The Risk of Not Being Resilient

This presentation does not necessarily reflect the views of the United States Government, and is only the view of the author

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12 June 2017

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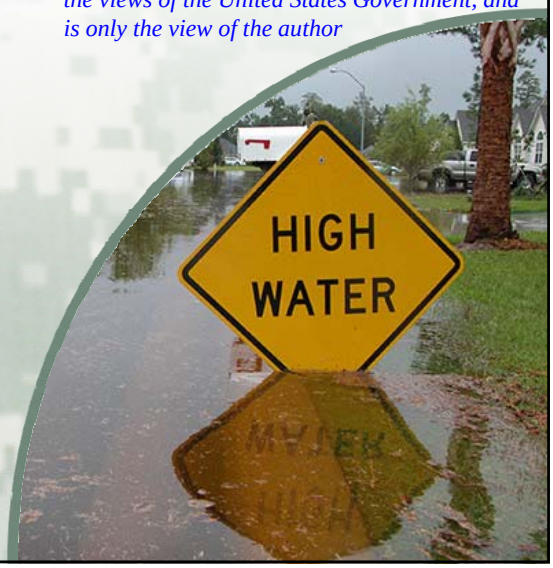
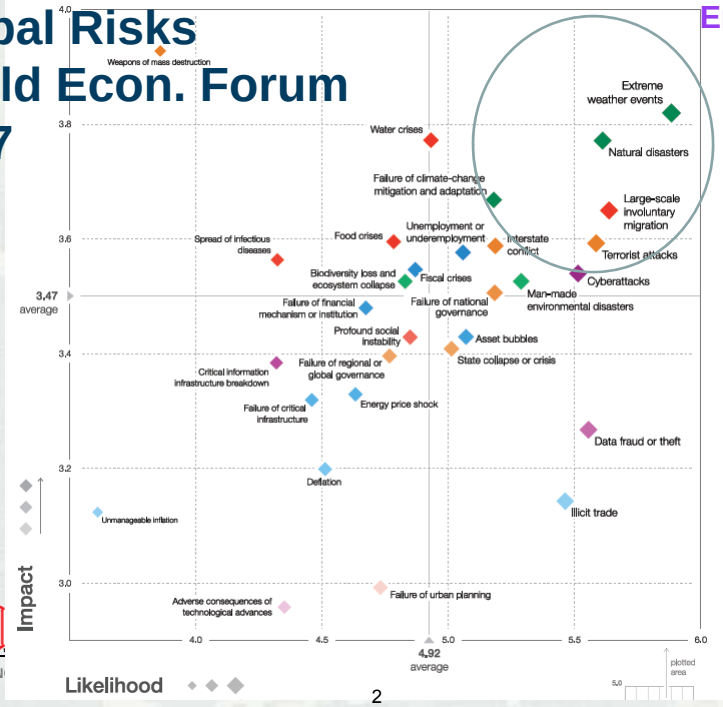
US Army Corps of Engineers



Global Risks World Econ. Forum 2017

Emerging Global Risks



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Risk Assessment and Management

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

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

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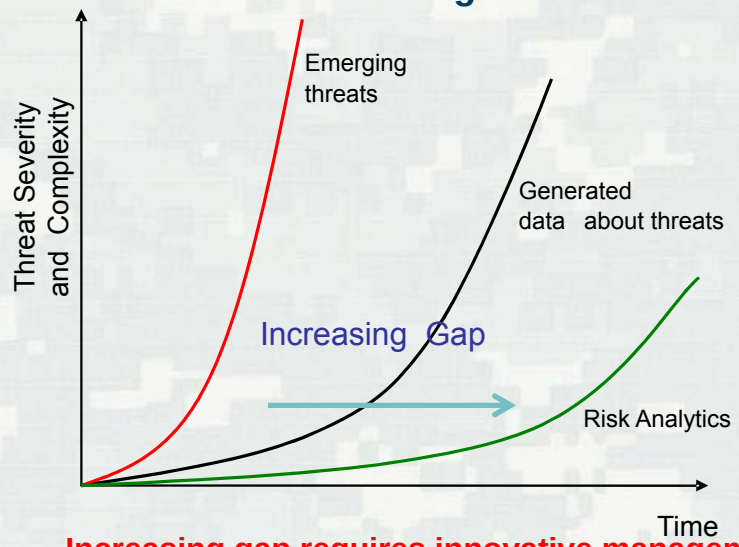
Challenge



