Northeastern University

Center for Resilience Studies

Bolstering Critical Infrastructure Resilience in the Face of Extreme Weather

A presentation to the MEMA 2016 Hurricane Preparedness Conference

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The Resilience Imperative

"The abiding strategy of our parents' generation was 'containment' of communism in order to be free. The abiding strategy of our generation has to be 'resilience.' We will only be free to live the lives we want if we make our cities, country and planet more *resilient*."

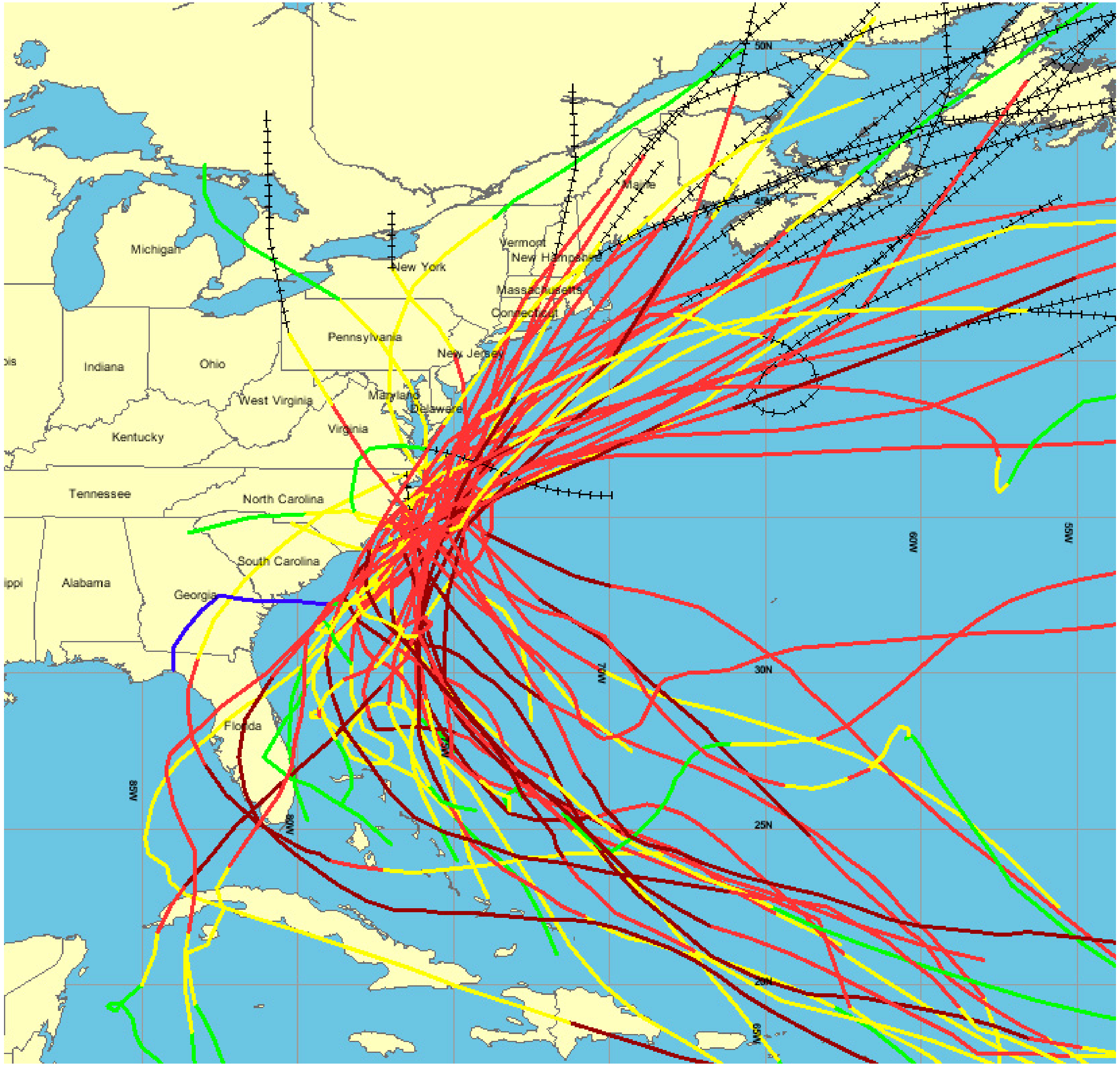
* Thomas L. Friedman, *The New York Times*, May 24, 2014

Resilience Defined

"The term *resilience* refers to the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.*

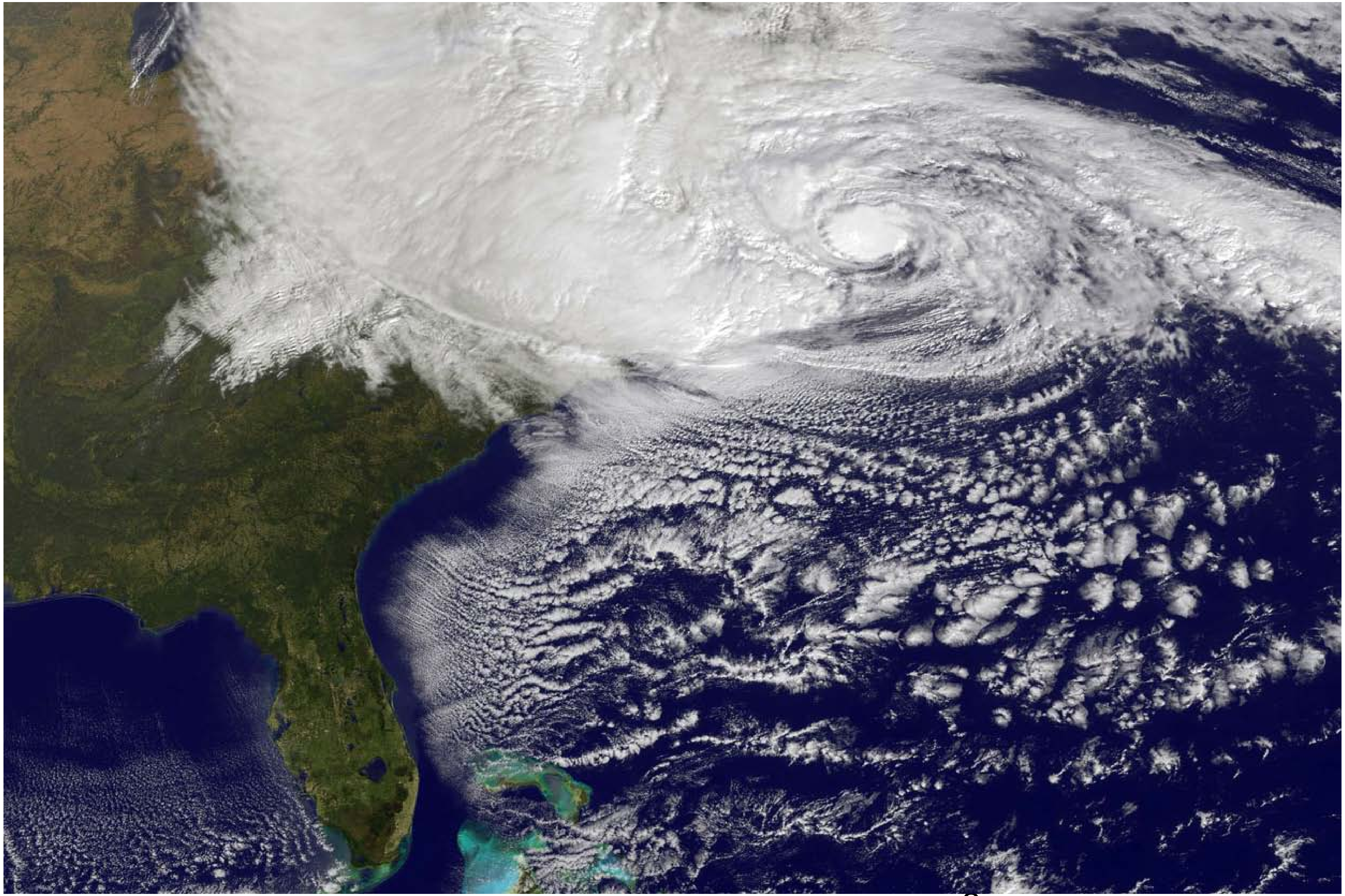
* Presidential Policy Directive 21 - Critical Infrastructure Security and Resilience February 12, 2013

