

Resilience of Geographically Distributed Lifeline Systems

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MCEER THRUST 1: LIFELINES

WATER SUPPLY PIPELINE SYSTEMS



ELECTRIC POWER

THE CONCEPT OF



r⁴

*The Four Fundamental
Properties of Resilience*

*r*obustness

*r*edundancy

*r*esourcefulness

*r*apidity

GOALS

- **High Performance Simulation of Complex Lifeline Systems with Application of Advanced Technologies for Multidisciplinary Decisions by Managers to Enhance Systems and Community Resilience**

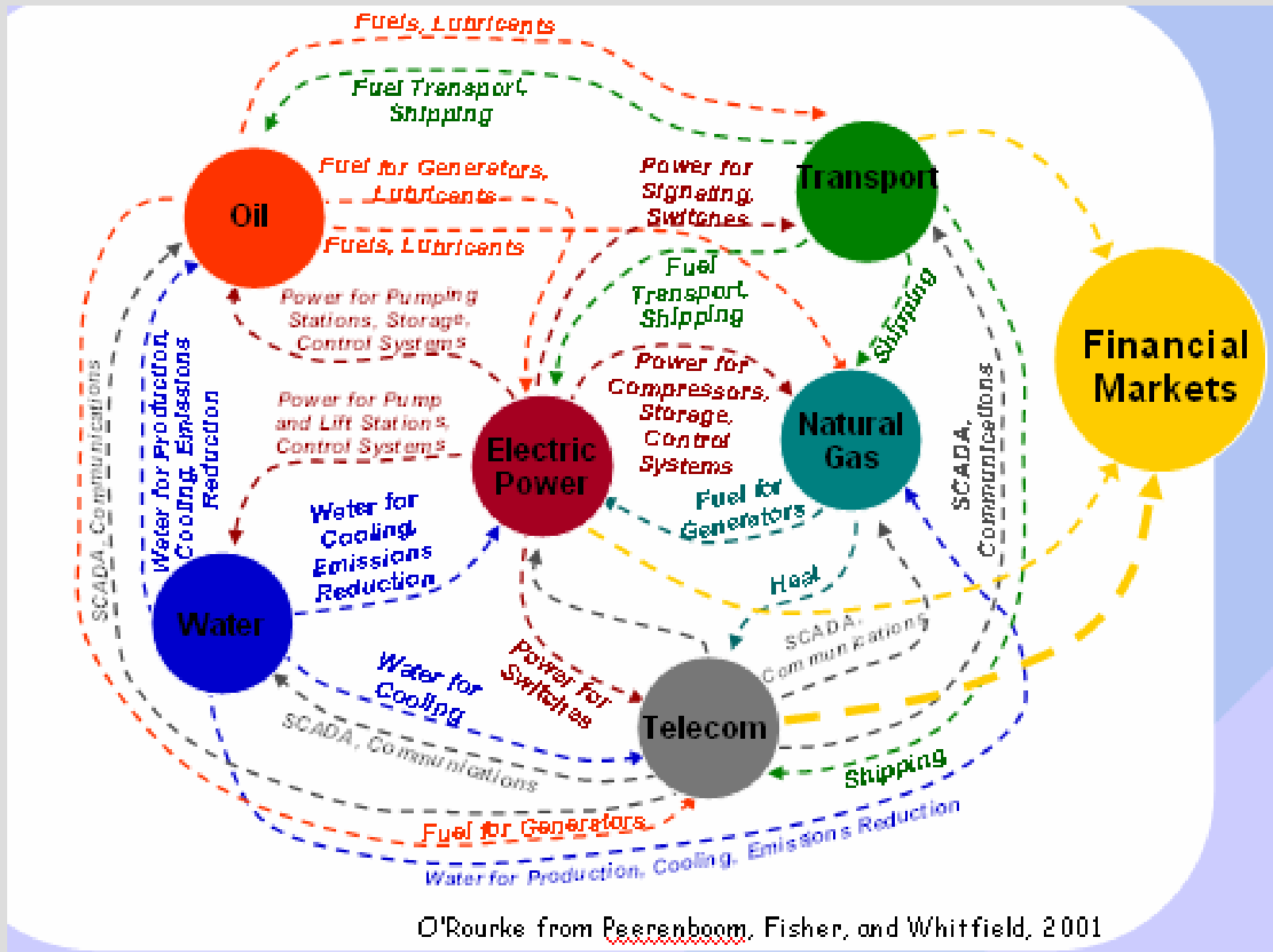
An aerial photograph of a road with power lines and trees, serving as a background for the text.

LIFELINES

- **Electric Power**
- **Gas and Liquid Fuels**
- **Telecommunications**
- **Transportation**
- **Wastewater Facilities**
- **Water Supply**

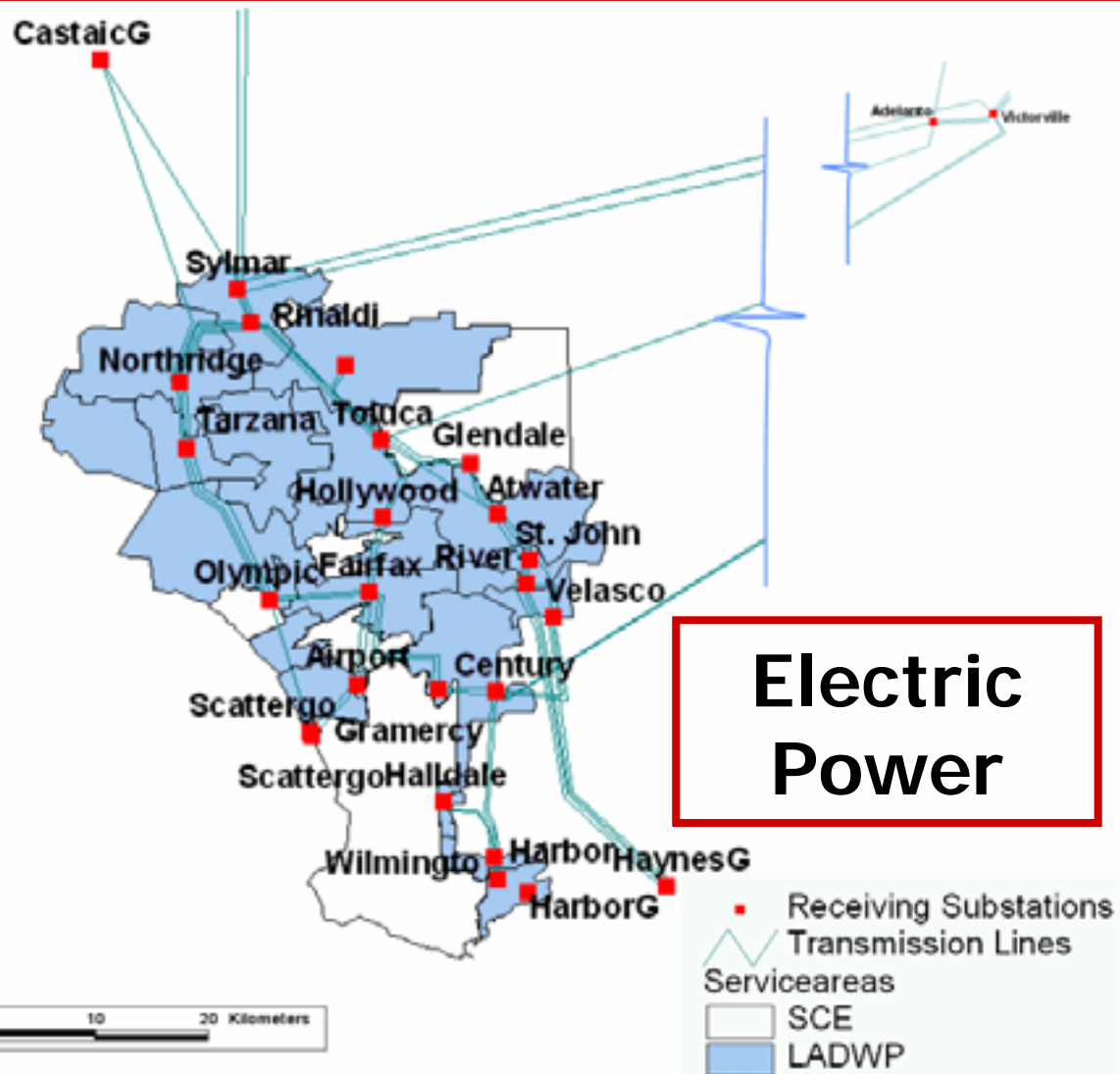
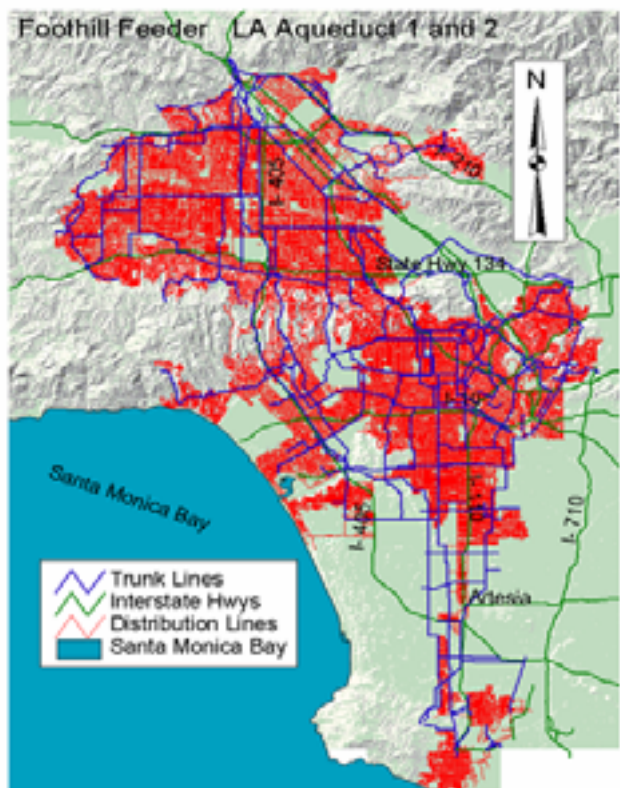


MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH



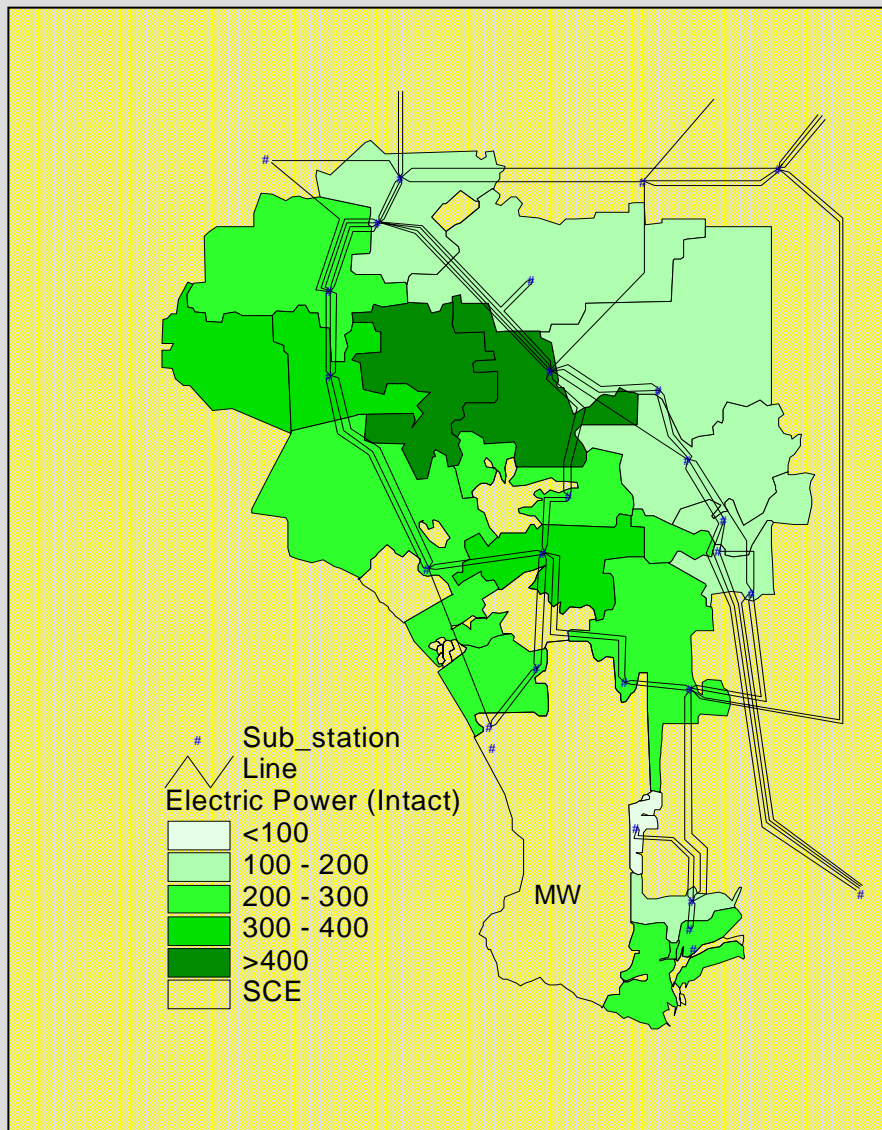
LOS ANGELES DEPARTMENT OF WATER & POWER

Water Supply

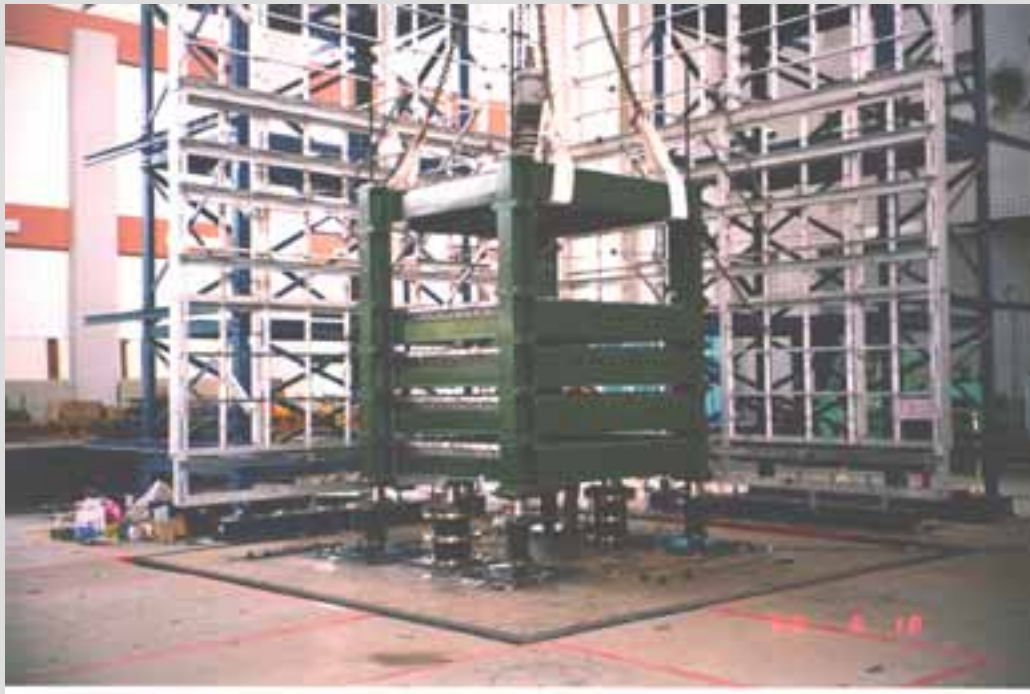


Electric Power

**LOS ANGELES:
6,300 MW at peak
hour for 3.8 million
customers**



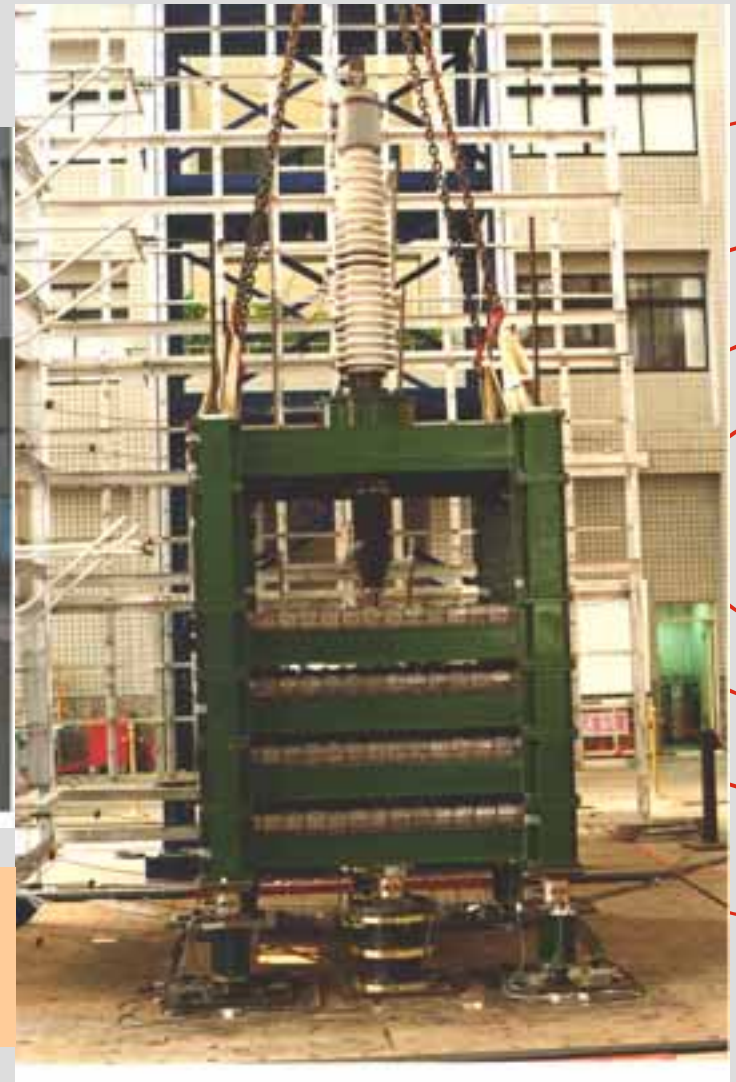
