Risk and Resilience:
Integrating Physical and Social Science

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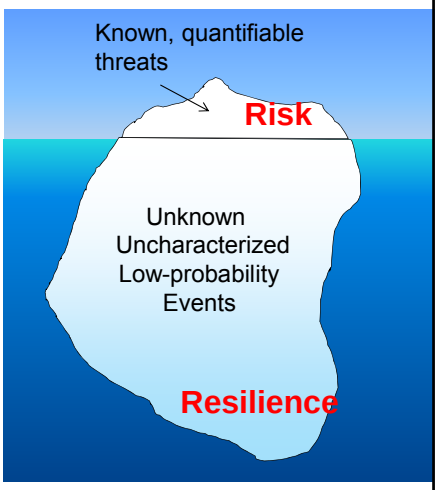
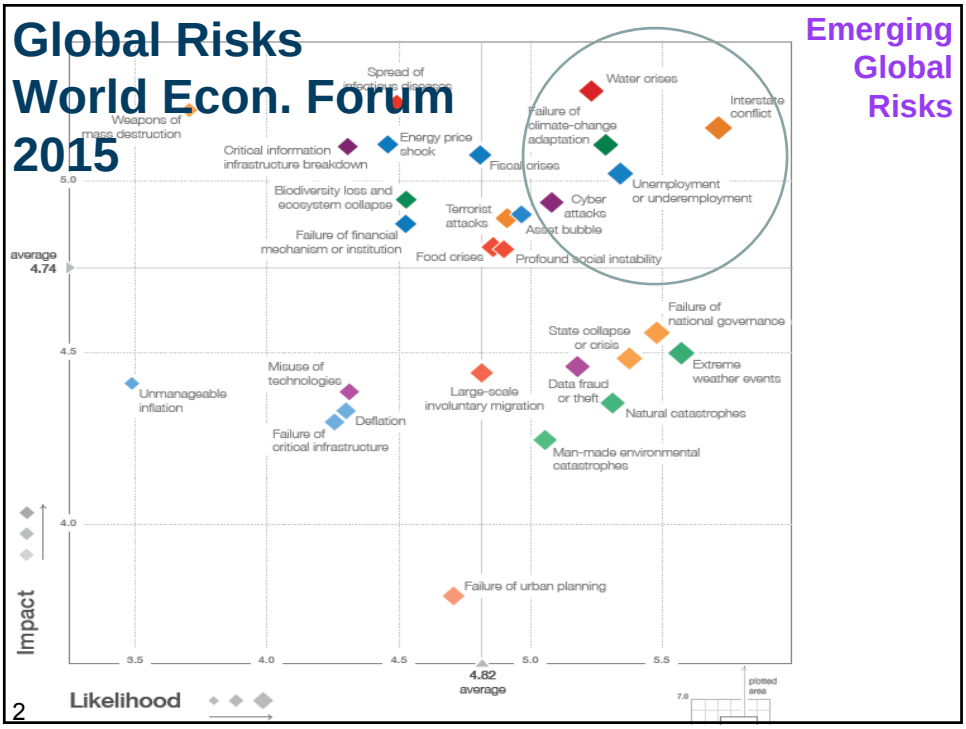
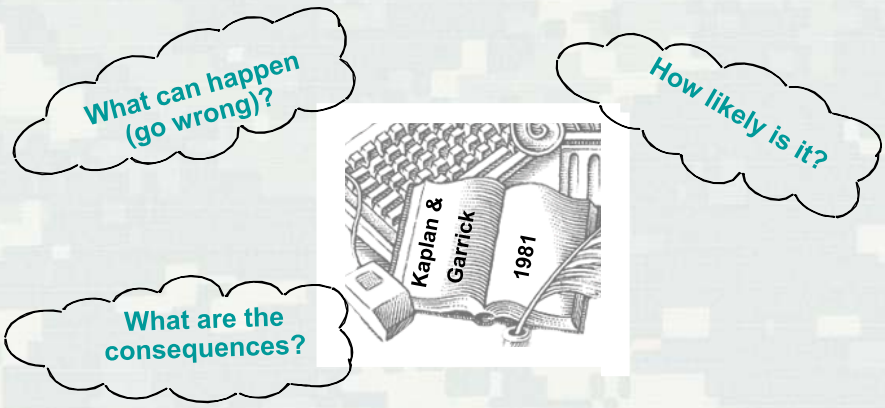


