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Energy Resilience:

A Framework and Case Studies for Community-Based Resilience

Policy Academy on Power Sector Modernization
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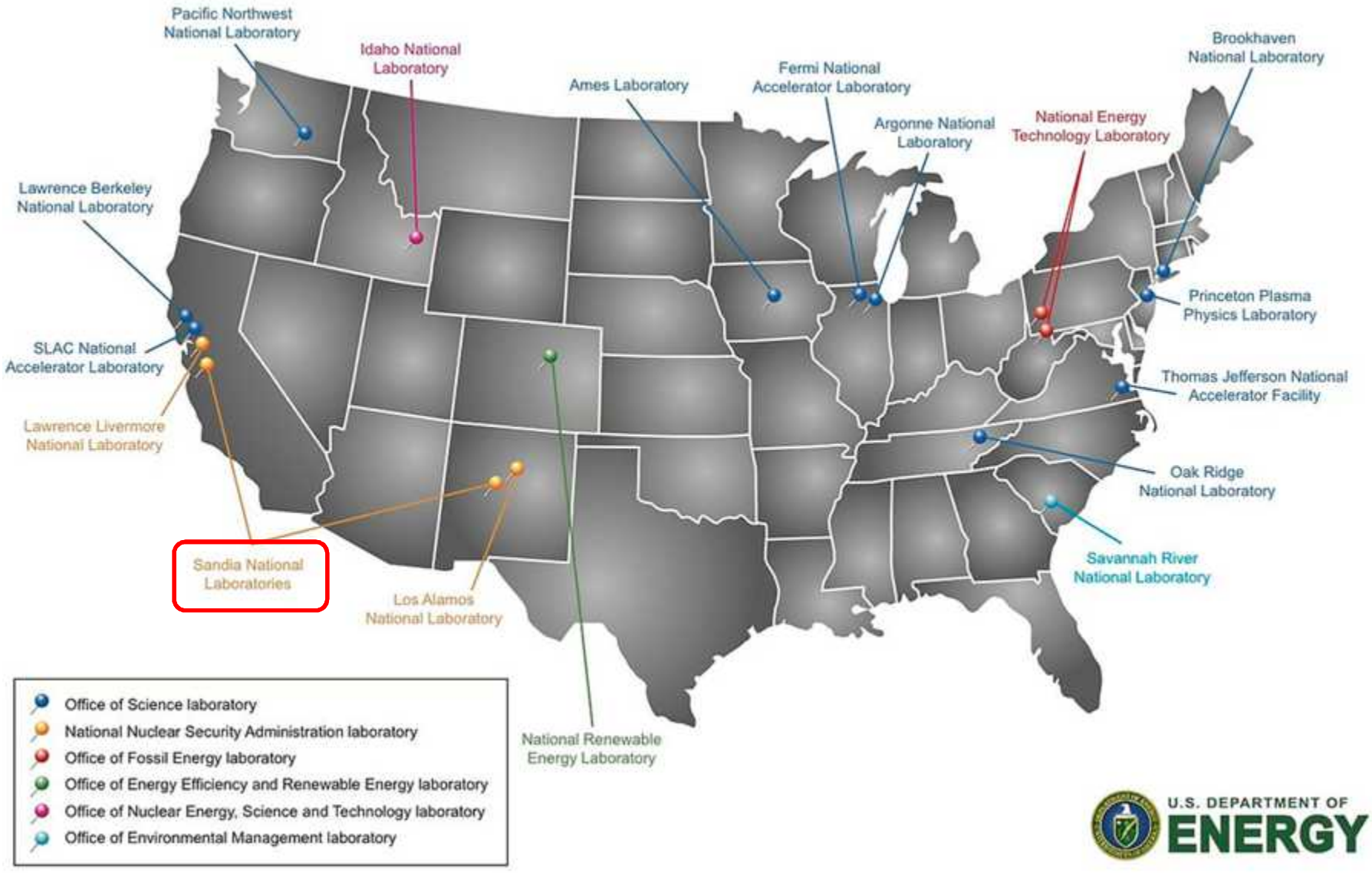
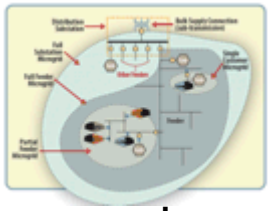
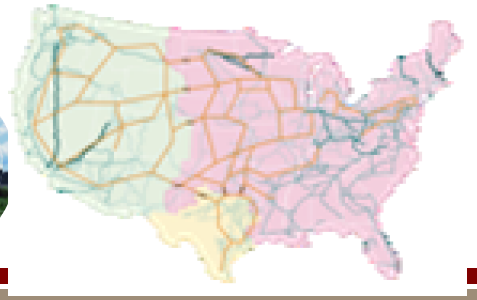


Sandia Expertise in Energy-Security Research

- Energy security is central to Sandia's mission
- Sandia has a broad range of competencies and technical capabilities:
  - Simulation and resilience modeling of critical infrastructures
  - Performance in high-consequence/low-probability environments
  - Identifying threats
  - Human-reliability and probabilistic risk assessme
- Portfolio of energy research includes renewable energy, storage fossil fuels, nuclear energy, transportation energy, demand-side management, efficiency, grid modernization, energy security…





Defining Resilience

Presidential Policy Directive 21:
The term "resilience" means 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.

Sandia's Definition of Grid Resilience:
To strengthen grid resilience, planners and operators should understand the *consequences* of specific threats to customers and have the ability to prepare for those *consequences* and react to them.

The concept of reliability is augmented with a resilience approach–one that looks at the grid not strictly as a flow of electrons but as *a grid that services, interfaces with, and impacts people and societies.* Put another way, it is the consequences, not the outages per se, that matter.

Resilience versus Reliability for the Grid

Resilience

Resilience **encompasses** the concept of reliability.

Focuses on ***low probability high consequence*** events.

Methods, metrics and tools are ***not well established or adopted.***

Reliability

Focuses on likely events such as failure or malfunction of system components, one at the time.

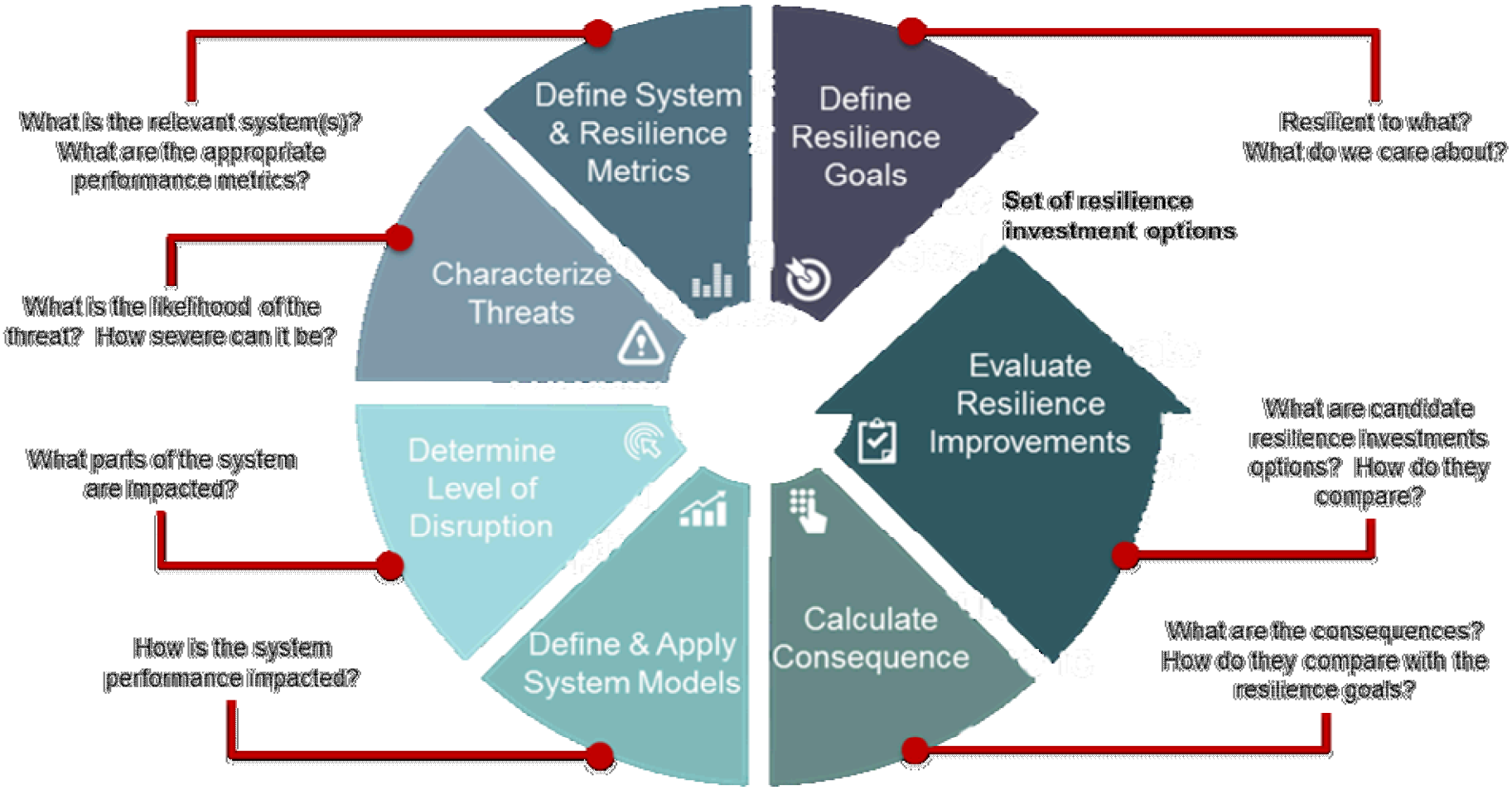
Methods, metrics and tools are well established and adopted.

