Cluster 4:Reducing the underlying risk factors
Session Number:4.8
Theme:Vulnerability of modern societies towards natural disasters – the impact on critical infrastructures

Enhancing the Resilience of Power Grids against Extreme Events

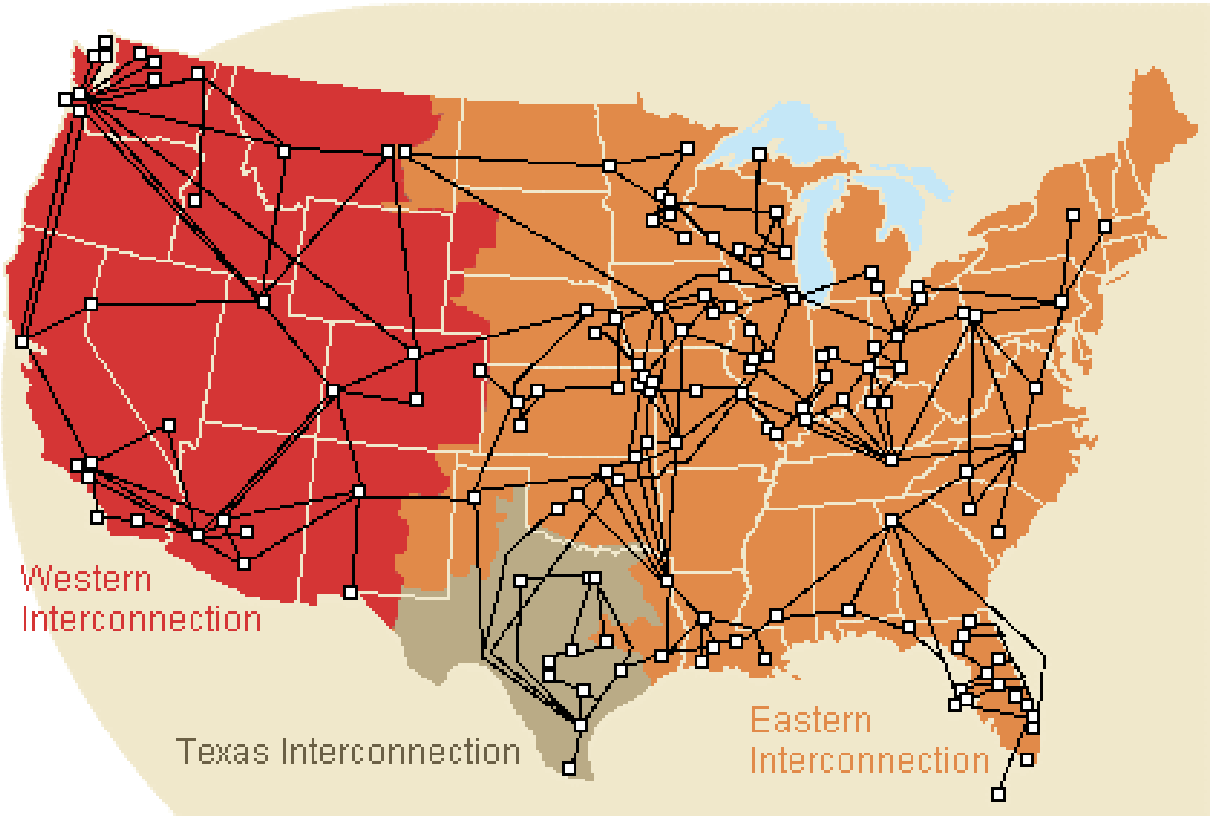
Masanobu Shinozuka
University of California, Irvine

United Nations
World Conference on Disaster Reduction
Kobe, Hyogo, Japan
18-22 January, 2005

U.S. Power Grid

The U.S. has:

- more than 6,000 power plants
- 500,000 miles of aboveground and underground transmission lines
- 150 Control Area Operators
- Three main power grids



Map source: CNN.com

Blackout of August 14, 2003

- Started at 4:11 pm
- Major Cities Affected include:
  - New York City
  - Cleveland, Ohio
  - Detroit, Michigan
  - Toronto & Ottawa, Canada
- 61,800 MW of load lost, affecting 50 million people. 21 power plants went off-line, including 10 nuclear plants
- "Cascading Blackout" destabilized the Niagara-Mohawk power grid.
- Cause is being investigated by a Joint U.S. – Canada Task Force.

