Transportation Resilience
& its impact on Project Determination

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Resiliency vs Sustainability

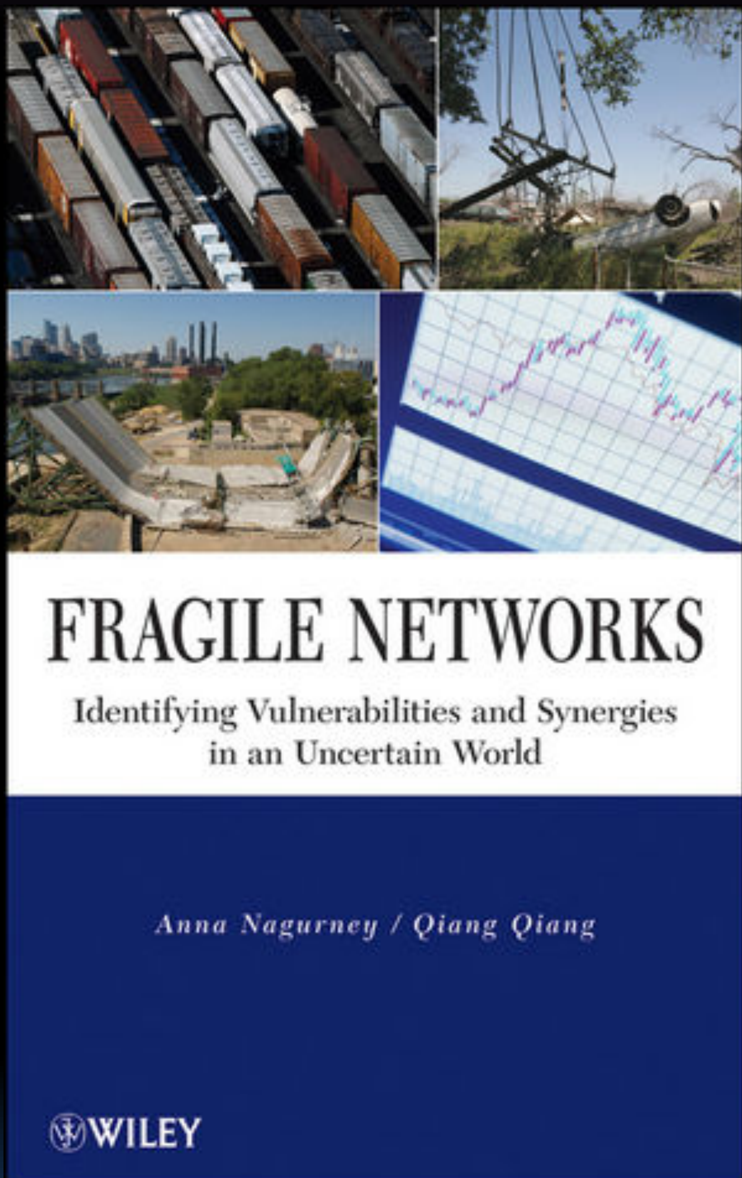
Sustainability – systemic evaluation of future options and devising strategies to obtain a desired outcome

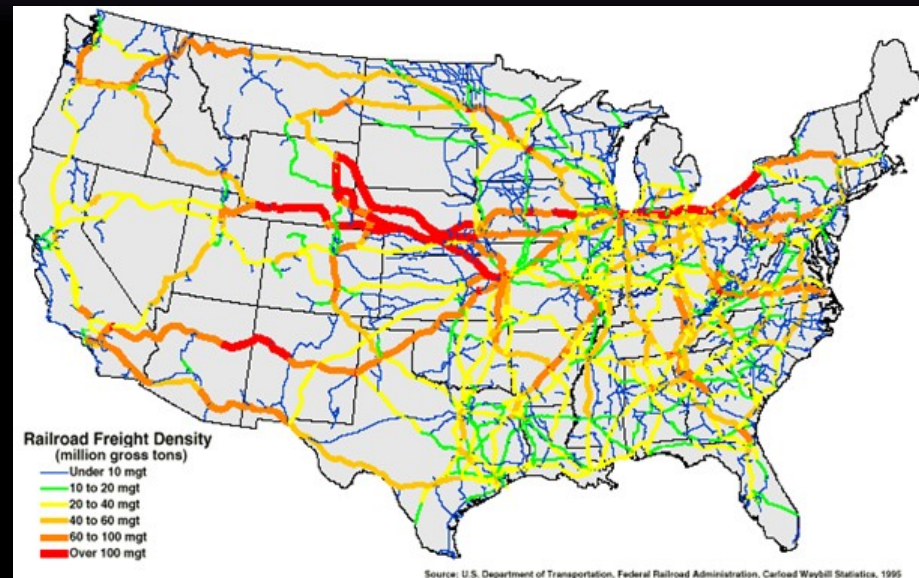
Resiliency – adaptive capacity and robustness to gracefully weather inevitable but unspecified shocks