Resilience Metrics

Typically, multiple resilience metrics are considered

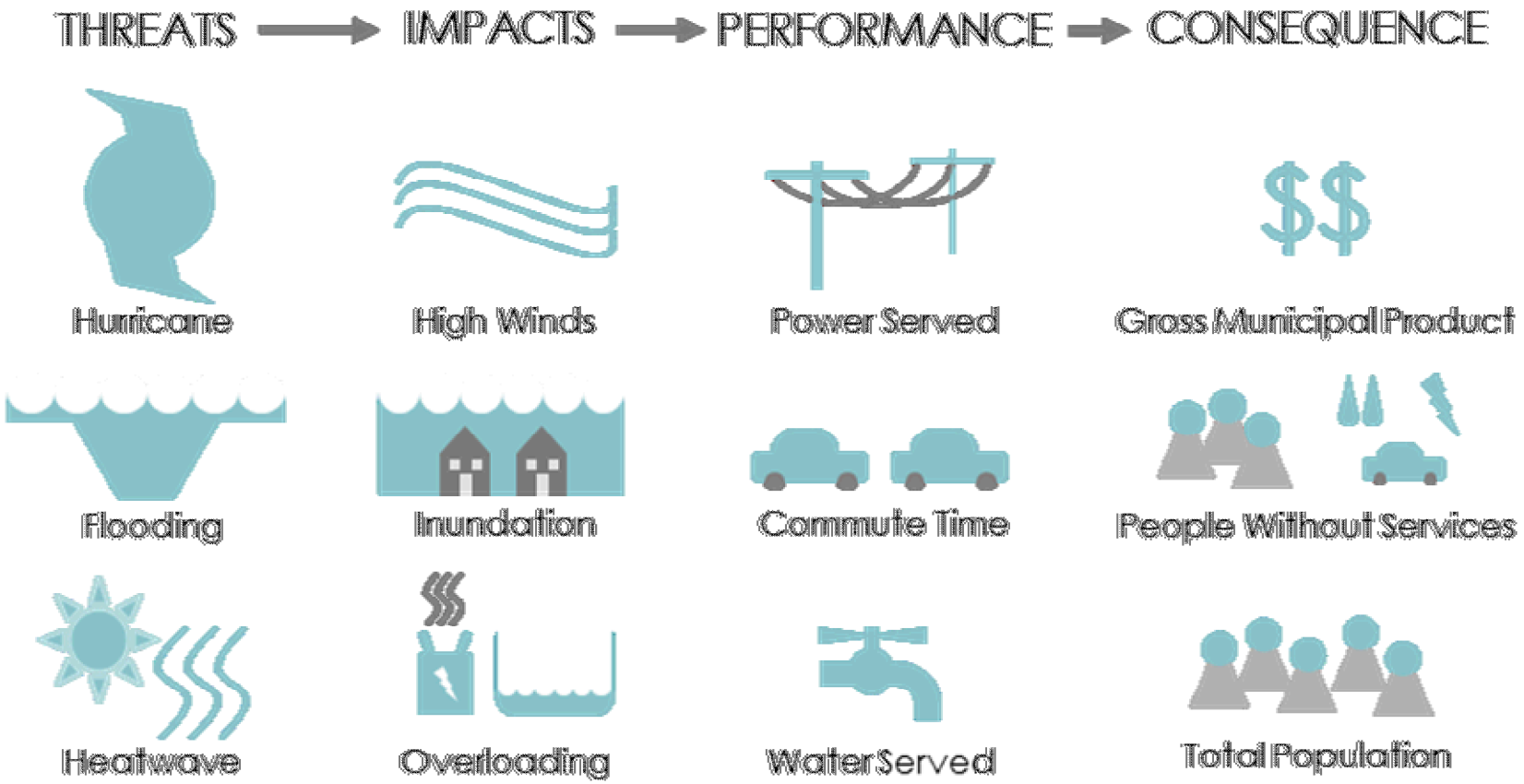
Category	Resilience Metric
Electrical Service	• Cumulative customer-hours of outages • Cumulative customer energy demand not served • Number or % of customers experiencing an outage
Critical Electrical Service	• Cumulative critical customer-hours affected by outages • Critical customer energy demand not served • Number or % of critical loads that experience an outage • Critical services without power (hospitals, fire stations, water utilities, etc.)
Social and Economic Impact	• Number of people without access to critical services • Cost of recovery effort • Loss of revenue or economic activity • Cost to repair/replace damaged equipment (transformers, etc.)

Sandia Resilience Analysis Framework



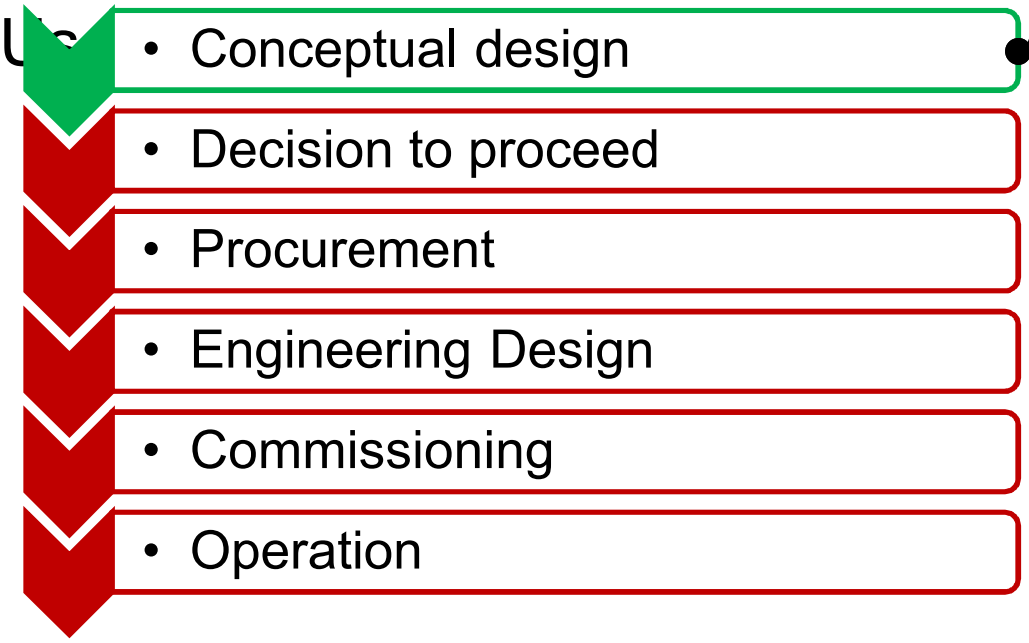
Source: SAND2014-18019—September 2014
A Resilience Framework published in the 2015 Quadrennial Energy Report (QER)

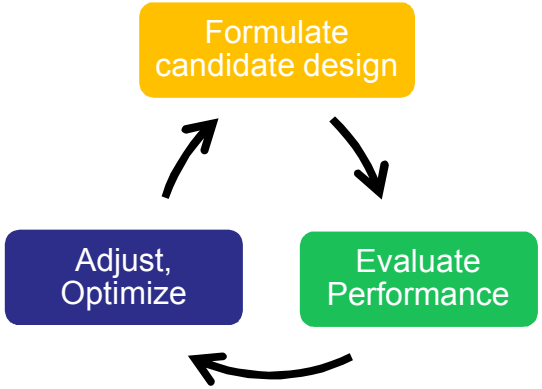
Mapping multiple threats to multiple consequences



Investment Options: Conceptual Design

- A resilience framework compares conceptual design options
  - Technical description of candidate resilience improvements and their respective cost estimates
  - Could involve optimization and analysis of trade-offs among options
- U[illegible] drive decision-making