Increasing gap requires innovative management

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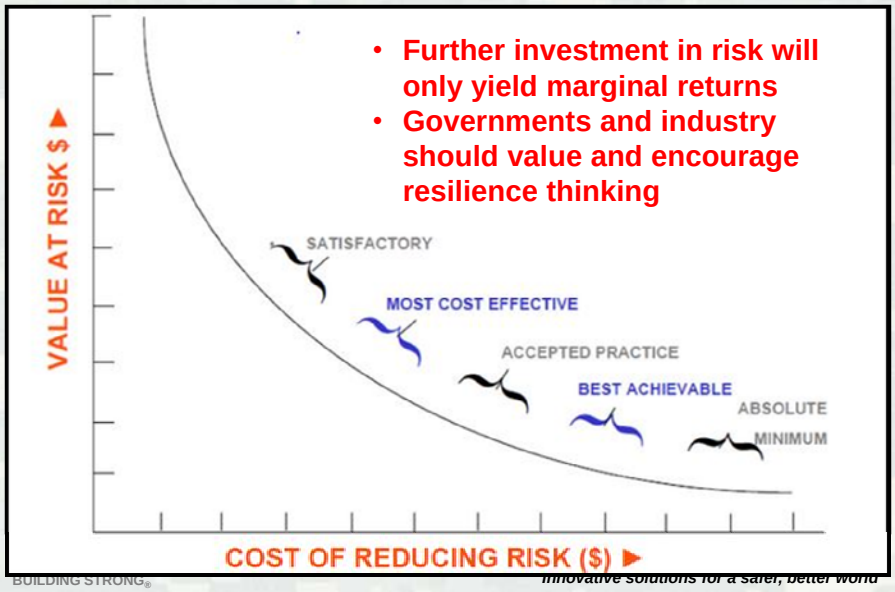
Costs of Buying Down Risk



- **Further investment in risk will only yield marginal returns**
- **Governments and industry should value and encourage resilience thinking**

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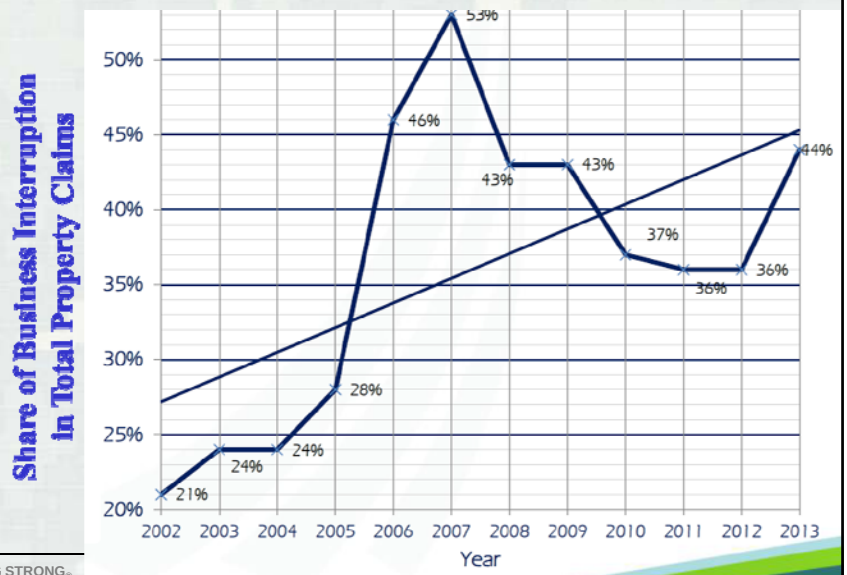
Costs of Business Interruption



Source: Zurich

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Resilience Definitions

- Definition released by OECD Public Governance Committee:
  - *"…the ability to resist, absorb, recover from or successfully adapt to adversity or a change in conditions*
- Consistent with the National Academies of Science (NAS) definition of resilience:
  - *"…the ability to plan and prepare for, absorb, recover from, and adapt to adverse events"*
- OECD directorates indicate that resilience needed to combat economic, social, and environmental risks on social systems

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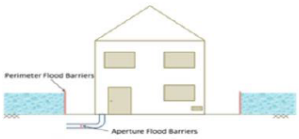
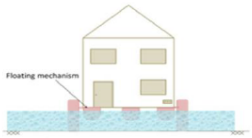
How Resilience can Help?

Water exclusion strategies:
Building resistance

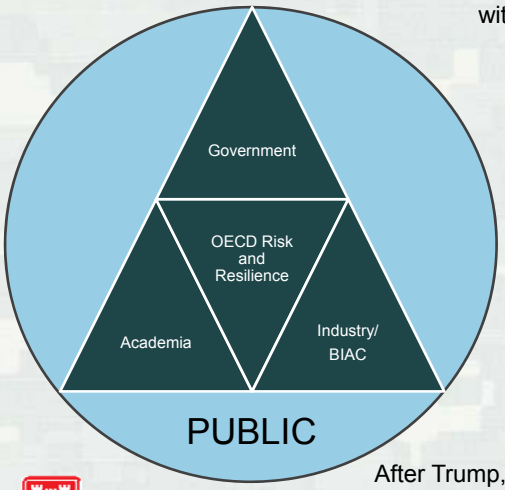


Water entry strategies :
Building resilience



http://www.architecture.com/Images/RIBAHoldings/ http://tech.floodresilience.eu http://www.planningportal.gov.uk

OECD's Role



Provide guidance for unique considerations within each governance jurisdiction:

What rules/regulations exist, and how do they capture the ***process*** and ***products*** of emerging risks?

How do the **unique political and institutional frameworks** of a given jurisdiction affect emerging risk governance?

Do these regulatory differences influence the ***perception*** of risk by local experts and regulators?

After Trump, Linkov et al 2016

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Regulatory change is typically slow in most democracies, particularly in the case of emerging technologies.