Global Risks World Econ. Forum 2015

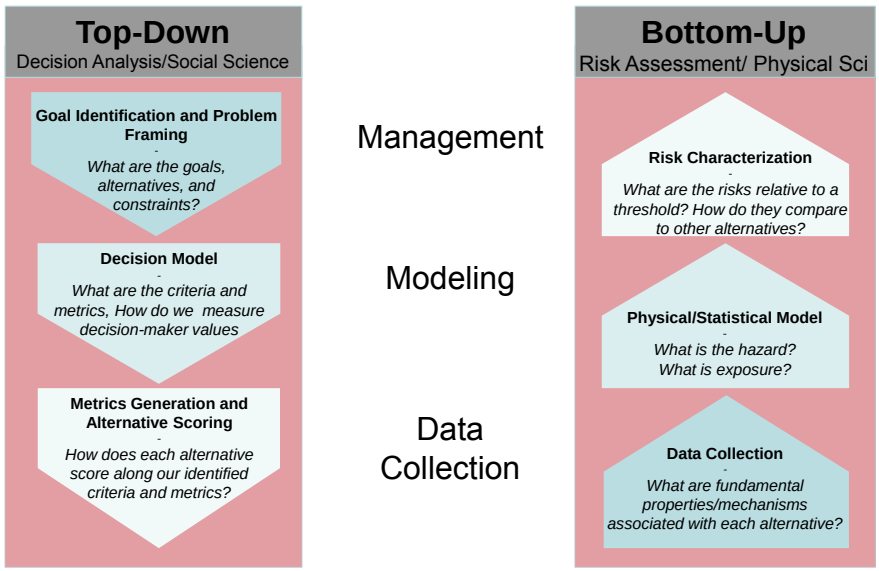
Emerging Global Risks



Risk Assessment Formulation



Risk-Resilience Integration

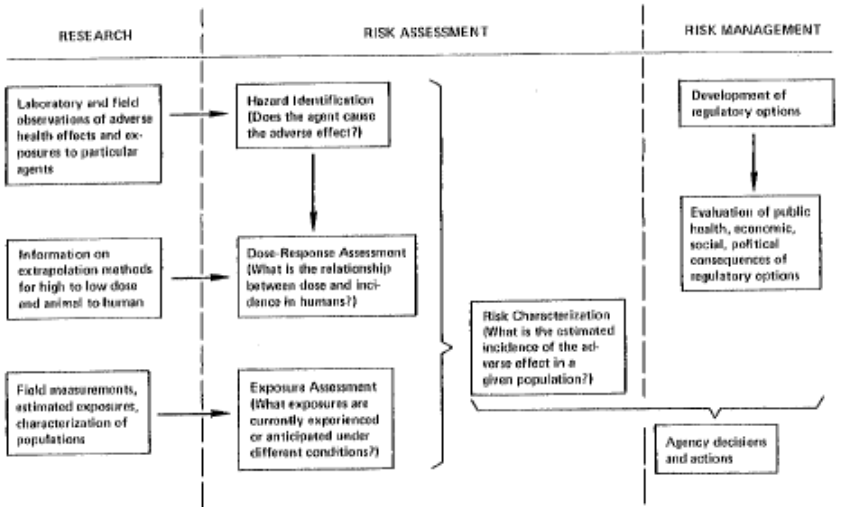


Linkov et al., 2014

Outline

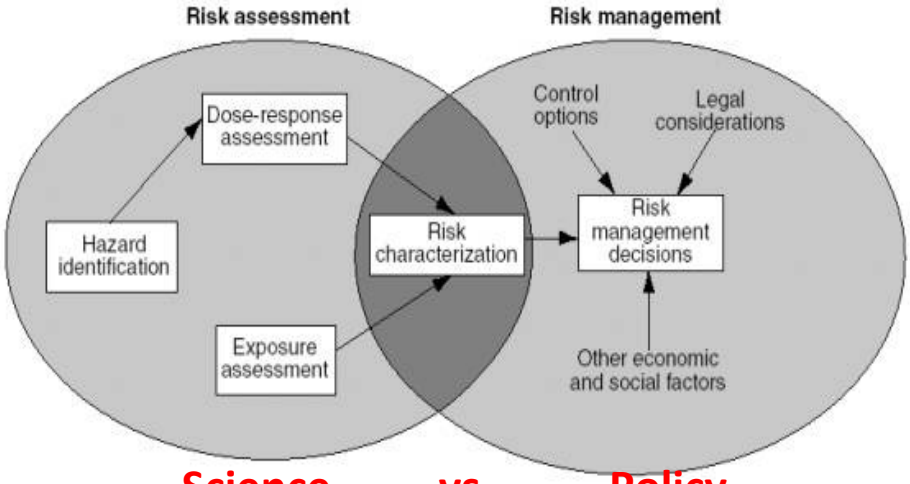
- From Risk to Resilience (Current Research)
  - Risk
    - Conceptualization
    - Risk Assessment Case Studies
    - Problems with Risk-based Approaches
  - Resilience
    - Conceptualization
    - Resilience Matrix Approach and Jamaica Bay Case
    - Network Science Approach
- Discussion

Risk Assessment and Risk Management



NRC 1983 (Red Book)

Risk Assessment vs. Risk Management?



Source: EPA Office of Research and Development.

Science vs. Policy

Risk Management Challenges

$$Risk = Threat \times Vulnerability \times Consequence$$

- Requires specific knowledge and quantification of all three components
- No temporal component
- Modern system complexity and threat uncertainty make risk management difficult and expensive.