Superstorm Sandy – a “predictive surprise”



Hurricane Track Map passing within 65 nautical miles of Cape Hatteras, NC: 1900-2010

Source: http://www.noaanews.noaa.gov/stories2010/images/cape_hatteras.jpg.




WESTCHESTER COUNTY
NEW JERSEY
Hudson River
Long Island Sound
BRONX
MANHATTAN
Harlem River
Hackensack River
Passaic River
East River
QUEENS
Newark Bay
Upper New York Bay
BROOKLYN
Kill Van Kull
STATEN ISLAND
Jamaica Bay
Lower New York Bay
Rockaway
Arthur Kill
ATLANTIC OCEAN
Raritan Bay
Sandy Hook
N
Legend
Inner Harbor
Upper East River - Western LIS
Lower Bay
Jamaica Bay
0 5 10 Miles


STEVENS
INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY
DAVIDSON LABORATORY
CENTER FOR MARITIME SYSTEMS
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HOBOKEN, NJ
Water Depth
> 8 ft
8 ft
6 ft
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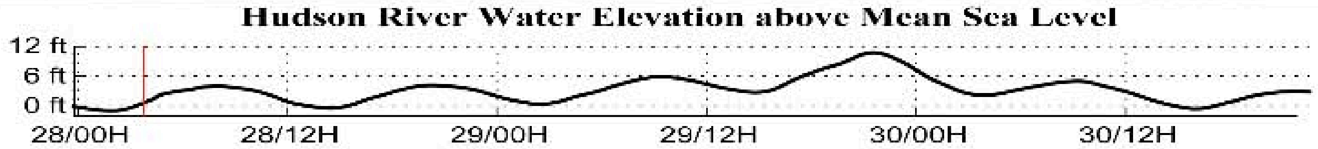
2 ft
Ground


Hudson River Water Elevation above Mean Sea Level
12 ft
6 ft
0 ft
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STEVENS
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Water Depth
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8 ft
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Ground

Goldman Sachs HQ, 200 West St. New York, NY on Oct 28 & 29, 2012

Goldman Sachs

October 28, 2012

October 29, 2012

HQ is dry and has electric power, but . . .

- *No employees due to disruption of transportation system.*
- *Little ability to telecommute due to region wide power outages*

Verizon Headquarters & Switching Center, 140 West St.

verizon

Verizon Headquarters & Switching Center, 140 West St.

Cable Vault Room at Verizon Headquarters, 140 West St.

verizon

Metro NY- NJ Mass Transit Case Study

Metropolitan Transportation Authority (MTA):