Kuzma, J., & Tanji, T. (2010). Unpackaging synthetic biology: Identification of oversight policy problems and options. *Regulation & Governance*, *4*(1), 92-112.

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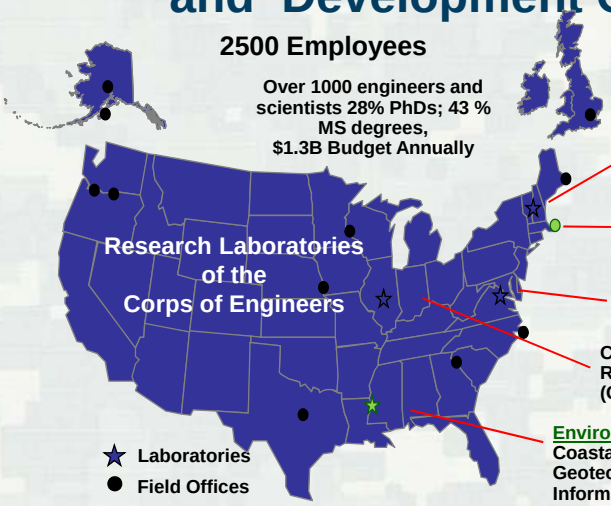
US Army Engineer Research and Development Center

2500 Employees

Over 1000 engineers and scientists 28% PhDs; 43 % MS degrees, $1.3B Budget Annually



Cold Regions Research Engineering Laboratory (Hanover, NH)

Risk and Decision Science Team Boston, MA)

Topographic Engineering Center (Alexandria, VA)

Construction Engineering Research Laboratory (Champaign, IL)

Environmental Laboratory
Coastal & Hydraulics Laboratory
Geotechnical & Structures Laboratory
Information Technology Laboratory
Headquarters (Vicksburg, MS)

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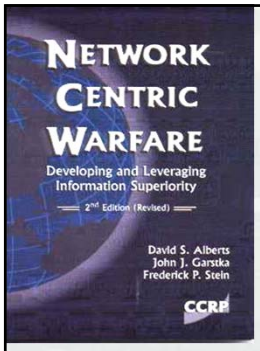
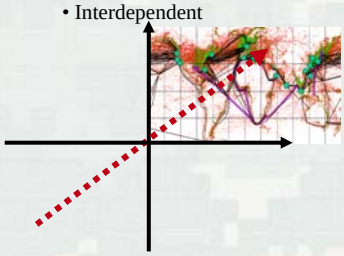


Global Trends and Military

Information Age
- Short Cycle Time
- New Competencies
- Adaptive Planning
- Integrated Joint
- Interdependent



Globalization III
- Emerging Rules
- Market Opportunities
- New Customer Base Emerging
- Security=All Else+Defense

Globalization II
- Developed Rules
- Mature Markets
- Narrowing Customer Base
- Security=Defense

Industrial Age
- Long Cycle Time
- Well Developed Tools/Processes
- Deliberate Planning
- Deconflicted Joint
- Tortured Interoperability

After Cebrowski 2003

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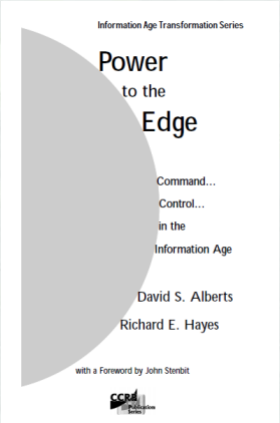
Military Systems Doctrine as a Foundation for Resilience



Command and Control actions in 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.

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Resilience: Political Importance and Challenge

The White House

Office of the Press Secretary

For Immediate Release Octo

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.

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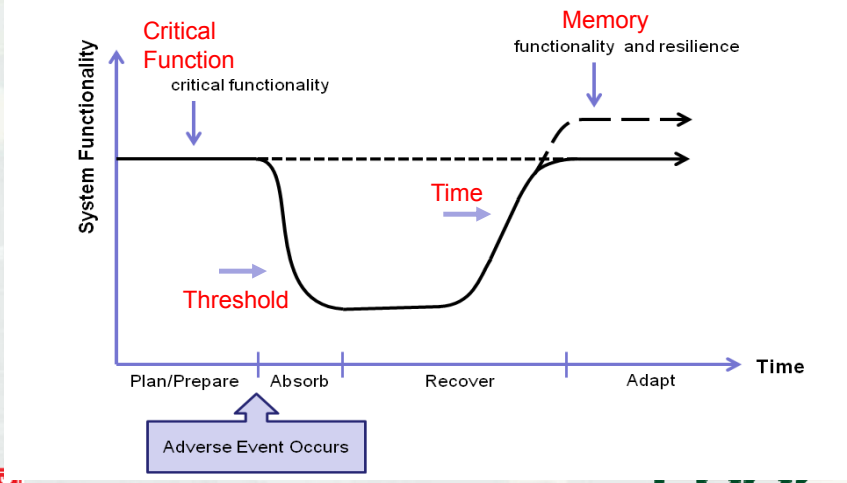
Resilience Formulation