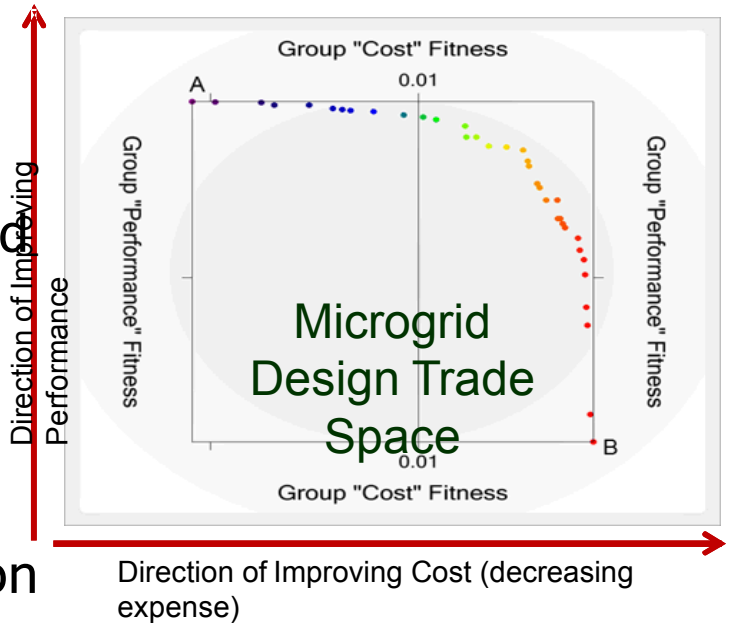


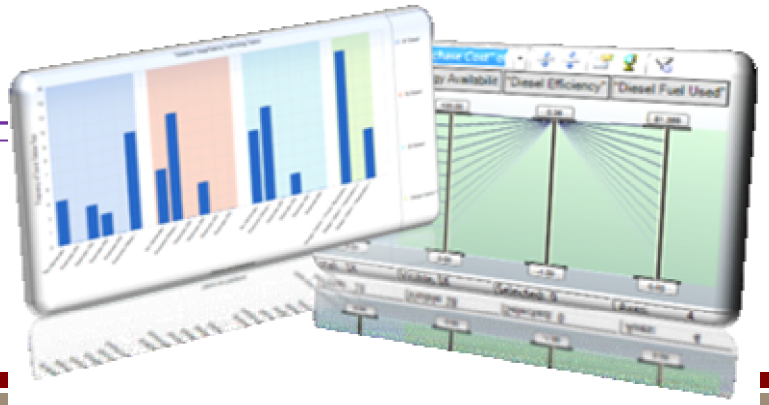


Resilience Optimization Tools

Sandia Microgrid Design Toolkit (MDT)

- A decision-support tool for early-stage resilience assessment and microgrid deployment
- Tool can identify and compare microgrid design options in terms of user-defined objectives such as cost, performance, and reliability
- Provides many views and features to explore trade-offs and extract information
- Publically available
  - http://www.energy.gov/oe/services/technology-development/smart-grid/role-microgrids-helping-advance-nation-s-energy-syst-0





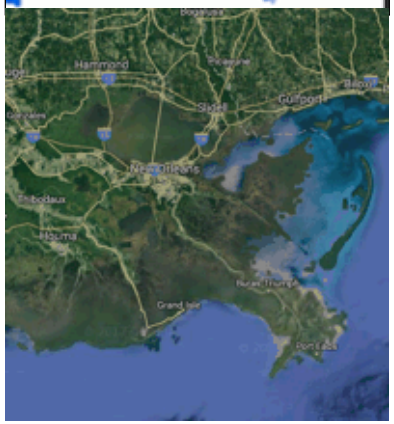
Two Energy Resilience Case-Studies

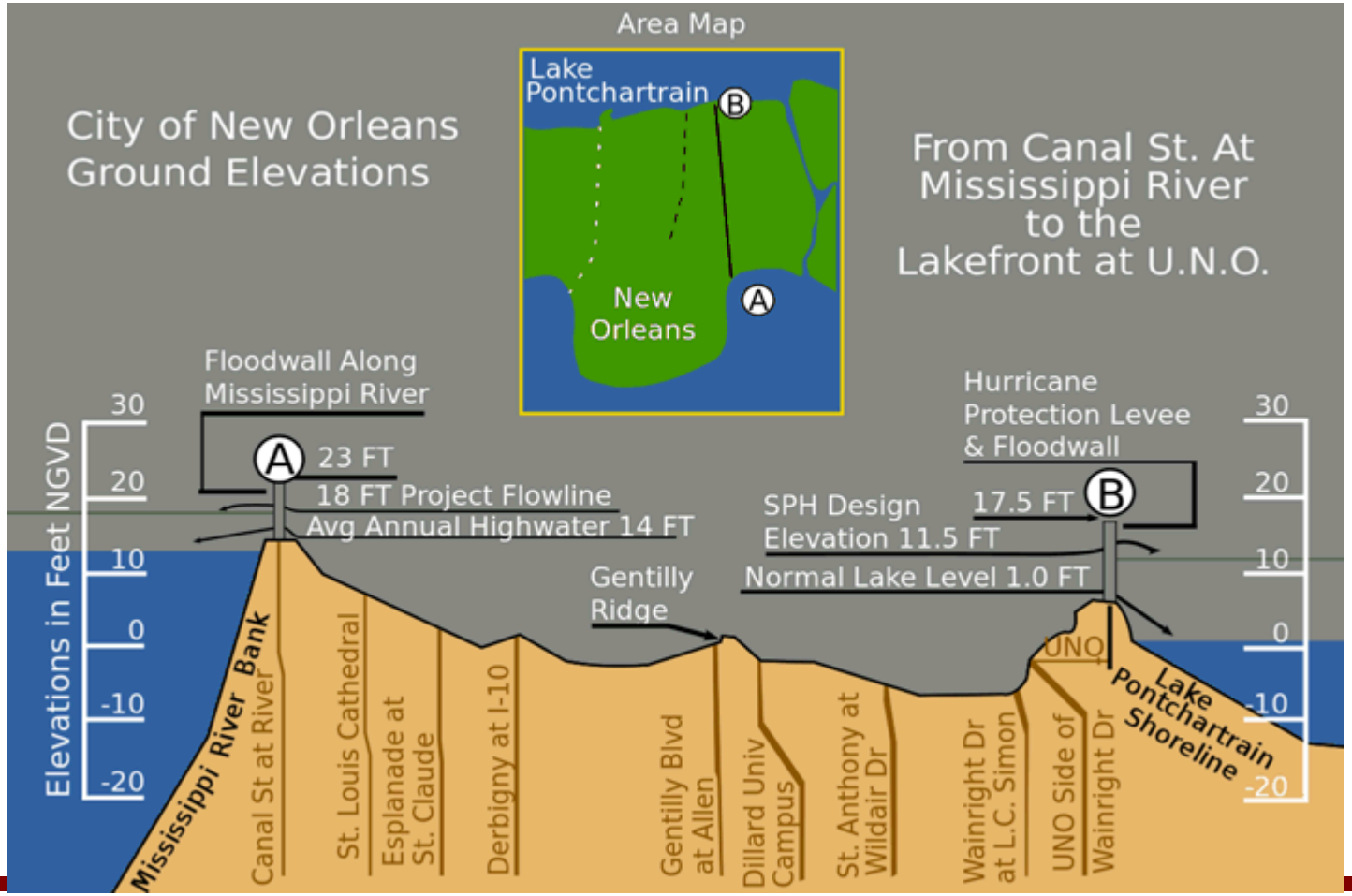
1. Urban Resilience
   - City of New Orleans, Louisiana

2. Transportation Resilience
   - New Jersey / NJ Transit

1. Urban Resilience: New Orleans, LA (NOLA)

City of New Orleans is at high risk of flooding due to topology and location





Reliant on Levees and Pumps for Flood Protection

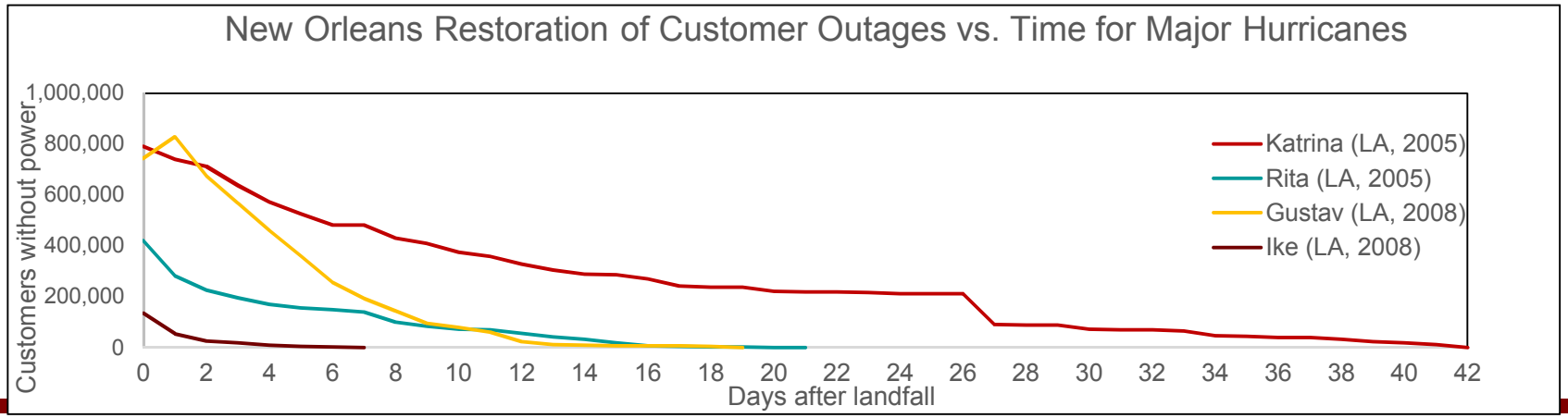
Lake Pontchartrain

Mississippi River

Atlantic Ocean

The strategy worked…until Katrina

- Costliest disaster in US history, until 2017
- 3M people without electricity
- Estimated property damage of $108 billion
- Estimated 1,170 fatalities in Louisiana
- Federal disaster declarations covered 90,000 square miles