Photo & map source: CNN.com

Blackout Impacts were widespread…

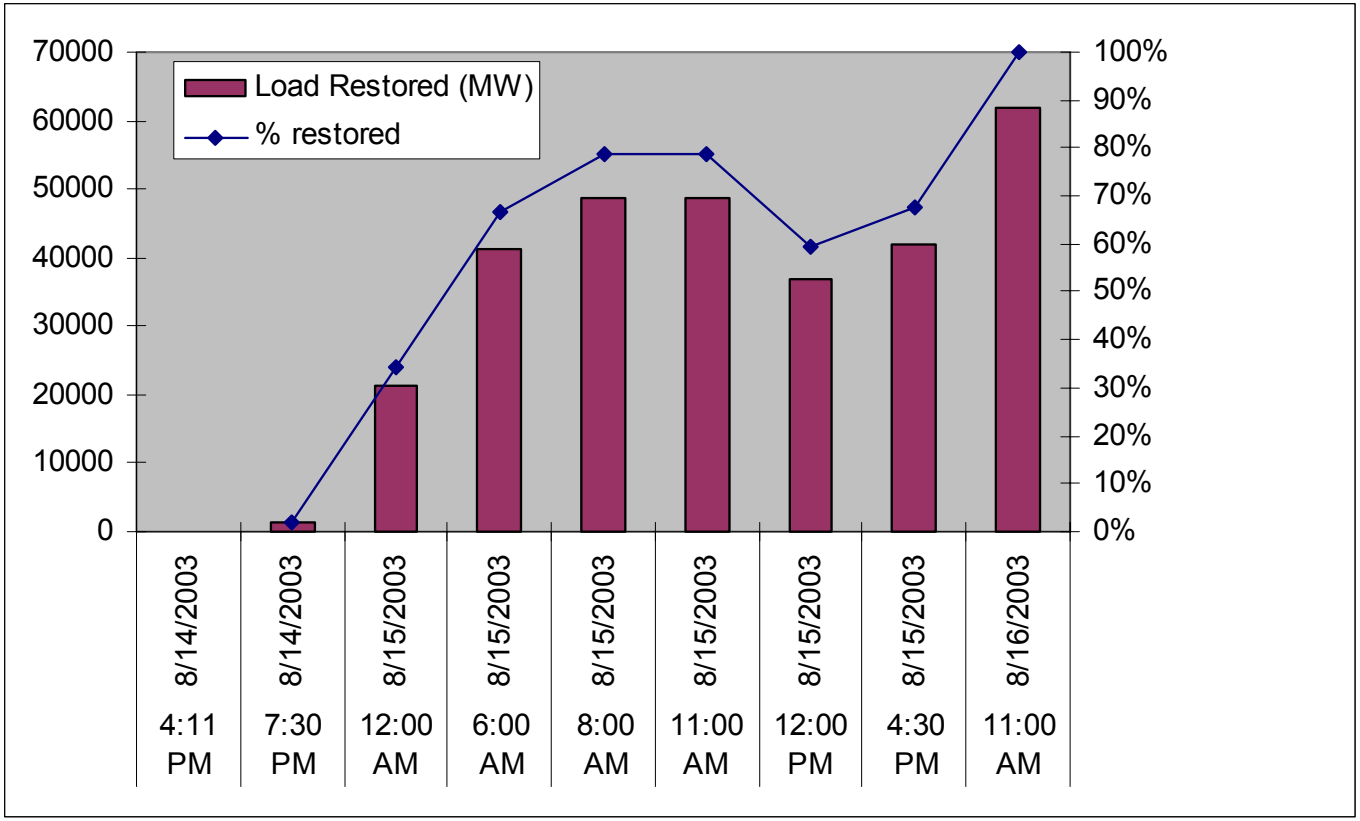
- **Transportation** Impacts included:
  - **Airports** – many airports suffered extended flight delays and temporary shutdowns (NY, Cleveland, Toronto)
  - **Subways** – it took 2-1/2 hours to evacuate passengers from stalled subway trains in NYC
  - **Commuter trains** stopped between NY & NJ. Ferries used as an alternate.
  - **Amtrak** stopped all trains leaving the NY area, and in Michigan
  - **Roadways** – traffic signals out, motorists advised to stay off roads.

Photos: CNN.com

Other Blackout Impacts Include…

- Slowdown of the Internet – servers in affected cities were down.
- "Boil-Water" orders were issued in Cleveland, Ohio and southeastern Michigan
- Lake Erie beaches (Cleveland, Ohio) closed due to sewage overflow.
- Additional ER visits in NYC hospitals for intestinal illness (diarrhea) related to consumption of spoiled food.