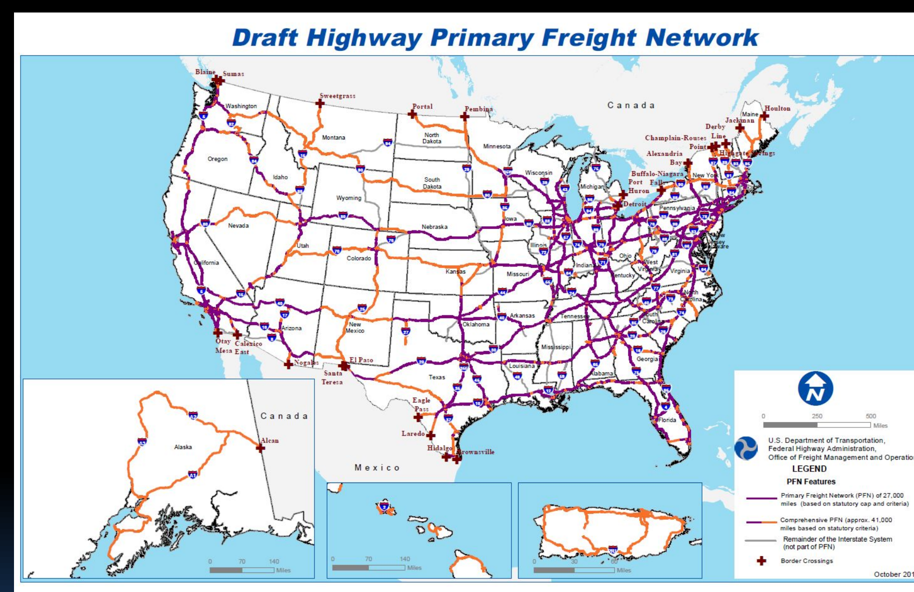
Resiliency – Transportation Sector

- Network Behavior of the transportation system
  - Bridges, Detour Route, & Fragility
  - Evacuation Route & Emergency Access
  - Operational performance and mode shifts
  - The Advent of Superusers
  - The need for Hardened Corridors
- Interdependencies & Hyper-connectivity
  - Other lifelines & access for assessment / recovery
  - Transportation / Power / Internet - cascading effects
- Non-stationarity
  - Changing return periods & deterministic design
  - Demographic shifts and unexpected behavior

Network Performance & Fragility







NIST Community Resilience Interdependencies

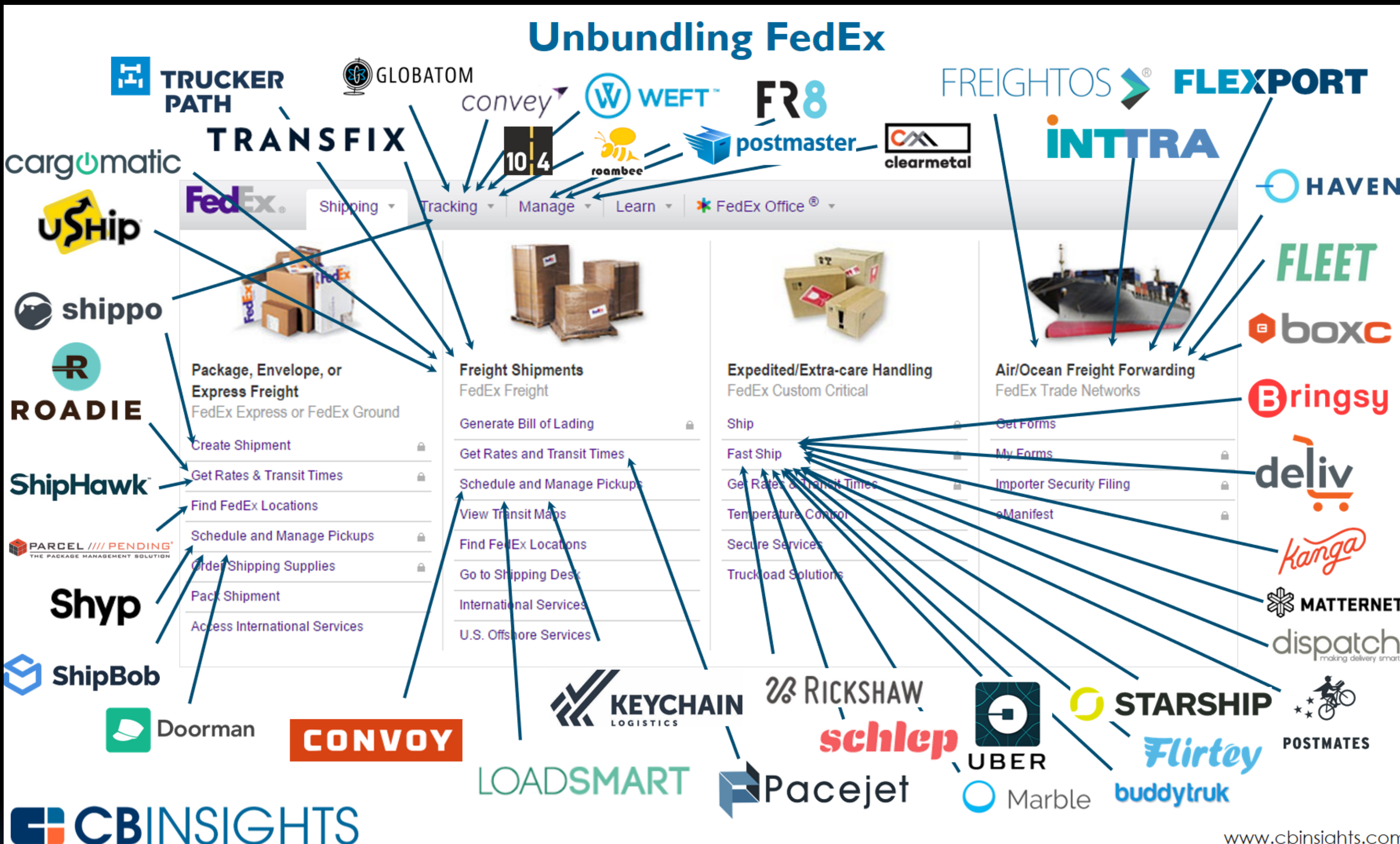
Functional vs Operational Fragility

- Disruption Time
  - Operational – measured in minutes / hours
  - Functional – Days/Weeks/Months
- Network Investment Strategies
  - Route flexibility – network redundancy / modal redundancy
  - Corridor enhancement – increased throughput
  - Selective de-commissioning

Superusers – Trucking Logistics

- Route Optimization
- Telematics & Instantaneous Feedback
- Durable Dataset
- How to Engage Trucking Industry to
  - Determine Investment Needs
  - Project Definition
    - Weight / Geometry / Robustness in Corridors
  - Influence not so super-users