Model for Transformer, Bushing and Base-isolation System



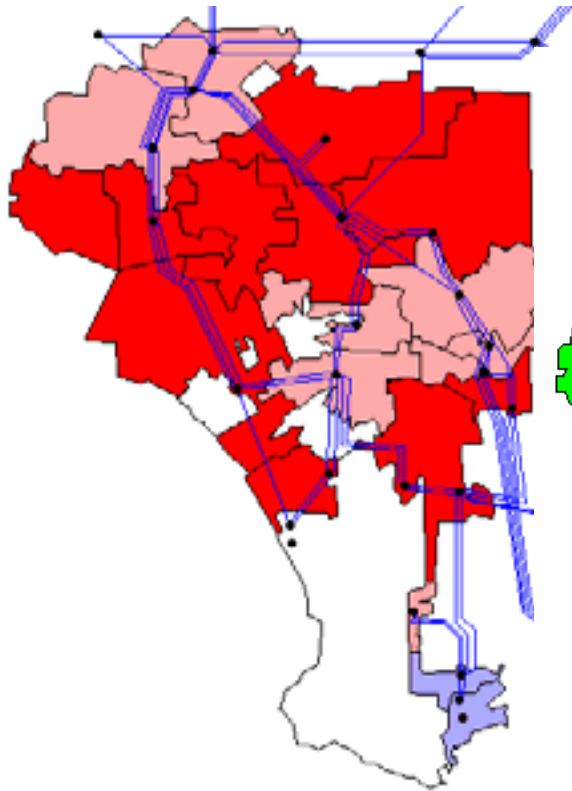
At National Center for Research
on Earthquake Engineering
(NCREE), Taipei, Taiwan

5x5 m

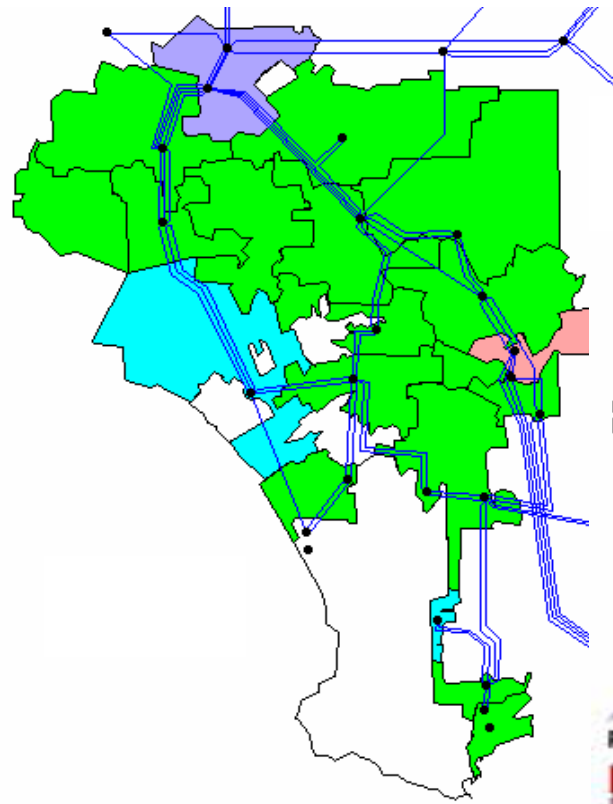
20 ton payload



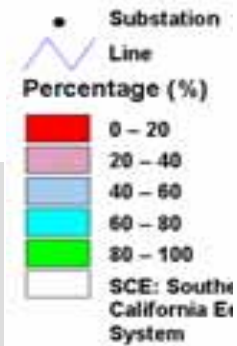
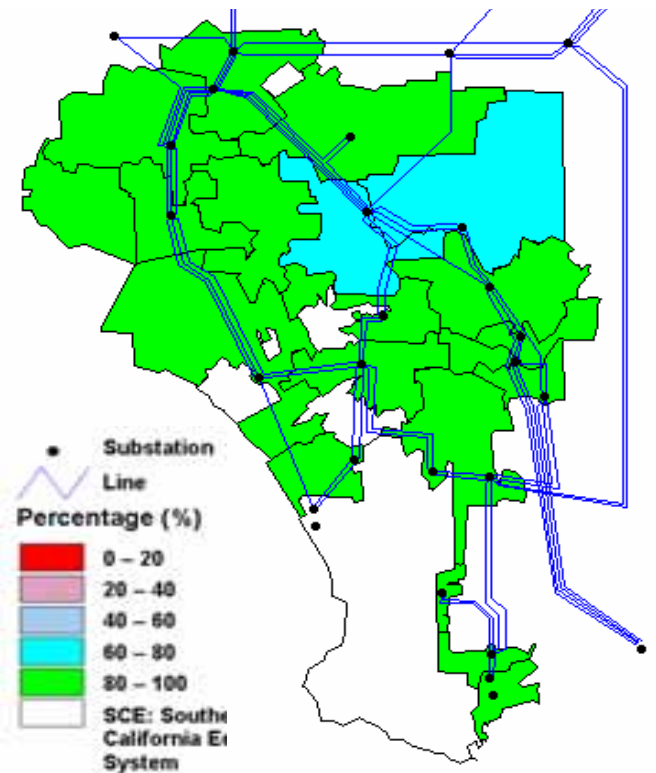
Case 1