As a Result…

- City's long-term resilience called into question
- Widespread recognition that new approach needed
- NOLA Resilience Project emerged, with Sandia leading the effort
- Multiple partners involved; funding provided by DOE

GRID MODERNIZATION LAB CONSORTIUM

Sandia National Laboratories

Los Alamos NATIONAL LABORATORY EST. 1943

100 RESILIENT CITIES

Entergy

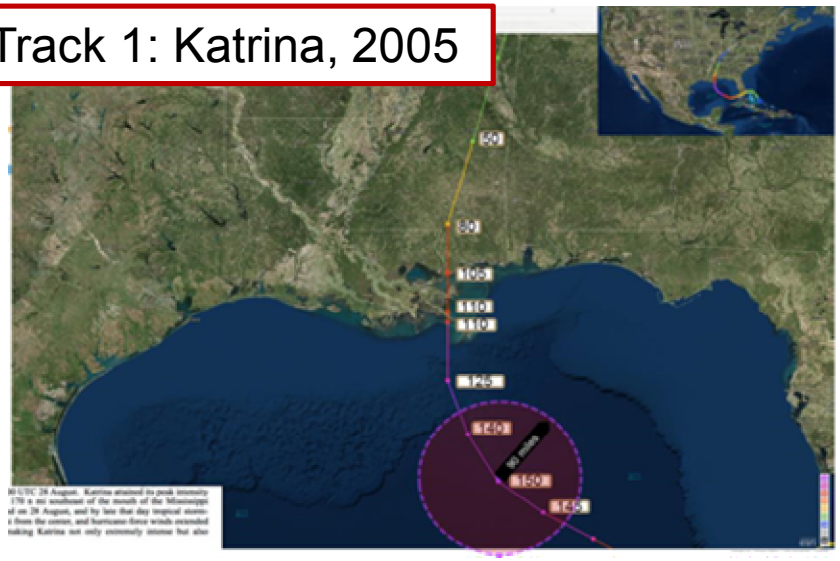
US Army Corps of Engineers

Defining the Threat for NOLA

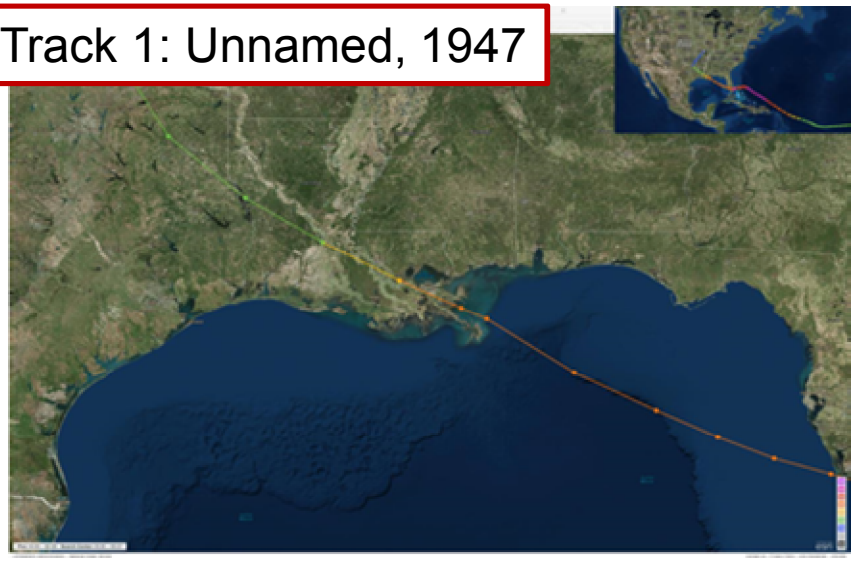
A high-category 2 or low-category 3 storm may lead to worst reasonable consequence

- If it stalls and drops >20" of rain in ~ 24 hrs
- The city does not call for a mandatory evacuation
- Address potential worst case: pumps perform at 50% capacity

Track 1: Katrina, 2005



Track 1: Unnamed, 1947



NOLA Resilience Project

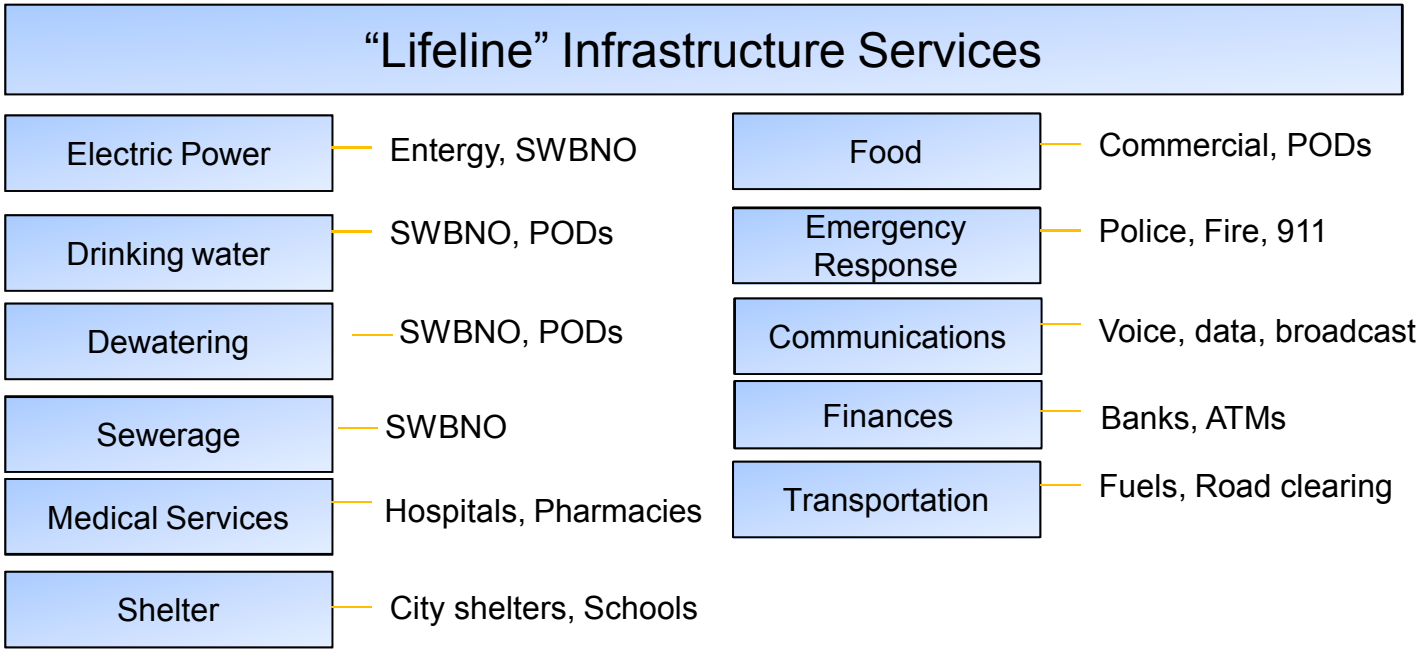
- **Objectives**
  1. Increase NOLA's ability to withstand extreme weather events

  2. Stakeholder/Community-driven Process
     -- NOLA, Sewerage and Water Board, Entergy engaged

  3. Focus on identifying grid investments that were
     -- Directly linked to a community resilience metric
     -- Cost-effective (also tapped into other non-resilience benefits)
- **Challenges:**
  1. Rigorous decision-making in the face of considerable uncertainty
  2. Multiple stakeholders with different values:
     - » Resilience definitions and metrics
     - » Benefits from resilience