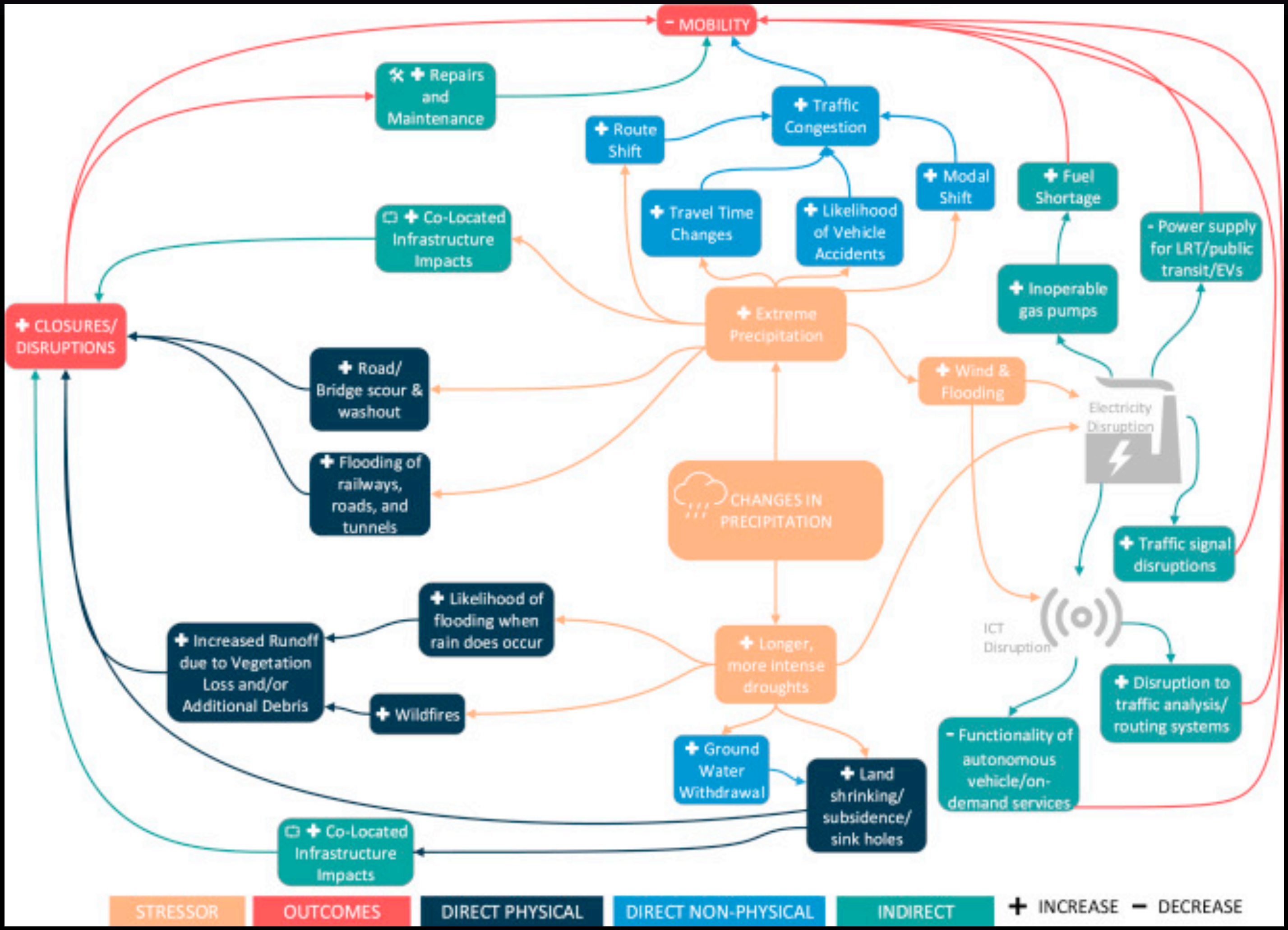
Explosion of Logistics Companies



Influence not so super-users thought experiment

- Is our commute time or are children any less valuable than our amazon package?
- What if bus routing was as sophisticated as UPS, USPS, Fedex?
- How to incentivize coordination between competing users
- How to better game repetitive trips, like our commute.
- Does this need to be fee based?

Pathways to Disruption



Markolf et al, Journal of Transport Policy, Nov 2018 *Transportation resilience to climate change and extreme weather events – Beyond risk and robustness*

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Forecasting & Extreme Events

TABLE 1 Current Scientific Confidence in Attribution Results Varies for Different Types of Extreme Events

● = high ◉ = medium ○ = low	Capabilities of Climate Models to Simulate Event Type	Quality/Length of the Observational Record	Understanding of Physical Mechanisms that Lead to Changes in Extremes as a Result of Climate Change
Extreme cold events	●	●	●
Extreme heat events	●	●	●
Drought	◉	◉	◉
Extreme rainfall	◉	◉	◉
Extreme snow	◉	○	◉
Tropical cyclones	○	○	◉
Extratropical cyclones	◉	○	○
Wildfire	○	◉	○
Severe convective systems	○	○	○

NOTE: Overall confidence in event attribution is strongest for extreme event types that are adequately simulated in climate models, have a long-term historical record of observations, and are linked to human-caused climate change through an understood and robustly simulated physical mechanism. The entries in this table, which are presented in approximate order of overall confidence, are based on the available literature and are the product of committee deliberation and judgement.

Built Environment – Beyond Code Investment in Buildings

Mitigation Category	Cost	Benefit	BCR
Riverine Flood	$11.51	$82.00	7:1
Wind	$13.60	$70.00	5:1
Earthquake	$2.20	$5.70	3:1
Wildland-Urban Interface Fire	$0.06	$0.17	3:1
Total for federal grants	**$27.40**	**$157.90**	**6:1**

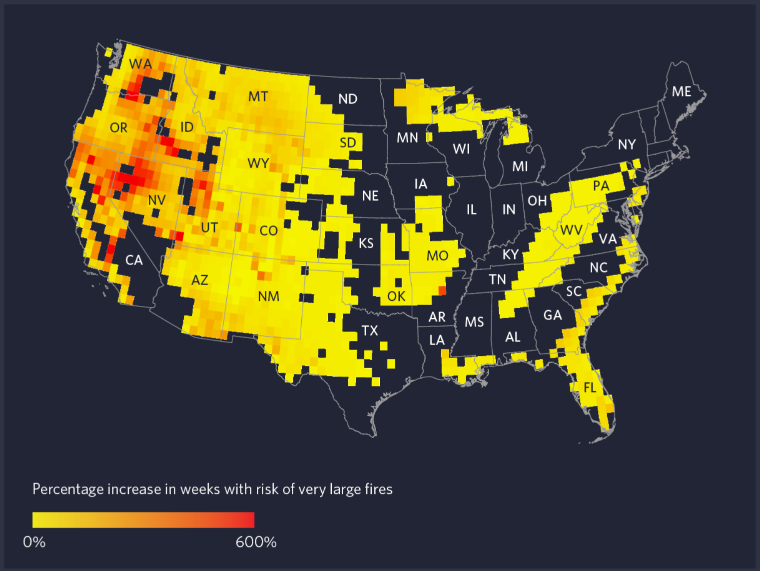
Table 2. Costs and benefits associated with 23 years of federal grants (in $ billions).

