council on Systems Engineering, and the American Society of Civil Engineers endorsed the workshop. The Society for Risk Analysis both endorsed and supported the workshop.

All papers and digital presentations have been reviewed, edited and accepted for publication in these proceedings by the editors.

Finally, we acknowledge the invaluable editorial work provided by Michael Malinowski, who has completed his M.S. in Systems Engineering at the University of Virginia and the administrative and production assistance of Rosemary Shaw, the Manager of the Center for Risk Management of Engineering Systems, University of Virginia. Also providing immeasurable technical and editorial support were Boyang Dai, Jianyu Su, Madeleine Fleshman and Tien Bui from the University of Virginia.

II. WORKSHOP PROGRAM

SYSTEMS OF SYSTEMS PERSPECTIVES ON CRITICAL INFRASTRUCTURE MANAGEMENT IN RESPONSE TO CLIMATE CHANGE AND SEA LEVEL RISE

A Workshop Designed for Academics, Engineers, Government and Public and Private Officials concerned with National Critical Infrastructure Adaptation to Climate Change

Workshop Co-Chairs:
Professor Yacov Y. Haimes, University of Virginia
Dr. Eugene V. Stakhiv and Dr. David A. Moser, United States Army Corps of Engineers, Institute for Water Resources

March 6-9, 2016
Rice Hall, University of Virginia
Charlottesville, Virginia

Co-sponsored by the *University of Virginia* with the support of *the National Science Foundation*

Sunday, March 6, 2016

5:00 - 6:00pm **Opening Reception:** The Garden Room, Pavilion VII The Colonnade Club; University of Virginia Grounds.

Monday, March 7, 2016

8:00 - 9:00am **Continental Breakfast:** Davis Commons, Rice Hall

9:00 - 12:00pm ***Session 1*: Systems of Systems Risk-Based Decisions for Critical Infrastructure under Climate Uncertainty-Plenary Session**
Chair: Professor Yacov Y. Haimes

9:00 - 9:05am **Welcome:** Dean Craig H. Benson, School of Engineering and Applied Sciences, University of Virginia.

9:05 - 9:15am **Introductory Remarks:** Dr. Elise D. Miller-Hooks, Program Director, Civil Infrastructure Systems (CIS) and Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP), Division of Civil, Mechanical & Manufacturing Innovation, NSF

9:15 - 10:00am **Welcoming Remarks:** Dr. Eugene Stakhiv and Professor Yacov Haimes;
Introduction of Workshop's Participants, and Workshop Overview

10:00 - 11:00am ***Critical Infrastructure Vulnerabilities and Adaptation Priorities***: Professor Jim Hall, Director of the Environmental Change Institute Oxford University Centre for the Environment

11:00 - 12:00pm ***Hydrologic Extremes: challenges in Forecasting and Predicting Droughts:*** Professor Soroosh Sorooshian, Director of the Center for Hydrometeorology and Remote Sensing, Distinguished Professor Civil and Environmental Engineering and Earth System Science, University of California, Irvine

12:00 - 1:00pm **Luncheon:** Davis Commons, Rice Hall

1:00 - 5:00pm ***Session 2:*** **Federal Agency Perspectives**
Chair: Ed Hecker, Senior Policy Advisor, USACE Institute for Water Resources

Jeff Payne, Acting Director, Office for Coastal Management, NOAA

Doug Bellomo, Senior Technical Advisor for Flood Risk Management, USACE

Kayed Lakhia, Director, Hazard Mitigation, FEMA

Samantha A. Medlock, Senior Advisor Office of Management and Budget, Executive Office of the President

Panel Discussion and Question and Answer Session

Tuesday, March 8, 2016

8:00 - 9:00am **Continental Breakfast:** Davis Commons, Rice Hall

9:00 - 12:00pm ***Session 3*****: Hurricane Katrina Recovery**
Co-Chairs: Ed Link, University of Maryland and Kenneth Crowther, MITRE Corporation

9:00 - 10:30pm **Past and Present of New Orleans**

Pre-Katrina Systems and Their Performance: Ed Link, Center for Disaster Resilience, UMD; Director IPET

Pre-Katrina Governance and Decision Impacts: Leonard Shabman, Resident Scholar, Resources for the Future

Post-Katrina Systems Progress and Remaining Systems Issues: Tom Holden, Director, Regional Business, USACE/MVD

10:30 - 12:00pm **Future Considerations/Opportunities for New Orleans**

Post-Katrina Designs for Architecting Systems-of-Systems to "Live *with Water"*: Dale Morris, Senior Economist, Royal Netherlands Embassy

Future Designs for Highly Connected Infrastructure Systems: Dane Egli, APL, Johns Hopkins University

Trends in Analytical Predictions: Susan Stevens, DHS Office of Cybersecurity and Infrastructure Analysis

12:00 - 1:00pm **Luncheon:** Davis Commons, Rice Hall

1:00 - 5:00pm ***Session 4*: North Atlantic Coast, Superstorm Sandy Recovery**
Co-Chairs: Professor Gerry Galloway, University of Maryland and Eugene Stakhiv, Institute for Water Resources

Adapting NYC Public/Private Infrastructure to Climate Change Risks: Challenges and Opportunities: Ke Wei, Mayor's Office of Recovery and Resiliency, New York City

Flood Risk Management for an Unconvinced Public: Dave Rosenblatt, Assistant Commissioner, Office of Engineering and Construction, State of New Jersey Department of Environmental Conservation

National Critical Infrastructure Security and Resilience R&D Plan: Advancing National Objectives: Erin Walsh: Advanced Research Projects Agency, Department of Homeland Security

Building Resilience into a System of Systems: Joshua Behr, Research Professor, Virginia Modeling, Analysis and Simulation Center, Old Dominion University

A Framework for Building Coastal Infrastructure Resilience: Gerry Galloway, Research Professor, Center for Disaster Resilience, University of Maryland

5:00 - 6:00pm **Reception:** Garden Room, Pavilion VII, The Colonnade Club; University Grounds

6:00 - 8:00pm **Workshop Banquet**:
Master of Ceremonies: Yacov Y. Haimes, University of Virginia
Introductory Remarks: Professor James H. Lambert, Associate Director, Center for Risk Management of Engineering Systems, University of Virginia Program
Banquet Speaker: Executive Vice President and Provost Thomas Katsouleas, University of Virginia

Wednesday, March 9, 2016

8:00 - 8:30am **Continental Breakfast:** Davis Commons, Rice Hall

8:30 - 10:30am *Session 5*: **Conceptual Approaches to Complex Systems of Systems**
Co-Chairs: Professor Yacov Y. Haimes and Professor Seth Guikema, University of Michigan

Risk Modeling and Management of Interdependent Complex Systems of Systems**:** Professor Yacov Y. Haimes

Sustainability, Resilience, and Reliability in Urban Infrastructure Systems of Systems**:** Professor Seth Guikema, Guikema Research Group, University of Michigan

10:30 - 12:00pm
Workshop Summary and the Path Forward: Eugene Stakhiv, USACE Institute for Water Resources

Rapporteur- Barry Ezell, Chief Scientist
Virginia Modeling, Analysis and Simulation Center, Old Dominion University

12:00 - 1:00pm **Box Lunch and Departure:** Davis Commons, Rice Hall

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III. SESSIONS

Session 1: Systems of Systems Risk-Based Decisions for Critical Infrastructure under Climate Uncertainty

Chair: Professor Yacov Y. Haimes

1. Introductory Remarks

Dr. Elise D. Miller-Hooks

Sea Level Rise

- Issue of future
- There exist problems like standards evolving through time, government agencies have their own principles and too many things are included in principles, which should be simple

Critical Infrastructure

Interdependent Critical Infrastructure

- Dependencies
- Interdependencies
    - Direct
    - Indirect
        - Socio-technical
        - Through several systems, human factors' influences (i.e., A → B → C)

Current Management

- Investing only probable
- Reactive vs. proactive (i.e., insurance)
- Global problems

Complex systems (Systems of Systems)

- Why use complex systems
- Highly uncertain environments
- Evolution over time – dynamics
- Multi-temporal and multi-spatial scales
- Large
- Social elements (i.e., investors, communities etc.)
- Prescriptive and descriptive models

Know how to:

A) Identify key challenges, work toward real solutions
B) Set a course for meaningful action

2. Introduction of Workshop Participants, and Workshop Overview

Dr. Eugene Stakhiv and **Professor Yacov Haimes**

The full presentation can be found in the **NSF Workshop Materials** folder titled *1.2 Systems of Systems Workshop* available in the online version.

The projected impacts of climate change, including sea-level rise and increasing severity and frequency of extreme weather events, can cause damage or disruptions that result in cascading effects across our communities, with immeasurable costs in lives lost and billions of dollars in property damage. Changes in the earth's climate – including higher temperatures, changes in precipitation, rising sea levels, and increases in the severity and frequency of extreme weather events – are underway and expected to grow more severe over time. These impacts present significant risks to the nation's energy infrastructure. While adaptation measures – such as raising river or coastal dikes to protect infrastructure from sea-level rise, building higher bridges, or increasing the capacity of storm-water systems – is costly, there is a growing recognition that the cost of inaction is greater.

The workshop's three major objectives were to (i) address projected national and international catastrophic impacts of climate change on sea-level rise, and the subsequent projected dire consequences on our coastal infrastructures and communities in a coherent and systematic hierarchical risk management framework, (ii) facilitate an ongoing process for the nation's and world's leading scientists and engineers to collaborate, and to ultimately partner with private and public professionals responsible for managing and increasing the nation's adaptive capacity to respond to the challenge of climate change, and (iii) document the synthesis of diverse approaches and mechanisms for adaptation under uncertainty by widely disseminating the proceedings of the workshop to increase its impact on the formulation of public policy that addresses scientific, engineering, public health and safety issues, and the imperative collaboration among all levels of government and the private sector.