SET EDITION: U.S. | INTERNATIONAL | MEXICO | ARABIC
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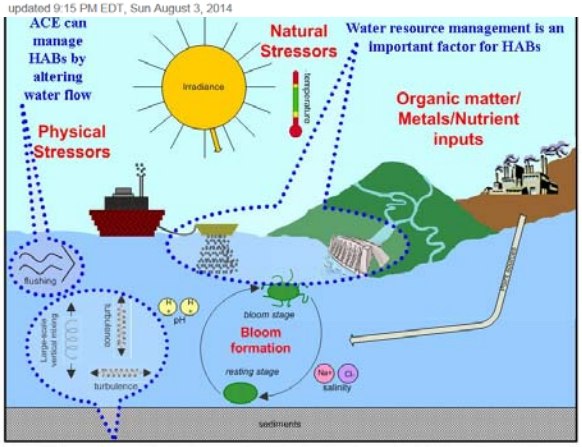
400,000 in Toledo, Ohio, water scare await test results

By Susanna Capelouto and Mark Morgenstein, CNN
updated 9:15 PM EDT, Sun August 3, 2014

Algal Blooms

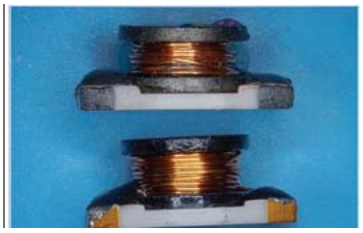
Hazard?
Exposure?
Effects?

Linkov et al., 2007



ACE can generate turbulence and mixing by altering water intake regimes and decreasing HABs.

PERSPECTIVES

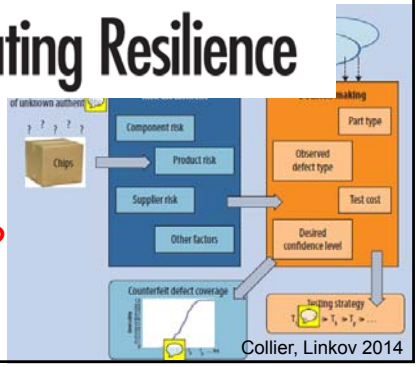


70 COMPUTER Published by the IEEE Computer Society 0018-9162/14/$31.00 © 2014 IEEE

Cybersecurity Standards: Managing Risk and Creating Resilience

Cybersecurity Risks

Hazard? Exposure? Effects?



Collier, Linkov 2014

Risk and Resilience: Political Importance and Challenge

The White House

Office of the Press Secretary

For Immediate Release Oct

Presidential Proclamation -- Critical Infrastructure Security and Resilience Month, 2013