Emerging Trends - Large Fire Risk

Evacuation & Emergency Response

Risk of 'Very Large Fires'

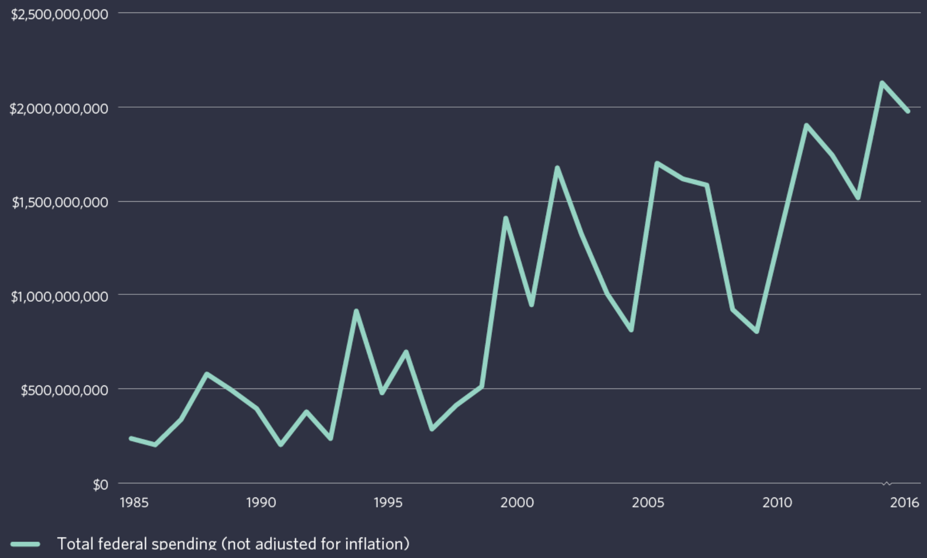
The wildfire season is likely to lengthen as the climate changes. By midcentury, the number of weeks when weather will be conducive to a very large fire — defined as a fire that spans over 100,000 acres — will increase sixfold in some parts of the United States.



Source: R. Barbero et al, "Climate change presents increased potential for very large fires in the contiguous United States," *International Journal of Wildland Fire*, 2015.

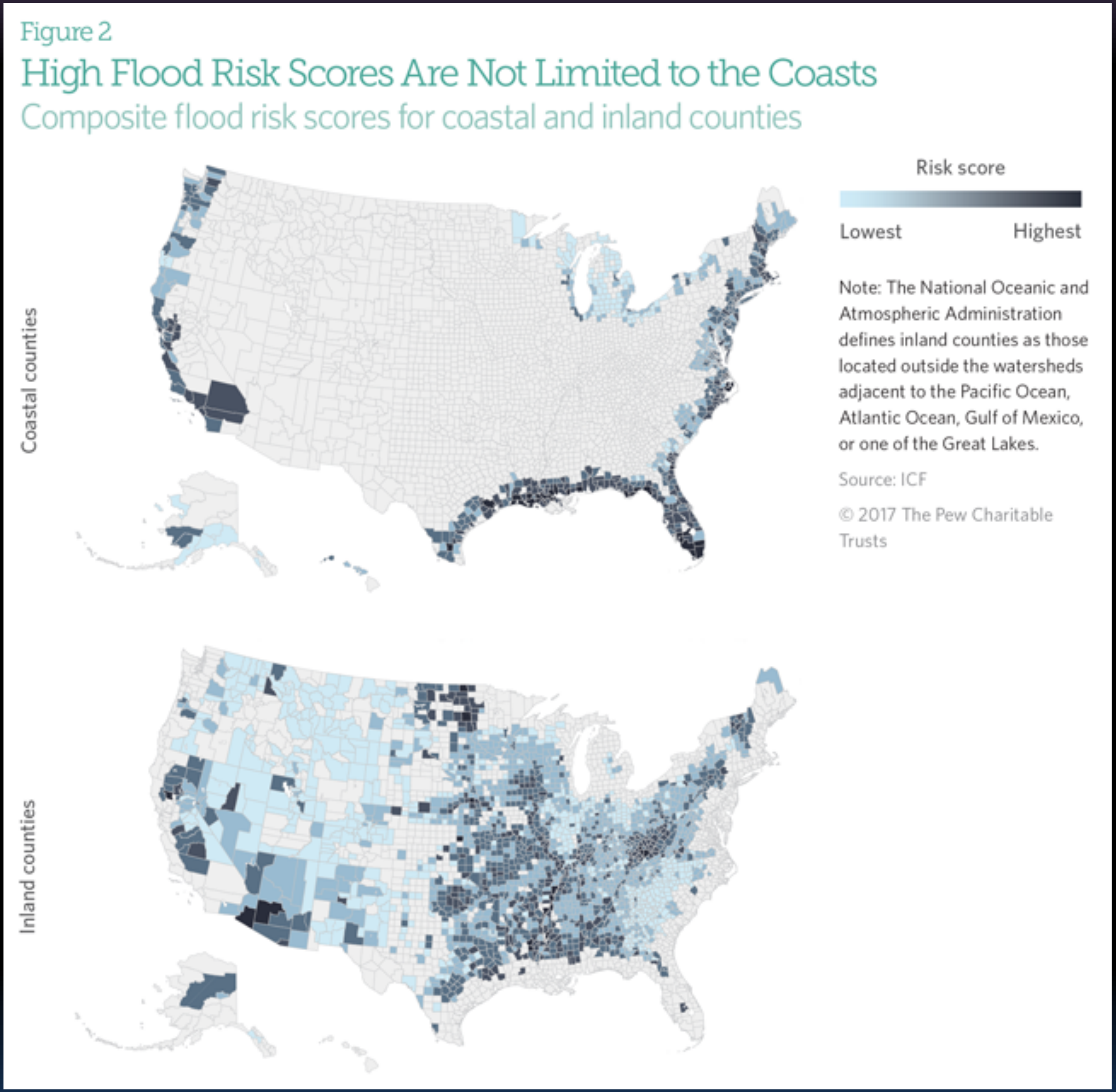
Federal Spending on Wildfires

The federal government has spent over $2 billion on wildfire suppression already in 2017, making it the most expensive wildland firefighting year in history.