3. Critical Infrastructure Vulnerabilities and Adaptation Priorities

Professor Jim Hall

The full presentation can be found in the **NSF Workshop Materials** folder titled *1.3 Critical Infrastructure Vulnerabilities and Adaptation Priorities*.

The lessons learned from infrastructural failures in the United Kingdom lead to the following key insights and techniques when striving to create a comprehensive framework: risk assessment, hazard, exposure, vulnerability, cost-benefit analysis, uncertainty analysis, learning from failures, and monitoring of progress with adaptation.

Infrastructure risks:

- Infrastructure failures in the UK alarmed the government into taking control risks (i.e., flooding)
- Cost-benefits extend
- Alarming for government
- Need to get risk under control

Disruptions to UK Infrastructure:

- Weather Incidents
- Railroad Systems

Adaption:

- Design and Location of new infrastructure
- Resilience of infrastructure services
  - Energy
  - Public water supply
  - Ports and airports
  - Roads and rail network
    - Most Challenging
  - Digital infrastructure
- Infrastructure interdependencies
  - Independency among systems

Key Questions:

- What are hazard scenarios?
- What is the probability of failure?
- What are the economic consequences?

Network vulnerabilities:

- Multi-scale critical national
  - Infrastructure dependent on electricity for their operation
- Criticality hotspot analysis
  - Geographical of infrastructure hotspot
  - Infrastructure criticality is linked with customers and infrastructures in the location
- Superimposing hazard maps
  - Systems affected by failures
- Network Mapping (Template)
- Multiple infrastructures
- Network interdependency
- Hierarchy graph
  - Railway systems
- Mapping customer demands and populations; for example, mapping based on populations
- Hotspot analysis: Infrastructure criticality is linked with customers and infrastructures in the location

Estimating Fragility:

Economic loss function

- Direct loss
- Primary loss
  - Infrastructure direct loss
  - Combined economic loss
- Probability of failure vs. return period of flood
- Calculate the probability
- Economic impact of disruptions

- Quantifying economic disruptions
- Help to build new systems

Prioritizing and adaption on interventions:

A. Prioritizing
B. Cross-benefit analysis
C. Sensitivity to impact

Risk Assessment:

- Hazard
- Exposure
- Vulnerability
- Cost-benefit analysis
- Uncertainty analysis
- Learning from failures
- Monitoring progress with adaptation

4. Hydrologic Extremes: Challenges in Forecasting and Predicting Droughts

Professor Soroosh Sorooshian

The full presentation can be found in the **NSF Workshop Materials** folder titled *1.4 Hydrologic Extremes*.

The "accuracy" of hydroclimate model predictions continues to improve, but falls short of meeting the requirements of water resources planning. Building trust in their projections requires testing and validation of their performance against historical observations of sufficient resolution, both spatial and temporal. *Precipitation measurement is one of the key hydrometeorologic challenges*. Despite advances to date, predicting the future hydro-climate variables will remain a major challenge. Nature is complex and observing and modeling its nonlinear behavior is very challenging. So, "have a will to doubt" the credibility of information "generated" by models, and long-term and sustained observation programs are critical, especially for model verification. Factoring in resiliency in water resources systems design and planning is still the safest approach.

Stress on Water Resources

- Population
- Climate
- Planet is getting dry

Global Warning & Hydrologic Cycle Connection (Drought & Flood)

- Model Projections
  - Predictions (different time-frame)
    - Hours → …… → Years → Decades
- Observations

Different Time Range
Short-time range

- Hydrologic Model
  - API model
  - Lumped conceptual
  - VIC model

Mid-time range

- Using La Nina and El Nino to make judgment
- IRI 3-month multi-model probability precipitation forecast

Long-range

- Ensemble approach
- IPCC climate models

Extreme: Stochastic Hydrology

Two hydrological variables

- Stream flow
- Precipitation

Three ways to measure precipitation

- Rain gauge
- Satellite
- Collecting data

Session II: Federal Agency Perspectives

Chair: Ed Hecker, Senior Policy Advisor, USACE Institute for Water Resources

1. Climate Change and Flooding

Samantha Medlock

Federal agencies incorporated the best available science and data, including sea level rise projections and climate resilience, into project planning and design. Building upon the immediate recovery efforts following Superstorm Sandy to ensure that we are better prepared before disaster strikes, the Administration announced the Federal Flood Risk Management Standard. A key deliverable of President Obama's Climate Action Plan and the Hurricane Sandy Rebuilding Strategy, the national standard directs agencies to account for the latest scientific projections and adopt stricter siting, design, and construction standards for all federally funded projects. The new standard provides a flexible framework for federal agencies informed by standards of practice of professional engineers and codes bodies, including the American Society of Civil Engineers and the International Code Council.

Flood disasters exploit and exacerbate underlying inequities and vulnerabilities, displacing families and shuttering small businesses that cannot weather the storm without assistance. Recognizing that low-income and underserved communities are often less equipped to prepare for and respond to the impacts of climate change, the Obama Administration has made equity a priority. The Resilience AmeriCorps pilot provides much-needed technical support for vulnerable communities to address climate-resilience planning and implementation by coordinating interagency assistance to high-need communities through smart growth strategies.

Private sector leaders, particularly the financial industry of insurers, lenders, and credit rating agencies, recognize that extreme weather and other effects of climate change pose potentially existential threats to the long-term viability of the regional economies and key commercial sectors. A partnership with insurers aligns three key interests in (i) sharing data, (ii) promoting resilience codes and standards, and (iii) developing innovative approaches to financing resilience for homes, businesses, and infrastructure to increase community resilience and insurability. The American Business #ActOnClimate is a group of 80 companies pledging specific commitments to climate actions, increasing energy efficiency, boosting low-carbon investing, developing innovative financing structures, and making solar energy more accessible to low-income Americans. The represented companies had more than $1.3 trillion in revenue in 2014 and a combined market capitalization of at least $2.5 trillion.

Problem

As documented in the National Climate Assessment, the growing threat of climate change could define the contours of this century more dramatically than any other.

Temperatures at Earth's surface, in the troposphere (the active weather layer extending up to about 5 to 10 miles above the ground), and in the oceans have all increased over recent decades. The largest increases in temperature are occurring closer to the poles, especially in the Arctic.

This warming has triggered many other changes to the earth's climate. Snow and ice cover have decreased in most areas. Atmospheric water vapor is increasing in the lower atmosphere because a warmer atmosphere can hold more water. Sea level is increasing because water expands as it warms and because melting ice on land adds water to the oceans.

Changes in other climate-relevant indicators such as drought and wildfire have been observed in many areas. Worldwide, the observed changes in average conditions have been accompanied by increasing trends in extremes of heat and heavy precipitation events.

It is the sum total of these indicators that leads to the conclusion that warming of our planet is unequivocal.

Heavy Downpours

Heavy downpours are increasing nationally, especially over the last three to five decades. The heaviest rainfall events have become heavier and more frequent, and the amount of rain falling on the heaviest rain days has also increased.

Since 1991, the amount of rain falling in very heavy precipitation events has been significantly above average. This increase has been greatest in the Northeast, Midwest, and upper Great Plains – more than 30% above the 1901-1960 average. There has also been an increase in flooding events in the Midwest and Northeast, where the largest increases in heavy rain amounts have occurred.

Floods

Worldwide, from 1980 to 2009, floods caused more than 500,000 deaths and affected more than 2.8 billion people. In the United States, floods caused 4,586 deaths from 1959 to 2005. Property and crop damage averaged nearly 8 billion dollars per year (in 2011 dollars) over 1981 through 2011.

Between 1980 and 2013, floods caused more than $260 billion in losses in the US alone. Global insured losses continue to rise, driven by a mix of factors including economic development, population growth, a higher concentration of people and assets, including infrastructure in exposed areas (particularly densely populated coastal or riverine flood prone areas), and a shift in the frequency and severity of extreme weather events.

The risks from future floods are significant, given expanded development in coastal areas and floodplains, unabated urbanization, land-use changes, and human-induced climate change. For example, by late this century, models, on average, project an increase in the number of the strongest (Category 4 and 5) hurricanes. Models also project greater rainfall rates associated with tropical cyclones in a warmer climate, with increases of about 20% averaged near the center of tropical cyclones.

Flood risk professionals have long recognized the "100-year" flood standard is not a safety standard, and is insufficient to protect life and property.

On average, more than 40% of flood losses occur outside the confines of the "100-year" floodplain. Although more than ten states and thousands of communities no longer rely exclusively on the so-called 100-year floodplain to drive development decisions and have adopted margins of safety to account for larger floods, Federal standards remained unchanged for the past 40 years, until now.

Three years ago, Superstorm Sandy made landfall in the Northeast, devastating homes, businesses, and major infrastructure assets in its path. Since then, the Administration has invested in hard-hit communities with a single focus: to ensure that affected communities do not just rebuild, but rebuild smarter. Recovery cannot be solely focused on short-term needs, but on long-term risk and vulnerabilities, which continue to rise as a result of climate change.

The Hurricane Sandy Rebuilding Task Force required that all Sandy-related rebuilding projects funded by the Federal government meet a uniform flood risk reduction standard informed by the best science and best practices. This standard required use of best-available data for elevation plus one-foot, the first use of a Federal freeboard recognizing that the 100-year standard is not enough when investing taxpayer dollars to assure resilient long-term recovery.

In the aftermath of Superstorm Sandy, Federal agencies incorporated the best available science and data, including sea level rise projections and climate resilience, into project planning and design. Building upon the immediate recovery efforts following Superstorm

Sandy, and to ensure that we are better prepared before disaster strikes, the Administration announced the Federal Flood Risk Management Standard.