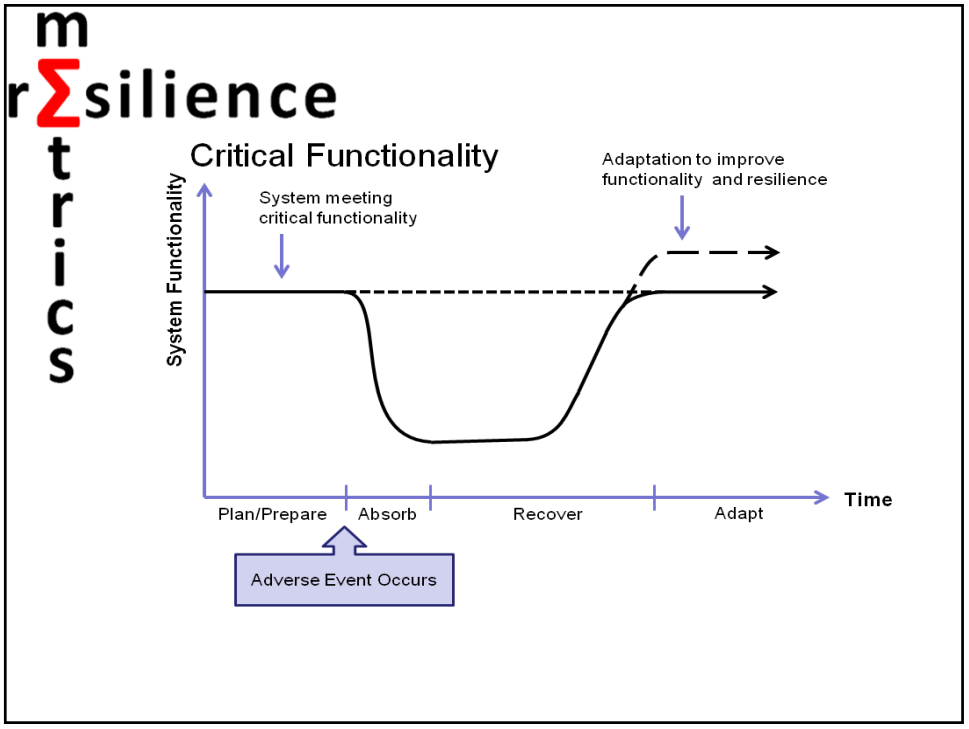
CRITICAL INFRASTRUCTURE SECURITY AND RESILIENCE MONTH, 2013

BY THE PRESIDENT OF THE UNITED STATES OF AMERICA

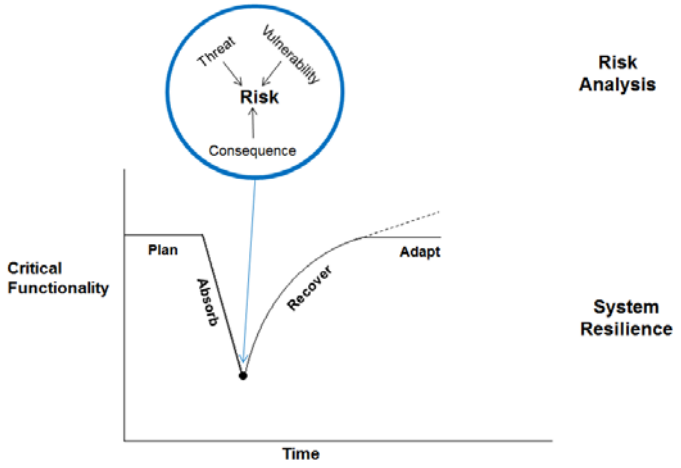
A PROCLAMATION

Over the last few decades, our Nation has grown increasingly dependent on critical infrastructure, the backbone of our national and economic security. America's critical infrastructure is complex and diverse, combining systems in both cyberspace and the physical world -- from power plants, bridges, and interstates to Federal buildings and the massive electrical grids that power our Nation. During Critical Infrastructure Security and Resilience Month, we resolve to remain vigilant against foreign and domestic threats, and work together to further secure our vital assets, systems, and networks.

Executive Order:
"resilience" means the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.

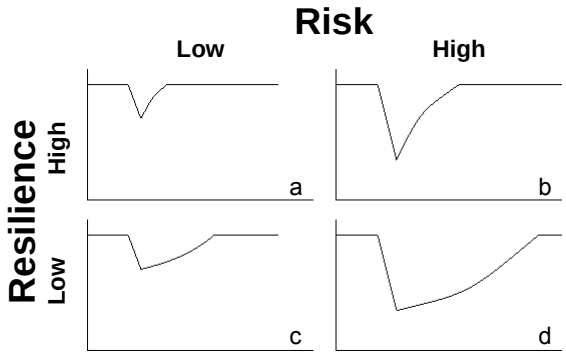


Risk Assessment is one part of Resilience



After Linkov et al, Nature Climate Change 2014

Importance of Recovery

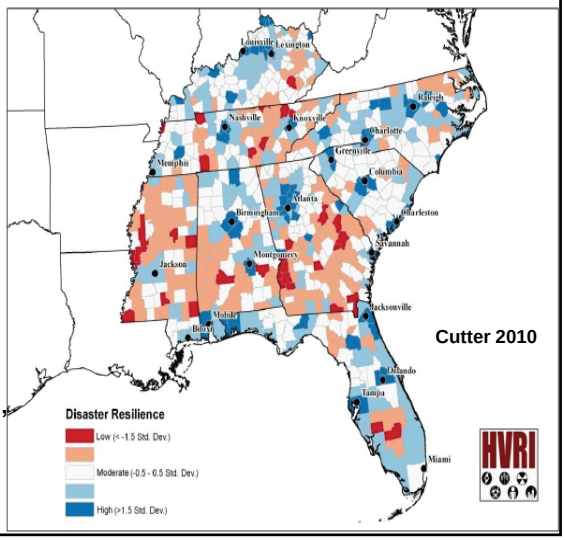


Traditional risk management focuses on planning and reducing vulnerabilities. Resilience management puts additional emphasis on speeding recovery and facilitating adaptation.

After Linkov et al, Nature Climate Change 2014

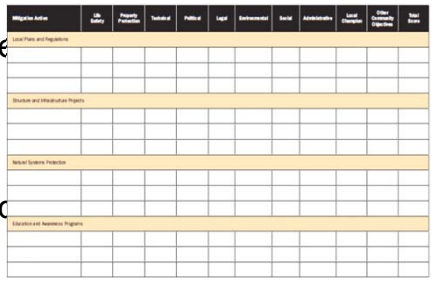
DHS Disaster Resilience Index

- Demographic data as indicators of scale of vulnerability and resilience/ ability to recover quickly.
- Metrics in categories of : social, economic, institutional, infrastructure, and community.
- All categories equally weighted.
- Regional assessment, county level resolution.
- Spatially reported results, comparative.
- All hazards assessment