1. Moved Trains to high ground and shelter

2. Provided incentive for workforce to stay on the job

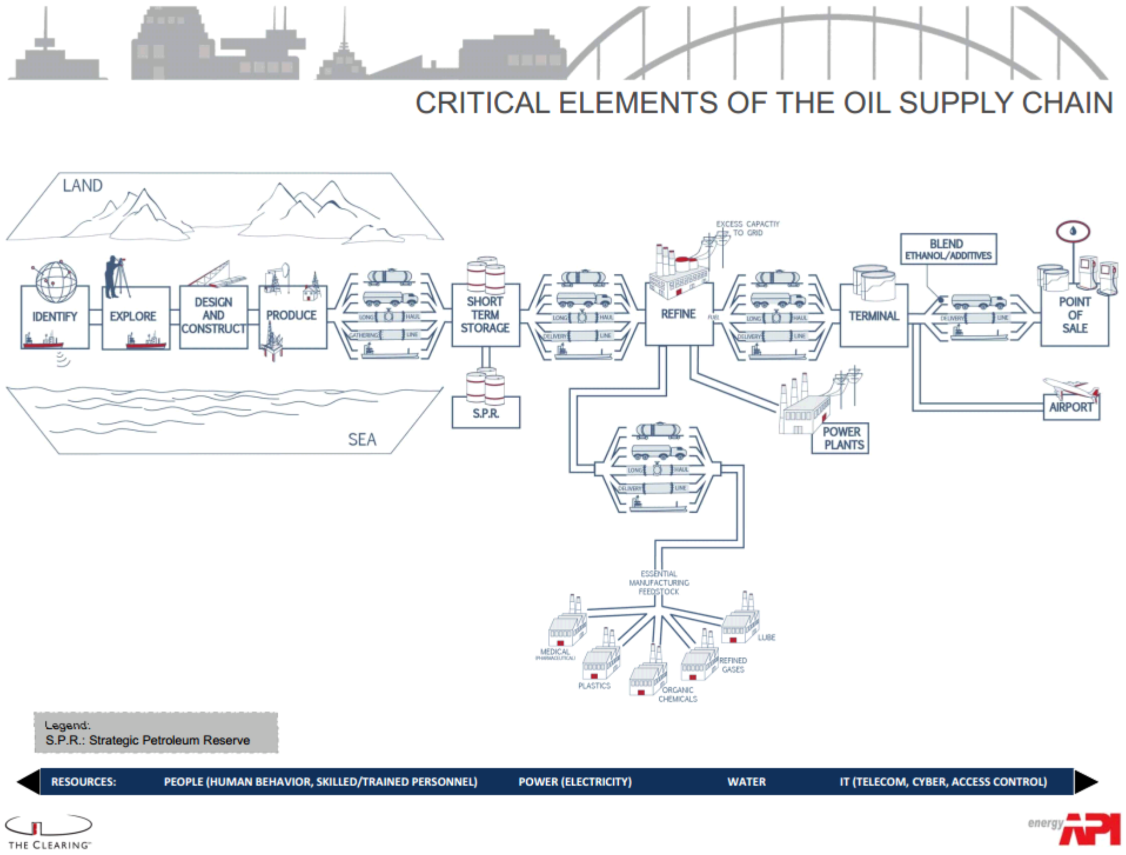
New Jersey Transit

Hoboken, NJ – Train and Ferry Terminal

NJ Transit Terminal - Hoboken

New Jersey Transit - 345 Trains damaged by flooding at the Meadowlands Maintenance Complex & Hoboken Yard totaling $120 million

Metro NY-NJ Liquid Fuels Distribution Case Study


CRITICAL ELEMENTS OF THE OIL SUPPLY CHAIN
LAND
SEA
IDENTIFY
EXPLORE
DESIGN AND CONSTRUCT
PRODUCE
SHORT TERM STORAGE
S.P.R.
REFINE
EXCESS CAPACITY TO GRID
TERMINAL
BLEND ETHANOL/ADDITIVES
POINT OF SALE
AIRPORT
POWER PLANTS
ESSENTIAL MANUFACTURING FEEDSTOCK
MEDICAL
PLASTICS
ORGANIC CHEMICALS
REFINED GASES
LUBE
Legend:
S.P.R.: Strategic Petroleum Reserve
RESOURCES: PEOPLE (HUMAN BEHAVIOR, SKILLED/TRAINED PERSONNEL) POWER (ELECTRICITY) WATER IT (TELECOM, CYBER, ACCESS CONTROL)
THE CLEARING
energy API

Hurricane Sandy's Impact on NY/NJ Liquid Fuels Distribution System

SUPPLY (42m gallons of petroleum products per day)

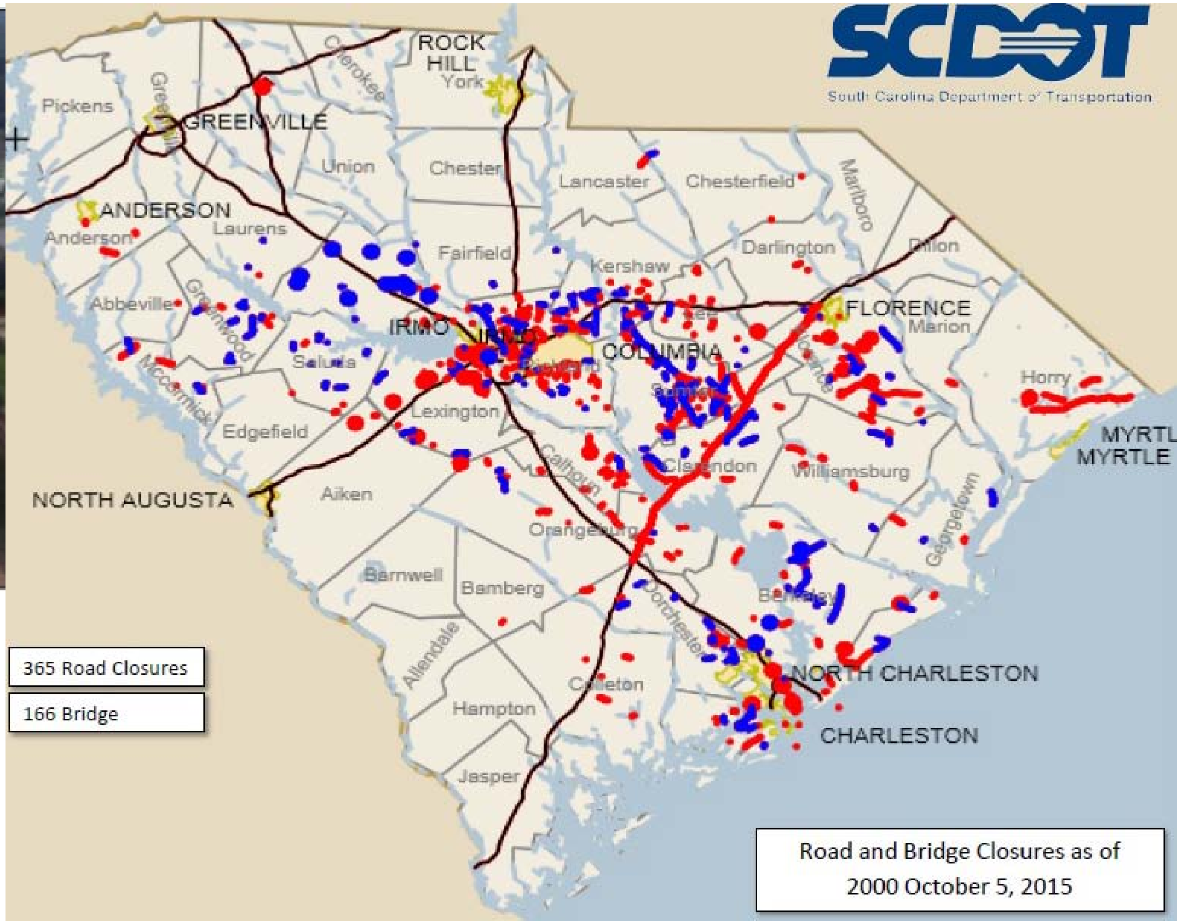
- Port closure during and following the storm halted all maritime shipments. (60+%)
- Bayway Refinery and Hess Port Reading Refinery disabled due to loss of commercial and generator power, damage to marine terminal, and damage to electrical equipment. (20%)
- Colonial Pipeline stopped deliveries to northern NJ due to damage to receiving terminals and power outages impacted its operations. This slowed product movement throughout entire pipeline back to the Gulf Coast (15%)

DISTRIBUTION:

- Damage to dock facilities disrupted barge movements of gasoline
- Gas station closures: 60% of NJ; 70% of Long Island
- Gas rationing implemented in New Jersey (11 days) and New York (15 days)

http://www.eia.gov/special/disruptions/hurricane/sandy/petroleum_terminal_survey.cfm

South Carolina Flooding , October 5, 2015



Road and bridge closures as of Oct. 5, 2015

("'Fire hose' of moisture slams South Carolina." *WSOCTV.com*. Cox Media Group. 5 Oct 2015. Web. 16 Nov 2015. <link>)