Agencies are currently updating their rules and procedures to implement the Flood Standard, and will benefit from SLTT input and insights. Agencies are engaging with stakeholders on implementation to ensure that programs not only reduce federal disaster costs but also support state and local efforts to build resilience.

Lastly, governments cannot and need not go it alone in addressing flood risk. The gap between total catastrophic losses and those covered by insurance has been growing. In the 1980s it stood in the low tens of billions of dollars, but by 2014 it had grown to $75 billion according to data from Swiss Re.

And global insured losses continue to rise, driven by a mix of factors including economic development, population growth, a higher concentration of people and assets, including infrastructure, in exposed areas (particularly densely populated coastal or riverine flood prone areas), and a shift in the frequency and severity of extreme weather events.

Since Hurricane Sandy made landfall, the national dialogue about recovery and resilience has shifted in the Federal government and led to efforts to integrate resilience into the fabric of how we build, rebuild, plan, and prepare for the impacts of climate change.

2. Local Sea Level Rise and Coastal Hazards Threaten Infrastructure: Natural-Based Solutions

Jeffrey Payne

The full presentation can be found in the **NSF Workshop Materials** folder titled *2.2 Federal Agency Perspectives*.

Sandy Recovery: The National Oceanic and Atmospheric Administration (NOAA) received $2.56 million to support recovery planning at the regional, state, and local levels. NOAA has supported six projects helping communities successfully address the negative impacts and increase coastal community resilience in New York, New Jersey, and Connecticut, and complement other regional recovery and adaptation.
Climate Resilient Cities Pilot: The Trust for Public Land is researching, planning, and creating strategic green infrastructure projects for Staten Island and Jamaica Bay, New York. The project team is assessing green infrastructure projects performed during Sandy to identify priority sites for new green infrastructure projects.
Regional Coastal Resilience Grants Program: The RCRG program supports regional approaches that build up the resilience of coastal regions, communities, and economic sectors to the negative impacts from extreme weather events, climate hazards, and changing ocean conditions.
Mitigation Federal Leadership Group Resilience Indicators: There is a broad interest in identifying key factors affecting community resilience, understanding where we stand as a nation related to those factors, and using this information to develop better-informed federal, state and local capacity building strategies.
Federal Flood Risk Management Standard: Executive Order 13690 – Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input and a revised Executive Order 11988 – Floodplain Management on January 30, 2015.

- Coastal Green Infrastructure

- Sandy Funded Efforts in New Jersey - Under the 2013 Disaster Relief Appropriations Act for Sandy, NOAA received $2.56 million to support recovery-planning efforts at the regional, state, and local levels. NOAA has supported six projects, each of which is focused on helping communities successfully address the negative impacts associated with climate change and other coastal hazards. These investments will increase coastal community resilience in New York, New Jersey, and Connecticut, and compliment other recovery and adaptation efforts in the region. The projects will be completed during FY 2016, delivering tools and information to communities across the Mid-Atlantic region and other regions to address both the mitigation and recovery mission areas under the new National Preparedness Goal.

- Climate Resilient Cities Pilot: The Trust for Public Land is researching, planning, and creating strategic green infrastructure projects for Staten Island and Jamaica Bay, New York. The project team is assessing how green infrastructure performed during Sandy and is developing a web based decision-support tool to identify priority sites for new green infrastructure projects. This tool will help identify areas that are most critical for protection and would receive the greatest benefit from green infrastructure applications. The team will also provide technical assistance to implement on-the-ground demonstration projects along New York City's waterfront.

- Regional Coastal Resilience Grants Program (RCRG): The RCRG program supports regional approaches that build up the resilience of coastal regions, communities, and economic sectors against the negative impacts from extreme weather events, climate hazards, and changing ocean conditions.

- Funded projects will result in improved information for decision makers and actions that reduce risk, accelerate recovery, and promote adaptation to changing social, economic, and environmental conditions.

- Awards are made to organizations that advance resilience strategies in plans for land and ocean use, disaster preparedness, environmental restoration, hazard mitigation, or other regional, state, or community plans.

- FY2015 awards injected $4.5M in federal dollars and an over 50% match of $2.4M in local, state and private resources into coastal resilience actions. FY2016 awards were announced in early March 2016. The FY17 President's Budget requests a total of $20M for this program. www.coast.noaa.gov/resilience-grant

- Example dealing directly with infrastructure: (FY15) Building Coastal Resilience through Capital Improvements Planning: Guidance for Practitioners

- The planning and construction of capital improvement projects, such as community buildings and infrastructure, present an opportunity to incorporate new, high-impact approaches for building resilience. The American Planning Association (APA) and the Association of State Flood Plain Managers (ASFPM) will work together to develop nation-wide guidance by researching cutting-edge techniques used in different sectors throughout the United States and through the experience gained in the two pilot communities: Toledo, Ohio, and Savannah, Georgia. The guidance developed through this project will be used to educate the 57,000 members of these organizations and others regarding the most successful techniques.

- Mitigation Federal Leadership Group Resilience Indicators - There is a broad interest in the United States in identifying key factors affecting community resilience, understanding where we stand as a nation in relationship to those factors, and using this information to develop better-informed federal, state and local capacity building strategies.

- Resulting from a Council on Environmental Quality-led Insurance Industry Roundtable in late 2014, FEMA and NOAA are co-leading an interagency effort under the Mitigation Federal Leadership Group (Mit-FLG) to identify key community resilience indicators with linkages to relevant federal capacity building programs.

- In addition to identifying potential indicators, this effort is also exploring available Federal data sets for possible use in measuring and tracking indicator progress over time at the national level.

- This effort will produce a summary report in April 2016 and provide an accompanying geospatial data application.

- Federal Flood Risk Management Standard (FFRMS)USGS - Following a directive in the President's Climate Action Plan (June 2013) and a recommendation in the Hurricane Sandy Rebuilding Task Force Report (August 2013), President Obama issued Executive Order 13690 – *Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input* and a revised Executive Order 11988 – *Floodplain Management* on January 30, 2015.

- Together, the Executive Orders will reduce the risk and cost of future flood disasters by ensuring that Federal investments in and affecting floodplains are constructed to better withstand the impacts of flooding. These are two critical policy changes affecting the planning, design, and construction of Federal infrastructure:

- Federal agencies shall use, where possible, natural systems, ecosystem processes, and nature-based approaches in the formulation of actions and alternatives.

- The subset of actions that are federally funded projects such as construction, substantial improvement, or repair of substantial damage to structures and facilities must be built to meet the increased level of flood resilience established by the FFRMS, which accounts for both current and future flood hazards.

- NOAA's level of involvement: NOAA, as one of the Department of Commerce's representatives to MitFLG, participated on the FFRMS Workgroup. NOAA was a leading voice on dimensions related to application of climate science and advocating use of natural infrastructure to support flood risk management. NOAA also led a "science subgroup" of agencies (United States Geological Survey, USACE, Department of Transportation, Federal Emergency Management Agency) that focused on the climate-informed science approach. NOAA was active in the formulation of the FFRMS itself and the recently approved (October 2015) interagency Implementing Guidelines for the Executive Orders.

3. Climate Resilient Mitigation Activities

Kayed Lakhia

Supplemental fact sheets can be found in the **NSF Workshop Materials** folder under the following document titles: *2.3a ASR Fact Sheet - Sept 2015*, *2.3b FDS Fact Sheet - Sept 2015*, *2.3c FSR Fact Sheet - Sept 2015*, and *2.3d GI Fact Sheet - Sept 2015*.

FEMA announced the eligibility of three Climate Resilient Mitigation Activities under the Hazard Mitigation Assistance (HMA) programs to support communities in reducing the risks and adverse impacts associated with climate change. These activities are: Aquifer Storage and Recovery, Floodplain and Stream Restoration, and Flood Diversion and Storage. Climate change can exacerbate natural hazard risks to a community by increasing the intensity and/or frequency of storms, floods, wildfires, and drought. The effects of the current drought in western states underscore the need to provide HMA program resources on mitigation methods for this hazard. FEMA encourages communities to incorporate climate resilient infrastructure into eligible HMA risk reduction activities. In addition to guidance on the three flood and drought Climate Resilient Mitigation Activities, FEMA is providing information on green infrastructure methods to reduce risk and increase resilience, and expand ecosystem service benefits.

The President’s 2015 Opportunity, Growth, and Security Initiative, Executive Order 13653 Preparing the United States for the Impacts of Climate Change, the President’s 2013 Climate Action Plan, FEMA’s Climate Change Adaptation Policy, and the 2014-2018 FEMA Strategic Plan, all identify the risks and impacts associated with climate change on community resilience to natural hazards and direct Federal agencies to support climate resilient infrastructure.

FEMA encourages communities to incorporate climate resilient infrastructure into eligible HMA risk reduction activities. In addition to guidance on the three flood and drought Climate Resilient Mitigation Activities, FEMA is providing information on green infrastructure methods to reduce risk and increase resilience, and expand ecosystem service benefits.

Four fact sheets are provided in the Supplementary Materials. Three of the fact sheets provide high-level technical information on the three mitigation activities, Aquifer Storage and Recovery, Floodplain and Stream Restoration, and Flood Diversion and Storage that best address the effects of drought within the HMA program framework. Also attached is a fact sheet on using green infrastructure methods as a sustainable approach to flood and storm water management that increases benefits to the ecosystem and increases community resilience to climate change impacts. Ecosystem services are beneficial goods and services provided by nature for people. FEMA is building on the existing ecosystem services that can currently be used for cost effectiveness evaluation for acquisition/open space projects to allow more ecosystem service benefits for Climate Resilient Mitigation Activities.