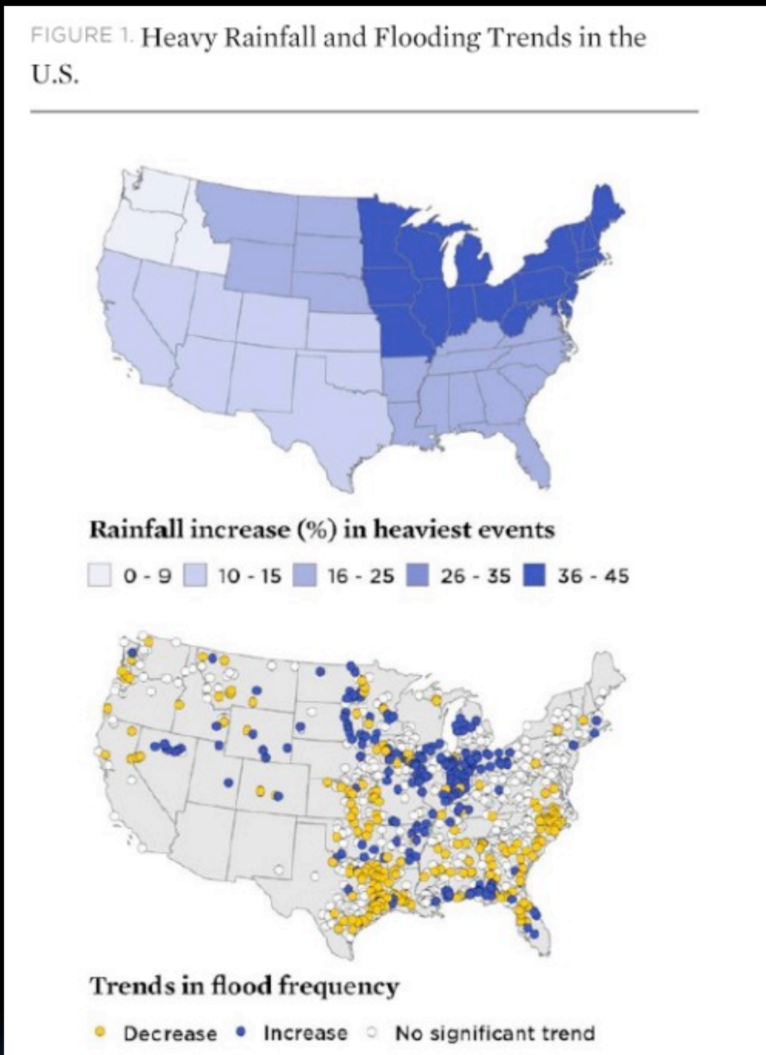


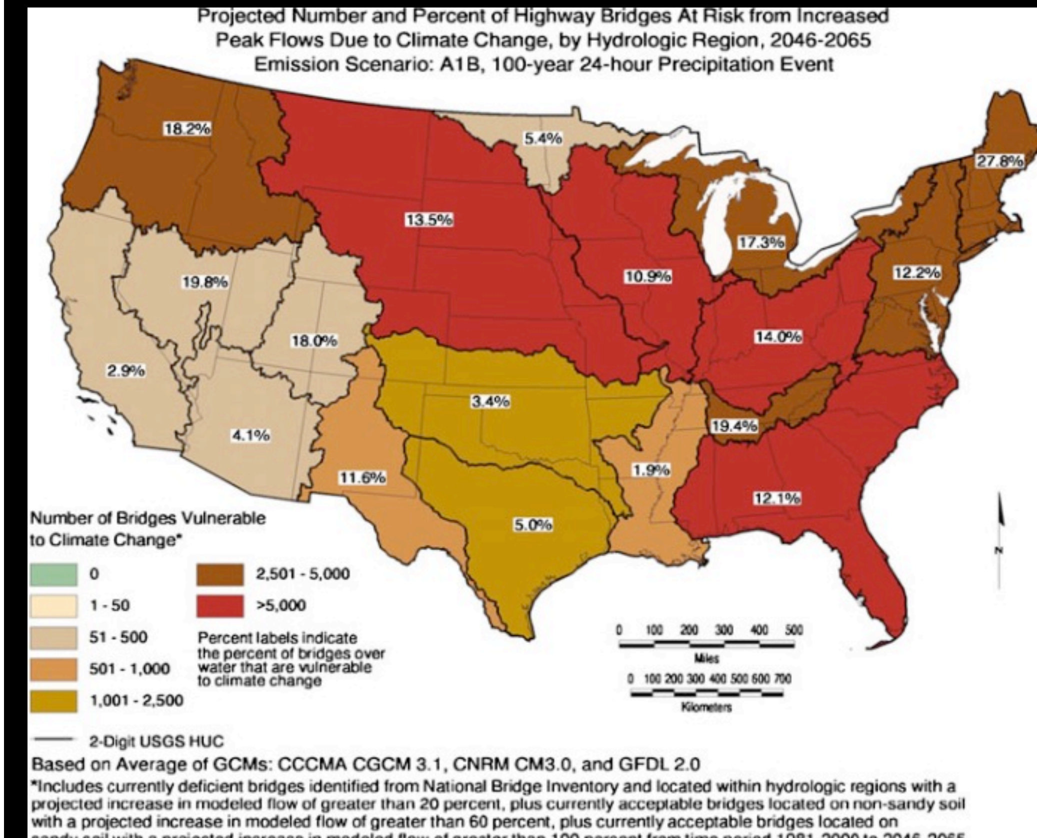
Source: National Interagency Fire Center.