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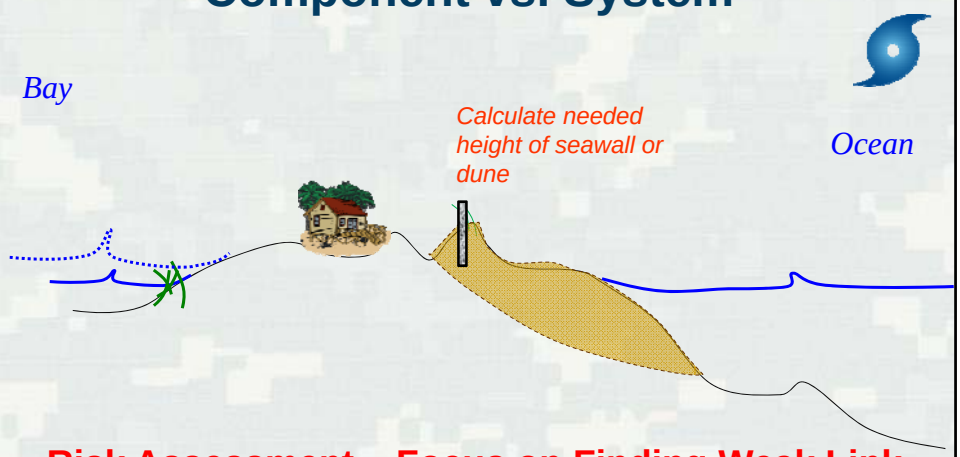
After Connelly et al., 2016

Component vs. System



Risk Assessment – Focus on Finding Weak Link:

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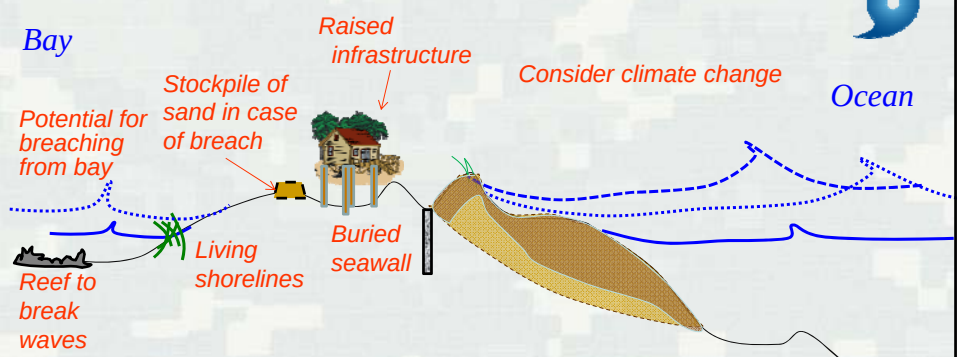
Resilience -- Management at System Level



- Anticipate weak links and be ready to recover. *Ex: sand to close new inlets.*
- Provide diverse and redundant protection. *Ex: buried seawall AND beach/dune system.*
- Ensure availability of alternate networks. *Ex: multiple electrical power circuits.*
- Provide accessible information for rapid decision-making. *Ex: raised homes, evacuation routes*

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Critical Function – Stakeholder Engagement

- System has multiple functions, but not all of them are equally important
  - Stakeholder elicitation is required
  - Prioritization of project alternatives
  - Values, preferences
  - Public education

"We want to include you in this discussion without letting you affect it"

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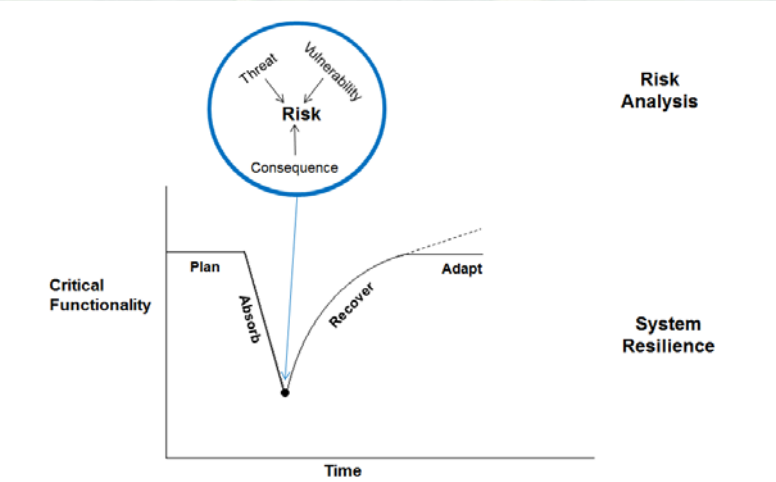
Risk and Resilience: Thresholds



After Linkov et al, Nature Climate Change 2014

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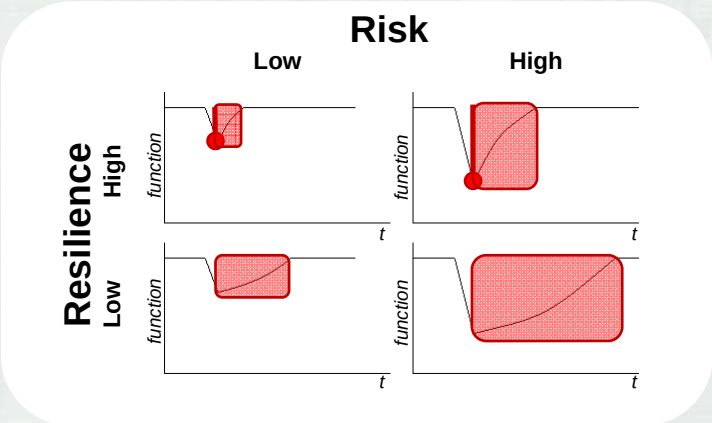
Importance of Recovery