North American Electric Reliability Council (NERC) Reports Document Restoration



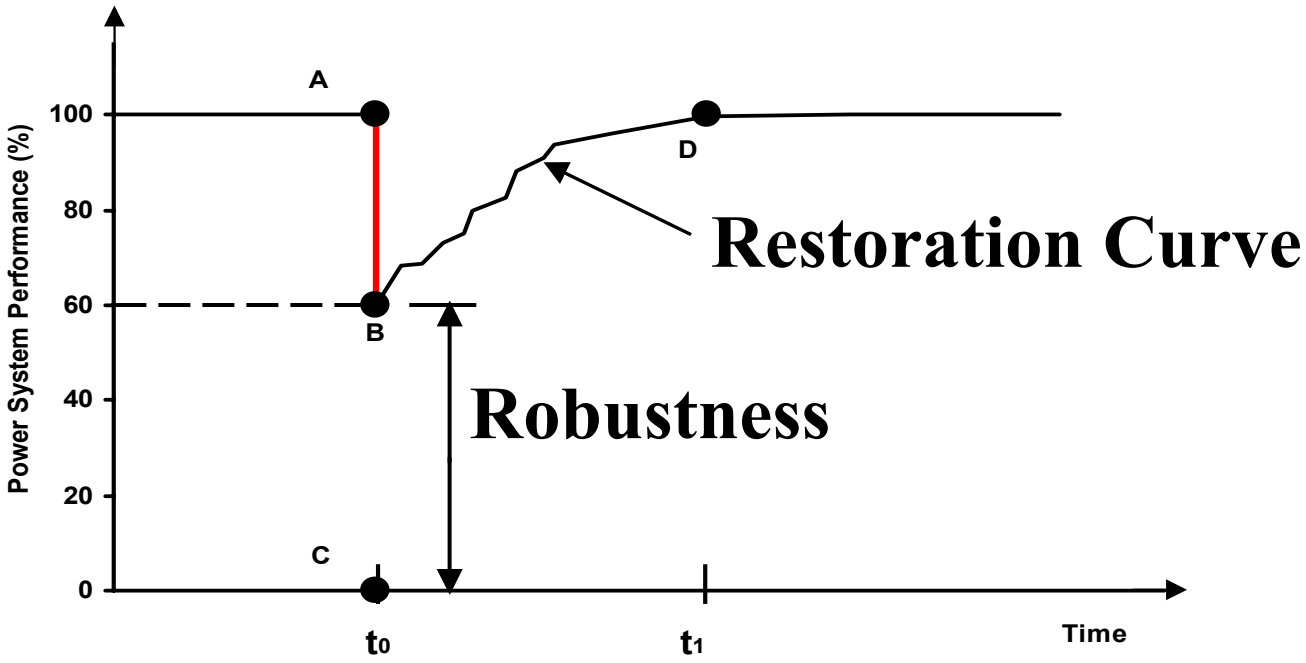
Load lost on August 14 includes:

- **PJM Interconnection (4,200 MW)**
- **Midwest ISO (13,000 MW)**
- **Hydro Quebec (100 MW)**
- **Ontario IMO (20,000 MW)**
- **ISO New Englanc (2,500 MW)**
- **New York ISO (22,000 MW)**

Total – 61,800 MW

Seismic Resilience of Power System

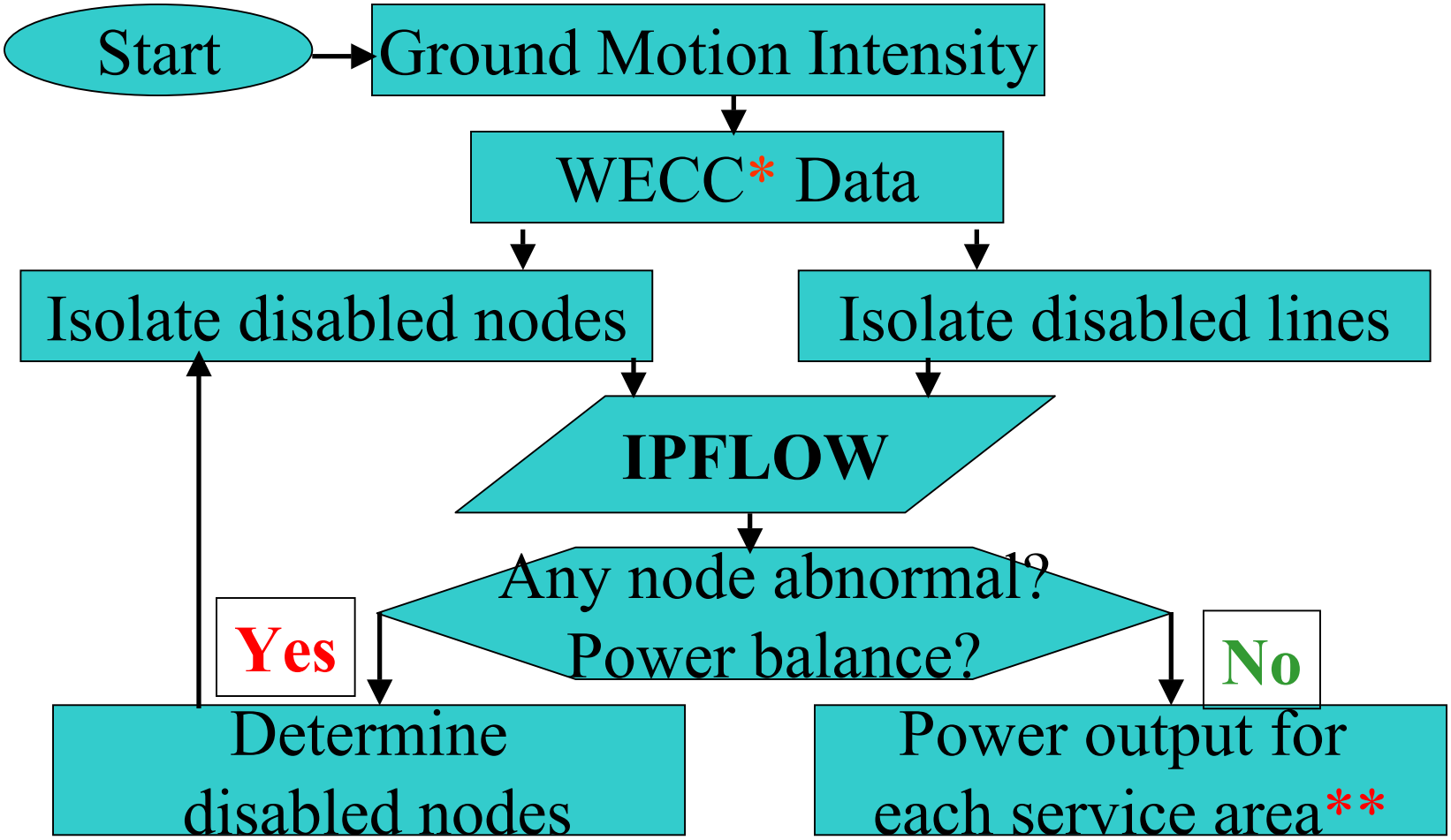
(Unique to Each Earthquake)