Coastal vs Inland Flood Risk



Extreme Precipitation Frequency & Bridge Risk





Inland Flooding & VTrans
Hurricane Irene – August 28th 2011

- 13 communities inaccessible for days
- State Highway System
  - 500 miles of roadway
  - 200 bridges
- Municipal System
  - 2000 roadway segments
  - 280 bridges
  - 960 culverts

Hurricane Irene
Airlift resources to isolated towns

Hurricane Irene
Rapid Road Reconstruction Efforts

Hurricane Irene
Extensive Bridge Damage Throughout State

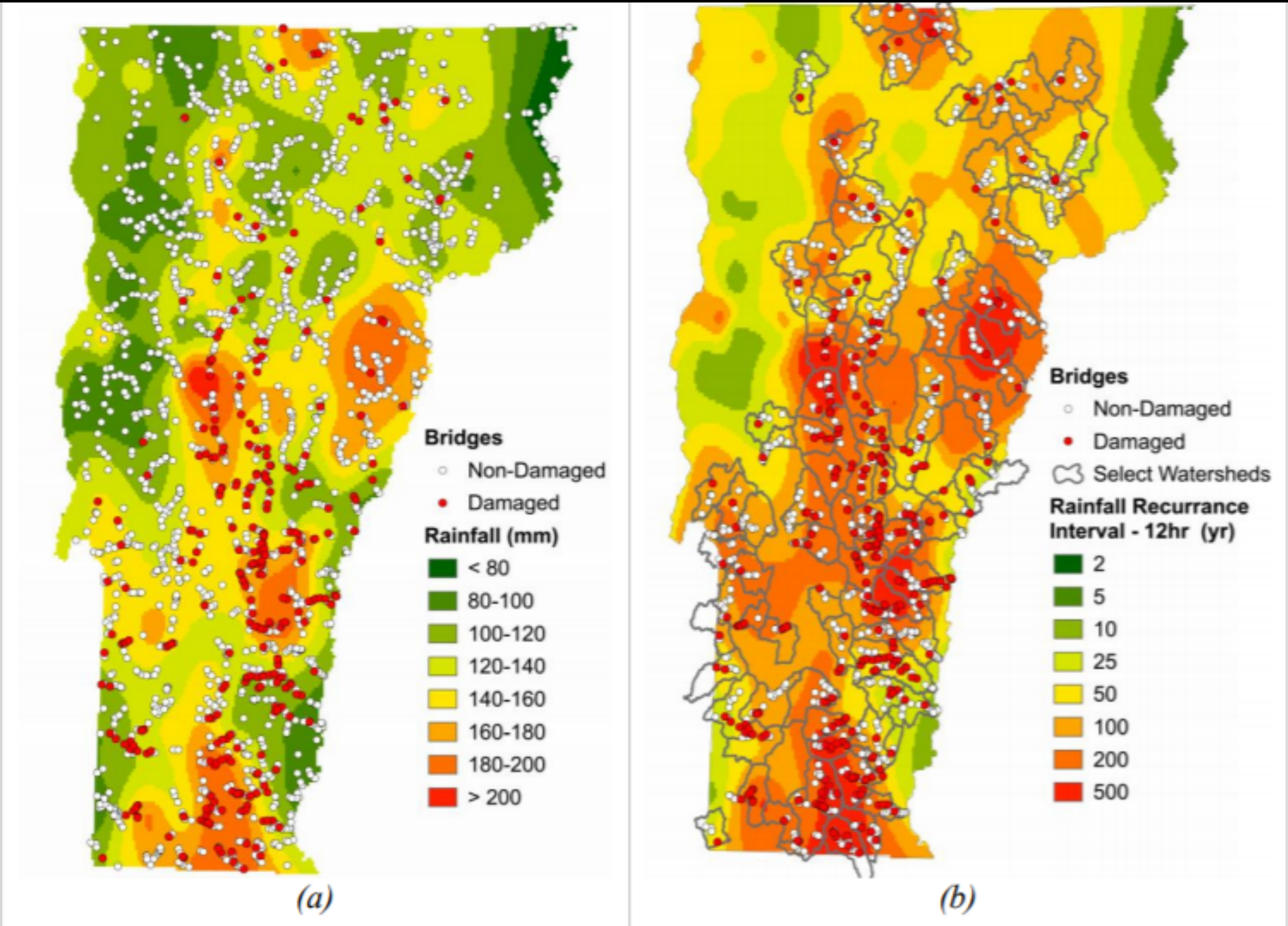
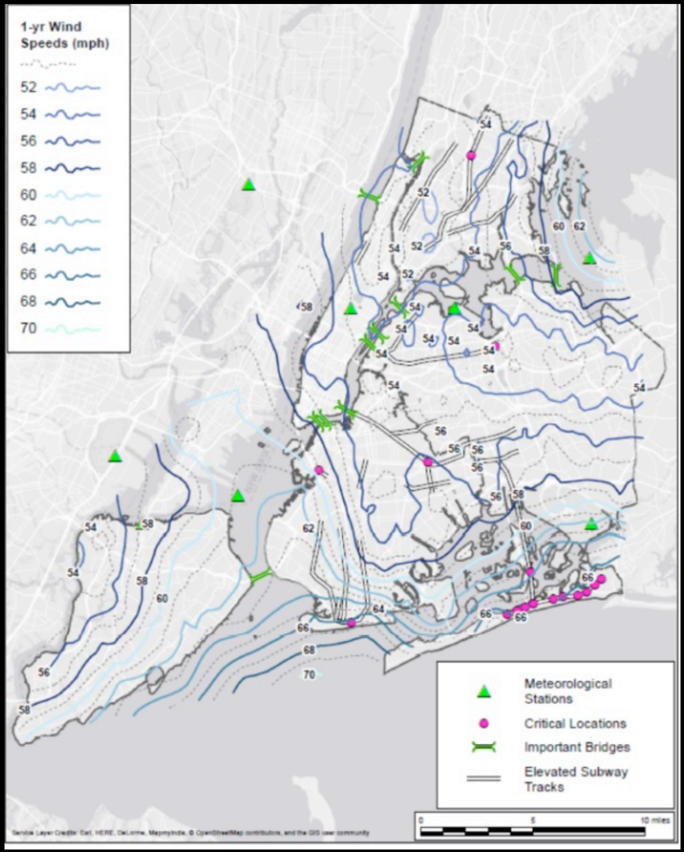