FEMA Disaster Resilience Index

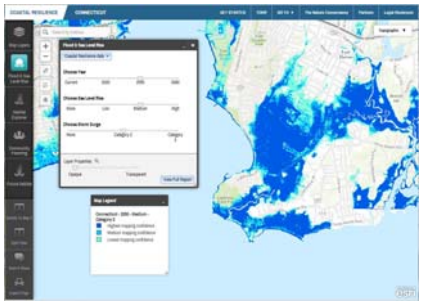
- Community member awareness and vulnerability survey
- Potential hazard severity identification
- Strength of social systems
- Relative importance of community structures
- Rate general mitigation measure on level of effectiveness or feasibility to improve each community component
- Guidance on developing specific mitigation actions.
- Supplements: specific hazard probability, functional loss, and cost calculator; local all-hazards risk assessment



http://www.dhses.ny.gov/oem/mitigation/documents/fema-local-mitigation-handbook.pdf

Nature Conservancy Coastal Resilience Mapping Tool

- ESRI powered geospatial analysis tool
- Pre-loaded map layers of relevant demographic and ecological data
- 4 apps available for decision making purposes
  - Flood and Sea Level Rise (future projections)
  - Habitat Explorer (weighing habitat importance)
  - Community Planning (current data map layers)
  - Future Habitat (projected marsh advancement)
- Local decision-makers and planners in coastal communities
- Used for land management and wetland preservation prioritization

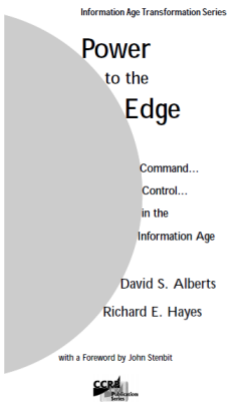


http://maps.coastalresilience.org/ct/

Weaknesses of Existing Methods

- Assessments built in ad-hoc manner based on specific expertise of agency.
- Most agencies efforts are not framed in context of larger system. These efforts are each components of the necessary changes.
- Assessments do not explicitly consider uncertainty
- Assume future impacts will reflect past impacts and that locations of past events will be equally important in future events.
- Tools largely assess vulnerability through risk metrics rather than assess resilience through capabilities to absorb, recover, and adapt.

Learning from Military



A highly networked system is governed by *domains of warfare* that organize system components and establish a basis for measurement.

Physical: system performance in space and time.

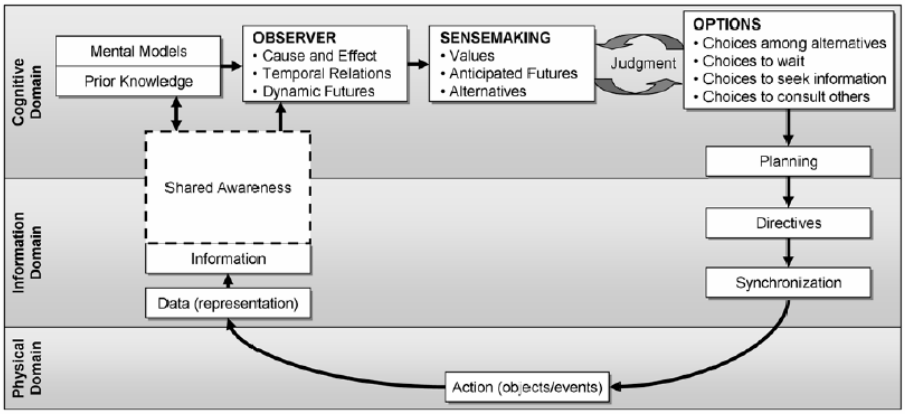
Information: creation, manipulation and sharing information.

Cognitive: translating, sharing, and acting upon information to enable system management.

Social: interaction, collaboration and self-synchronization between individuals and entities.

Need for Analytical Tools

Mental Modeling **Decision Analysis**



Risk Assessment

After Smith, 2006

Mental Modeling

Risk Analysis, Vol. 32, No. 3, 2012

Perspective

Using Our Brains to Develop Better Policy

Igor Linkov,[1,*] Susan Cormier,[2] Joshua Gold,[3] F. Kyle Satterstrom,[4]

Risk Analysis, Vol. 32, No. 8, 2012

DOI: 10.1111/j.1539-6924.2012.01832.x

Flood Risk Management: US Army Corps of Engineers and Layperson Perceptions

Matthew Wood,[1] Daniel Kovacs,[2] Ann Bostrom,[3] Todd Bridges,[1] and Igor Linkov[1,*]