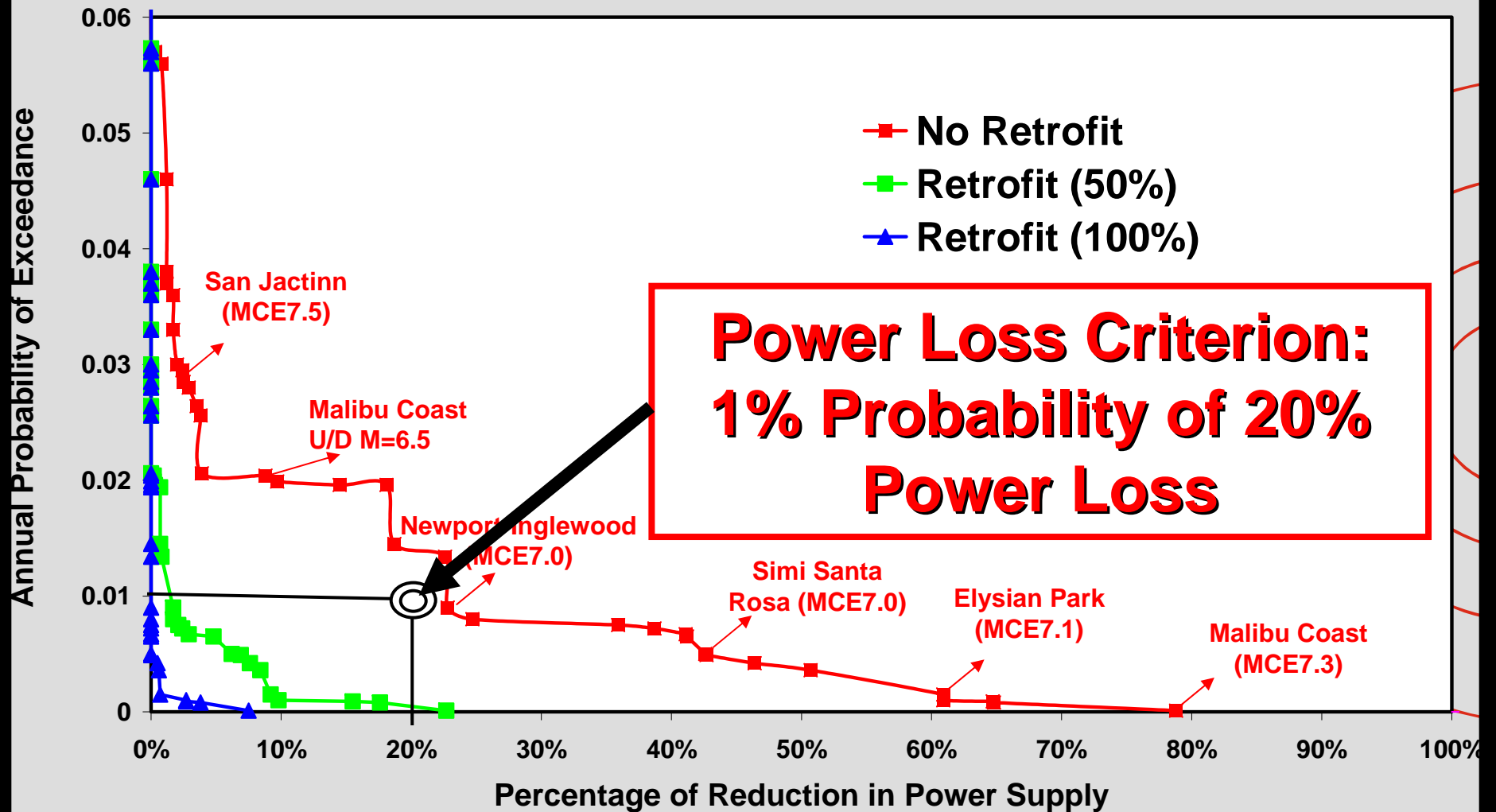
Case 2



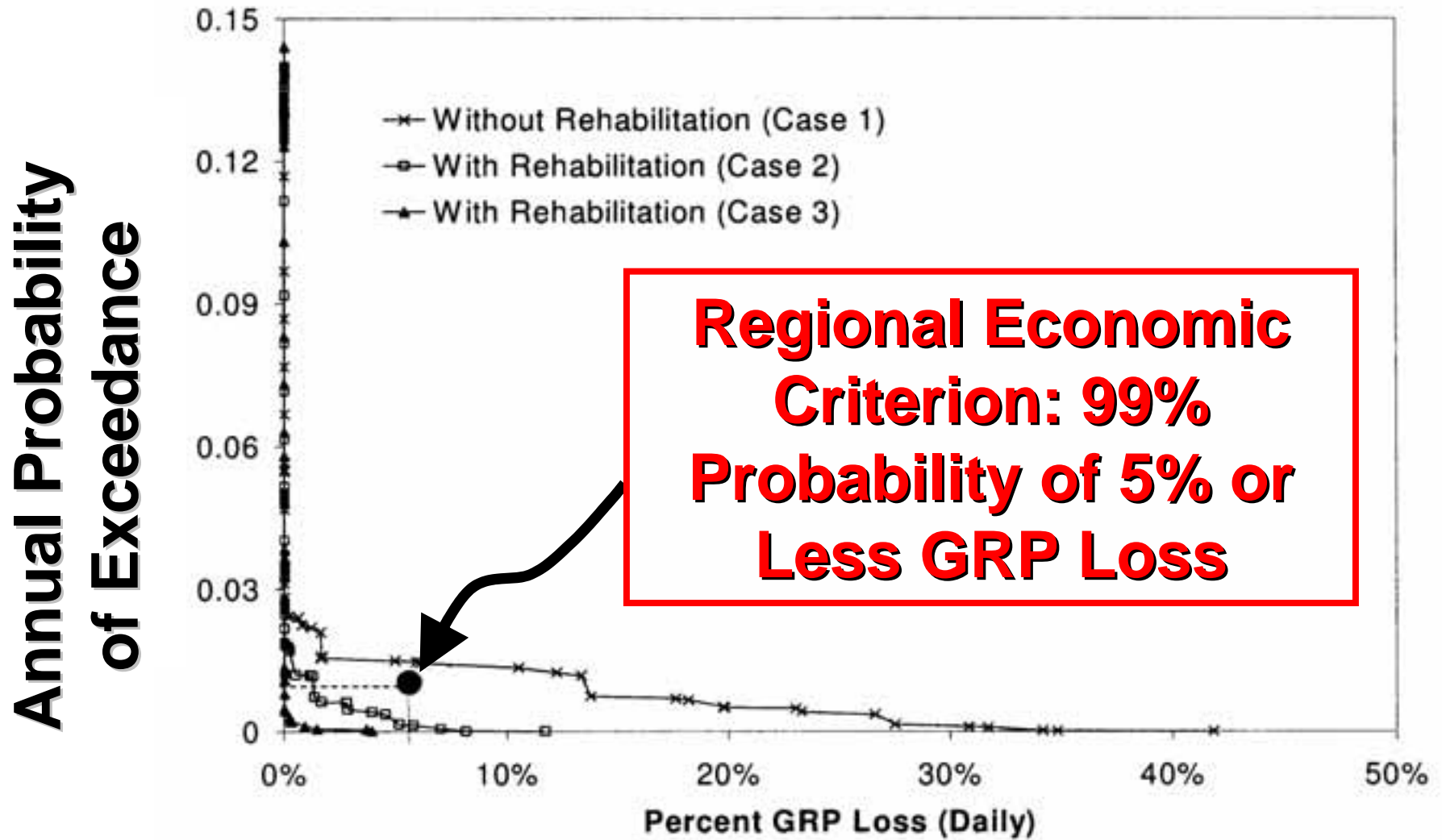
Case 3



RISK CURVES FOR POWER SUPPLY REDUCTION

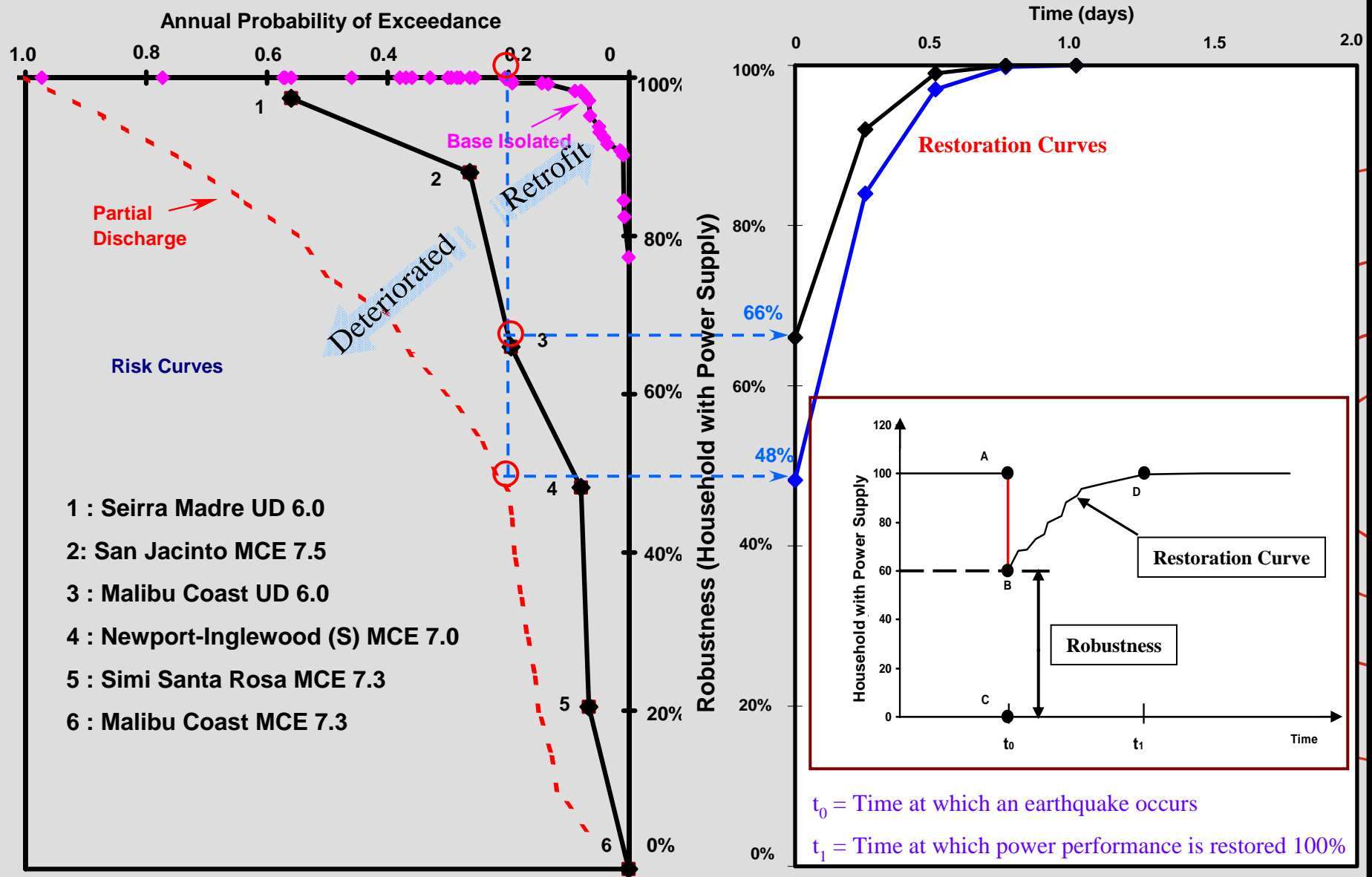


RISK CURVES FOR POWER SUPPLY REDUCTION

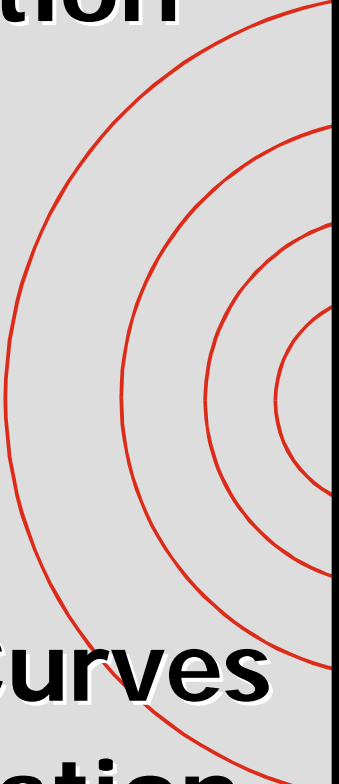


Percentage of Households Without Power

RISK & RESTORATION CURVES

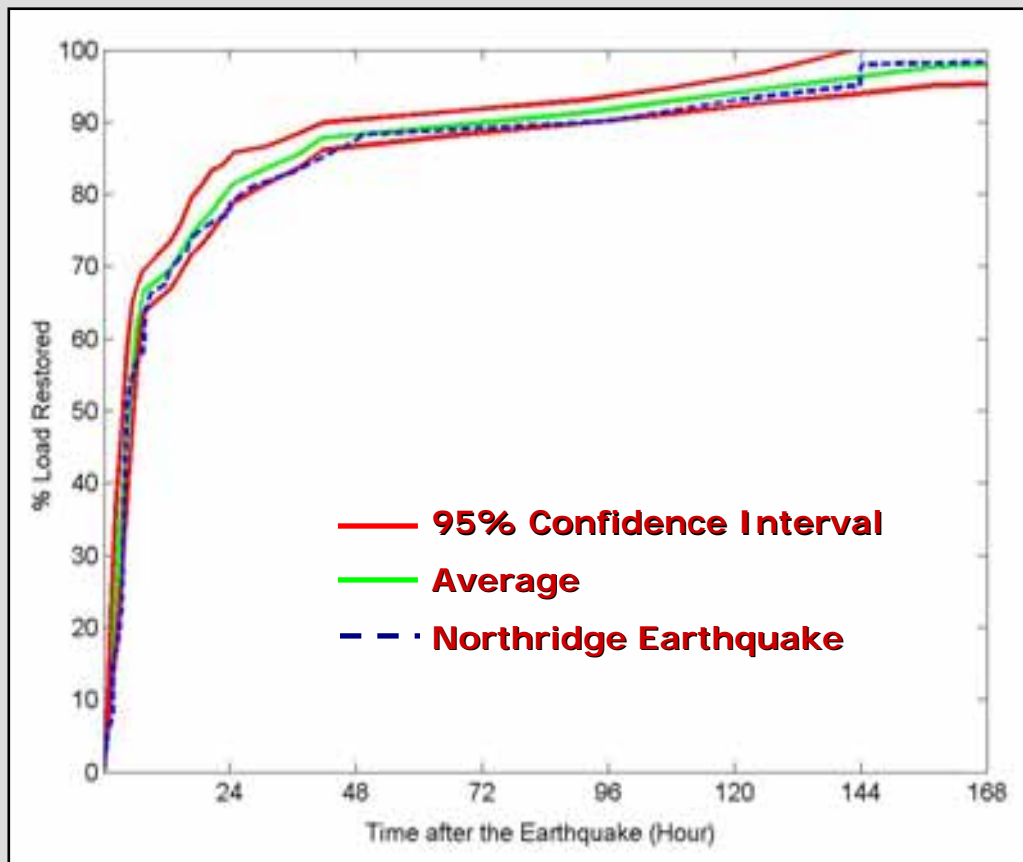


DISCRETE EVENT SIMULATION

- **Explicit Modeling of Restoration Process**
 - **Initial Inspection**
 - **Damage Assessment**