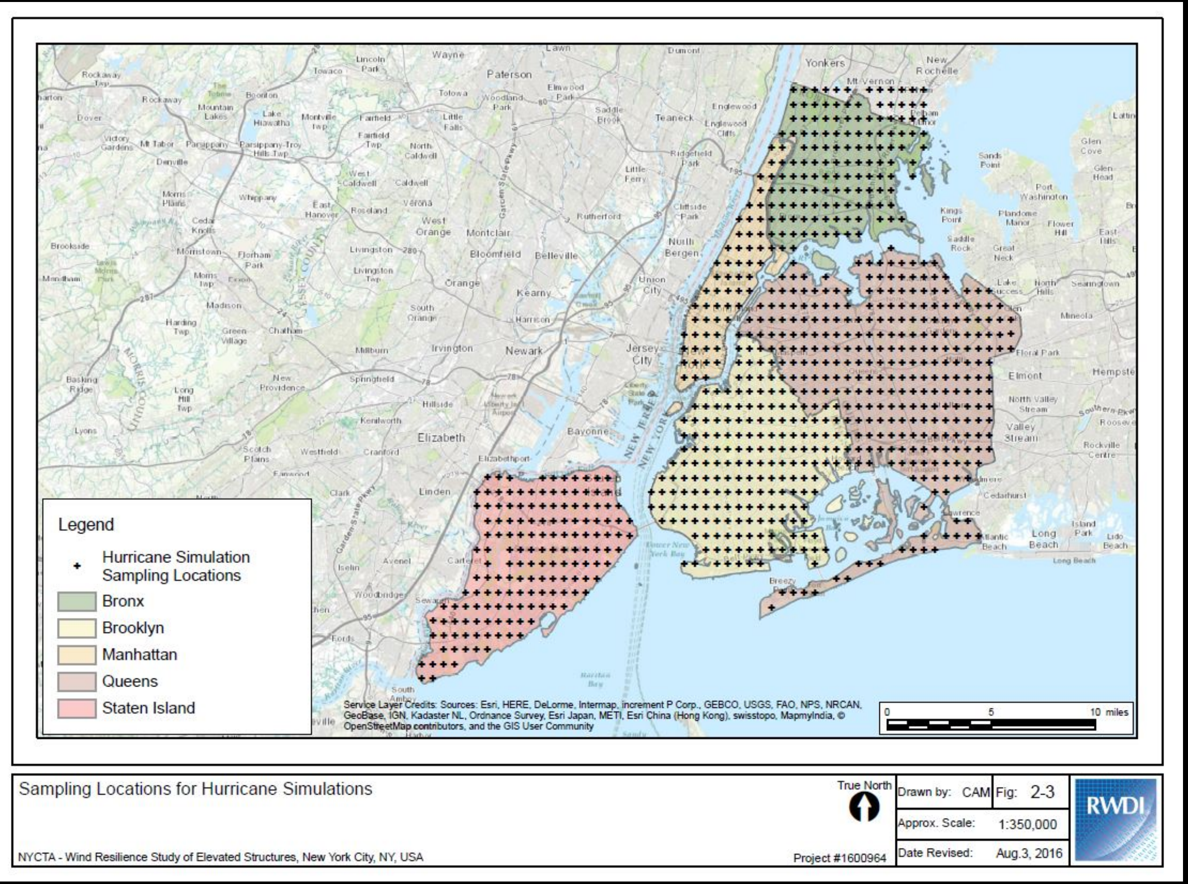
Figure 4.1: Locations of damaged and non-damaged bridges in Tropical Storm Irene (a) state-wide superimposed on rainfall data, and (b) in watersheds where bridge damage was observed superimposed over recurrence interval estimates

Hurricane Irene
How should we have built it?
How do we build it back?

- Post Damage Reconstruction
  - Need for speed, replace in kind
- Riverine corridor improvements?
  - Hydraulics & bridge damage
  - Emergent Risk with Climate Change
  - Bridge as dam & property damage