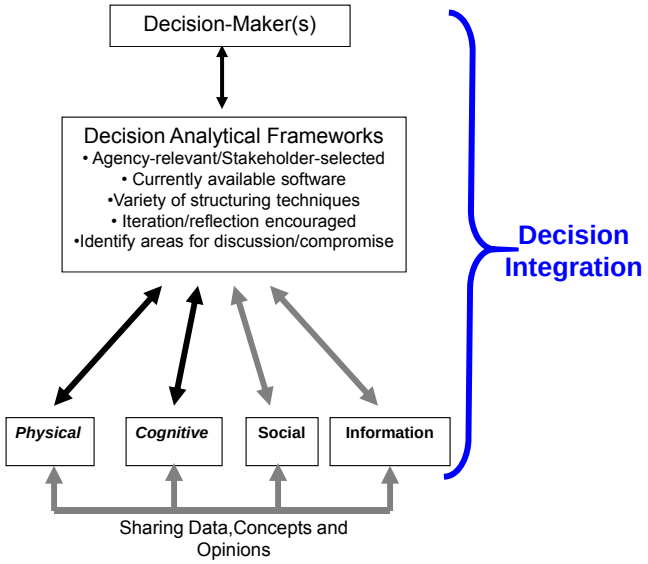
Environ Syst Decis
DOI 10.1007/s10669-013-9461-6

Climate change risk management: a Mental Modeling application

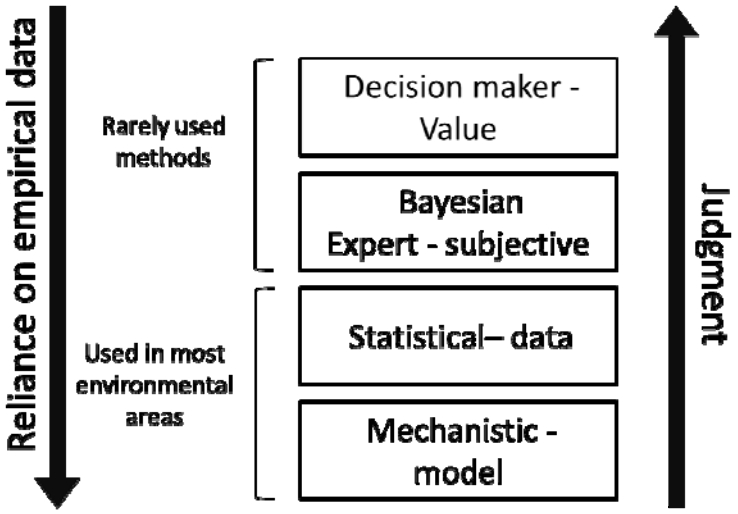
Todd S. Bridges · Daniel Kovacs · Matthew D. Wood · Kelsie Baker · Gordon Butte · Sarah Thorne · Igor Linkov

Linkov and Kelsler (2014)

Decision Analysis



Ways to Quantify



From Keisler and Linkov, 2014

Resilience: Matrix Approach

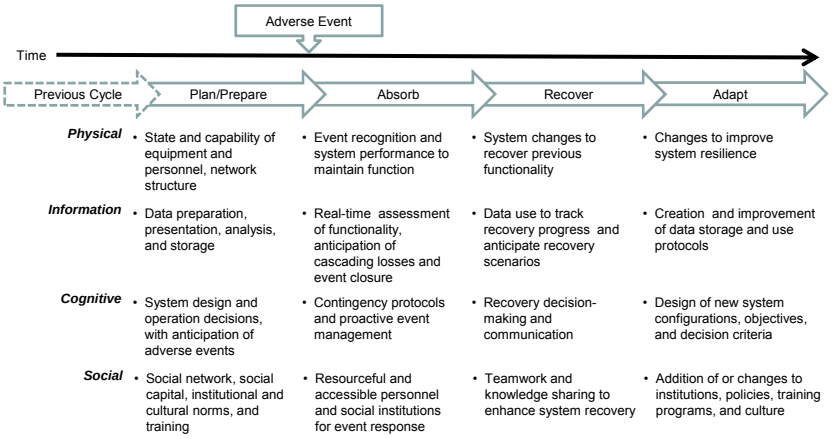
Resilience Matrix:

Analyze the functionality of each **domain** of the system across each **stage** of the event timeline

	Prepare	Absorb	Recover	Adapt
Physical				
Information				
Cognitive				
Social				

- Uses general metrics for measuring relative system resilience
- Different from vulnerability assessment – threats unknown
- Useful for identifying weak areas and prioritizing investment to improve overall resilience