From Linkov et al, Nature Climate Change 2014

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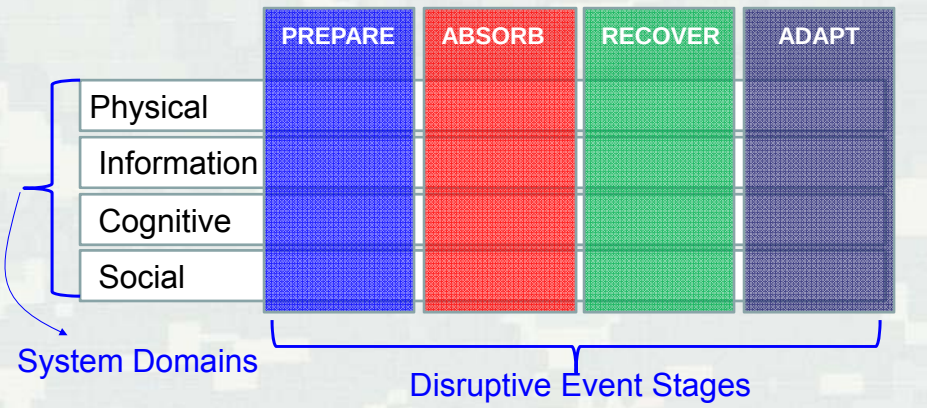
Quantifying Resilience - Resilience Matrix



Scale

Home Neighborhood Town County Region State Country

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General Form of Resilience Matrix

Adverse Event

Time

	Previous Cycle	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*

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Resilience at OECD

OECD Directorate	Document	Plan	Absorb	Recover	Adapt
ITF	(Lofquist, 2017)	■	■	▪	■
ED	ENV/EPOC/WPCID(2016)3	■	▪	▪	▪
IEA	(OECD/IEA, 2015)	▪	▪	▪	▪
DCD-DAC	DCD/DAC/RD(2016)18/RD1	▪	▪	▪	▪
	OECD (2014b)	■	▪	▪	▪
DSTI	OECD (2008)	■	▪	▪	▪
	OECD (2015)	■	▪	▪	▪
DELS	COM/ECO/CPE/WP1/DELSA/ELSA/WP5 (2017)1	▪	■	■	▪
DPGTD	OECD (2011)	■	▪	▪	▪
	OECD (2014a)	▪	▪	▪	▪
	GOV/RDPC/URB(2016)4	▪	▪	▪	▪
	GOV/PGC/HLRF(2016)10	▪	▪	▪	▪
	GOV/RDPC/RD(2015)2	▪	▪	▪	▪
	OECD (2016c)	■	■	■	■
	GOV/PGC/HLRF(2016)9	▪	▪	▪	▪
	OECD (2013)	■	■	▪	■

OECD Directorates Resiliency Involvement. OECD directorate publications denoted as they discuss the four stages of resilience "directly" vs. "indirectly," or not at all.

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Discussion of Quantitative Approaches

OECD Directorate	OECD Directorate Publications	Quantitative Approaches
ITF	(Lofquist, 2017)	Maritime Safety Analysis
ED	ENV/EPOC/WPCID (2016)3	Vulnerability Assessment Economic Analysis Cost Benefit Analysis Climate Risk Screening Tool
IEA	(OECD/IEA, 2015)	Climate risk auditing Risk Assessments Vulnerability Assessments Climate forecasts
DSTI	OECD (2008b)	Risk Assessment
	OECD (2015b)	Risk Assessment
DCD-DAC	DCD/DAC/RD (2016)18/RD1	Resiliency systems analysis framework
	OECD (2014b)	
DELS	COM/ECO/CPE/WP1/DELSA/ELSA/WP5 (2017)1	Econometric analysis
DPGTD	OECD (2011)	Risk Governance Framework/ National Strategy Foresight Analysis Global Risk Monitoring Systems Hazard and Risk Assessments (e.g., multi-hazard, multi-stakeholder) Early Warning Systems Needs Assessment Global Value Chain Modelling Cost Benefit Analysis Multi-Criteria Decision Analysis As Low As Reasonable Practice (ALARA)
	OECD (2014a)	
	OECD (2013)	
	GOV/RDPC/URB (2016)4	
	GOV/PGC/HLRF (2016)10	
	GOV/RDPC/RD (2015)2 OECD (2016c)	
	GOV/PGC/HLRF (2016)9	
	OECD (2013)	

OECD Resilience Quantitative Approaches. Examples of resilience-based quantitative analyses discussed among OECD directorate publications.