Operational Decision-Making & Blowover Risk
Severe Convective Systems



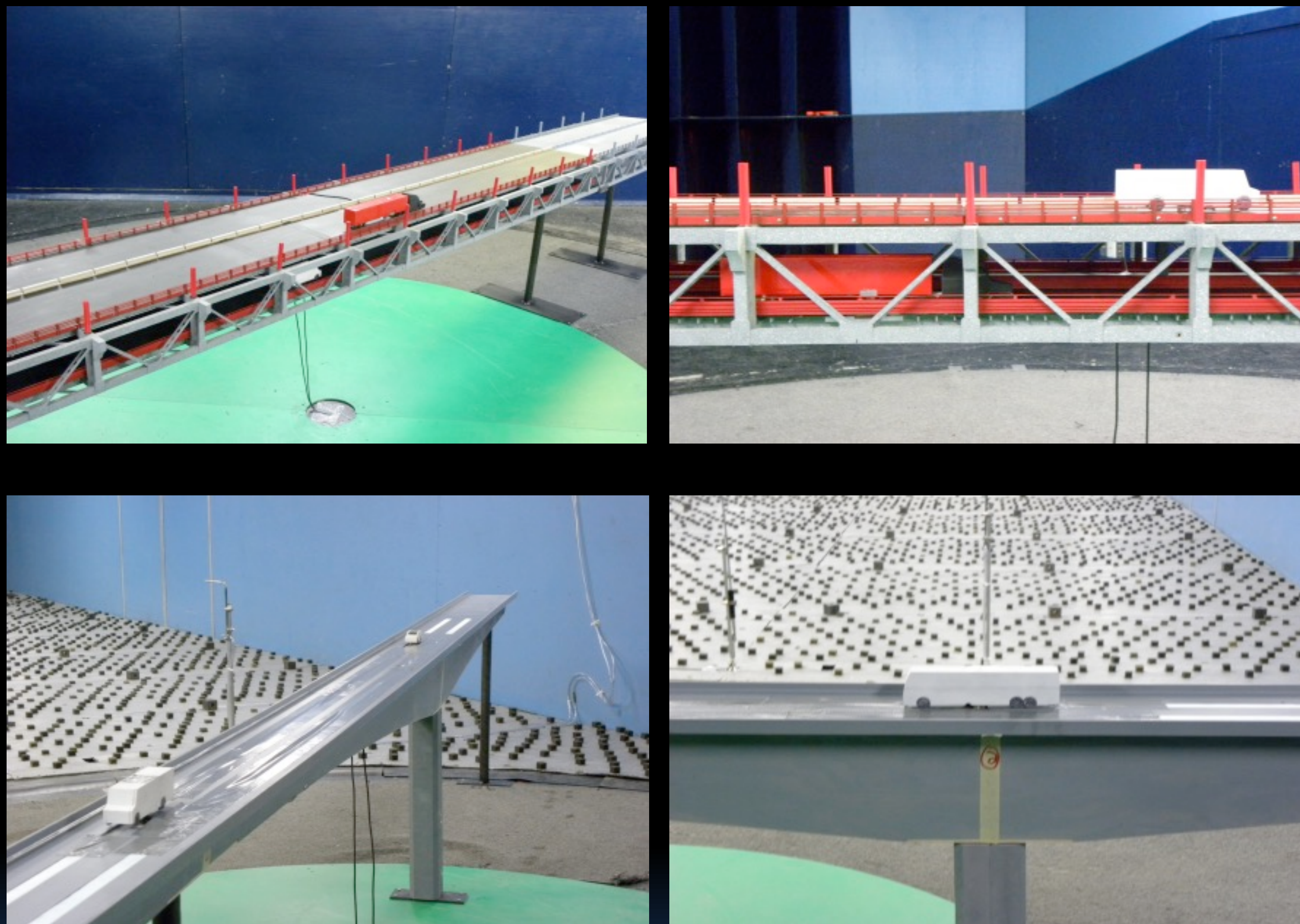


Severe Convective Systems (High Winds)

Operational Decision-making & Blowover Risk

Severe Convective Systems (High Winds)

Operational Decision-making & Blowover Risk

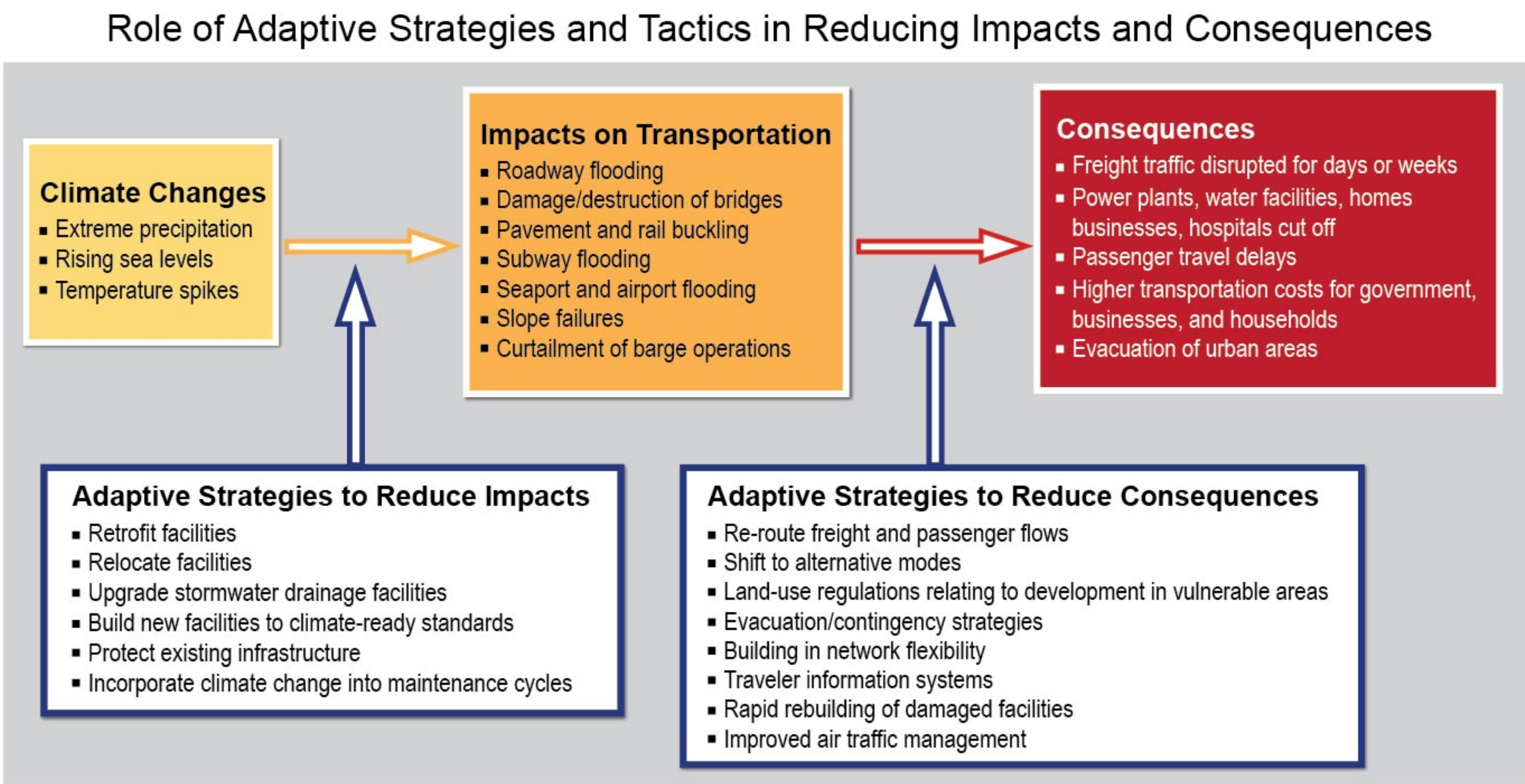


b) Test on Confederation Bridge, NB to PEI, Canada

Severe Convective Systems (High Winds)

Operational Decision-making for Transit Systems

Adaptive strategies



Resiliency in Transportation

- Operational Decision-Making Driving Needs Assessment
  - Evacuation Routes & Timing + Emergency Response
  - Disaster Logistics, Preplacement of Key Assets
  - Network Performance & Hardened Corridors
- Enhanced Infrastructure Robustness
  - Damage tolerant structural systems
  - Design for Repairability
- Emergency Bridge Replacement Designs
  - Dramatic Reduction in Time to Fabricate, Ship & Erect
  - Modularity & One-size fits all