Gills Creek (SC) Watershed Flooding , October 5, 2015

- The Gills Creek watershed is a **system** of waterways, lakes, dams, residential, and commercial development

- Damage to the water treatment plant resulted in a boil-water order that lasted for 10 days

- 541 roads were closed throughout South Carolina as a result of the storm, including a 13-mile stretch of I-95 for ten days

- 26 roads that were built on top of dams closed due to dam failure and remained closed for over two months

- 24 remain closed to this day

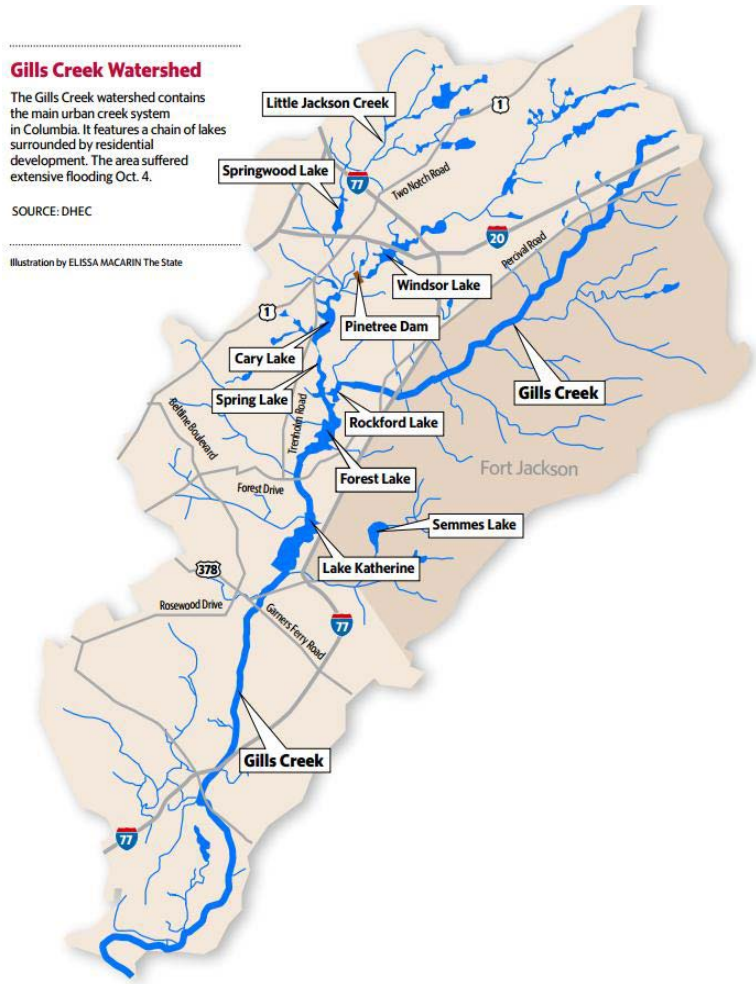


Image: (Fretwell, Sammy. “Aging dams spark questions in waterlogged Columbia.” *The State*. TheState.com. 10Oct 2015. Web. 16 Nov 2015. <link>)

Hypothetical Case study: Category 1 hurricane in Boston

CAT 1 hurricane, 60mph wind, heading west by northwest causes 6.5ft of surge above ground level at **Aquarium T-Station**