These Climate Resilient Mitigation Activities may be used to mitigate any applicable natural hazard. However, the activities and their benefits are especially focused on mitigating the impacts of flood and drought conditions through measures that increase water storage and recovery and groundwater re-charge, and on using green infrastructure principles for sustainable water resources management. FEMA encourages communities to be innovative in developing mitigation projects that reduce risk and offer creative methods to mitigate the impacts of climate change.

Over the next several months, FEMA will be developing and releasing more detailed technical guidance on these Climate Resilient Mitigation Activities, implementation tools for ecosystem services as part of the cost effectiveness evaluation, and guidance on the principles of green infrastructure and methods of incorporating them into mitigation activities. This will include an assessment and guidance on any special environmental, historic, or cultural resource considerations associated with these activity types.

The Climate Resilient Mitigation Activities are available for Hazard Mitigation Grant Program funding resulting from a major disaster declared on or after the date of this memorandum, and for PDM funding for which the 2016 application period opens March 15. FEMA's programmatic strategy for implementing the National PDM program is to continue to build on the successes of the past several years. By establishing clear national funding priorities and selection criteria, the national competitive portion of the PDM program provides states, tribes, and local governments with the information they need to compete for funding. The total amount of funds distributed under the FY 2016 PDM Grant Program will be $90,000,000. The top priority for selecting PDM projects this year is Climate Resilient Mitigation Activities, including Aquifer Storage and Recovery, Floodplain and Stream Restoration, Flood Diversion and Storage, and pre- or post-wildfire mitigation activities or any mitigation action that utilizes green infrastructure approaches.

The total amount of funds distributed under the FY 2016 FMA Grant Program will be $199,000,000. As in prior years, the emphasis for FMA in FY16 is to buy-out Severe Repetitive Loss (SRL) and Repetitive Loss (RL) properties.

Sources of Uncertainty:

- Baseline information
- Future physical drivers
- Species response
- Technical guidance
- Performance, longevity self recovery
- Monitoring, adaptive management, metrics
- Financing and partnership

Use of Ecosystem Services for Decision Making:

- Quantify benefits of integrated systems
- Quantify monetary and socio-cultural value

Three Dimensions:

1. Social
2. Economic
3. Environmental

How to model based on these three dimensions?
Questions:

1. Does the natural-based solution take into account of extreme scenarios?

The core of this solution is to find the balance between social values and economic values.

2. How about rare events? The time frame of re-invest?

There are limitations in terms of rare events. Does the government have any plan deal with worst-case scenario sea level rise?

4. Resilient Adaptation to Increasing Risk

Doug Bellomo, Senior Technical Adviser for Flood Risk Management, USACE

The full presentation can be found in the **NSF Workshop Materials** folder titled *2.4 North Atlantic Coast Comprehensive Study*. URL

The USACE is reaching out to improve the way it interfaces with others who rely on infrastructure, influence the risk, and share in the responsibility of ensuring how it fits into a broader SoS perspective. With increased downward pressure on government budgets at all levels (federal, state, local) finding ways to show how our missions intersect as SoS is key to ensuring our effectiveness. Cross-disciplinary collaboration (financial, legal, technical, political, and social) is critical. Embracing uncertainty, deliberately managing change, and improving adaptability is needed to manage risk to critical infrastructure.

A variety of ongoing efforts are underway within the USACE to standardize and improve how it manages its infrastructure and the risks to it within the confines of its legal authorities and available resources. Examples include Silver Jackets - a program aimed at bringing together federal and state government partners sharing in flood risk and other challenges; Levee Safety - where relationships are being improved as risks are more effectively communicated to local sponsors and new ways of tackling the challenges that emerge are being deployed; System-wide Improvement Framework (SWIF); and the National Flood Risk Management Program which is now expanding its vision to include making our SoS (economy, society, and environment) more resilient to flooding.

With increased downward pressure on government budgets at all levels (federal, state, local), we must improve how we work together to reach common goals. Having an appreciation for the differences in our missions is important, but finding ways to show how those missions link together from a SoS perspective is key to ensuring we are more effective in accomplishing goals. Finding ways to cut across disciplines (financial, legal, technical, political, and social) rather than working within stovepipes is critical. Embracing uncertainty, deliberately managing change, and improving adaptability are needed to make progress at managing the risks to our critical infrastructure and the essential services it provides yet government processes (legal and fiscal), programs, and culture tend to under appreciate these principles.

Changing climate, demographics, social values, and physical landscapes will continue to require active management of the critical infrastructure needed to ensure prosperity, health, and happiness. Investments to defend those existing assets will be required along with other strategies including adapting them to better serve and abandoning them when newer technologies and approaches make more sense. The building of new critical infrastructure projects will need to be properly financed, designed, operated, and maintained with change and the potential for their total loss in mind. That will require long term thinking, embracing the idea that complete loss could occur and planning for it, and effectively communicating using a broad system of systems approach.

Superstorm Sandy project:

- Flood diversion and storage
- Flood clean and stream

Questions:

1. Where is the section of quantifying analysis in the program?

This project is to give an outline of what should be done rather than quantifying loss, benefits and probability. There are other programs doing quantifying jobs.

2. Is there a leading agency taking charge of sea-level rise?

No single leading agency but several agencies working together. But there are many agencies primarily taking charge of one facet of the project. It is early stage; there is no quick remedy for dramatic rise of sea level right now.

Session 3: Hurricane Katrina Recovery

Co-Chairs: Ed Link, Center for Disaster Resilience, Department of Civil and Environmental Engineering, University of Maryland and Kenneth Crowther, Homeland Security Systems Engineering and Development Institute, MITRE Corporation

Part 1: Past and Present of New Orleans

1. *Pre-Katrina Systems and Their Performance*

Ed Link

The full presentation can be found in the **NSF Workshop Materials** folder titled *3.1.1 New Orleans Hurricane Protection System*.

The New Orleans Hurricane Protection System was a system in name only. There were many weaknesses: the system was incomplete, datum/elevations were deficient, components were not integrated, there were outdated hazard and design criteria which resulted in an outdated system, there was a lack of infrastructure robustness/resilience, there was a lack of emergency preparedness and response.

2. *Pre-Katrina Governance and Decision Impacts*

Leonard Shabman

The reality of the governance system is that governance is always about making unavoidable tradeoffs, whether explicitly or by default. Furthermore, there is no "single client" with unlimited resources. Governance is dispersed to some degree. Change follows failure. Lastly, change is a response to the specific circumstances of the failure.

Avoid Presentism- " Presentism is a mode of historical analysis in which present-day ideas and perspectives are anachronistically introduced into depictions or interpretations of the past."

3. Post-Katrina Systems Progress and Remaining Systems Issues

Tom Holden

The full presentation can be found in the **NSF Workshop Materials** folder titled *3.1.3 Post Katrina HSDRRS Progress and Remaining Challenges*.

The USACE's action for change will utilize (i) Comprehensive systems approach: (ii) risk-informed decision making, (iii) communication of risk to the public; and (iv) professional and technical expertise. Furthermore, some best practices include system program management and risk management and communication. Policymakers can drive down the risks with an informed and engaged public. Additionally, all stakeholders contribute to reducing risk. For New Orleans, the future challenges are climate change/sea level rise, land subsidence, coastal erosion, and a lack of equity and opportunity.

Best Practices: System Program Management:

- Acquisition Strategy
  - Design build / cost plus contracts
  - Best value source selection
  - Early contractor involvement
  - Program management support contract
- Construction Materials
  - Government furnished borrow
  - Supply contracts for sheet piles and borrow
- Improved Techniques
  - Value Engineering –systems study complete
  - Pile Load Tests –in advance of contract award
  - Press Pile, Spiral welded piles
  - Deep soil mixing, sand blanket and wick drains
- Leverage International, National and Regional Resources

Risk and Risk Communication – Drive down the risks with an informed and engaged public. All stakeholders contribute to reducing risk

New Orleans:

- Future Challenges
  - Climate change/sea level rise
  - Land subsidence
  - Coastal erosion
  - Lack of equity and opportunity
- Resilience
  - Strike balance between human needs and the environment
  - Combat violence, poverty and inequity

Part 2: Future Considerations and Opportunities for New Orleans

1. *Post-Katrina Designs for Architecting Systems-of-Systems to "Live with Water"*

Dale Morris

The full presentation can be found in the **NSF Workshop Materials** folder titled *3.2.1 New Orleans Urban Water and Resilience Plan*.

New Orleans' Urban Water and Resilience Plan: New Orleans has a hurricane protection system - 350 miles of floodwall and a pumping station. But they are not enough for hurricanes like Katrina. Safety infrastructure is necessary, not sufficient, to revitalize New Orleans. The previous infrastructure was not robust. There were many infrastructure failures in the Katrina. According to the database provided, if the system is robust enough, it could have reduced the loss significantly. Using the methodology: Chance of hazard x system performance = vulnerability to flooding x consequences = risk. Generating a map simulating the risk of many different hurricanes in the future for multiple locations in New Orleans is a challenge.

Deficits in infrastructure:

- Incomplete (walls intended to be built have not been constructed)
- Elevation deficient (not enough for 1/100 year storms)
- Components not integrated
- Designed for outdated hazards (I walls; T walls are more useful)
- Lack of infrastructure robustness/resilience
- Lack of emergency preparation

Safety Infrastructure Necessary, Not Sufficient to Revitalize New Orleans:

- Recurrent 1/5 and 1/10 year storms driving people away
- Nuisance impacts, high individual and business insurance rates
- Neighborhoods divided by outfall canals; loss of real estate values
- How to integrate
    - Protection / safety
    - Improved pumping and groundwater management
    - Reinvestment and redevelopment plans / funds
    - Land-use planning

Interior Drainage/Pumping

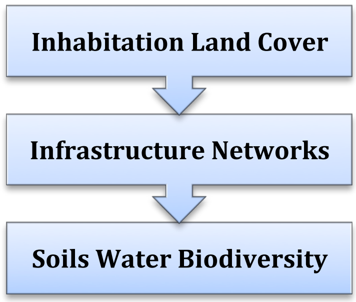
Pros:

- Robust against rainfall/flooding

Cons:

- Expensive
- Not sustainable
- Drainage system regularly overwhelmed by too much run off causing flooding
- Excessive pumping causes the land to sink by lowering groundwater levels

- Critical water assets are wasted, hidden behind walls, buried underground, or pumped out of the city
- Empty lots, loss of economic activity, ecology, etc.