 - **Repair of Facilities**
 - **Re-energizing**
 - **Uncertainty in Restoration Curves**
 - **Regional Variation in Restoration**
- 

NORTHRIDGE EARTHQUAKE SIMULATION

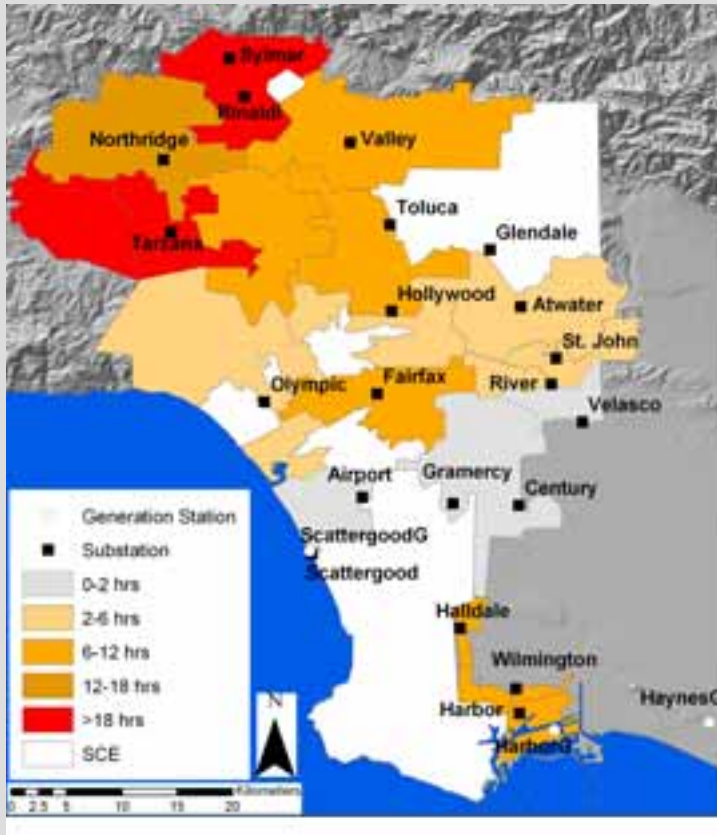
System restoration curve



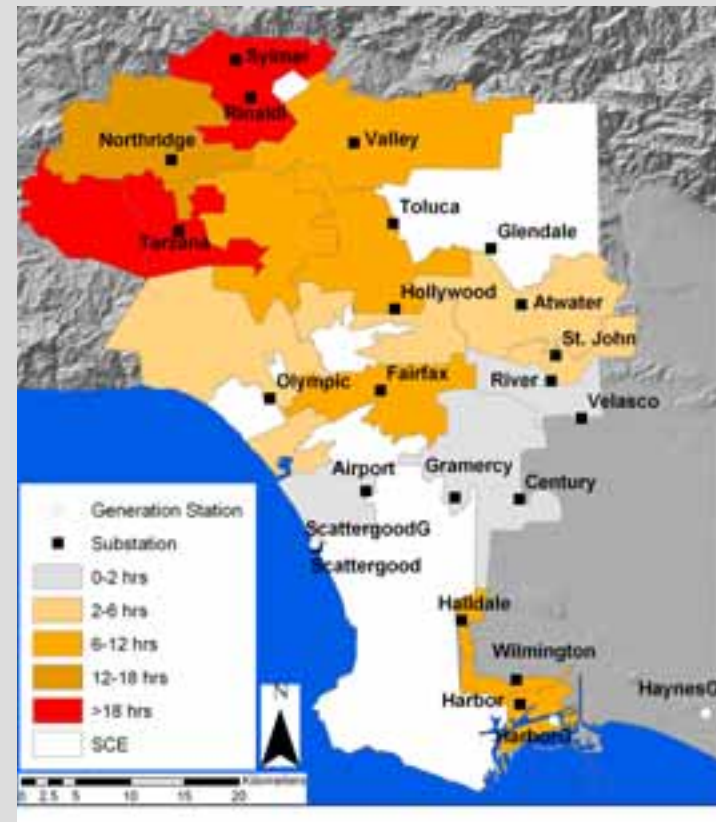
- The real restoration curve lies between the 95% confidence intervals
- The exponential shape agrees with observed data
- With additional data on distribution system, restoration curves for each service area can be constructed