Community-Based Approach to Resilience

Multiple community stakeholders need to be involved in the process

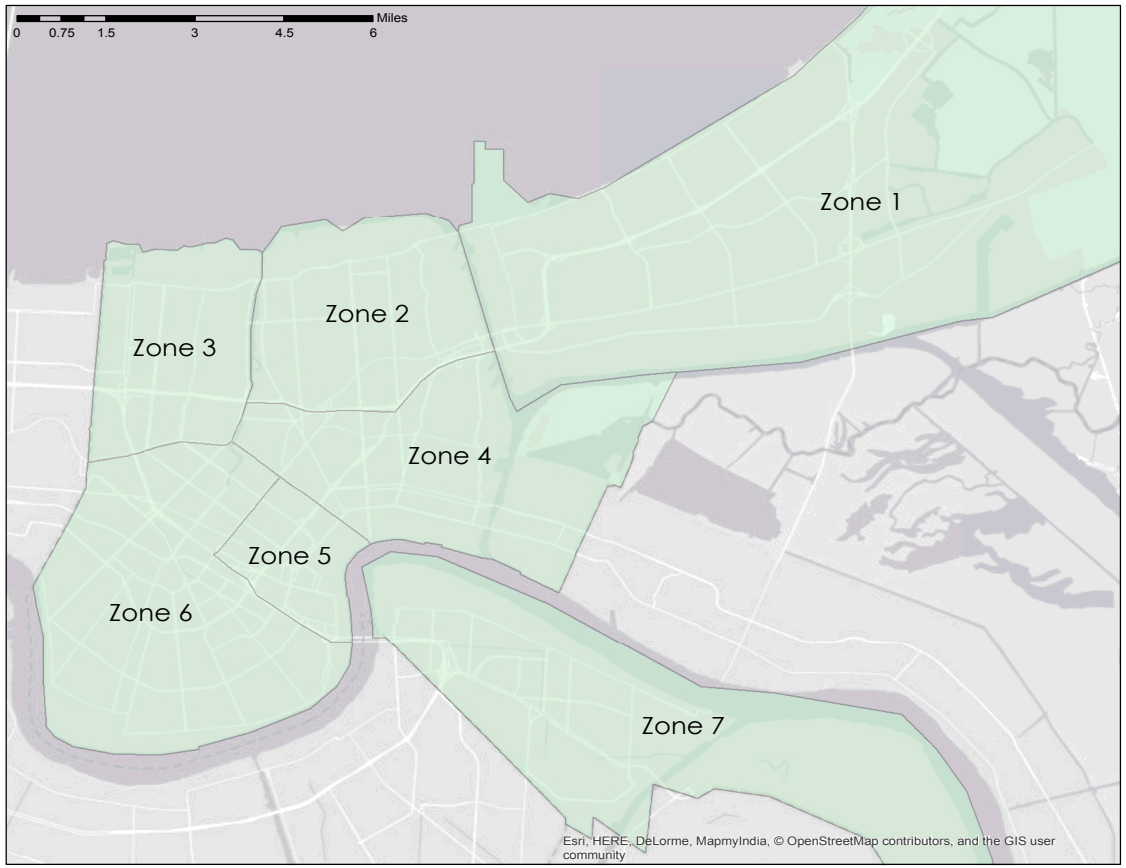


Community Resilience:

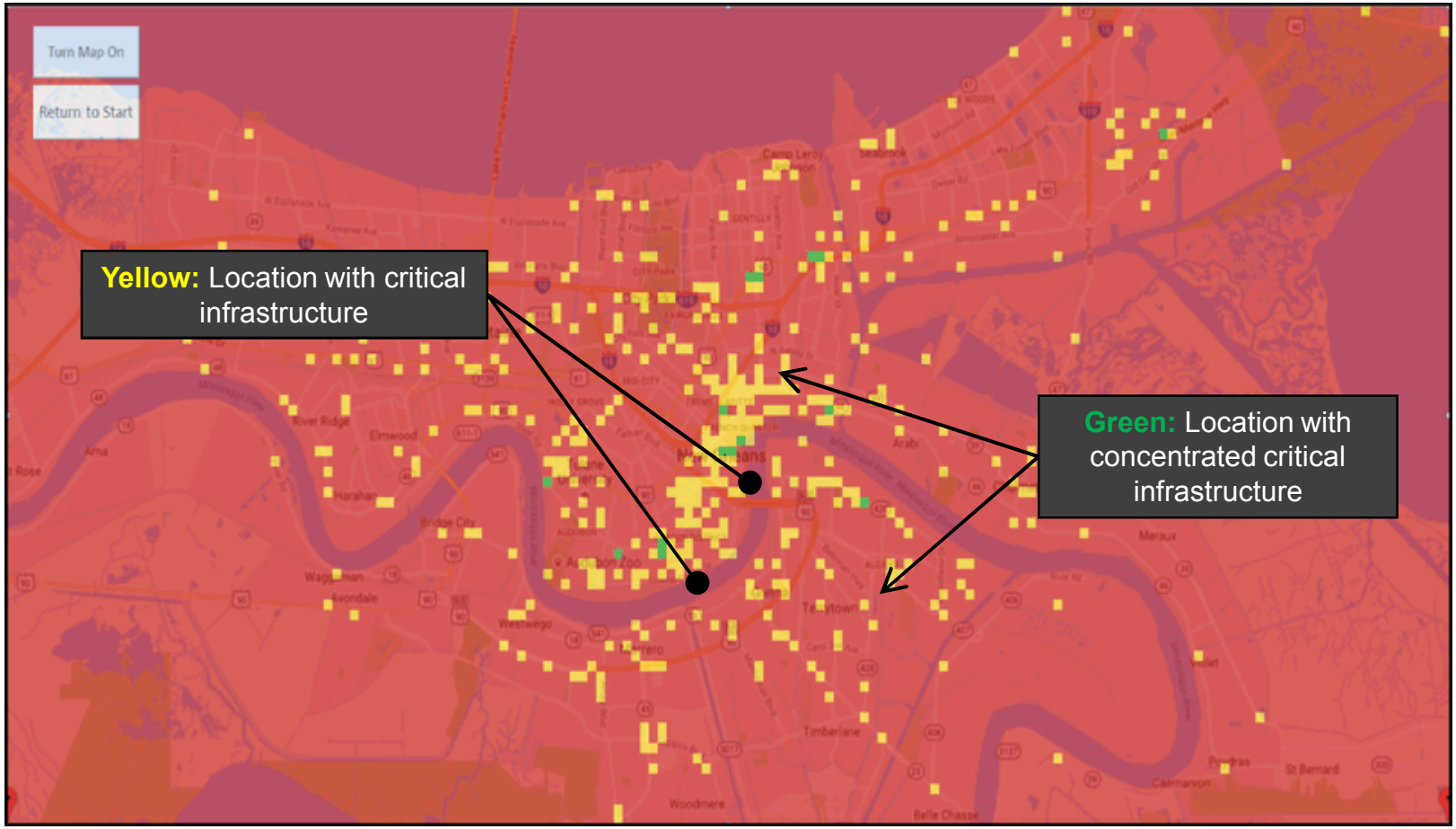
- Ability to prepare for, adapt to, and recover rapidly from changing, non-normal events
- Metrics can include people without access to lifeline services, for how long, and at what consequence
- Consider upstream and downstream supply-chain impacts

Tackling Equity in the Face of Disaster

Goal: to ensure backup services in each zone, helps ensure citizens have broad array of services close to home