General Form of Resilience Matrix



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

From Linkov et al, Env. Sci. & Tech 2013

Assessment using Decision Analysis

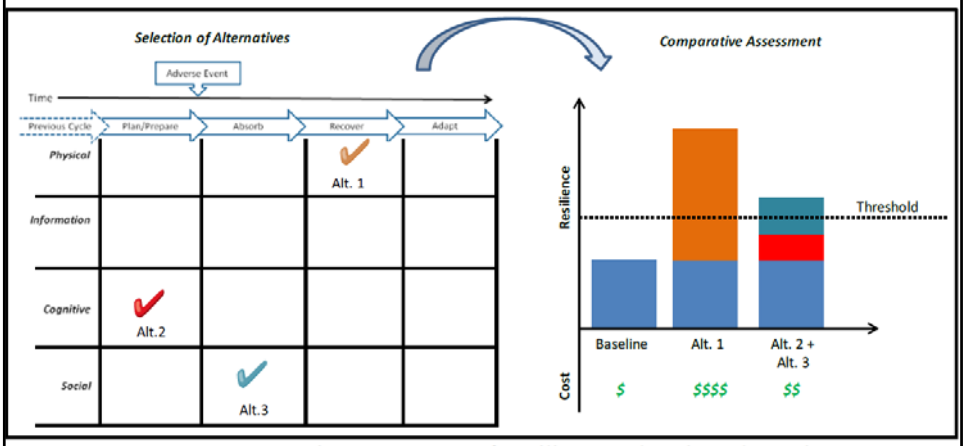
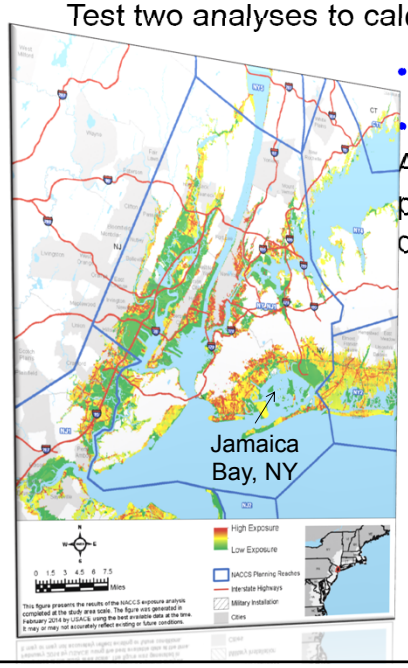


Figure 5: Comparative Assessment of Resilience-Enhancing Alternatives

Use developed resilience metrics to comparatively assess the costs and benefits of different courses of action

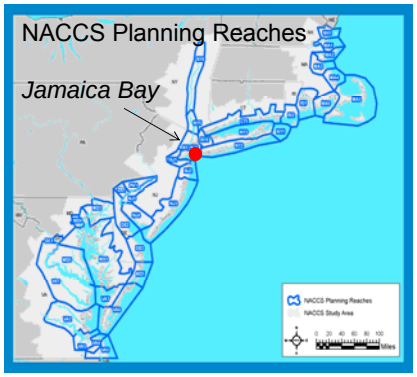
Pilot Study in Jamaica Bay, NY

Test two analyses to calculate present-day resilience



- **Tier 1:** Resilience Matrix, screening
- **Tier 2:** Integrated Risk/Resilience Assessment using Bayesian probabilistic analyses; appropriate for design

POC: Julie Rosati, ERDC, CHL



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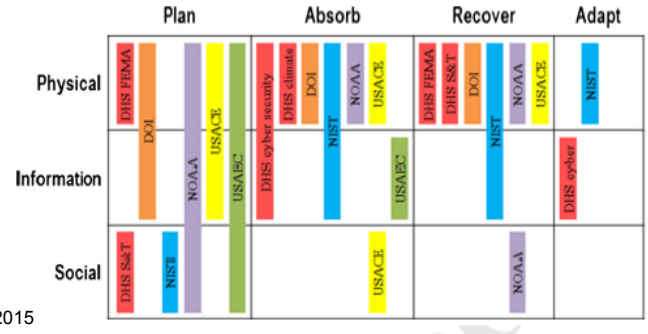
Resilience Matrix: Agency Roles

Environ Syst Decis

Fig. 1 Agency resilience actions addressed (relative to NAS definition) in physical, information, and social domains



Larkin, Fox-Lent, Linkov et al., 2015

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Future: Network Science

We quantify resilience by using network science approach by considering the different domains as interdependent multiplex networks.

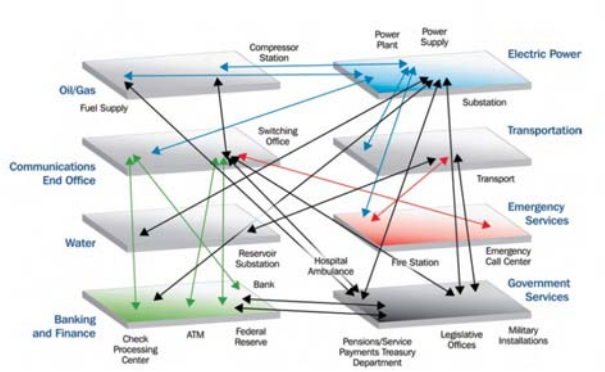

FIGURE 3.1 Connections and interdependencies across the economy. Schematic showing the interconnected infrastructures and their qualitative dependencies and interdependencies. SOURCE: Department of Homeland Security, National Infrastructure Protection Plan, available at http://www.dhs.gov/xprevprot/programs/editorial_0827.shtm.

Why Network Science Approach?