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Application of Resilience in OECD

- The emerging science of resilience has not been adequately featured in the body of work delivered by OECD
  - For many documents, a focus on Planning and Absorbing Risk, with less attention paid to system Recovery and Adaptation
- While the OECD directorates agree that resilience should be considered in systems development, OECD directorates focus heavily on resilience planning and preparation
  - Emphasis on other resilience features including system threat absorption, recovery, and adaptation are less prevalent

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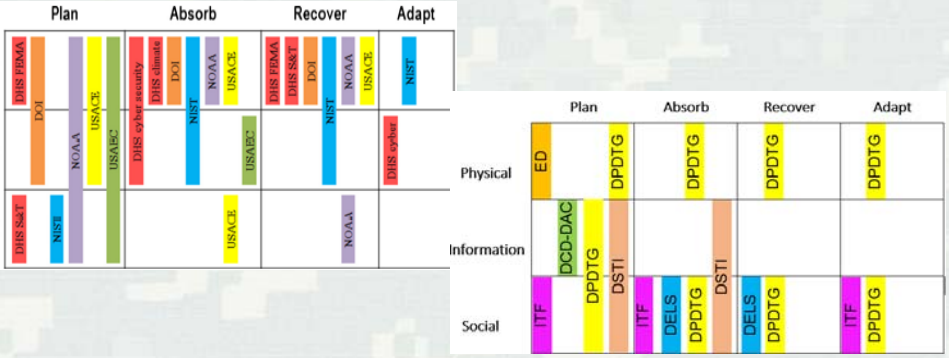
Resilience Matrix: OECD Divisions vs. US Agencies



OECD Directorate vs. US Agency resilience actions "directly" addressed (relative to NAS definition) in physical, information, and social domains. OECD publications discuss resilience within social domain while US agencies discuss resilience heavily within infrastructure domain.

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Recommendations and Way Forward

- A normalized and operationalized definition of resilience within the OECD is useful to build adequate quantitative measures across directorates

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1. Assessment using Decision Analysis

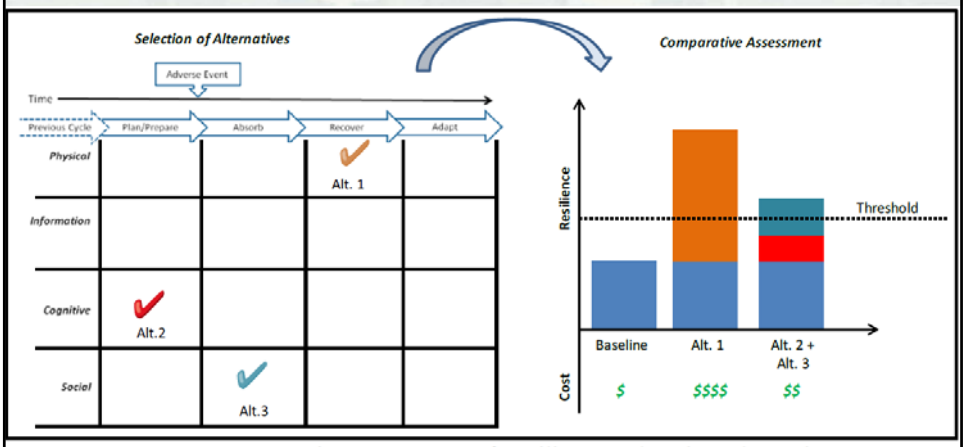

Figure 5: Comparative Assessment of Resilience-Enhancing Alternatives

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

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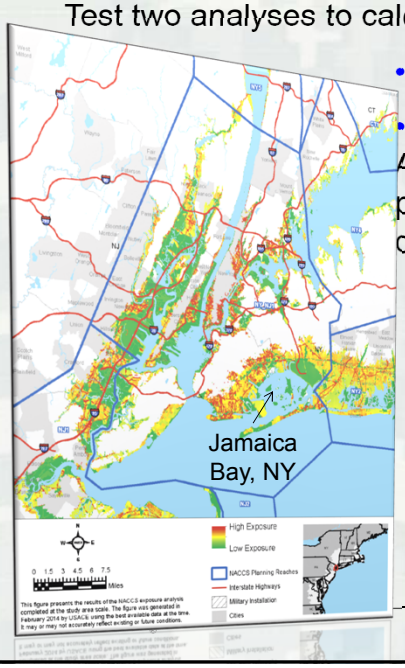
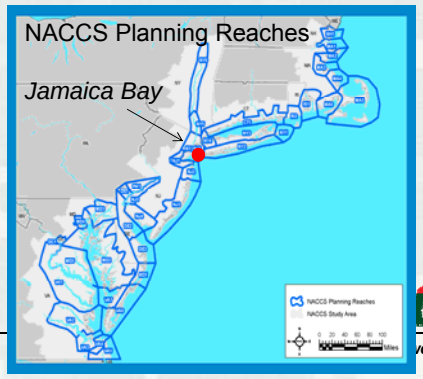
Pilot Study in Jamaica Bay, NY

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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How it works: Project Evaluation

- Baseline assessment can be used to evaluate proposed projects

	Prepare	Absorb	Recover	Adapt
Physical	71	16	60	10
Information	63	45	21	18
Cognitive	90	49	38	27
Social	82	54	12	52

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Project 1

	Prepare	Absorb	Recover	Adapt
Physical	+10	+18	+9	+32
Information	+8		+17	
Cognitive				
Social				