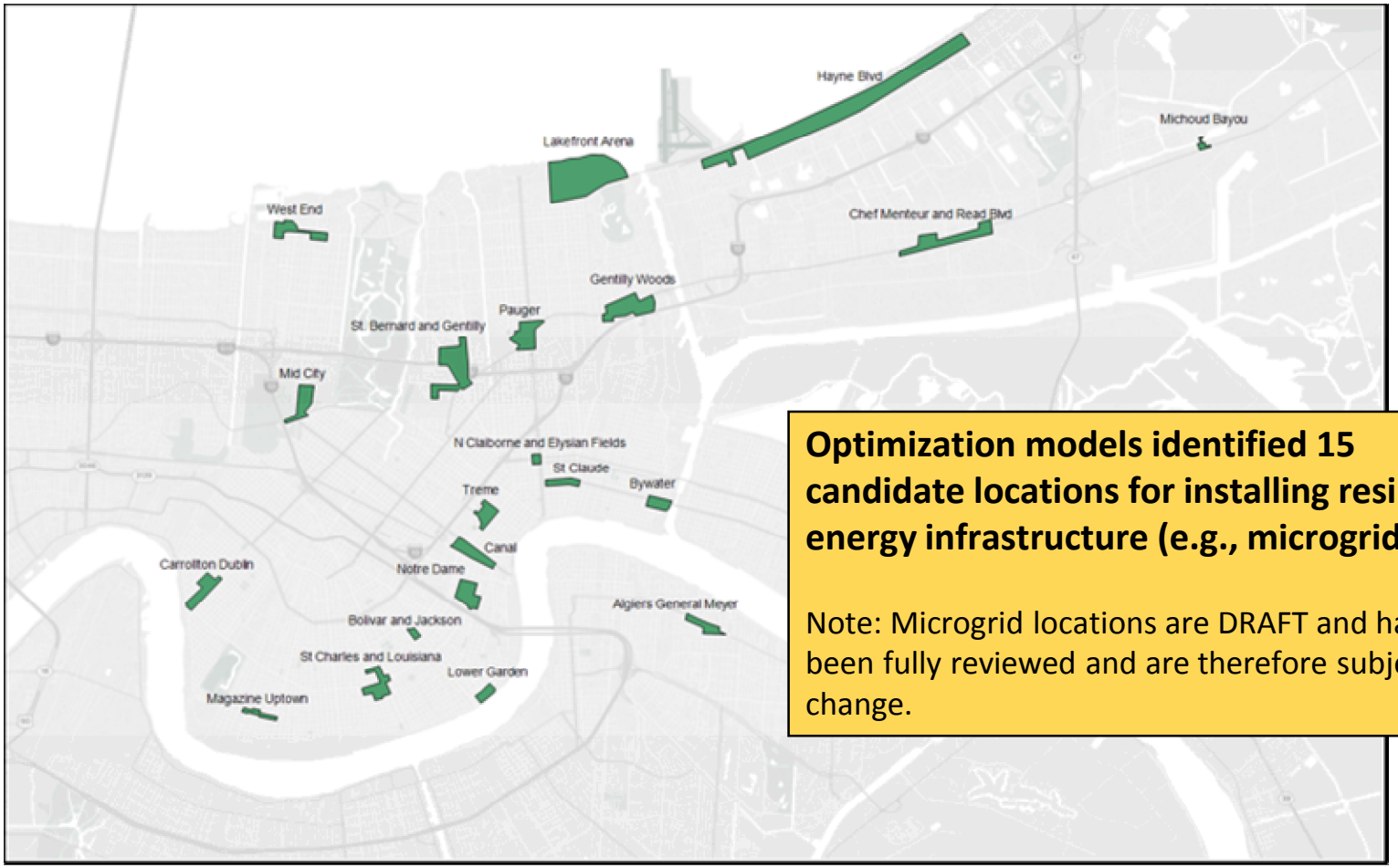


GIS Analysis as a Tool



NOLA Energy Resilience Nodes

Further analysis identified candidate resilience nodes, considering all technical and social factors.



Optimization models identified 15 candidate locations for installing resilient energy infrastructure (e.g., microgrids)

Note: Microgrid locations are DRAFT and have not been fully reviewed and are therefore subject to change.

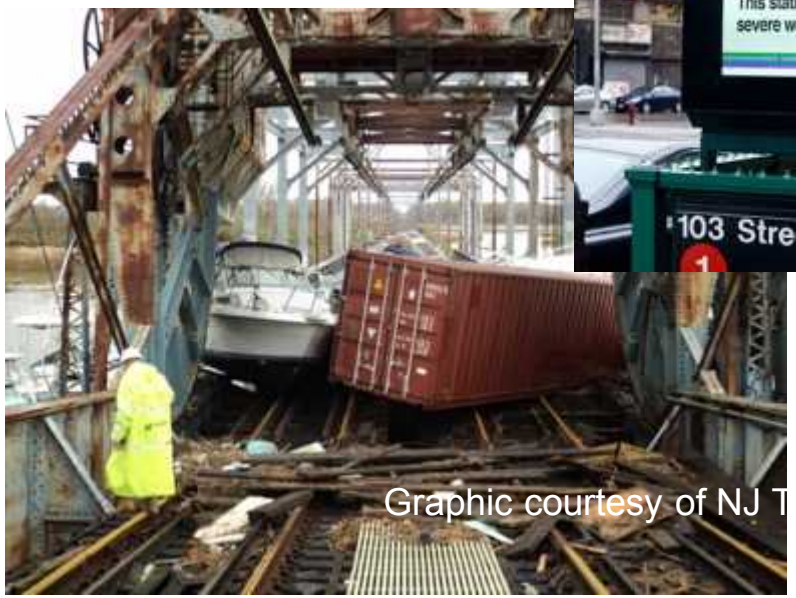
NOLA Project Results

- Report to be released in Q1 '18
  - Recommendations for resilience nodes made to New Orleans and Entergy
  - Barriers to ongoing resilience investment identified
    - » Entergy New Orleans lacks strong explicit incentive for resilience investment
    - » Therefore Entergy's definition of resilience is less consequence-focused
- Other spin-off projects
  - Regulatory approaches to incentivize resilience investment
  - Populating an economic (avoided losses) resilience metric to complement the "citizens without services" metric
  - Assisting New Orleans in developing a resilience solution for the Gentilly Resilience District

2. Transportation Resilience: NJ Transit

In 2012, Hurricane Sandy devastated large portions of the coastal Northeast:

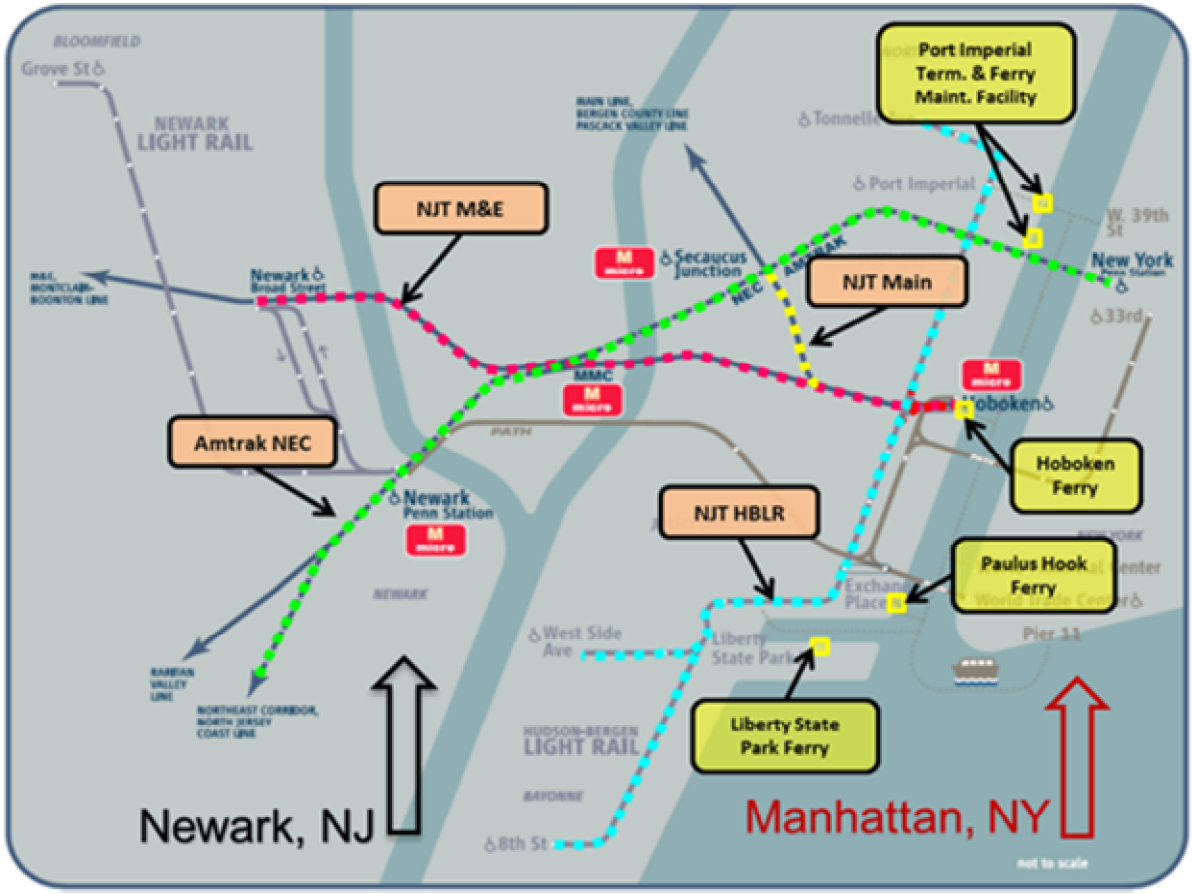
- Major human and economic losses: 110 deaths, $63 billion in cost
- 8.7M customers in the dark; took 2 weeks to restore service to 90% of customers affected
- Transportation system linking NJ/NY severely disrupted for weeks, hampering evacuation and recovery efforts.