Change Paradigm

a. pipe + pump + drain

b. slow → store → drain (i.e.: facilitate natural process)

Ripple effect core:

Three-part collaboration among:

1. Teachers
2. Design professionals
3. Water

Questions:

1. Is it a new method of computing?

Yes, it is. And it has been published.

2. Is Congress using this method?

It will be answered in the next section. This method has been applied to various areas.

3. Is it universally applicable?

Yes. A similar analysis was used in other cities (e.g., project in New York).

4. Can this project be transferred to other cities?

Yes. The New York project will demonstrate it.

5. Are there projects going on in Houston and Gulf coast?

Some projects are researching this area.

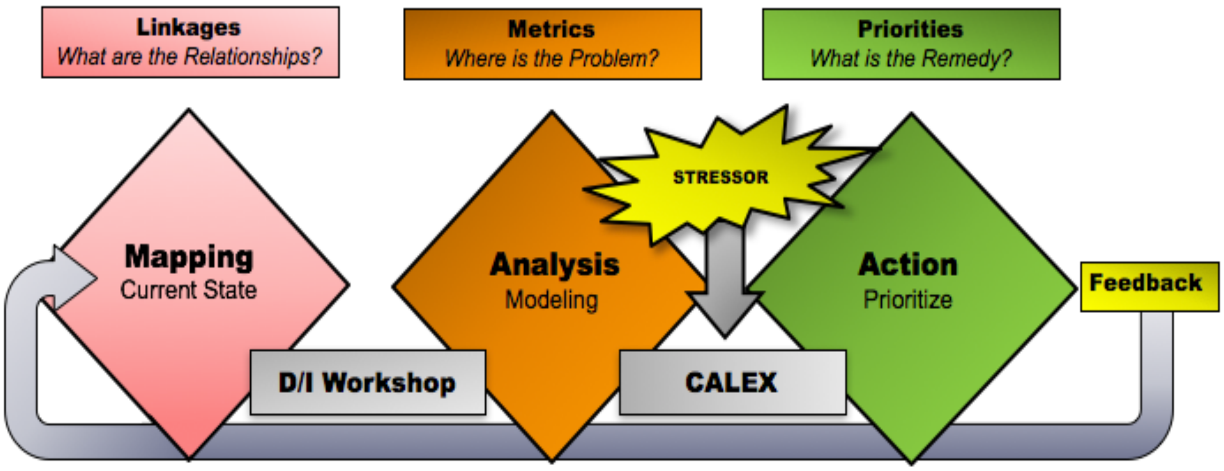
2. Future Designs for Highly Connected Infrastructure Systems

Dane Egli

The full presentation can be found in the **NSF Workshop Materials** folder titled *3.2.2 Bouncing Forward through Analysis & Adaptation*.

Resilience requires an understanding of the current state and collection of data to map, model, and analyze to enable better decisions and prioritizing in a resource scarce environment. Given the complexities and interdependencies of all critical infrastructure sectors and subsectors, resilience must be quantified in a way that demonstrates value and return on investment to small and medium-sized businesses, supports sustainability and business continuity, incentivizes sectors to partner and collaborate, and keeps the economy stable and improving.

Resilience Implementation Framework



Key Findings from Field Test

- Coordination
  - Building a modeling framework to engage cross-sector stakeholders and reveal information-sharing barriers.
- Interdependencies
  - Cascading impacts were visualized through modeling.
  - Newsector interdependencies were identified in fuel distribution, IT, communications interoperability, and treated water.
- Analysis
  - Collecting data, finding reliable metrics, building high-fidelity critical infrastructure interdependency models is a painful process.
- Data Sharing
  - The necessary level of model fidelity is not achievable without full buy-in from critical infrastructure sectors.
- Modeling Framework
  - Full buy-in is unlikely. A modeling framework is needed that stimulates sharing of results across sector stakeholders.
- Future Study
  - Implement rigorous systems engineering approach to identify requirements with a "coalition of the willing."

Summary

- Not only hardening systems
    - Public-private sector leaders recognize need for improved emergency preparedness, CIP, and information sharing.
- Disaster events continue
    - Current threats and vulnerabilities overwhelm capabilities due to complexities and reduced budgets.
- Local leaders need help
    - Greater understanding of CI networks and their interdependencies will help leaders make better decisions.
- Metrics that matter
    - Operationalize resilience through an adaptable modeling framework that simplifies data collection and baselines critical infrastructure relationships.
- Smart resilience
    - Analytics can illuminate interdependencies and cascading effects showing the cost/benefit and ROI to private and private leaders.

3. *Trends in Analytical Predictions*

Susan Stevens

The full presentation can be found in the **NSF Workshop Materials** folder titled *3.2.3 Trends in Analytical Predictions OCIA*.

Vision

- Strengthen the security and resilience of the nation's critical infrastructure through innovative cyber and physical analyses
- Inform the decisions that protect the nation's critical infrastructure

Principles

- Innovation, collaboration, boldness, excellence

Risk Analytics and Services Branch Role

- Provide the relational, methodological, technical, and data solutions that enable the Office of Cyber and Infrastructure Analysis (OCIA) of the Department of Homeland Security (DHS) to be bolder, more innovative, collaborative and excellent

Problems

- Complex systems fail in complex ways
- Society is not structured to anticipate and address systemic risks
- Managing infrastructure risk is complex
- The complexity of the decision making context leads to complex cost and schedule considerations
    - Technically Difficulties
        - To sort out the interdependencies of infrastructure systems

        - To account for the ability of operators to innovate in an emergency
        - To recognize and value cascading effects
    - Politically
        - Federal agencies, state and local emergency responders, shareholders, customer
- These issues have been a historic challenge to public and private decision making; considering the complexity and systems effects may help make them more manageable

Case Studies

A. Katrina

- Pre-Katrina Approaches
    - 2003-2005 DHS was defining and sorting out its work, being a new department
    - Traditional owners/operators and state and local authorities were responsible for taking appropriate actions to manage risk
    - Anecdotally, infrastructure failure from a natural hazard would have been considered the owner/operator's concern, the state and local authorities' headache, and a FEMA planning challenge
    - If the same risk was attributed to sabotage, an entirely different group of government agencies would be involved
- Post-Katrina Changes
    - FEMA and IP began making efforts more holistic
    - As government resources increased in growing organizations, it was difficult to apply lessons learned
    - Subtle, unaddressed issues percolated
        - Different authorities and responsibilities creating alternative views that obscured problems
        - Arguments over details preventing consensus over core issues
        - Complexity of infrastructure
        - Complexity of society and governance
    - Organization began experimenting with changes to how we manage analytic work, to address these issues

B. Cascadia Earthquake and Tsunami Risk Baseline (2010)

- Offered to do the risk baseline analysis for FEMA Regions 8 to 10
- Analytic team was proficient at interdependency analysis and modeling complex response and recovery issues in post-disaster environments
- The purpose was to help decision makers, planners, and first responders plan for and respond to a major earthquake in the Cascadia region off the coast of Oregon and Washington, analyzing the possible direct and cascading impacts from a large earthquake and ensuing tsunami on population and infrastructure
- Addressing complexity
    - Concerns of high-level-view questions

    - Asked the 50-60 state and local authorities to help identify experts in earthquake and tsunami
    - Formed a study team, including our own modeling team, academic and federal experts
        - ***Expected outcome*** was a useful risk baseline that planners could work on.
        - ***Desired outcome*** was that a second line of experts would be there, know the plan and how to interpret it in case the first line was lost in the earthquake and tsunami.
- Results of the work
    - In 2011, a draft was delivered and then a final product to the planners
    - Researchers recognized the importance of working together. Ease in decision making and planning by police, infrastructure owners, and other stakeholders was recognized when researchers provided a consistent message.
- Unexpected Results
    - Reports of proactive public actions to mitigate risk
    - Resources requested to begin moving some buildings, which are newly identified as at-risk for tsunamis, to safer locations
    - More public articles talking about the earthquake and public and private efforts to prepare for and mitigate risks were disseminated

C. Poe Lock Closure Study (2011)

- Asked to analyze the potential impacts of the closure of the Poe Lock. Initial two rounds of analysis were each doomed by erroneous assumptions.
    - There was an unfounded belief that we could transport iron ore by rail to replace the Soo Locks shipments.
    - There was an unfounded belief that all steel is interchangeable.
- Errors were later recognized and the final product, "The Perils of Efficiency – An Analysis of the Unexpected Closure of the Poe Lock and Its Impact," was released.

Lessons Learned

- The complexity of government, public-private partnerships, and collaboration between researchers and decision makers seems difficult to overcome.
- Scientists and experts working together can create clarity and make the case for action:
    - Individually they are sometimes unaware.
    - At best, they may be "singing solos" that were individually defensible, but together, "singing in chorus," gave them advantages.
    - Decision makers do not have time to sort out why past research does not "agree." Assumptions, data, scenarios are too weedy.