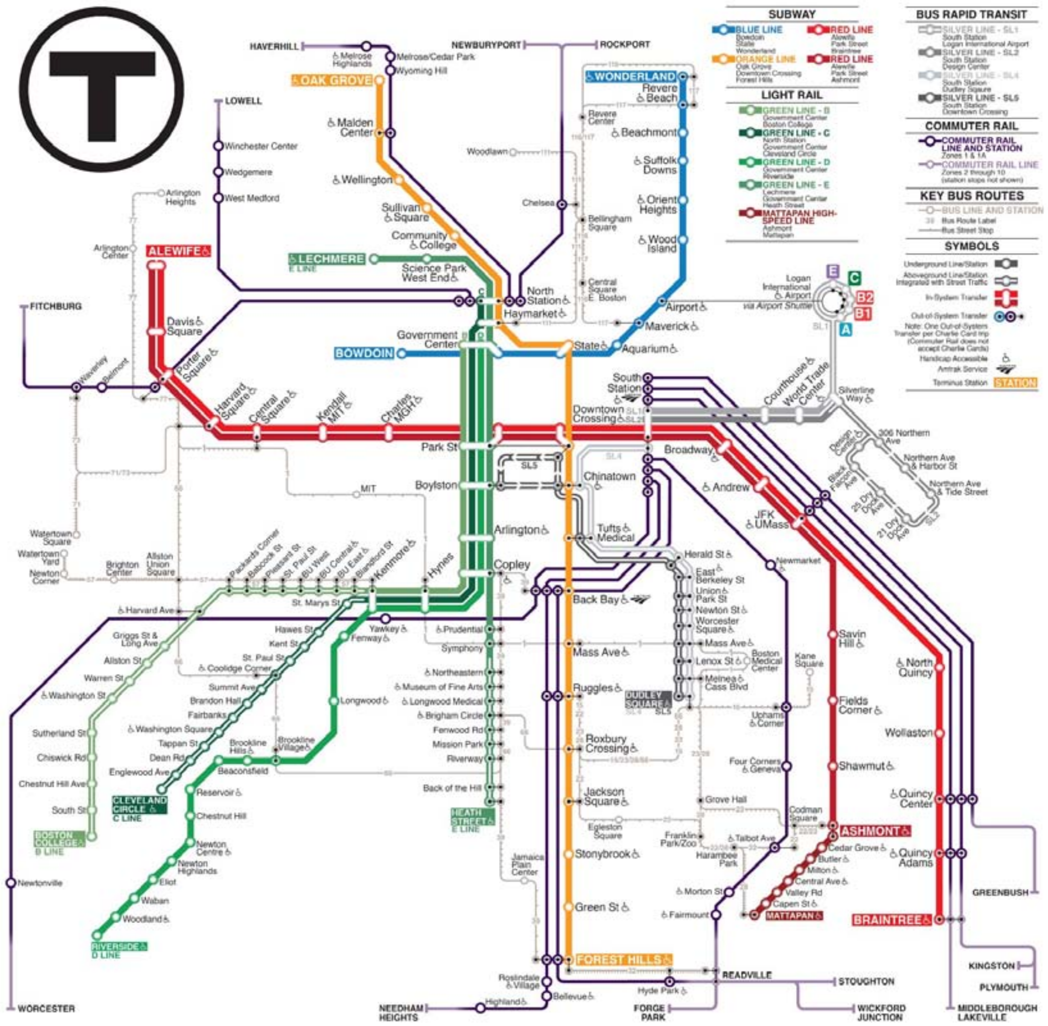
Complex Network Representation of MBTA

Network Enabled Visualization

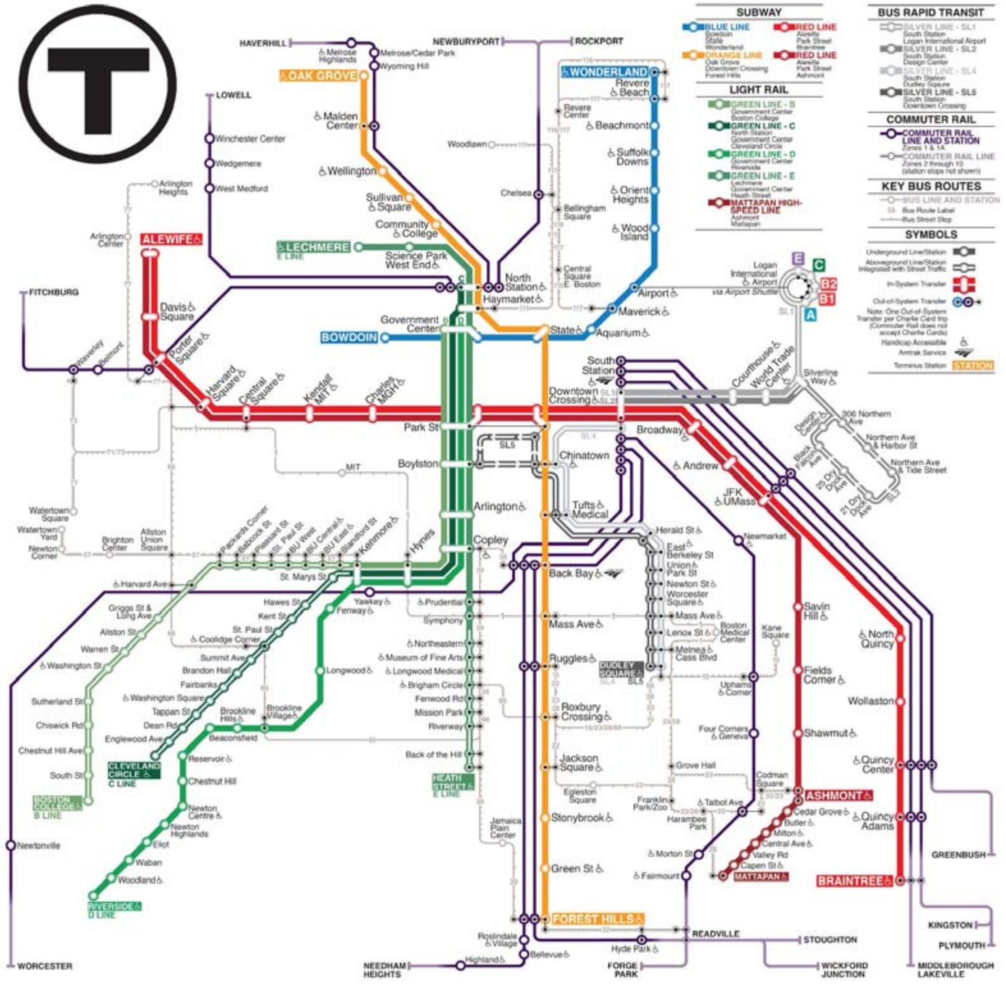
Draws on open-source datasets of the Boston public transportation system.

Understanding Robustness: Complex network based tools help decision makers to simulate and visualize parts of the system that is compromised would cause the most disruption.

Planning for recovery: Complex network based tools can inform the prioritization sequence, time and resources required to promote efficient and faster restoration.