t_0 = Time at which an earthquake occurs

t_1 = Time at which power performance is restored 100%

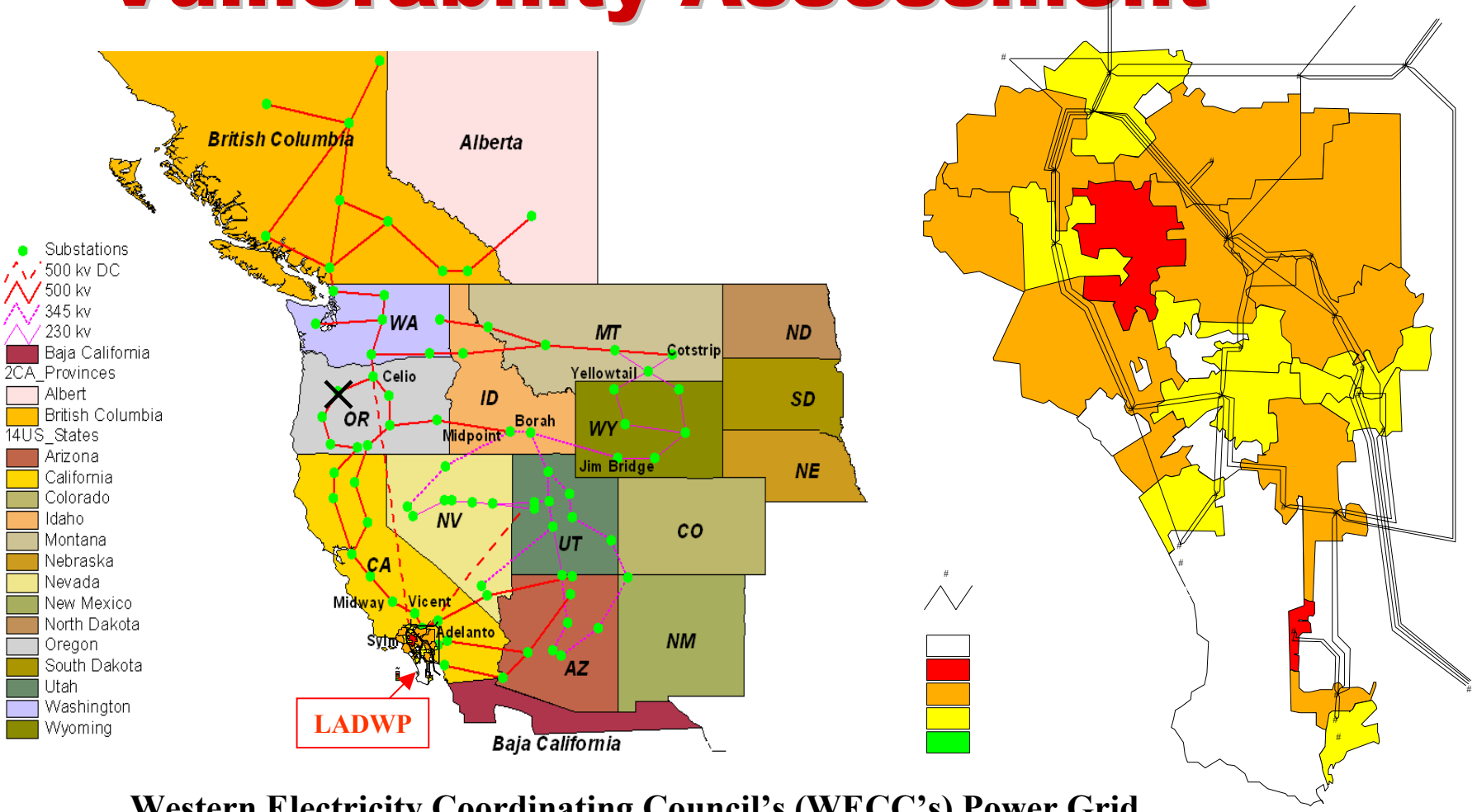