  - It is important to prepare a message that is consistent, that they all endorse, that captures the attention of decision makers. Suddenly, science is more "settled."
- Our team looks back on the reverberating action from and attention to these studies as some of our greatest successes.
- We are beginning to see a pattern for extremely complex SoS problems benefiting from studies with broader scope, fewer assumptions, and iterative validation and clarification with experts.
- In some ways this may be a systemic opportunity (the opposite of a systemic risk).
  - Accepting the project risk and social aspects of the extremely complex project had unanticipated amplifying benefits.
  - Our organization is focused on societal risks from incidents and conditions that affect infrastructure. We can be a key collaborator.

Epilogue

Systems of Systems are inherently complex, but SoS can be further categorized according to their complexity and adaptive nature. The infrastructure risk management and resilience goals are confounded by our need to understand and navigate effectively what may be among the most complex and adaptive SoS because the stakeholders are in competition among each other to transfer risks and costs to others. This creates an enormous societal cost by sinking energies into understanding risks without understanding the mechanisms to address them, and by building animosity among organizations that should effectively partner to address risk. It further obscures risk management options that could benefit society because the full set of potential partners is rarely identified.

Research is needed to define different critical infrastructure security and resilience stakeholder groups and their systems of interaction, ownership of portions of dependency-defined fault trees, and incentive structures that affect decision making. Given better understanding of the hidden risk transfers among these stakeholders, we can provide both Congress and future administrations with options that may clarify what is going on and provide better incentives to the aggregate risk management SoS to function efficiently and effectively.

Session IV: North Atlantic Coast, Superstorm Sandy Recovery

Co-Chairs: Professor Gerry Galloway, Center for Disaster Resilience, Department of Civil and Environmental Engineering, University of Maryland and Eugene Stakhiv, Visiting Scholar, USACE Institute for Water Resources

1. Adapting NYC Public/Private Infrastructure to Climate Change Risks: Challenges and Opportunities

Ke Wei, Senior Policy Advisor for Energy
The full presentation can be found in the **NSF Workshop Materials** folder titled *4.1 OneNYC*.

After Hurricane Sandy, a global conversation on resiliency emerged. What does resiliency mean for NYC? Will our neighborhoods, economy, and public services be ready to withstand and emerge stronger from the impacts of climate change and other 21st century threats? As we look toward the future, we must take stock of our current challenges, including Hurricane Sandy, a growing population, increasing equality, and an aging infrastructure.

The goal of OneNYC: Providing plans for growth, equity, sustainability, and resiliency of NYC.

Major Concerns:

- A growing population in NYC
- Increased impact from extreme weather events
- Vulnerability of neighborhoods in NYC
- More economic loss in the future flood disaster

OneNYC

With OneNYC, every city neighborhood will be safer by strengthening community, social, and economic resiliency.
Major Facets of Our Resilient City:

- Buildings - the city's buildings will be upgraded against changing climate impacts.
- Neighborhoods - every city neighborhood will be safer by strengthening community, social, and economic resiliency.
- Infrastructure - infrastructure systems across the region will adapt to maintain continued services.
- Coastal Defense - New York City's coastal defense will be strengthened against flooding and sea level rise.

The entire effort will benefit from a continued advocacy for federal reforms, policy changes, new legislation, and funding.

U.S. Congress

- Secure additional funds and allocate existing funds for resiliency investments
- Continue to advocate for long-term affordability of flood insurance

FEMA / National Flood Insurance Program

- Develop flood protection standards for existing buildings and offer premium credits
- Collect elevation data on existing buildings to better assess risk-based premiums
- Clearly articulate projected rate changes for all categories of buildings
- Support the City's application for state-allocated hazard mitigation grant funds

USACE

- Authorize new USACE projects in New York City to address vulnerable areas
- Streamline USACE processes to expedite necessary projects
- Complete all projects authorized under the Sandy supplemental bill (P.L. 113-2)

Department of Energy

- Convene regional liquid fuels supply chain working group

2. **Flood Risk Management for an Unconvinced Public**

Dave Rosenblatt, Assistant Commissioner

3. **National Critical Infrastructure Security and Resilience R&D Plan: Advancing National Objectives**

Erin Walsh, Advanced Research Projects Agency

The full presentation can be found in the **NSF Workshop Materials** folder titled *4.3 National CISR RD Plan*.

The National CISR R&D Priority Areas include **Area A:** Develop the foundational understanding of critical infrastructure systems and systems dynamics, **Area B:** Develop integrated and scalable risk assessment and management approaches, **Area C:** Develop integrated and proactive capabilities, technologies, and methods to support secure and resilient infrastructure, **Area D:** Harness the power of data sciences to create unified, integrated situational awareness and to understand consequences of action, and **Area E:** Build a crosscutting culture of CISR R&D collaboration.

National CISR R&D Priority Areas

Area A: Develop the foundational understanding of critical infrastructure systems and systems dynamics

- Develop a foundational understanding of CI systems, systems dynamics, and the relationships underlying interdependencies and cascading effects
- Develop avenues of foundational science research, including structural dynamic attributes, effects of human factors, and linkages to natural systems, to support enhanced security, resilience

Area B: Develop integrated and scalable risk assessment and management approaches

- Develop and field integrated risk assessment methodologies across the critical infrastructure community
- Develop an integrated system of systems approach to risk assessment and risk management to include external cross-domain factors and characteristic
- Develop the technical basis and analytical tools needed to incorporate dependencies and interdependencies into risk assessment and risk management methodologies

Area C: Develop integrated and proactive capabilities, technologies, and methods to support secure and resilient infrastructure

- Characterize the predictive and proactive capabilities needed to forecast and prepare for threats and hazards
- Identify policies, governance structures, and regulations that support and enable timely and responsive actions

Area D: Harness the power of data sciences to create unified, integrated situational awareness and to understand consequences of action

- Harness data sciences for integrated situational awareness
- Investigate the potential for increased situational awareness from data sciences and the increased used of sensor networks, augmented by networked intelligent systems and analysis.
- Develop the data sciences to support unified, integrated situational awareness
- Develop modeling and analysis capabilities that properly characterize critical infrastructure systems and integrate cross-sector dynamics

Area E: Build a crosscutting culture of CISA R&D collaboration

- Build culture of collaboration
- Encourage broad initiatives to develop a crosscutting culture of CISR R&D collaboration
- Develop a crosscutting culture and skills to examine and communicate the operational complexity and interdependencies of critical infrastructure, through integrated multidisciplinary and interdisciplinary teams

Advancing the R&D Priority Areas

- Requires active <u>collaboration</u> and <u>information sharing</u> across the broad critical infrastructure community, including academic and research institutions
    - Documenting and sharing current R&D activities and their transition to use
    - Aligning sector R&D planning with the National CISR R&D Priority Areas
    - Coordinating the planning and execution of new and future R&D activities
    - Identifying barriers to implementation

4. Building Resilience into a System of Systems

Joshua Behr

The full presentation can be found in the **NSF Workshop Materials** folder titled *4.4 Building Resilience into a System of Systems*.

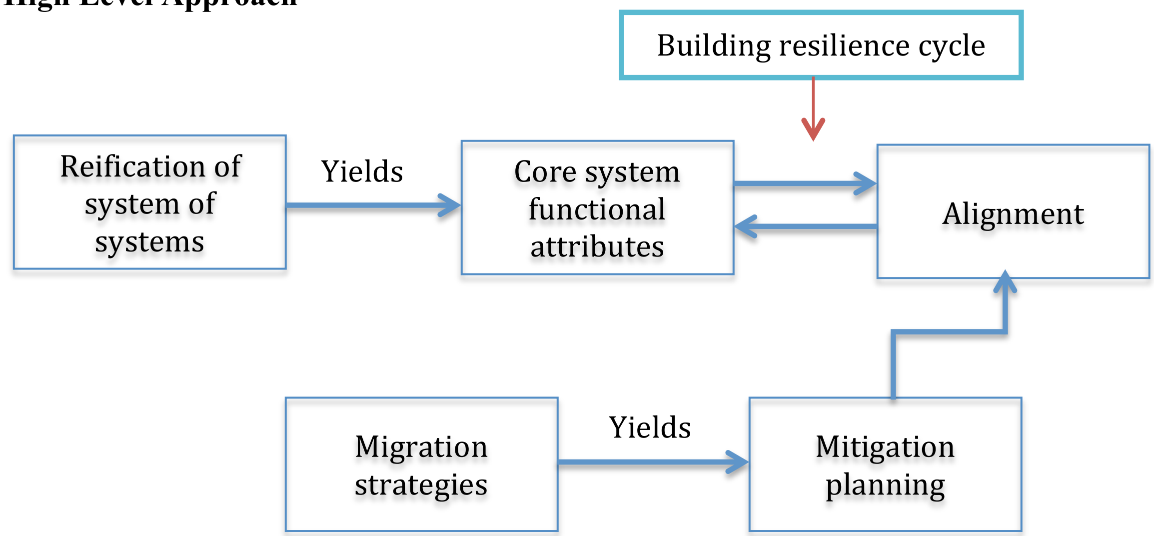
Guiding Principle #1: Building resilience means altering the recovery curve.

- The challenge is to think globally – operate within the context of local constraints and processes (regional resilience is not optimized by thinking solely within the local box)
- Decrease the impact delta → shift recovery curve to the left → new normal exceeds pre-event normal

Guiding Principle #2: Our premise is that in order to enhance resilience there must be an alignment between core systems and the prioritization of mitigation strategies.