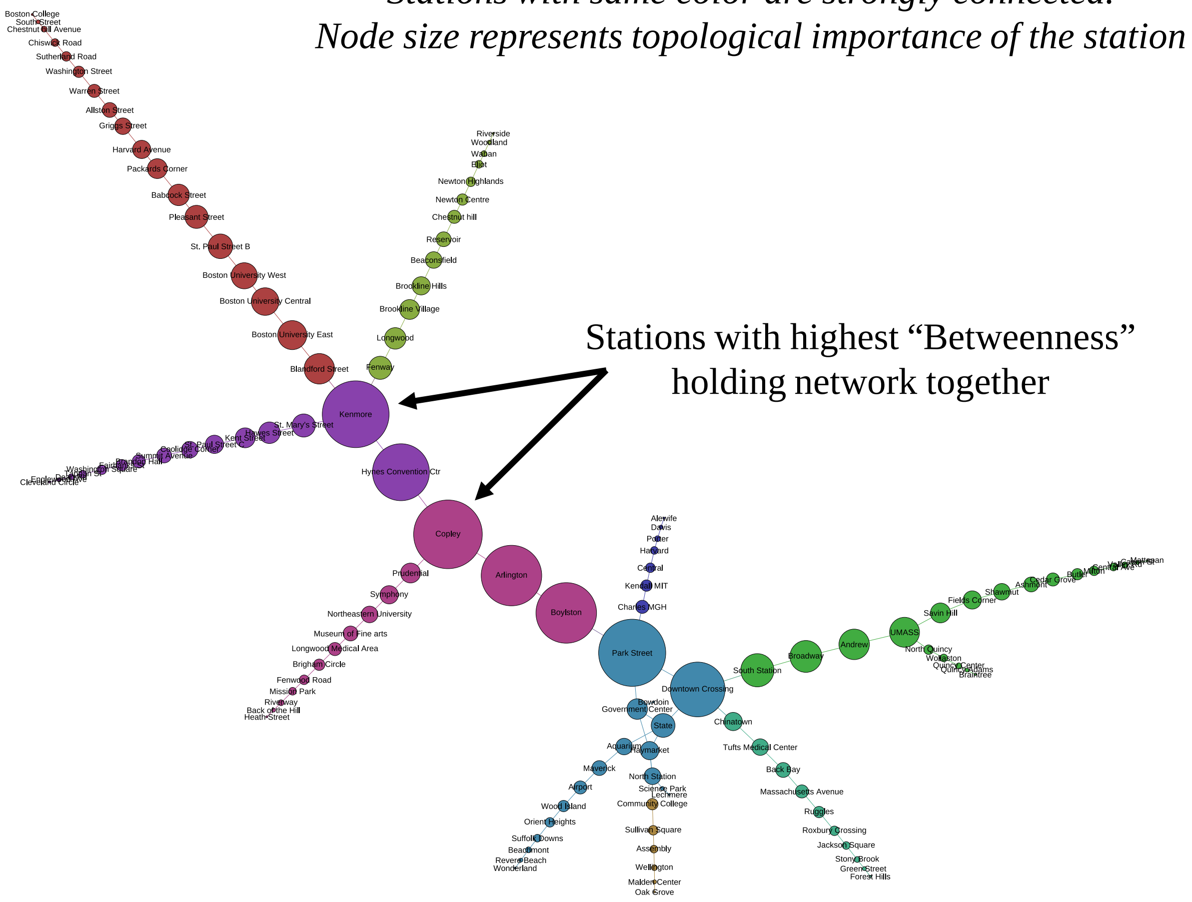


Complex Network Representation of MBTA



Route map: MBTA

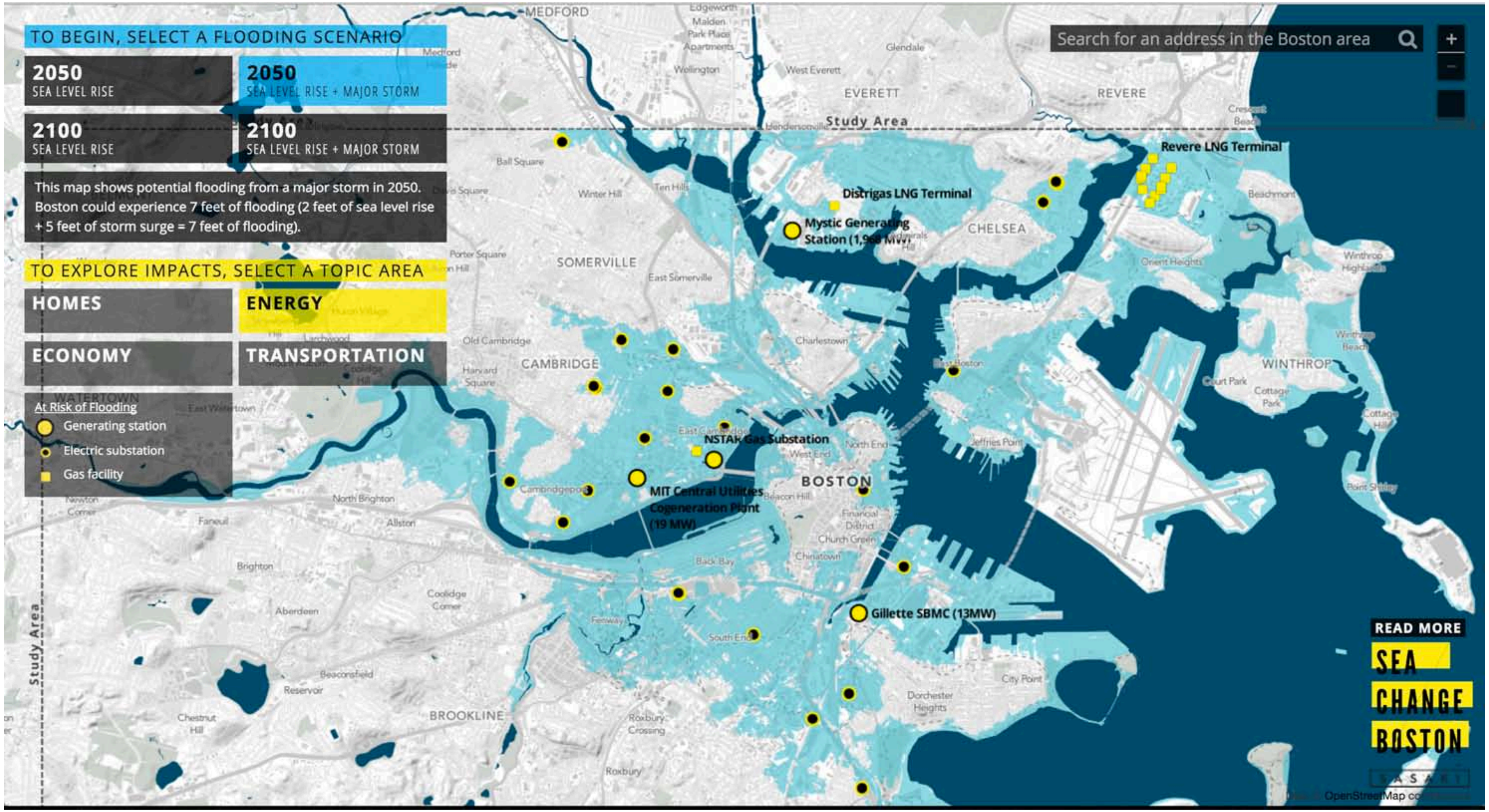
Stations with same color are strongly connected.
Node size represents topological importance of the station