Graphic courtesy of NJ T

Project Scope and Stakeholders

- In the aftermath of Sandy, NJ Transit Authority requested technical assistance from Sandia to define resilience options for the Northeast Corridor, a critical transportation route



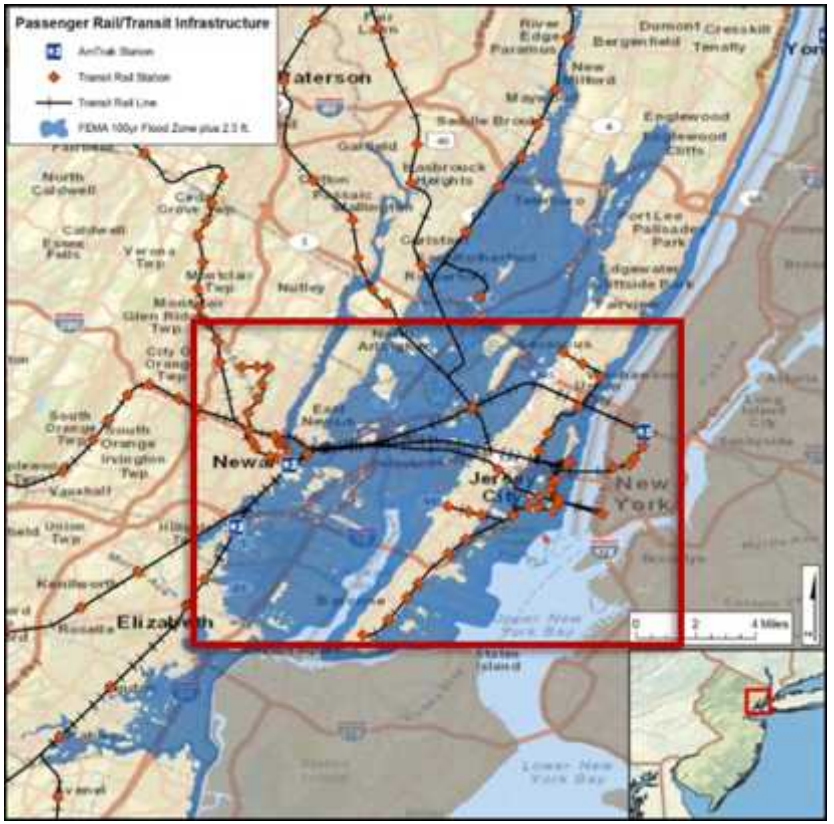
NJ Transit Resilience Study Launched in 2013

- Project Goals
  1. Improve resilience of the transportation system for the following scenarios:
     - Major flood event 2.5 ft. above the FEMA 100-year flood level
     - Extended regional grid outage
  2. Focus on train, buses and ferry-services linking NY and NJ

- Performance Objectives
  - During **extreme** events**, enable rail, bus and ferry transportation for up to 7 days** to support evacuation & recovery efforts.
  - During **blue-sky** conditions, **support grid reliability**, **increase transit capacity**; **generate revenue** through participation in energy, capacity and ancillary markets; **generate renewable energy credits**.

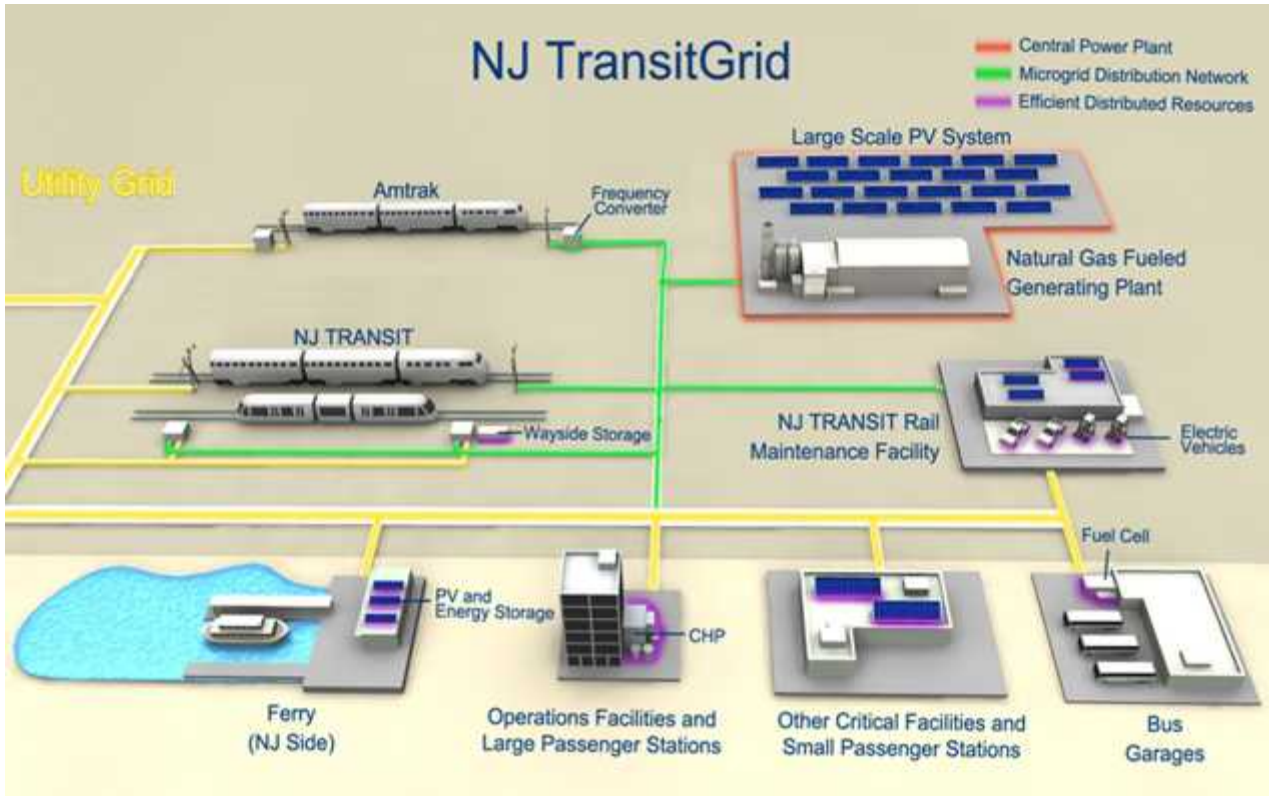
Characterizing the Threat

- Identify critical infrastructure:
  - Rail/port passenger stations; critical operations facilities
  - Rail lines, tunnels, roadways
  - Critical transmission and distribution substations and other electric facilities.
  - Fuel pumping stations for ferries and buses
- Provide analysis: e.g, the economic and social benefits of resilience enhancements



Resilience is an Iterative Process

- Developed progressively more detailed resilience concepts, with stakeholder feedback
- Provided analysis and conceptual designs to assess project's technical viability and estimated cost and resilience benefits.
- Project is currently under development



Major Project Components

- 100 MW gas-fired plant
- 50 MW frequency converter
- 6 MW of PV
- 6 MW of CHP
- Wayside energy storage (regenerative braking)
- PV+storage facilities
- Electric vehicles
- New distribution lines and switches
- Flood protection

Summary

1. Critical infrastructure resilience is a topic of high interest:
   - Extreme weather and other catastrophic events are projected to increase
   - Resilience increasingly considered in policy and investment decision-making
2. The resilience challenge is difficult to address
   - Technically complex, high uncertainty
   - Impacted by diverse stakeholder interests and values
3. Useful frameworks, metrics and tools exist…
   - Application examples show that it is possible to improve critical infrastructure resilience in a rigorous manner
4. …but more work is needed
   - to ensure full and widespread adoption of resilience principles to support critical infrastructure planning

Questions?