Analysis Flow Chart



* Western Electricity Coordinating Council

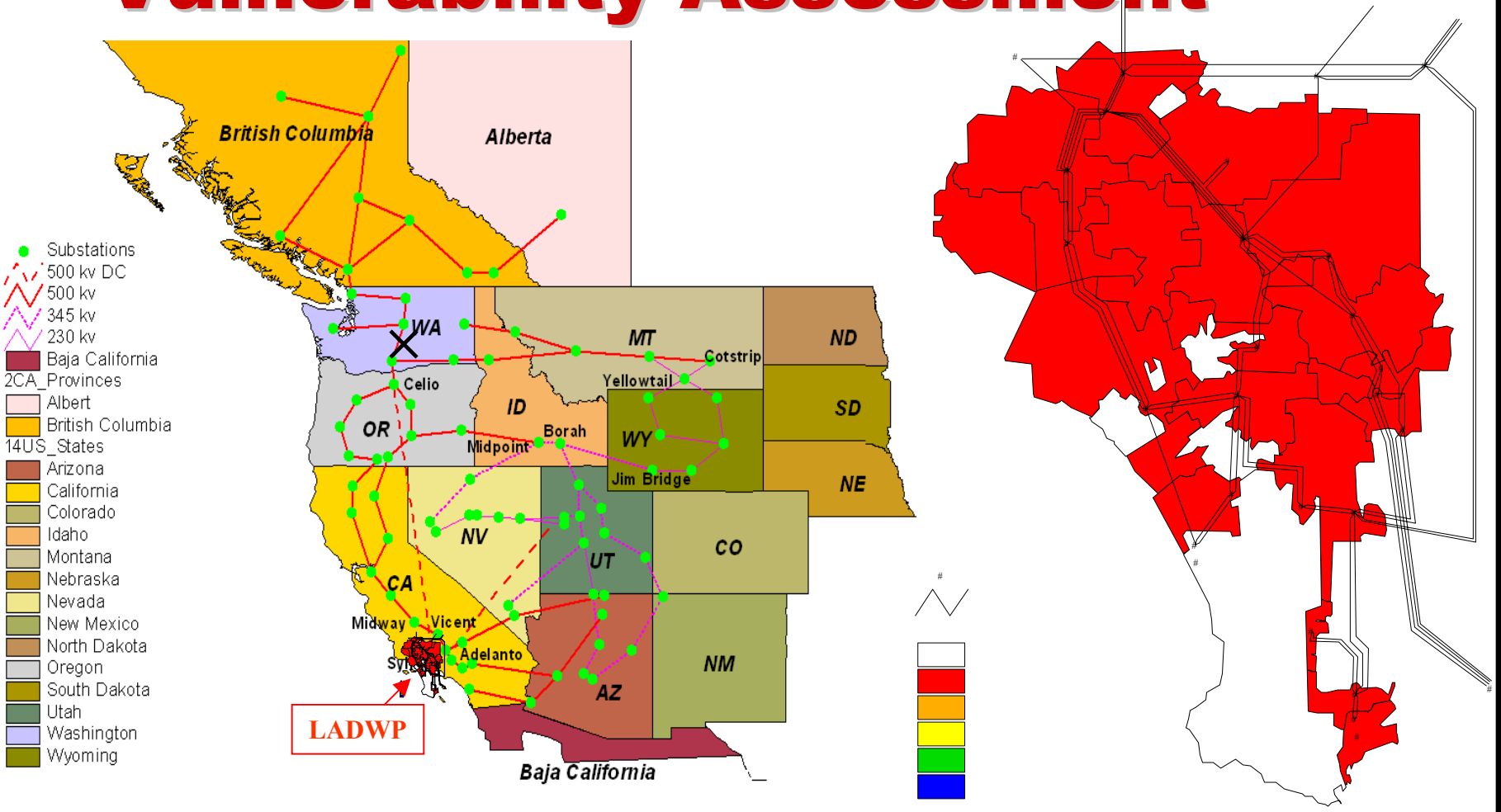
** Includes the case of system-wide blackout