	Prepare	Absorb	Recover	Adapt
Physical	81	34	69	42
Information	71	45	38	18
Cognitive	90	49	38	27
Social	82	54	12	52

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Project 2

	Prepare	Absorb	Recover	Adapt
Physical				
Information		+5	+15	+22
Cognitive				
Social	+3		+12	+21

	Prepare	Absorb	Recover	Adapt
Physical	71	6	60	10
Information	63	50	36	40
Cognitive	90	49	38	27
Social	85	54	24	73

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*Projects may have (+) or (-) in other matrices

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Problems with Metrics-Based Approaches

•Measuring for emerging threats remains difficult: the gap between measures and increased vulnerabilities can be hard to close

•Many measurement programs utilize data that does not contribute to informing decisions or changing behavior.

Not everything that counts can be counted, and not everything that can be counted counts.
Albert Einstein

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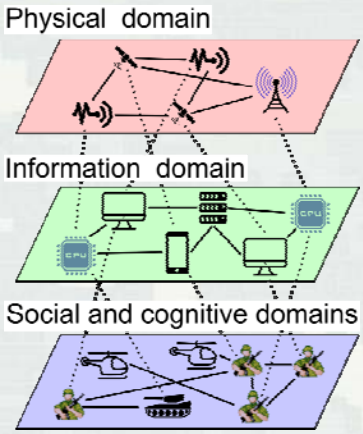
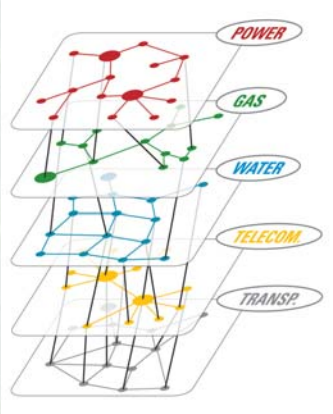
2. Future: Network Science

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





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

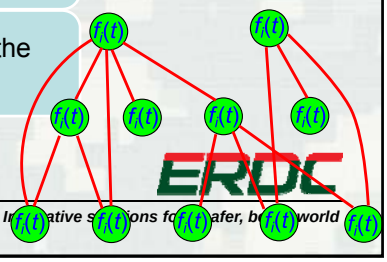
Network-based Resilience Theory?

System's *critical functionality* (K)

Network topology: *nodes* ($\mathcal{N}$) and *links* ($\mathcal{L}$)

Network *adaptive algorithms* ($\mathcal{C}$) defining how nodes' (links') properties and parameters change with time

A *set of possible damages* stakeholders want the network to be resilient against ($\boldsymbol{E}$)



$$R = f(\mathcal{N}, \mathcal{L}, \mathcal{C}, \boldsymbol{E})$$

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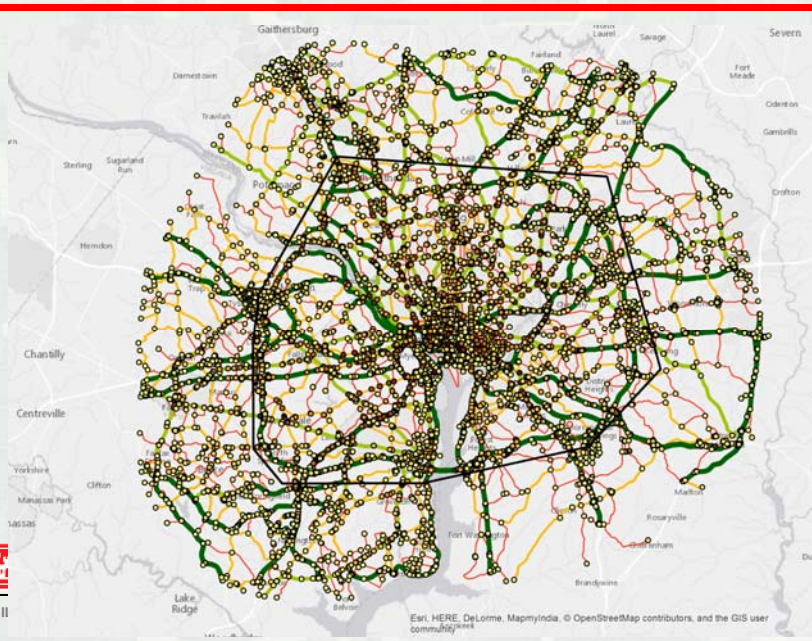
Transportation Networks – DC



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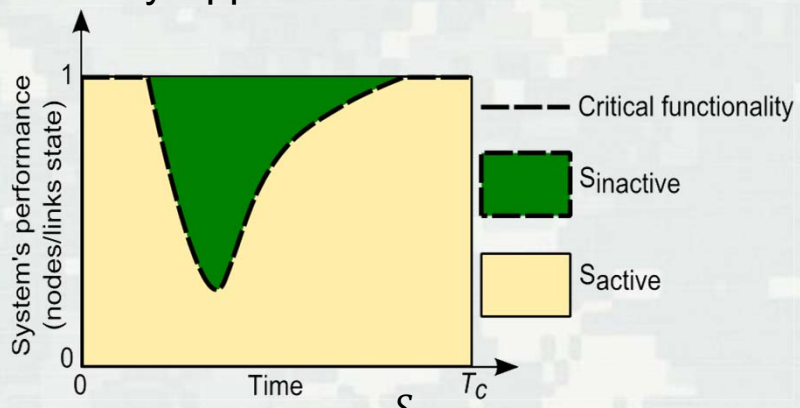
Resilience Quantification