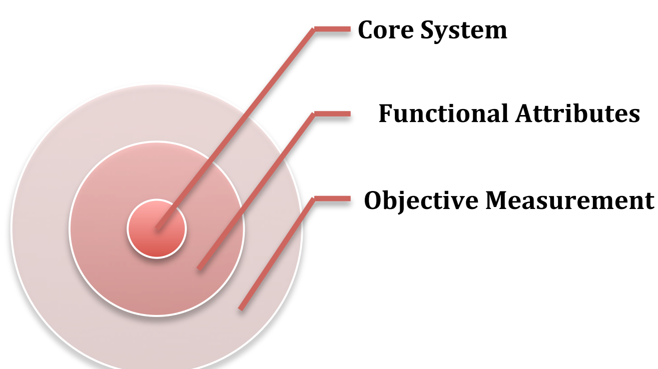
- Core systems are those that are essential to the life, limb, and well-being of the populations, especially vulnerable, medically fragile, and traditionally underserved populations.

High Level Approach



Taking the healthcare system as an example, a supply-demand equilibrium is at the core. There are functional attributes like medical treatment venues, clinical and professional staff, medication and pharmaceutical inventory and so on. In addition, we have objective measurements like utilized square footage, number of staff by training and discipline, which is easier to quantify.

Process #1



Core system

Healthcare system supply-demand equilibrium

Functional Attributes

Medical treatment venues, medication and pharmaceutical inventory, medical equipment and supplies, etc.

Objective Measurement

Utilized square footage, quantity and age of stock, number access points, number by training and disciplines, etc.

Dimensions of vulnerability

- Hyper-vulnerability

    - Several dimensions of
- Risk perception
    - Safer than evacuation
        - Safer than traveling in chaos or on highway
    - Fatalism
- Storm as opportunity => risk
    - Cleanup = cash
        - Debris removal
        - Tree/year waste removal
    - Skilled labor and trade services
        - Housing roofing repair
        - Auto repair
    - Catch-up
        - House chores

Household adaptive capacity recurrent flooding

- Perception variables
- SLR (Sea level rise) will limit economic opportunity for citizens
- NIMBY: Restrict permitting of new homes/renovations
- Mold, Asthma, and ED visitation

Background:

- Agency, interagency, and tribal collaboration
- Alignment
- **Shared responsibility**, and shared tools, between all levels of government and partnerships
- Rethink approaches to **adapting to risk**
- Resilience and sustainability must consider a combination and **blend of measures**

Outcomes: Coastal Storm Risk Management Framework

- Managing coastal storm risk is a shared responsibility
- The framework is a 9-step process

Technical Products:

- Conceptual regional sediment budget
- Coastal geographic information system geo-database
- Condition reports

Community resilience is the capability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change.

Self-assessment steps:
- Defined spatial and temporal boundaries

Modeling
- Regional storm suite modeling

Economic analyses
- Economics

Opportunities for coastal resilience integration
- Mitigate future risk with improve pre-storm planning
- Identify acceptable flood risk at a community and state scale
- Prioritize critical infrastructure
- Rebuild with redundancy
- Develop creative incentives to promote use of resilience measure
- Stylize a collaborative regional governance structure
- Nine focus areas
    - Rhode Island coastline
    - Connecticut coastline
    - New York – New Jersey harbor and tributaries
- Nassau county back bays, New York
- A Chesapeake Bay example
    - National actions
        - Chesapeake Bay agreement climate resilience goal
        - DoD Resilience
        - Federal Agency Implementation of Federal Flood Risk Standard
    - State actions
        - Maryland Silver Jackets Interagency Coastal Workshop
    - Local Actions
        - Establish Local Flood Proofing Teams

Summary:

Coastal storm risk management is a shared responsibility, and there should be shared tools used by all decision makers to assess risk and identify solutions.

5. A Framework for Building Coastal Infrastructure Resilience

Gerry Galloway, Research Professor

Session V: Conceptual Approaches to Complex Systems of Systems

Co-Chairs: Professor Yacov Y. Haimes and Professor Seth Guikema, Associate Professor, Industrial and Operations Engineering, University of Michigan

1. Risk Modeling and Management of Interdependent Complex Systems of Systems

Professor Yacov Y. Haimes

The model for SoS is inadequate and needs to be modified. Numerous disasters illustrate our failure to anticipate complex SoS. The sources of risk to SoS, or to their subsystems, are magnified because they can originate internally as well as externally and may adversely affect their specific states. Risk analysts and decision makers must be responsive to dynamic shifting rules and realities, which is called the "Evolving Base," where entities are always changing as the time frame changes and each subsystem is likely to be affected by the Evolving Base and respond differently.

Essential questions for modeling:

- How to model systems of systems?
- How to manage systems of systems?
- How to understand interdependencies and interconnection?
- What is the time frame

Risk Assessment, Management, Modeling, and Communication:

Models for system of system is inadequate and need to be modified. Numerous of disasters illustrate our failure to anticipate complex systems of systems.

Decision Making Process:

- Exogenous Variables
- Random Variables
- Decision Variables

Essential entities:

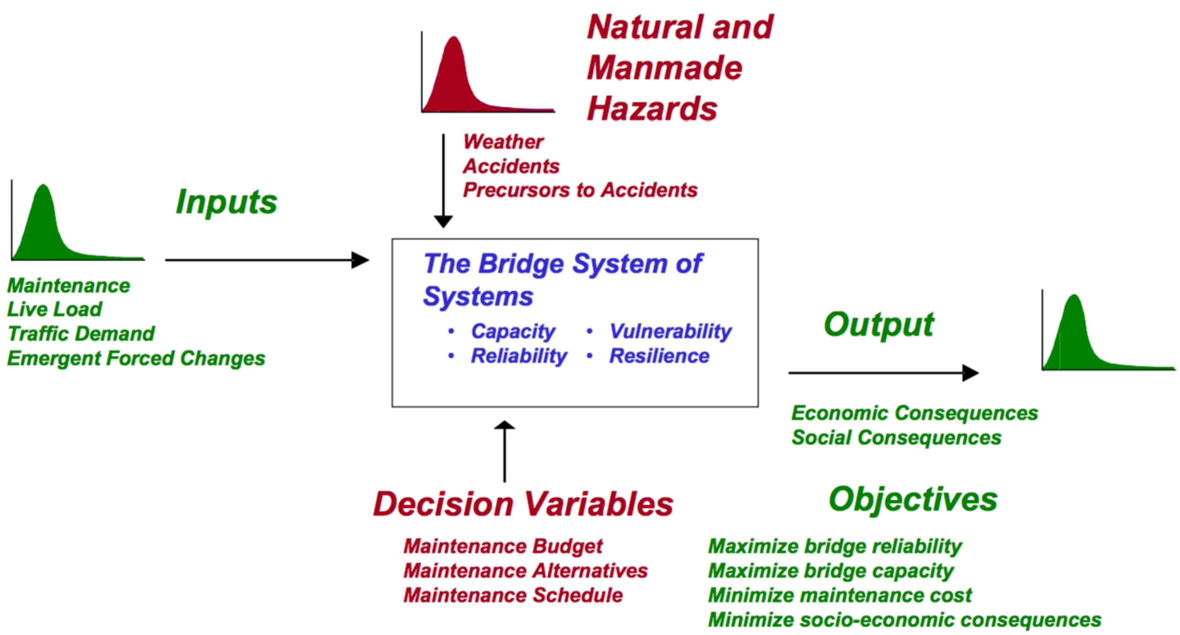
- Decisionmakers
- Stakeholders
- Organizational setups
- Others

The sources of risk to systems of systems or to their subsystems are magnified because they can originate internally as well as externally and may adversely affect their specific states. Risk analysts and decision makers must be responsive to dynamic shifting rules and realities, which we call the "**Evolving Base.**"

Evolving Base:

- Entities are always changing as the time frame changes.
- Each subsystem is likely to be affected by the Evolving Base and respond differently.

Building Blocks of a Bridge Infrastructure System:



Questions:

1) How many subsystems do you like to have?

Modeling – Used to answer specific questions, model must be as simple as possible but as complex as required.

2) How to model a system?

Sources of uncertainty dominate most modeling and decision making processes.

3) How to address uncertainties for a system of a subsystem of systems of systems?

We need to modify and update the risk assessment and management questions when applied to systems of systems.

4) Why make a system too complex by putting things together?

5) How to deal with trade-off, opportunity cost?

Multiple-objective problems.

<u>Pareto-optimal</u>

Two policies today might be on the same Pareto-optimal frontier, but would be in different Pareto optimal frontiers in the future, given a new time t_0. Decisions will change overtime.

6) How to deal with the gap between decision making and system?

Government did not take strategies from the model. A system's failure might be caused or triggered by the failure of the other subsystems.

2. Sustainability, Resilience, and Reliability in Urban Infrastructure Systems of Systems

Professor Seth Guikema

The full presentation can be found in the **NSF Workshop Materials** folder titled *5.2 Climate Change Risk Analysis: From Simulation to Behavior*

With regard to infrastructure, the key stakeholders include: infrastructure users, infrastructure operators through decisions of how to respond to event and users in operating the system, infrastructure managers who make decisions about resource investments, infrastructure 'antagonists' that affect the system state through attacks, and policy makers and regulatory agencies. There is potential for climate change induced changes in hurricane risk to coastal energy systems. However, not all areas of the country are equally sensitive to changes in hurricane hazards. Thus, a validated predictive model of storm impacts is of critical importance. There are several mitigation options: structural change on houses, simple decision rules (baselines: parcels return to same resistance level), and mitigation decisions that will impact community vulnerability.

With respect to regulation and policy, incentives that get people to mitigate must be targeted and vetted to be effective. On the engineering side, community vulnerability and resilience is a dynamic principle that is impacted by an array of factors. Future steps to mitigate flood risk should involve improving understanding of temporal changes in community flood risk through combined analysis of behavioral, engineering, and physical hazard aspects. Additionally, interactions of community actions, engineering measures, and individual behavior may result in unanticipated changes to flood vulnerability that are not captured by standard models. Behavior can affect vulnerability and time and we need to think beyond engineered proactive measures and consider behavioral responses to protective strategies.