Network Analysis for Vulnerability Assessment

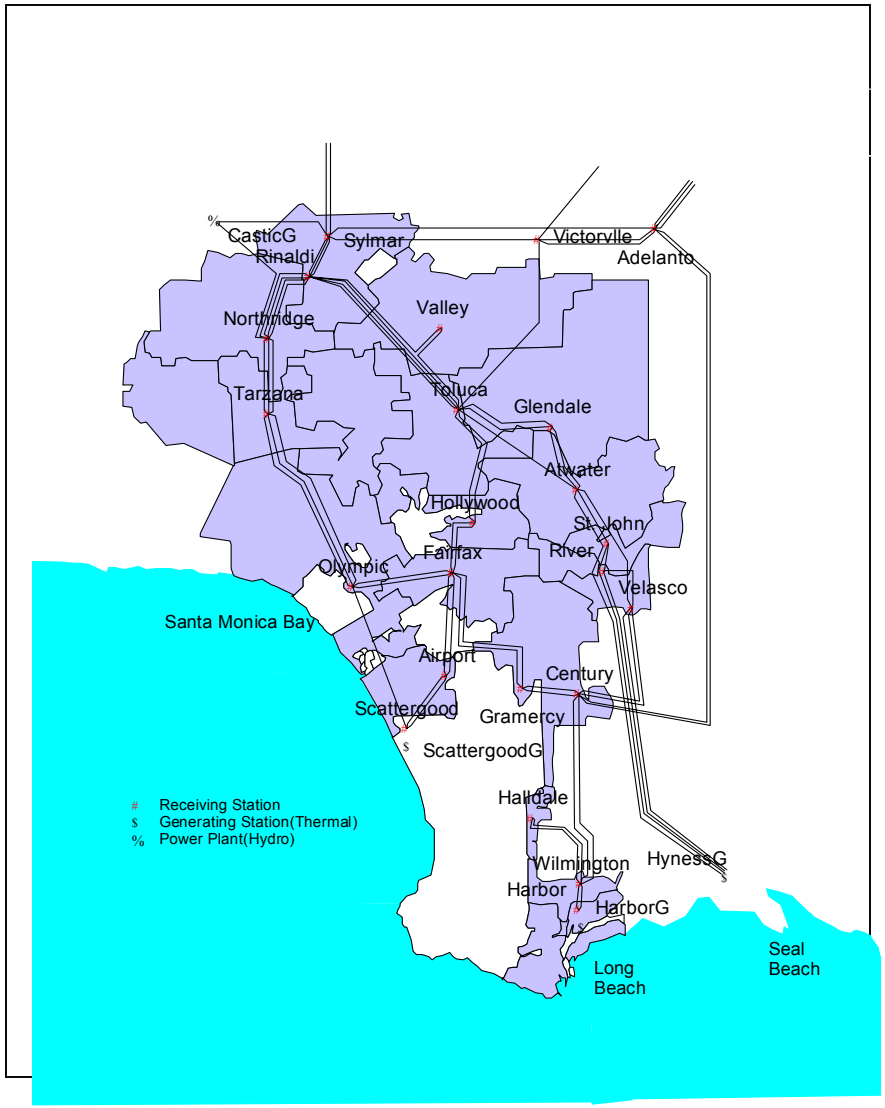


Western Electricity Coordinating Council's (WECC's) Power Grid

Network Analysis for Vulnerability Assessment

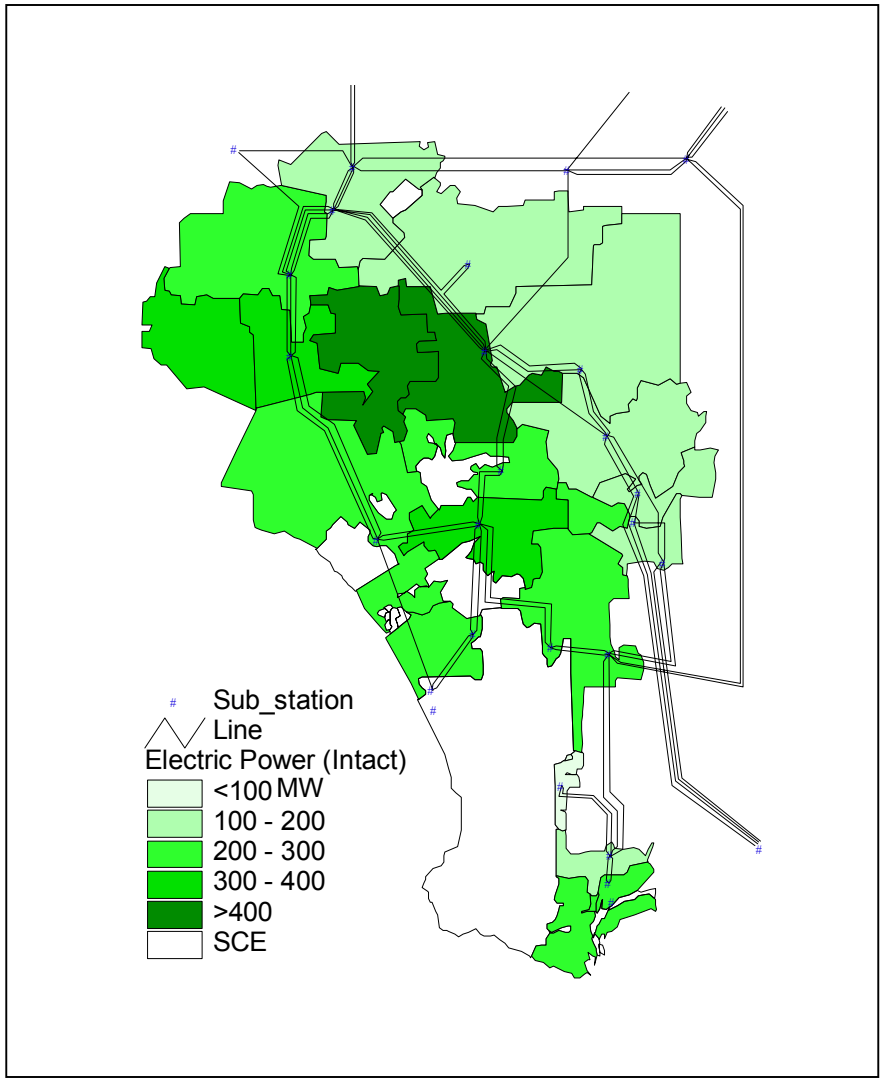