Stations with highest "Betweenness" holding network together

Network representation
121 Nodes and 124 links

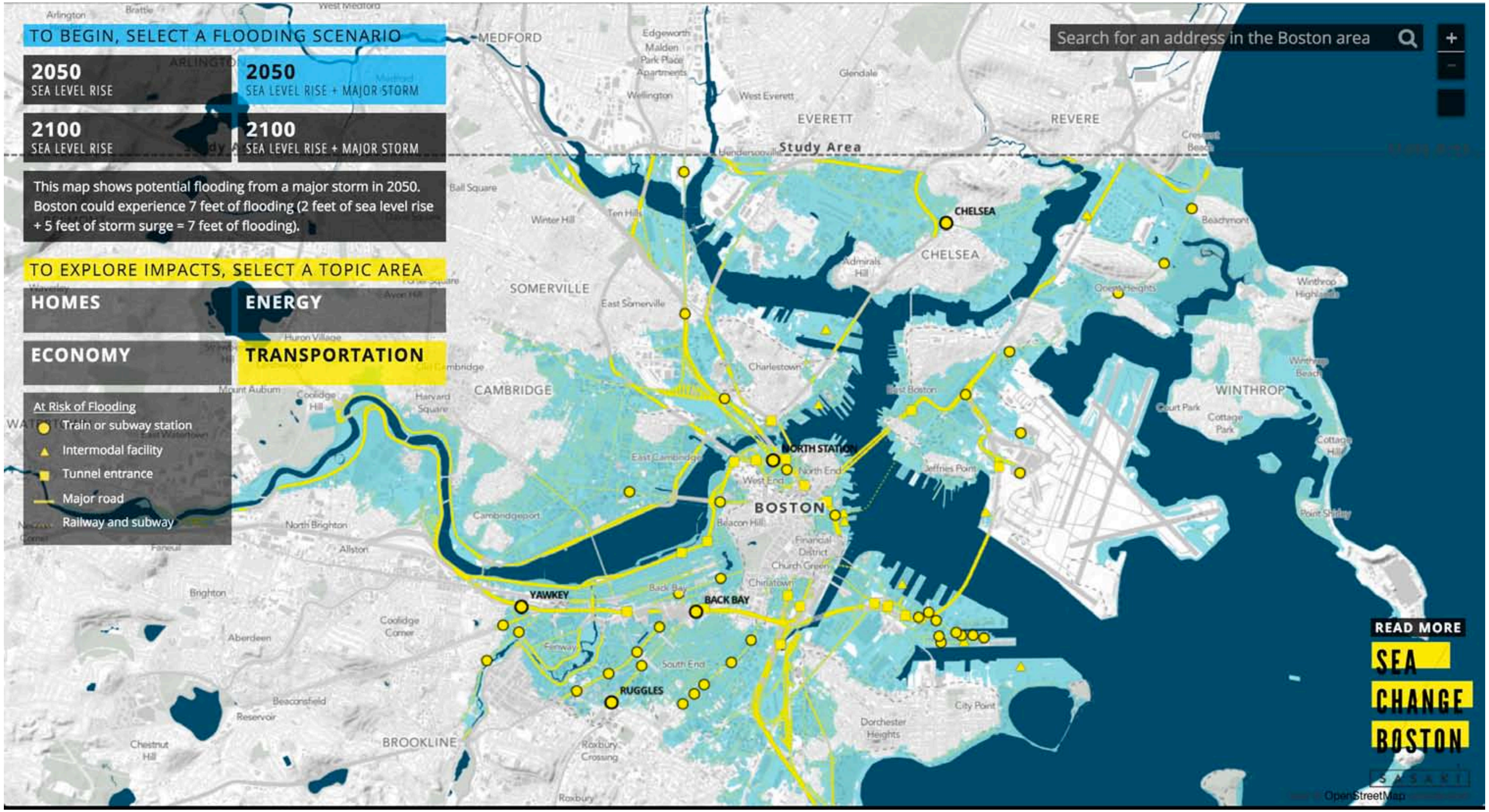
Simulating Hazards: Storm Surge and Sea Level Rise



Potential flooding of energy sector from a major storm in 2050
(2 feet of sea level rise + 5 feet of storm surge = 7 feet of flooding)

SOURCE: http://seachange.sasaki.com/

Simulating Hazards: Storm Surge and Sea Level Rise



Potential flooding of transportation sector from a major storm in 2050
(2 feet of sea level rise + 5 feet of storm surge at high tide = 7 feet of flooding)

SOURCE: http://seachange.sasaki.com/

Attributes for Bolstering Infrastructure Resilience

The stepping off point for establishing resilience priorities is to identify the *elemental capacity*, *essential function* and *full/ normal function* for infrastructure, systems, and networks

There are five resilience attributes:

- ***Cushionability***
- ***Resistance***
- ***Robustness***
- ***Redundancy***
- ***Graceful extensibility***

Collectively these attributes contribute to mitigating the risk of disruption, support rapid response and recovery, and advance adaptation in the face of naturally-occurring and human-made disasters.

Elemental Capacity

Elemental capacity represents the prerequisite system conditions that must be in place in order for an infrastructure, system, or network to provide its function to its users.

Examples include:

- Electrical power to support the HVAC system for a hospital operating room.
- Electrical power for a retail filling station be able to operate its gas pumps.
- Fuel to allow public safety vehicles to respond to emergencies.

Essential Function

Essential function is the minimal level of function an infrastructure, system or network needs to provide in order to (1) meet the critical needs of its users, and (2) support recovery.

Examples include:

- An airport is able to safely support landings and takeoffs for aircraft providing emergency relief.
- A cellular provider is able to provide sufficient cellular coverage to for users to send text messaging.
- A water utility is able to provide adequate water to support coolant systems required for power generation.

Full/ Normal Function

Full/ normal function is that which an infrastructure, system, or network provides in order to satisfy the routine needs of its users and to remain economically viable.

Examples include:

- A hospital can perform elective surgeries which is an important source of revenue.
- An airport is able to support scheduled daily landings and takeoffs of commercial airliners.
- An electric utility can provide power to support demand for residential and commercial air conditioning on a hot day.

Cushionability

Cushionability is the capacity to support graceful degradation of non-essential function during periods of stress. Examples include:

- Hospitals who evacuate non-critical patients to make additional beds and medical personnel available in advance of a hurricane to better respond to post-storm emergencies.

- Highways that are closed to all non-emergency vehicles just prior to a major snow storm to facilitate snow removal operations and rapid recovery of road transportation after the storm.

- Commercial buildings and other large power consumers who enter into arrangements with large electric utilities where they agree to reduce their normal demand during peak load days.

Resistence

Resistance involve measures that redirect a threat of hazard away from where it can cause damage to elemental capacity or disrupt essential function.

Examples include:

- Creating a fire line around a critical facility so an advancing wildfire will veer in a direction that will cause less destruction.

- Fabricating floodways that channel storm surge into large underground parking garages or on to playgrounds that can serve as temporary reservoirs, reducing the risk of flood damage to other facilities in the flood zone.

- Lowering the risk posed by explosive-laden vehicles by only allowing small vehicles and prohibiting large commercial trucks on streets adjacent to a critical facility.

Robustness

Robustness involves investing in measures that harden or protect **elemental capacity** and **essential function**.

Examples include:

- Installing back-up generators on a high-floor where they will not be damaged by storm surge.
- Deploying inflatable plug at the entrance of a tunnel in advance of a storm.
- Constructing a floodwall around a low-lying electrical substation.
- Placing protective conduit around bridge cables so they cannot be severed by a cutting torch

Redundancy

Redundancy involves investing in back-up systems or spare components to support immediate recovery of **elemental capacity** and **essential function**.

Examples include:

- Back-up data processors located in another region
- Back-up air compressor to keep cable conduit under pressure so as to prevent floodwater from seeping in and causing damage to the wiring.
- Back-up turbine engine to operate a compressor for moving gas or fuel along a pipeline.
- Sufficient protective clothing on-hand at a hospital to support providing emergency medical care in the event of disruption to the transportation/supply system.

Graceful Extensibility

Graceful extensibility focuses on providing the capacity for an infrastructure, system, or network to adapt to surprises and uncertainty associated with the future risk environment.

Examples:

- Constructing the foundation of flood protection barrier to support adding height to the walls should sea-level rise go beyond expected projections.
- Distributed energy that decentralizes the generation and storage of electricity to provide a reliable source of power in the face of a variety of disruptions.
- Authorizing and supporting people to use their initiative to manage operations outside the standard operating procedures as situations change.