NORTHRIDGE EARTHQUAKE SIMULATION

Spatial order of restoration

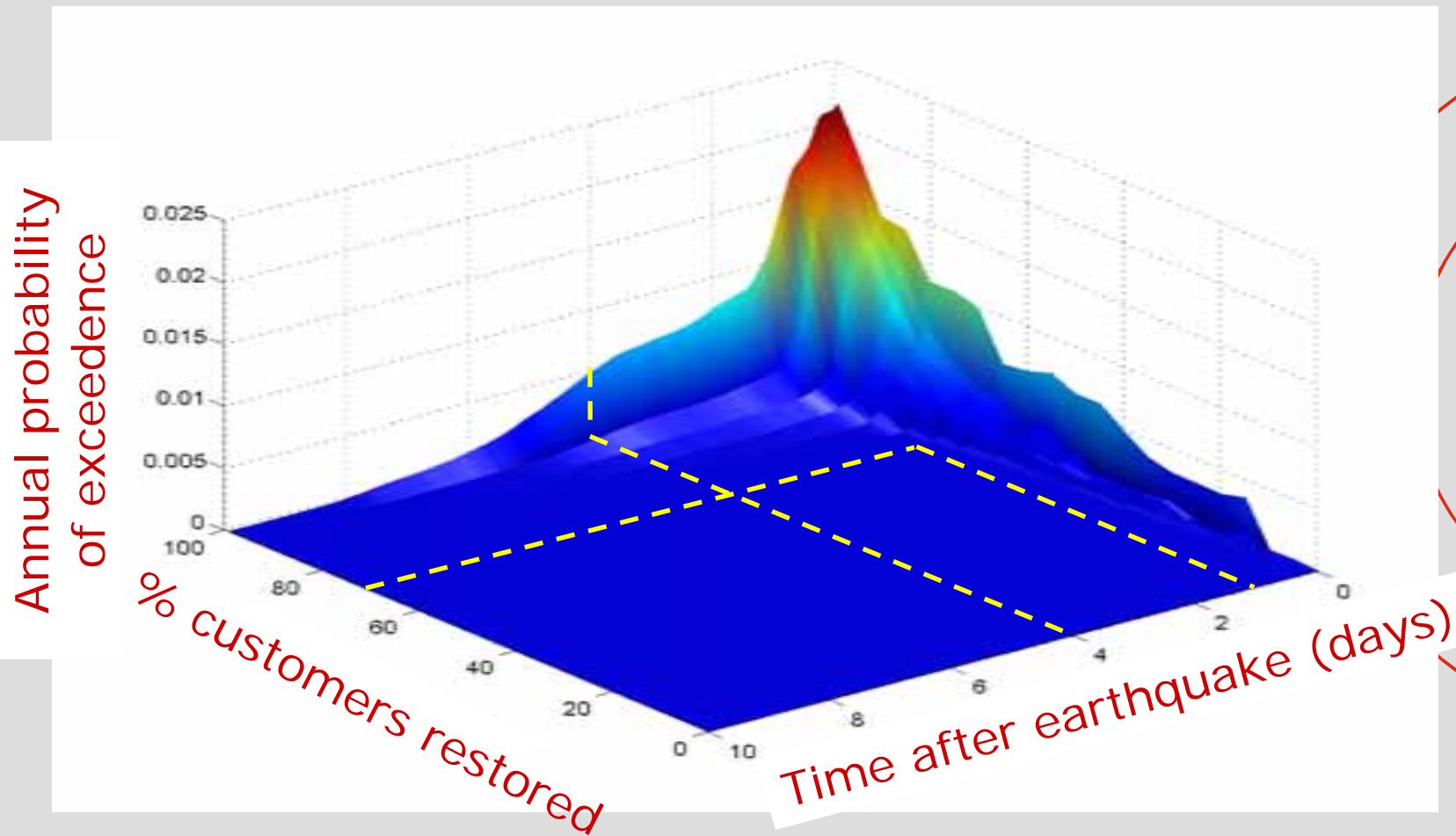


Northridge Earthquake

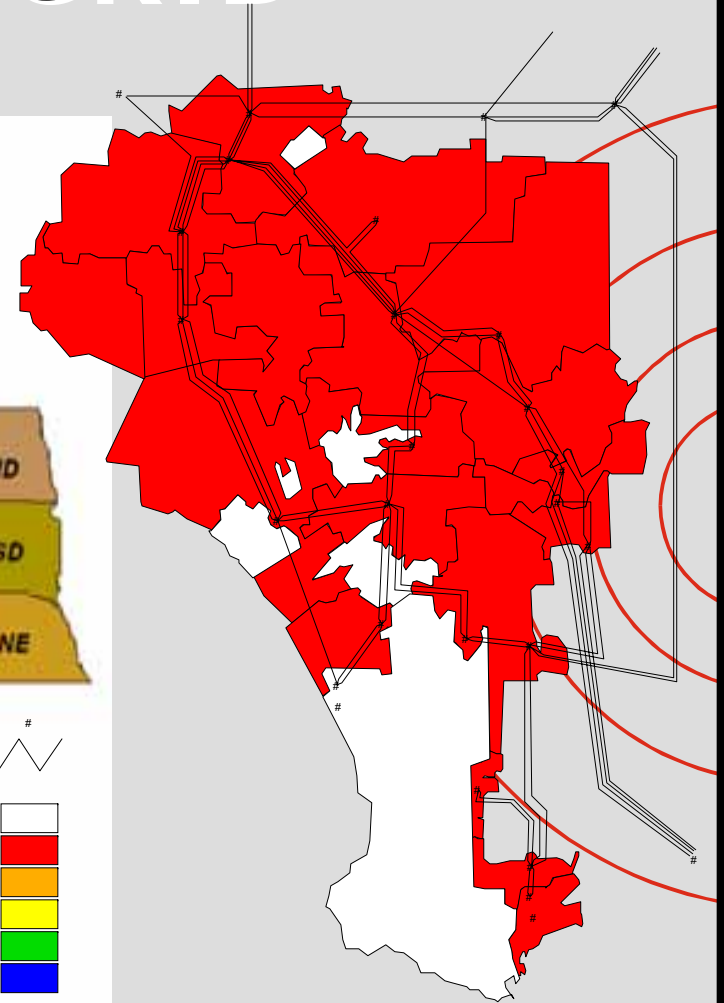


Simulation Results

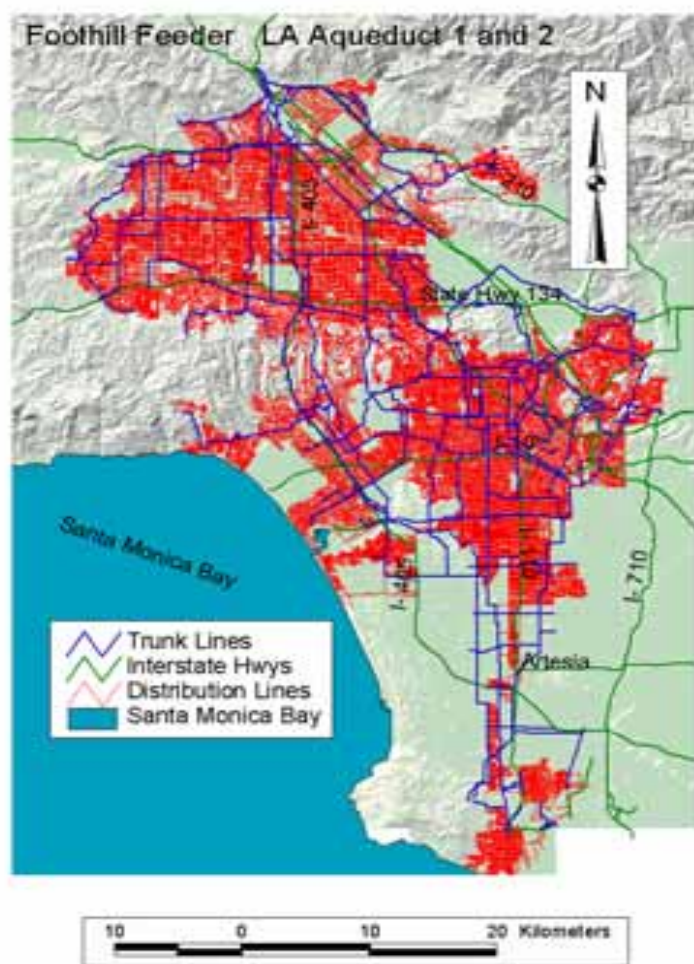
RESULTS - POWER RAPIDITY RISK SURFACE



NETWORK VULNERABILITY OF WESTERN GRID



Los Angeles Department of Water and Power (LADWP)