Seismic Vulnerability of LADWP's Transmission Network



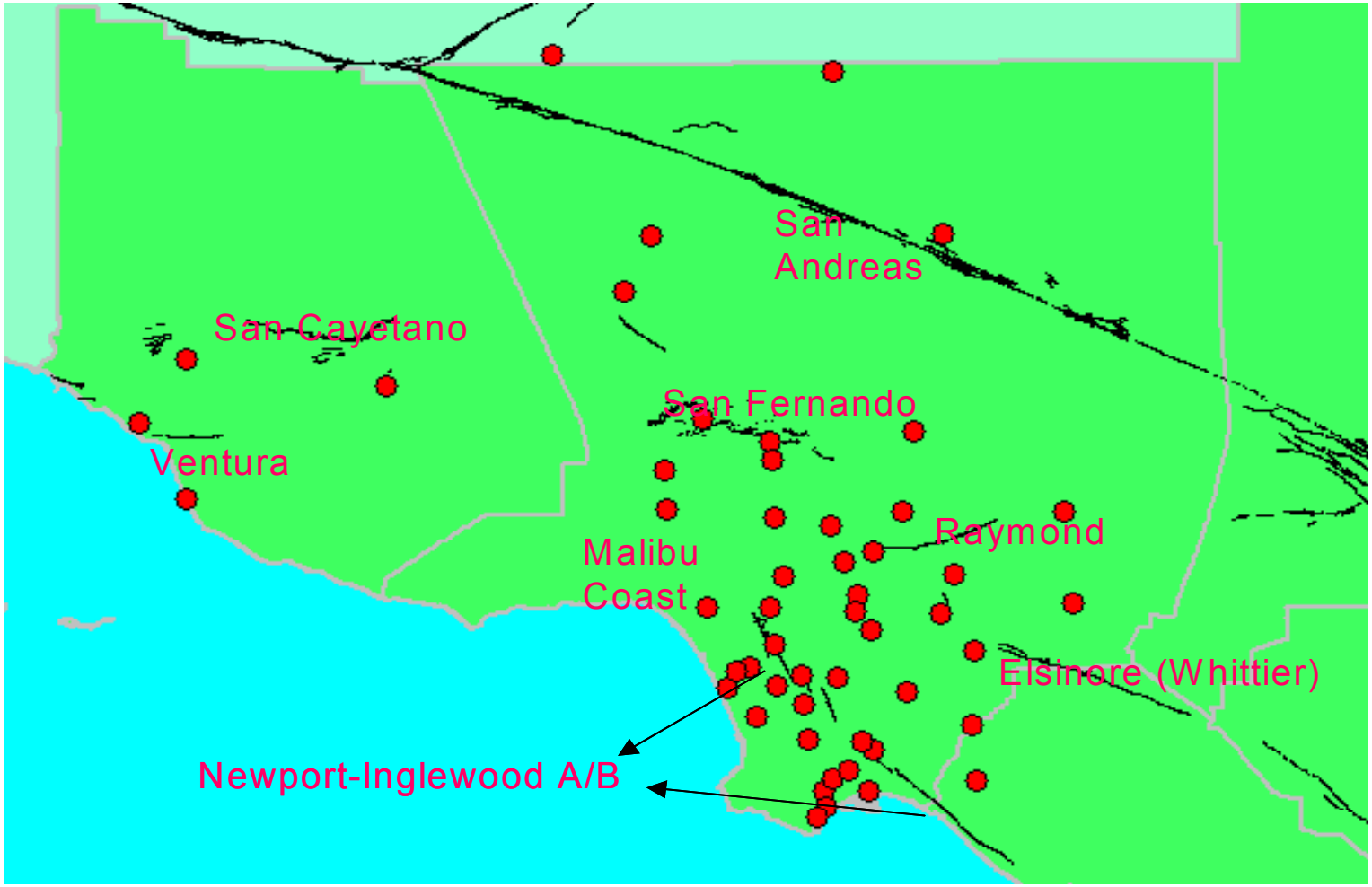
Part of Western Electricity Coordination Council's (WECC's) network covering 14 US western states, 2 Canadian provinces and northern part of Baja California