Source: Woods, D. D., Chan, Y. J. and Wreathall, J. (2013). The Stress-Strain Model of Resilience Operationalizes the Four Cornerstones of Resilience Engineering. In Proceedings Fifth Symposium on Resilience Engineering: Managing trade-offs, 24-27, June 2013, Soesterberg, Netherlands. http://hdl.handle.net/1811/60454 or search at http://kb.osu.edu

Putting Enterprise Resilience in Practice

Resilience measures need to be incorporated into managing the risk of infrastructure disruption:

- Prior to a disaster
- During a disaster
- Following a disaster

Pre-Disaster

- Develop *models* and conduct *simulations* to:
  - Raise awareness and understanding of the potential for system disruption and its consequences
  - Support "what-if" decisions including cost-benefit analysis associated with investing in resilience design
  - Inform contingency planning and conducting exercises.
- Prioritize and identify resilience attributes that should be deployed to safeguard and rapidly recover the elemental capacity and the essential function of an infrastructure, system, or network in the face of naturally-occurring and human-made disasters.
- Devise policy and market-based *incentives* for making and sustaining investments in the attributes of resilience design.
- Deploy tools and processes that provide situational awareness for early detection and to guide nimble response and recovery when there are disruptions to the elemental capacity and function of an infrastructure, system or network.

During a Disaster

Resourcefulness involves undertaking appropriate decisions and operational measures that mitigate consequences and support rapid recovery.

Examples are:

- The timely movement of trains to sheltered areas at high elevations to reduce the risk of damage via storm surge.
- Authorizing overtime and providing temporary housing and canteen services that will allow workers to be available to support response and recover efforts.
- Mobilizing collaborative networks that support informed and flexible decision-making for addressing cascading disruptions across multiple infrastructure sectors.

Following a Disaster

GOAL: To direct limited resources so as to support response, recovery, and adaptation.

- Prioritize actions that restore *elemental capacity* and *essential function* of an infrastructure, system, or network that has been disrupted by the event.
- Undertake actions that restore full/normal function.
- Learn from the event to inform how to: (1) improve the design and deployment of resilience attributes, and (2) refine the operational measures used to support response and recover.

Enhancing Resilience has economic value by reducing loss of function

Performance (Percent)

D R

100

80

A

C

60

B

B_T

40

20

T_1 T_2 T_3

0

Time

RED area represents loss of function when there is a disruption:
A = Mitigation; B = Response; C=Recovery

Resilience Parameters

D = Disruption to System

R = Capability to attenuate or mitigate effect prior to or at time of event

A = Capability to absorb and degrade

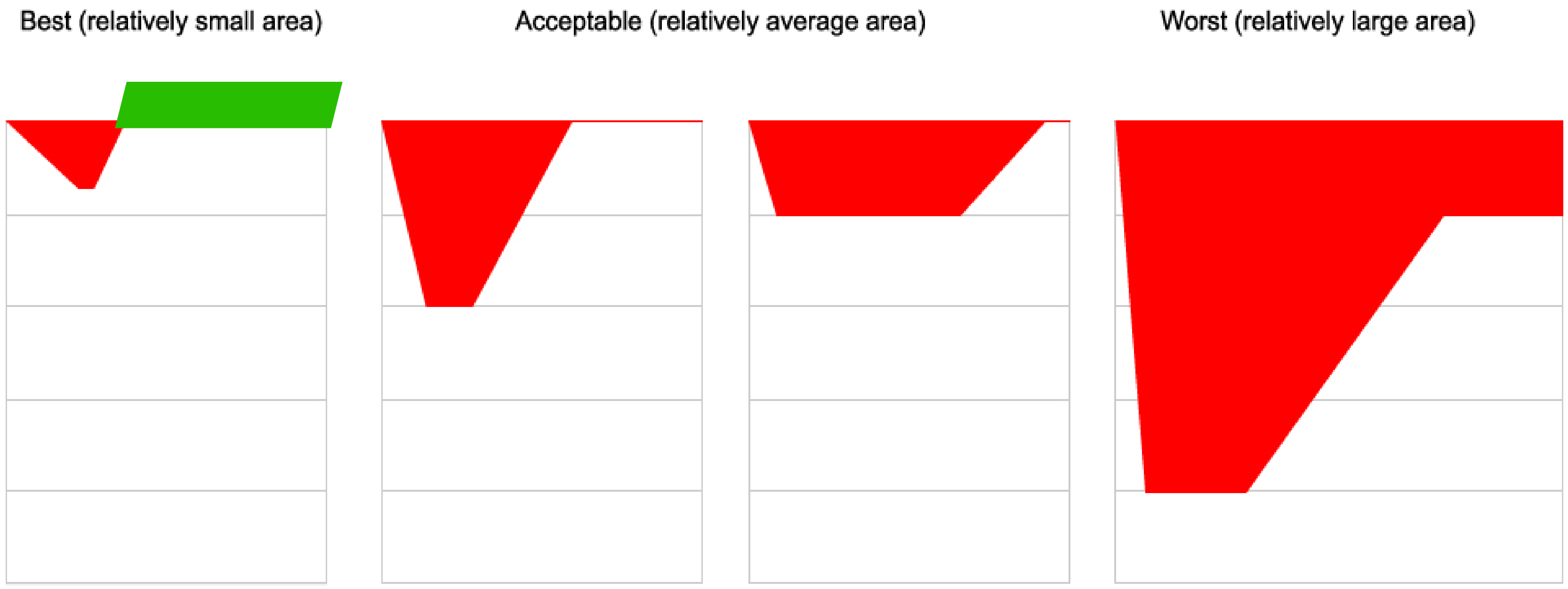
B = Bottom out; Threshold Level

B_T = Length of time at bottom

C = Capability to reconstitute back to initial level

Source: J. Kahan, et. al., *Risk and Resilience: Exploring the Relationship*, Homeland Security Studies and Analysis Institute, Nov 20, 2010 & Mary Ellen Hynes, "Extreme Loading of Physical Infrastructure" presentation at the 4th *DHS University Network Summit*, March 11, 2010;

Investment in resilience prior to a disaster and swift adaptation after a disaster can result in a net gain in enterprise function



Good mitigation & rapid response w/ *GREEN* representing new enterprise function gained from investing in adaptation after the disruption.

Red is the loss of function due to limited mitigation measures, but is reduced due to rapid response

Red is the loss of function due to slow response, but is reduced due to good mitigation measures

Red is the extreme loss of function due to both weak mitigation measures and a slow response—that reduces the capability to achieve long-term recovery.

How to Advance Societal Resilience?

It will require accomplishing 3 things concurrently:

1. Conducting research that informs infrastructure resilience and community resilience

2. Supporting early and widespread adoption of resilience applications, tools, and protocols by establishing best practices, and where appropriate - standards, codes

3. Identifying and deploying public policy and market-based incentives for adopting infrastructure and community resilience best practices