- Based on NAS Definition
- Widely Applicable



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

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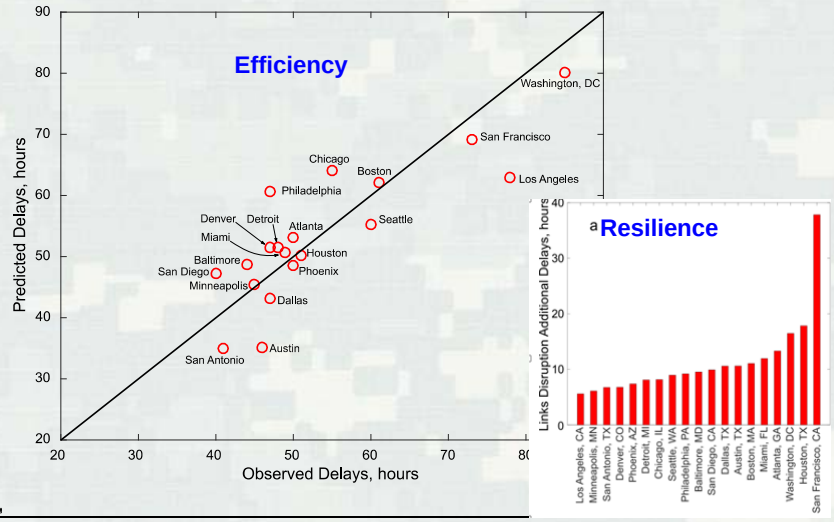
Efficiency vs. Resilience

R^2: 0.704; Pearson: 0.839; Spearman: 0.825



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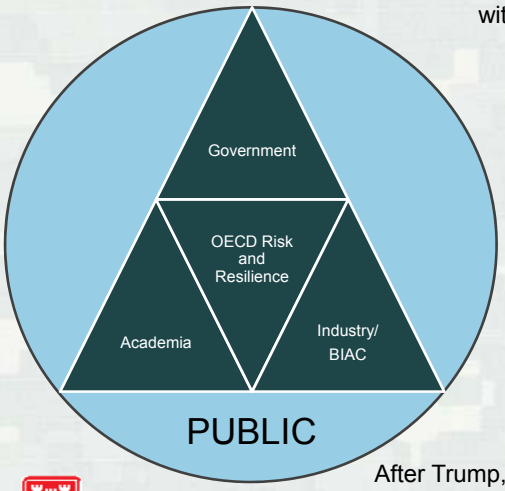
OECD's Role



Provide guidance for unique considerations within each governance jurisdiction:

What rules/regulations exist, and how do they capture the ***process*** and ***products*** of emerging risks?

How do the **unique political and institutional frameworks** of a given jurisdiction affect emerging risk governance?

Do these regulatory differences influence the ***perception*** of risk by local experts and regulators?

After Trump, Linkov et al 2016

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Comparative Assessment of Risk and Resilience Culture

Case	Adversarial vs Cooperative	Degree of Transparency in Regulatory Process	Formal/ Informal Reliance on Dispute Resolution	Multiple Veto Points in Regulation Development	Concentration of Regulation
USA	Adversarial	High	Formal	Yes	Decentralized
European Union	Cooperative	High	Informal	Yes	Decentralized
Singapore	Cooperative	Low	Informal	No	Centralized

Cross-comparison of Regulatory Risk Culture of Three Cases

After Trump et al 2017

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Risk-Resilience Integration

Top-Down
Decision Analysis/Social Science

Goal Identification and Problem Framing
-
What are the goals, alternatives, and constraints?

Decision Model
-
What are the criteria and metrics, How do we measure decision-maker values

Metrics Generation and Alternative Scoring
-
How does each alternative score along our identified criteria and metrics?

Management

Modeling

Data Collection

Bottom-Up
Risk Assessment/ Physical Sci

Risk Characterization
-
What are the risks relative to a threshold? How do they compare to other alternatives?

Physical/Statistical Model
-
What is the hazard?
What is exposure?

Data Collection
-
What are fundamental properties/mechanisms associated with each alternative?

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Linkov et al., 2014

Future: Evolution of Approaches for Flood Risk Management

Live with floods
- Individuals and small communities adapt to nature's rhythm.

Use the floodplain
- Fertile land in floodplain is drained for food production.
- Permanent communities develop on the floodplain.

Control floods
- Large scale structurel approaches are implemented through organized governance

Reduce flood damages
- A recognition that engineering alone has limitations.
- Effort to increase the resilience of communities should a flood occur.

Manage risk
- Not all problems are equal.
- Risk management is an effective and efficient means to maximize the *benefit of* limited investment.

From: Sayers et al., 2012

Manage resilience?
- Not all problems need to be solved
- Systems approach & integration of communities is the key

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