- Most of the complex systems can be modeled as interconnected networks – as soon as a system is represented as a network it becomes a mathematical object
- Network representation allows better analysis of interplay between individual components comprising the system
- Better visualization

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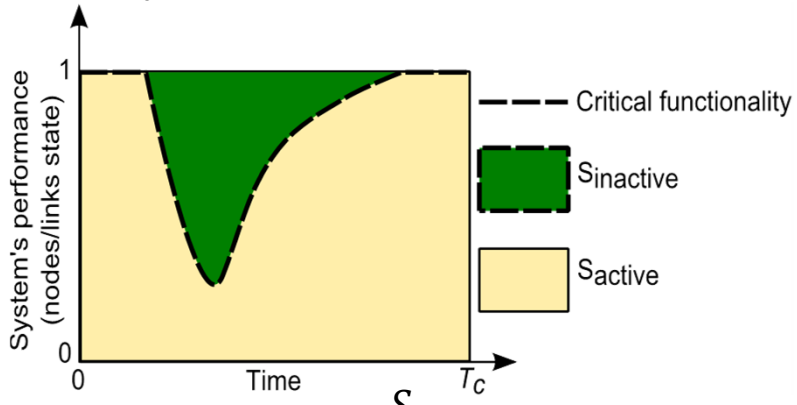
Resilience Quantification

- Based on NAS Definition
- Widely Applicable



$$R = \frac{S_{active}}{S_{active} + S_{inactive}}$$

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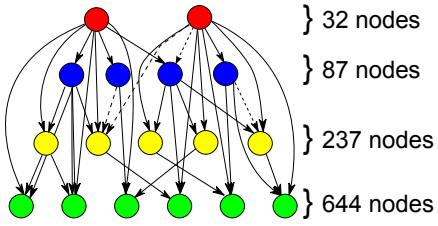
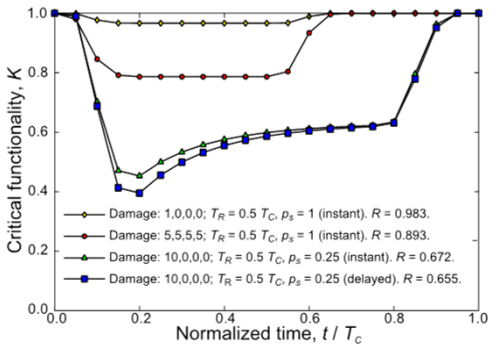
Case 1: Supply-Demand Network (Infrastructure)



Hierarchical network of 4 layers with redundancy



Resilience profiles for different scenarios in synthetic networks over a normalized time interval

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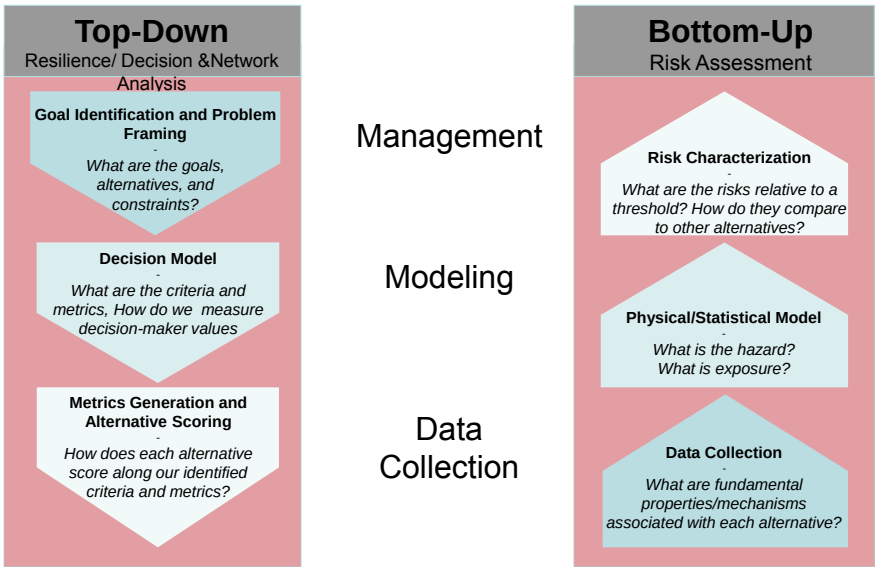
Risk-Resilience Integration



Linkov et al., 2014

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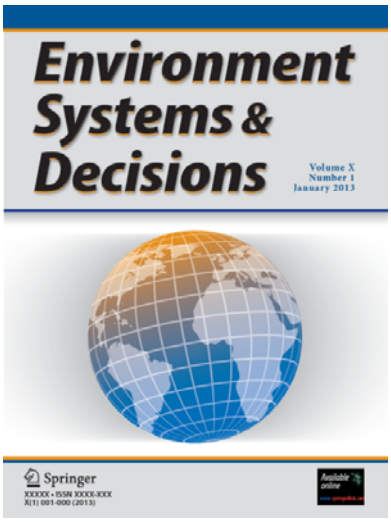

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