Decisions and infrastructure

- Infrastructure users
- Infrastructure operators effect through decisions of how to respond to event and users in operating the system
- Infrastructure managers: effect through decisions about resource investments
- Infrastructure 'antagonists': effect system state through attacks
- Policy makers and regulatory agencies

NOTE: Potential for climate change induced changes in hurricane risk to coastal energy systems.

Questions of concern:
1) How might risk to coastal systems change along with climate change?

2) How would potential changes in hurricane hazards – intensity, frequency, location – influence with related power systems?

3) Which areas of United States coastline are most sensitive to changes in hurricane hazards?

4) Can the possible changes be simulation in a way that will help support long-term utility hardening decision-making?

Goal:

- Estimate power outages before landfall and update every six hours

Unit of analysis:

- Spatially general model: census tracts
- Utility-specific model, by grid cells

Data:

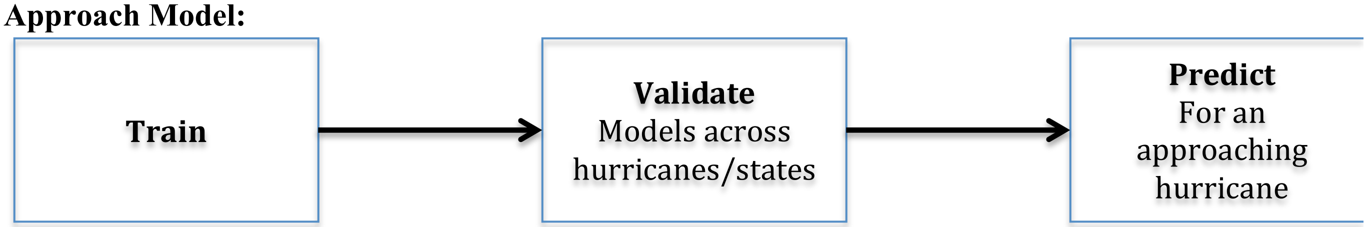
- Hurricane wind speed and duration

Validation approach:

- Random hold-out validation
- State-based holdout validation
- Storm-based holdout validation
- Hold-one-out validation
- Random forest
- Addressing track uncertainty
  - Use Monte Carlo wind speed probability model to simulate synthetic tracks
- Spatial generalization
  - Can a model be developed that can be used for entire coast using only publically available data

NOTE: Good fit does not yield strong predictive accuracy in many cases. Validation is critical to balancing bias-variance tradeoff, particularly for complex data mining model.

Approach Model:



Learn from storms and refine models.
Train & Validate models within service area using only public data.

Media Response:
- Substantial national coverage, some international coverage
- Focus of media interest
    - Overall forecast
    - Limited to no interest in uncertainty

How to do?
- Predict **cumulative** outages, utilities generally report **peak** outages

** Cannot find reliable sources of actual outage data at the scale at which we are making predictions.

Results of study:
- Not all areas of the country are equally sensitive to changes in hurricane hazards
- A validated predictive model of storm impacts of critical importance

Mitigation options:
- Structural change on households
- Simple decision rules, e,g. baselines - parcels return to same resistance level
- Mitigation decisions will impact community vulnerability

Regulatory/policy
- Incentives that get people to mitigate must be targeted and vetted to be effective

Engineering
- What we assume about how people mitigate really matters
- Community vulnerability and resilience is a dynamic principle that is impacted by an array of factors

Evolving community flood risk
- Improve understanding of temporal changes in community flood risk through combined analysis of behavioral, engineering, and physical hazard aspects
- Interactions of community actions, engineering measures, and individual behavior may result in unanticipated changes to flood vulnerability that are not captured by standard models
- Components
    - Base model: simulate risk over time. How does risk vary based on differing stochastic elements?
    - Mitigation alternatives: how do community interventions impact flood risk over time?
    - Climate change: how does risk change based on climate change scenarios?

Simulation steps:
- Annual flood
    - Sampled from historic flood data
    - Damage tallied
    - Population at-risk tallied

- Agent action
    - Decision based on risk perception, coping perception, utility
- Community action
    - Decision based on percentage
        - Mitigation project
            - Levee
            - Diversion
- Floodplain restoration

Conclusion:
Behavior can affect vulnerability and time-need to think beyond engineered proactive measures and consider behavioral response to protective strategies.

IV. SUMMARY AND PATH FORWARD

Dr. Eugene Z. Stakhiv

The intent of the workshop was to bring together practitioners and theoreticians to gain a better understanding and some insights regarding the comprehensive nature of systems risk analysis issues through the venue of dissecting large systems case studies, in the form of Hurricane Katrina's impact on New Orleans, and that of Superstorm Sandy on the New York metropolitan area. Five topics were covered that facilitated discussion to frame the path forward:

1. What are the main contrasts in Katrina verus Sandy response and recovery?
2. What are the gaps in critical infrastructure management in response to climate change and sea level rise?
3. What issues can we solve; not solve?
4. What models and analytics are needed?
5. What is the role of academia?

In February 2013, President Obama issued Presidential Policy Directive 21, *Critical Infrastructure Security and Resilience* (PPD-21) and Executive Order 13636, *Improving Critical Infrastructure Cybersecurity*. The coordinated release of these two policies underscored the Administration's commitment to integrating cyber and physical security and strengthening resilience across interrelated systems. Directive PPD-21 directed the Secretary of the DHS, in coordination with the Office of Science and Technology Policy, sector-specific agencies, the Department of Commerce, and other federal departments and agencies, to provide to the President a National Critical Infrastructure Security and Resilience Research and Development Plan (hereafter the National CISR R&D Plan or the Plan) that takes into account the evolving threat landscape, annual metrics, and other relevant information to identify priorities and guide R&D requirements and investments.
Increasing complexity is at the center of two major challenges: reliable operations and the mitigation of threat vectors. Rapid changes in technology and its use, operational dependencies on other sectors, and uncertainties in the world's natural and political environment have geometrically increased the complexity of operations. In addition, there is a sense of urgency and concern for the growing fragility of lifeline systems in the face of a growing number of catastrophic natural events, and the growing human-originated cyber and physical threats targeting them. The expanding range of threats adds to the complexity of making informed decisions that meaningfully reduce risk within an environment where resources are subject to multiple demands and priorities. [NIAC; 2014]

An R&D strategy for CISR can encompass a broad range of activities, including but not limited to: characterizing infrastructure systems to build an integrated systems understanding, developing technology solutions to secure and enhance the resilience of cyber and physical systems, researching and establishing policies and regulations that enable and incentivize CISR enhancements, and applying social and behavioral sciences to model and manage the human role in CISR. This Plan establishes CISR R&D priority areas that rise to a national level because they are likely to improve the security and resilience of critical lifeline functions or because they address threats and hazards facing one or more sectors that could cause broad regional or national-level consequences. These National CISR R&D priority areas are intended to serve as a broad, overarching construct under which ongoing activities can continue and future innovative endeavors can develop over time. By contrast, sector-level R&D priorities address threats, hazards, and vulnerabilities or gaps in knowledge and capabilities deemed important by sectors, subsectors, and individual critical infrastructure entities. [DHS, 2015]

The 2011 Strategic National Risk Assessment (SNRA) evaluated known threats and hazards that have the potential to significantly impact homeland security and grouped these into three categories: natural, technological/accidental, and adversarial/human-caused. In addition to the episodic events identified in the SNRA, the CISR R&D priority areas consider threats and hazards that result from lasting changes to the operating environment, including economic, environmental, and societal dynamics such as urbanization and climate change.

The workshop group agreed that the national critical infrastructure strategy documented in 4.3 of the supporting materials presented an excellent blueprint for added research in all areas noted below.

National CISR R&D Priority Areas

Area A: Develop the foundational understanding of critical infrastructure systems and systems dynamics

- Develop a foundational understanding of CI systems, systems dynamics, and the relationships underlying interdependencies and cascading effects
- Develop avenues of foundational science research, including structural dynamic attributes, effects of human factors, and linkages to natural systems, to support enhanced security, resilience.

Area B: Develop integrated and scalable risk assessment and management approaches

- Develop and field integrated risk assessment methodologies across the critical infrastructure community
- Develop an integrated system of systems approach to risk assessment and risk management to include external cross-domain factors and characteristic
- Develop the technical basis and analytical tools needed to incorporate dependencies and interdependencies into risk assessment and risk management methodologies

Area C: Develop integrated and proactive capabilities, technologies, and methods to support secure and resilient infrastructure

- Develop integrated and proactive capabilities for CISR
- Characterize the predictive and proactive capabilities needed to forecast and prepare for threats and hazards
- Identify policies, governance structures, and regulations that support and enable timely and responsive actions.

Area D: Harness the power of data sciences to create unified, integrated situational awareness and to understand consequences of action

- Harness data sciences for integrated situational awareness

- Investigate the potential for increased situational awareness from data sciences and the increased use of sensor networks, augmented by networked intelligent systems and analysis.
- Develop the data sciences to support unified, integrated situational awareness
- Develop modeling and analysis capabilities that properly characterize critical infrastructure systems and integrate cross-sector dynamics

Area E: Build a crosscutting culture of CISR R&D collaboration

- Build culture of collaboration
- Encourage broad initiatives to develop a crosscutting culture of CISR R&D collaboration
- Develop a crosscutting culture and skills to examine and communicate the operational complexity and interdependencies of critical infrastructure, through integrated multidisciplinary and interdisciplinary teams

Advancing the R&D Priority Areas

This requires active collaboration and information sharing across the broad critical infrastructure community, including academic and research institutions.

- Documenting and sharing current R&D activities and their transition to use
- Aligning sector R&D planning with the National CISR R&D Priority Areas
- Coordinating the planning and execution of new and future R&D activities
- Identifying barriers to implementation