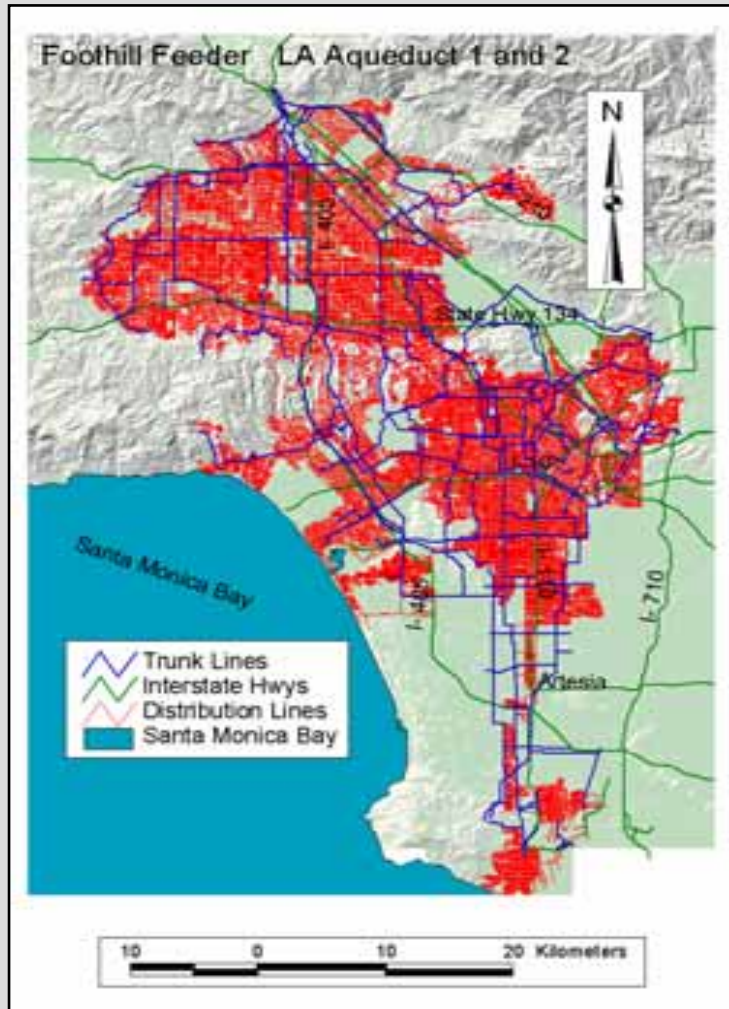


- Serves 3.8 million People
- 12,000 km Distribution & Trunk Pipelines
- 1200 km²

MCEER ACCOMPLISHMENTS

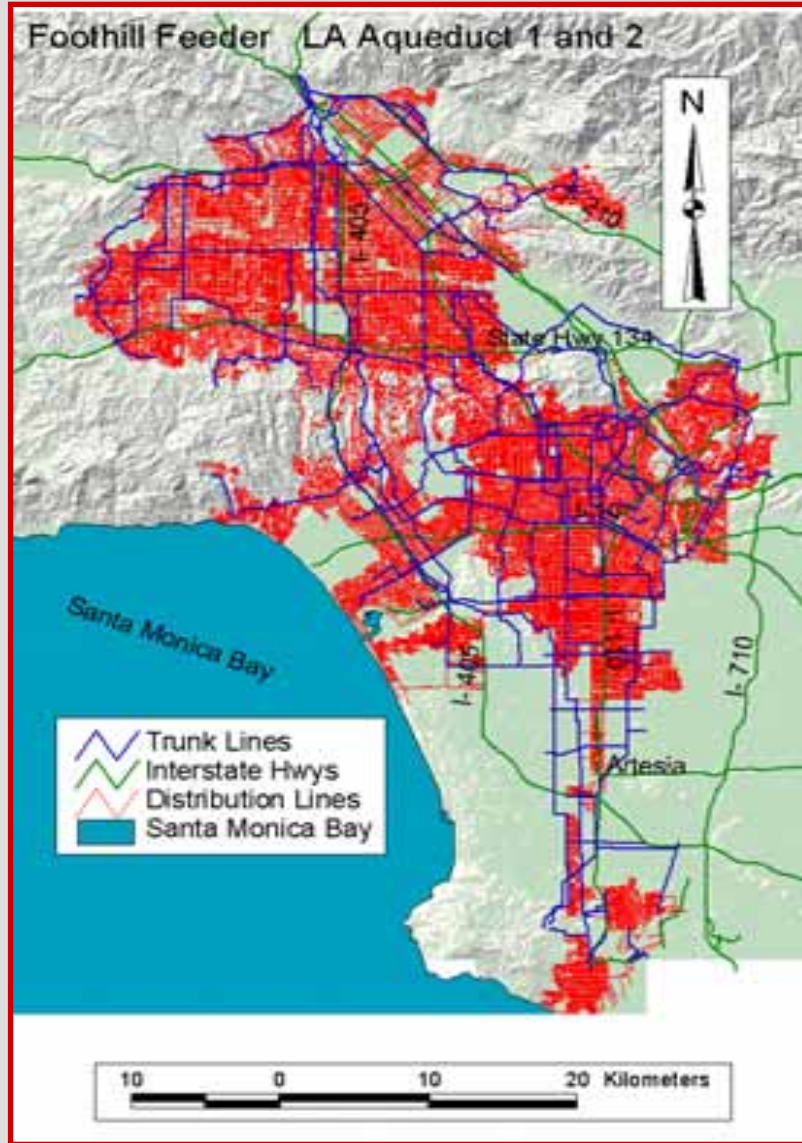
- **State-of-the-Art Decision Support System Implemented by LADWP**
- **Advanced Technologies for Pipeline & Facility Retrofit & Rehabilitation**
- **Full-Scale Experimental Validation of Protective Technologies**
- **High Performance GIS, Internet, & Remote/Distributed Sensing**
- **Lifeline System Interdependencies**

DECISION SUPPORT SYSTEM



- Simulates 12,000 km pipelines & facilities
- Comprehensive seismic & geohazards
- Special software for damaged hydraulic network analysis
- System risk & reliability
- Water & electric interaction
- Economic/social impacts
- Adv tech application assessment

LADWP SYSTEM



LADWP
MODEL



GIS

ELECTRIC POWER AND WATER SYSTEM INTERACTION

- Coupling water and power systems
- Failure mechanisms of pump motors
- Inventory and modeling of LADWP & SCE