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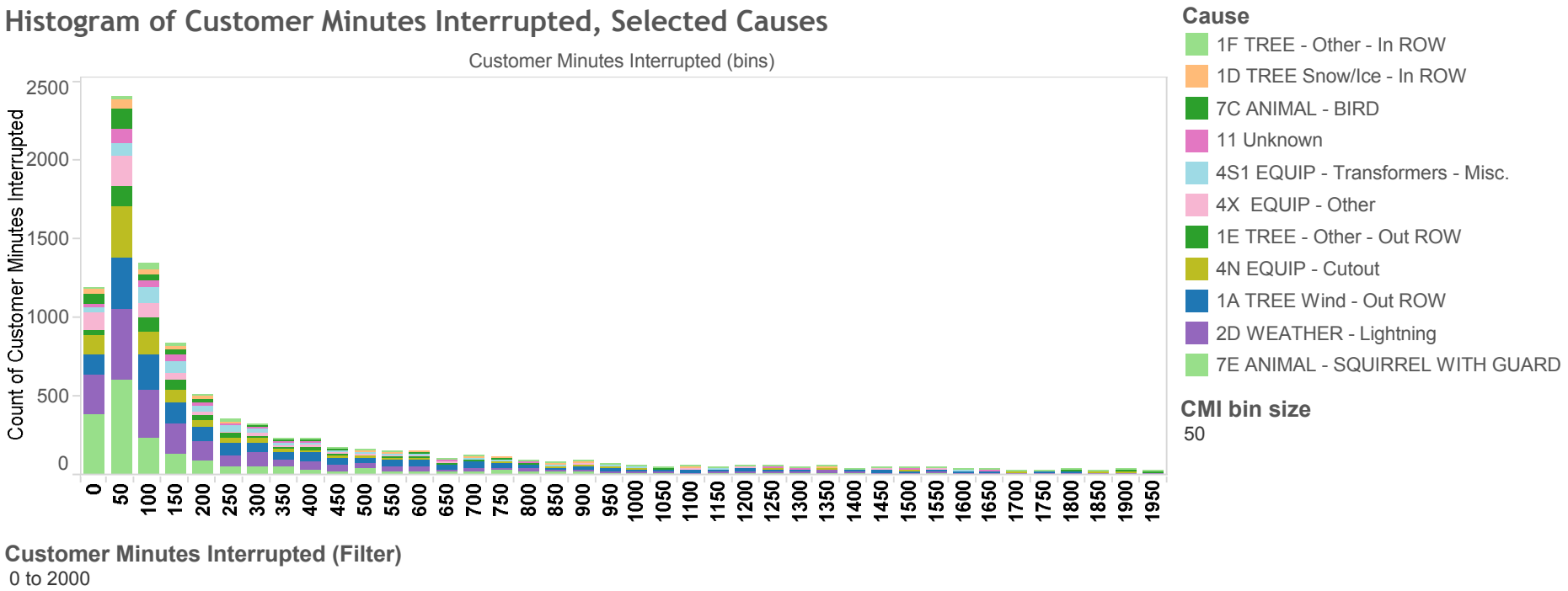
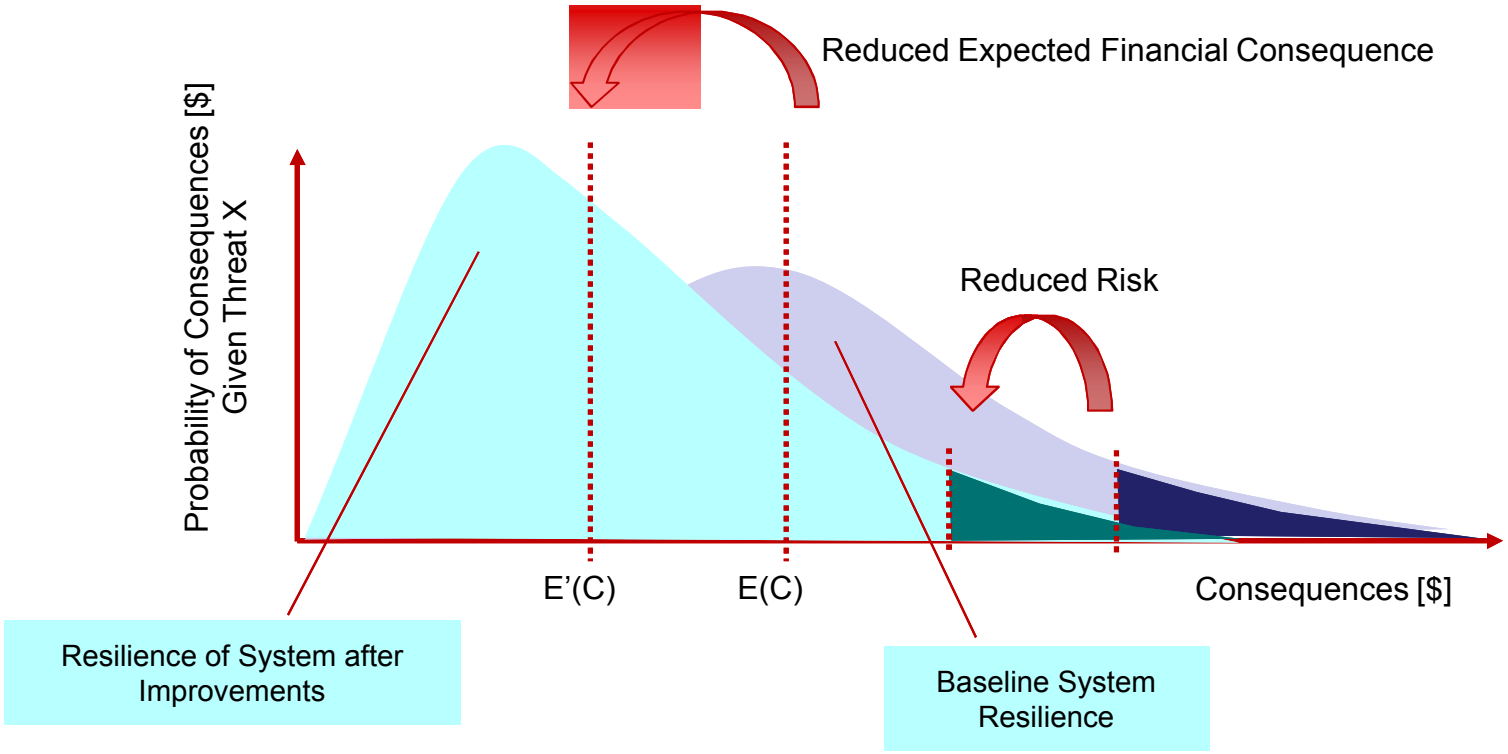
Resilience and Reliability

Grid resilience and reliability can be described along a single dimension: (e.g. customers * minutes interrupted)



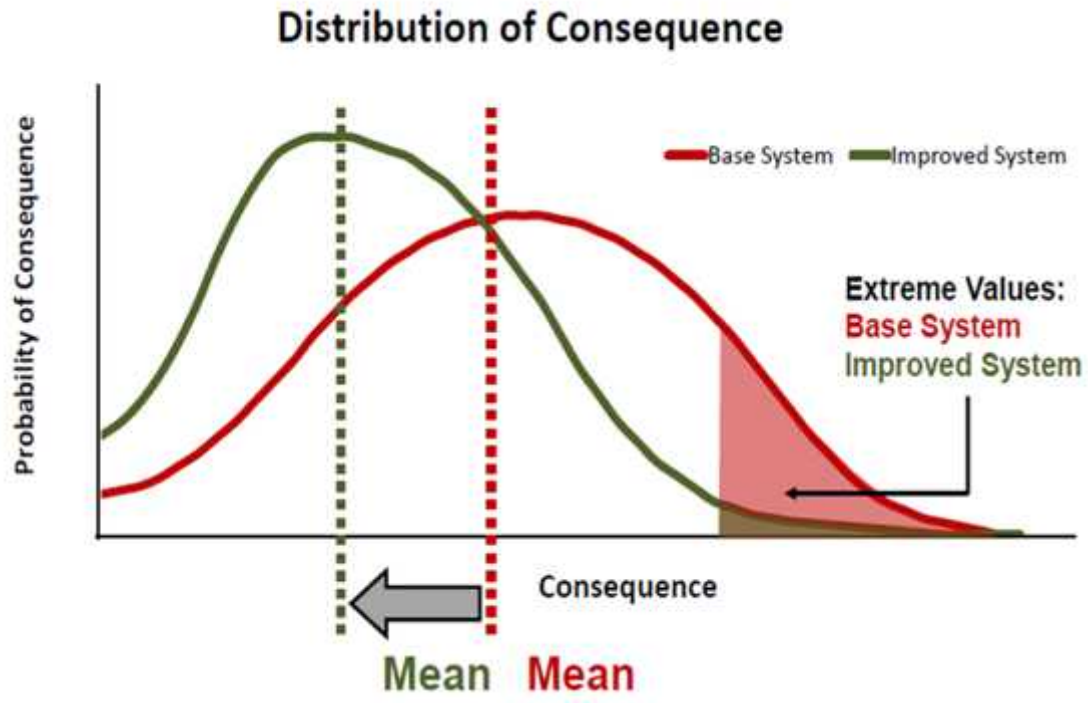
Resilience Quantification Incorporating Uncertainty

The following framework was developed for the *Quadrennial Energy Review* and supports decision-making to obtain demonstrable resilience improvements



Resilience Metrics - Desired Attributes

- Specific to the threat (*resilience to what?)*
- Performance-based (*how resilient is the system?) or*
- Attribute-based (*what makes the system resilient?*)
- Expressed in terms of ***consequences***
- Risk-based (probabilistic)
- Consistent
- Scalable
- Practical

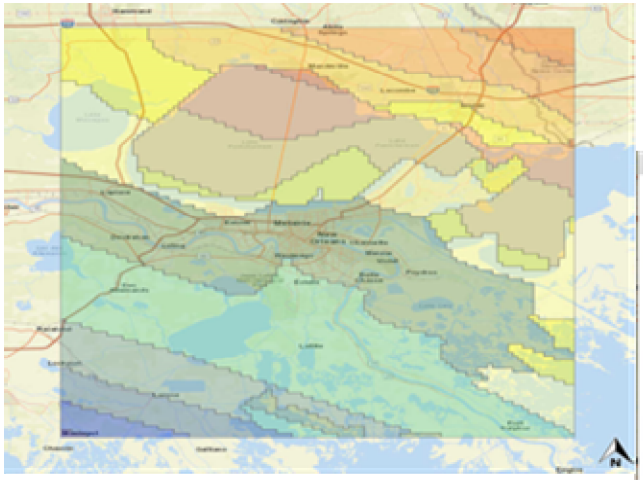


Characterizing the Threat

Max Wind – 1947 Track

Flooding – 1947 Track

Cat 2 Storm



Cat 4 Storm