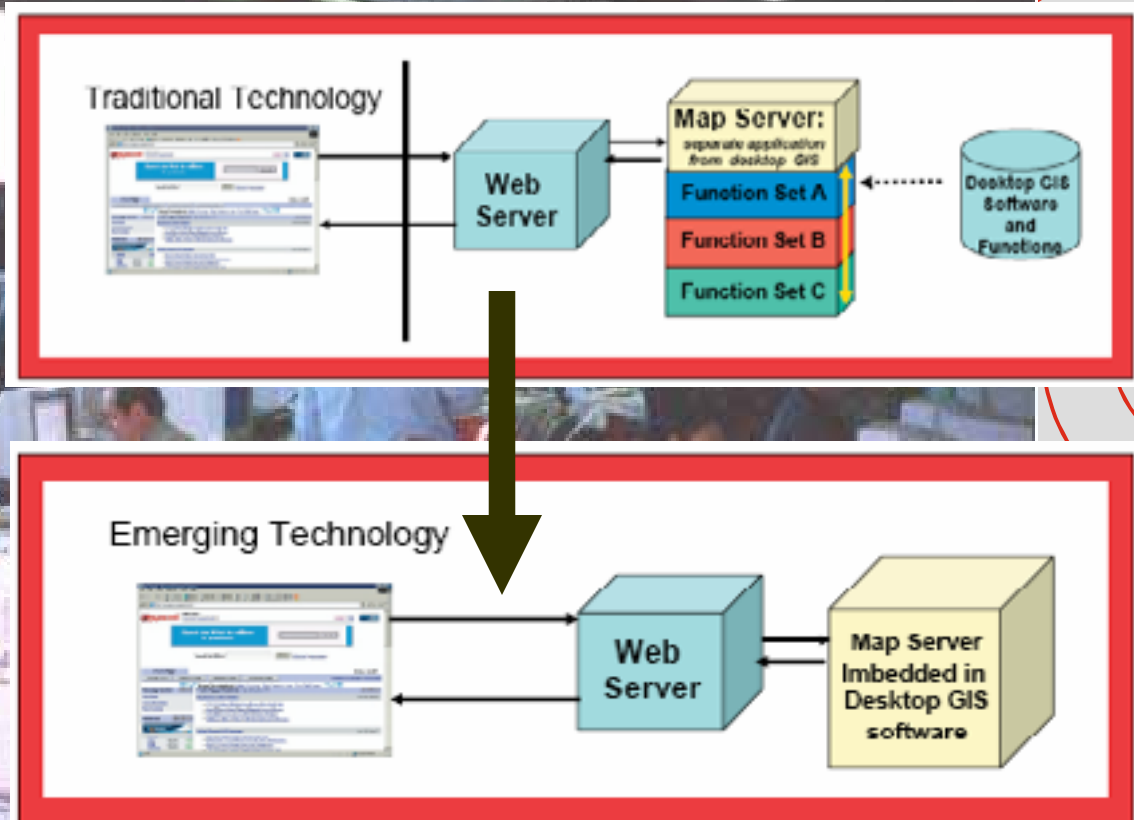


Regional Economic Impacts of 2-Week Water Outage in LA

- Total output decreases by \$20.7 billion in the absence of any post-disaster resilience
- Several types of resilience (e.g., conservation, production rescheduling) reduce losses to \$2.3B
- Resilience potential erodes, however, with the magnitude and duration of the outage

GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

**Web-
Based GIS
Embedded
Internet
Map
Server**

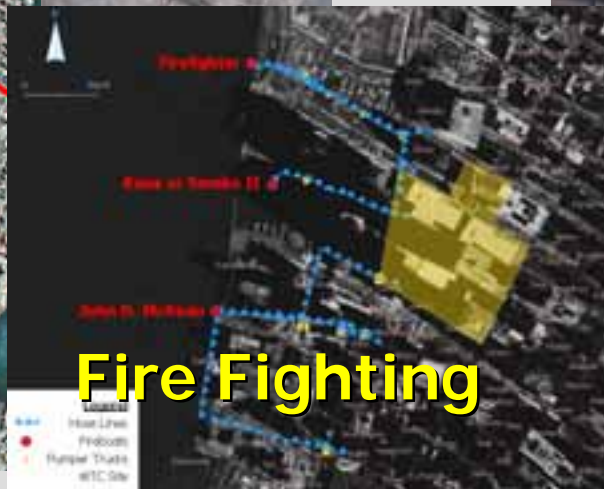


LIFELINE INTERDEPENDENCIES

WORLD TRADE CENTER DISASTER LIFELINES STUDY



**Documentation
of Lifeline
Performance &
Interactions**



LARGE SCALE SOIL-LIFELINE INTERACTION



- Largest Lab Experiment of Ground Rupture Effects on Lifelines Ever Performed, Sponsored by **Tokyo Gas**

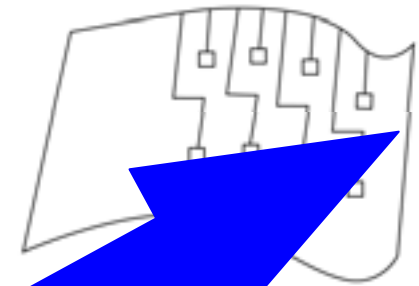
ADVANCED SENSORS FOR WATER SUPPLIES

Flexible Substrate Technology:

- Polymer substrate
- Thousands of sensors
- Adaptable to field conditions
- Proven durable & reliable



Flexible Sensor Substrates



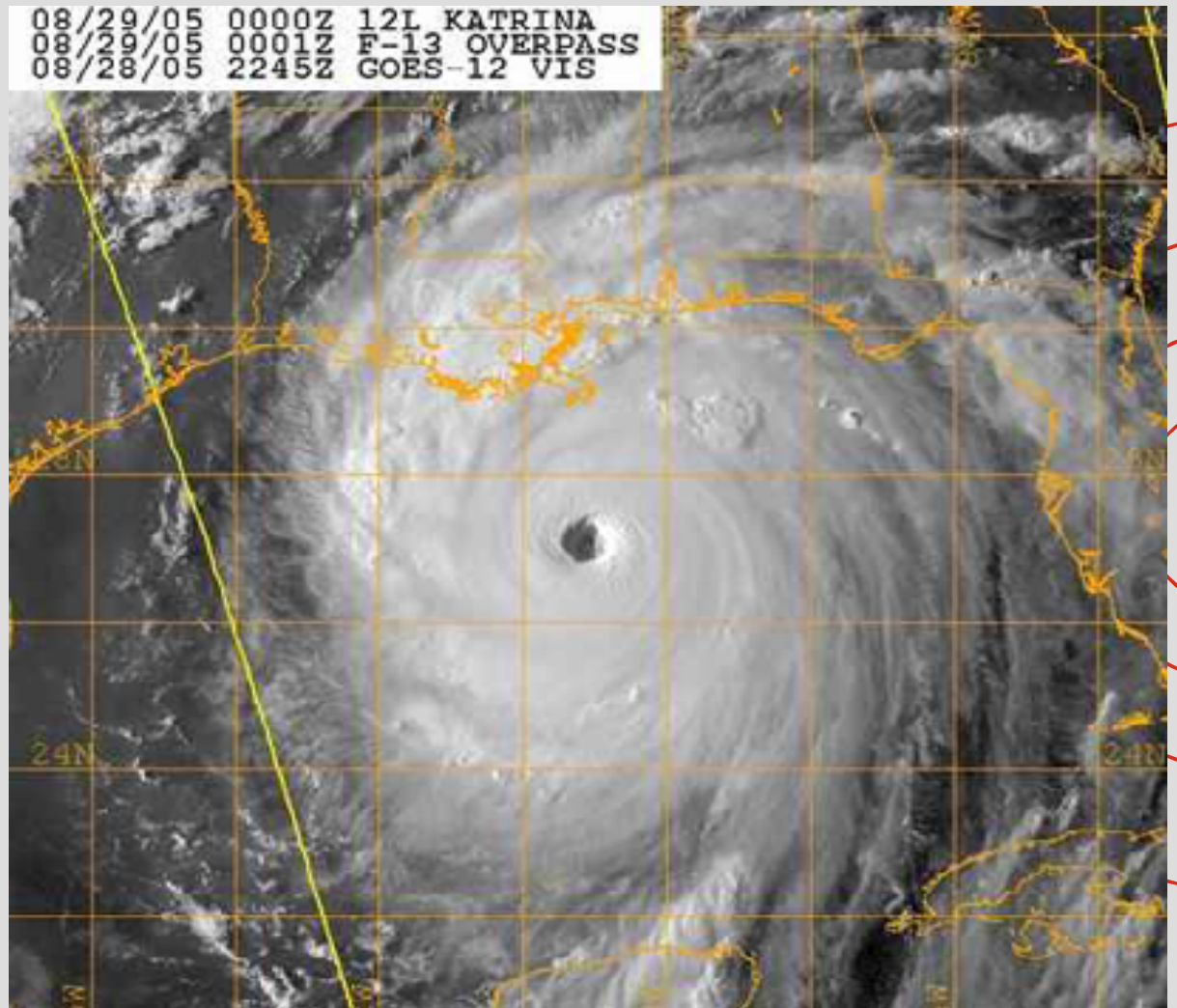
Spiral Sampling Geometry



- Any # of sensors
- Any # of analytes
- Interrogate individually
 - sensitivity
- Sum sensor responses
 - dynamic range
- Faster time response

HURRICANE KATRINA

- MCEER Field Reconnaissance & Remote Sensing
- National Academies Committee on New Orleans Regional Hurricane Protection Projects



ACCOMPLISHMENTS

- **High Performance Simulation of Complex Lifeline Systems with Application of Advanced Technologies for Multidisciplinary Decisions by Managers to Enhance Systems and Community Resilience**