Electric Power Output for Service Areas under Intact Condition



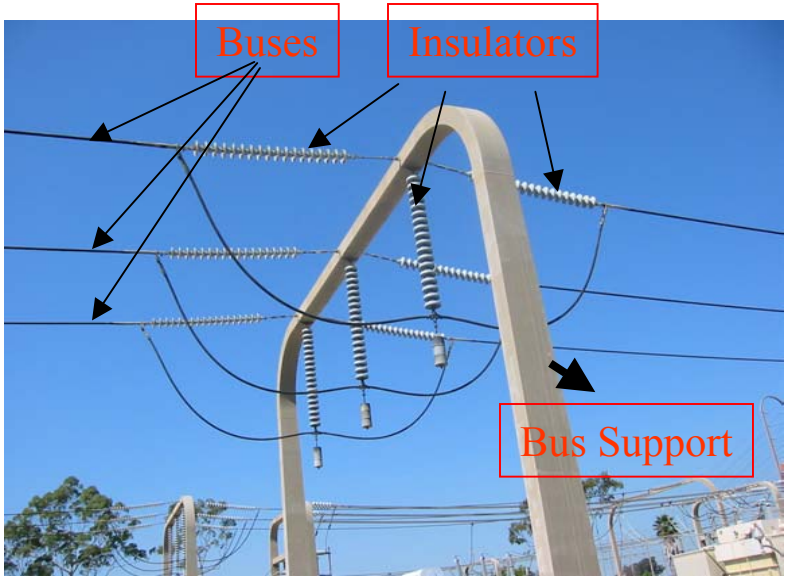
6,300 MW at a typical peak hour for a population of 3.7 million

Exposure and Hazards



500kV/230kV Transformer

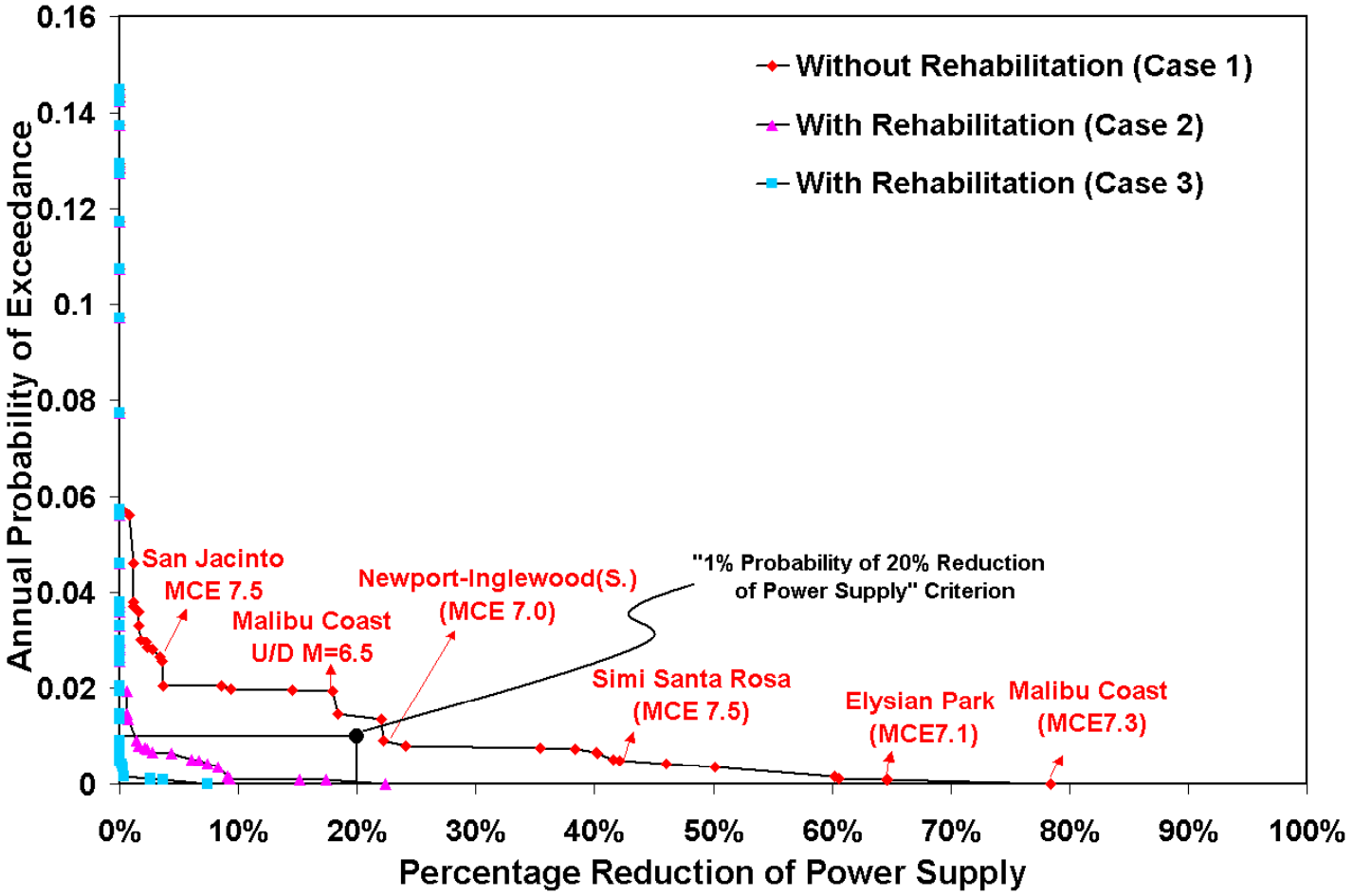
Bus



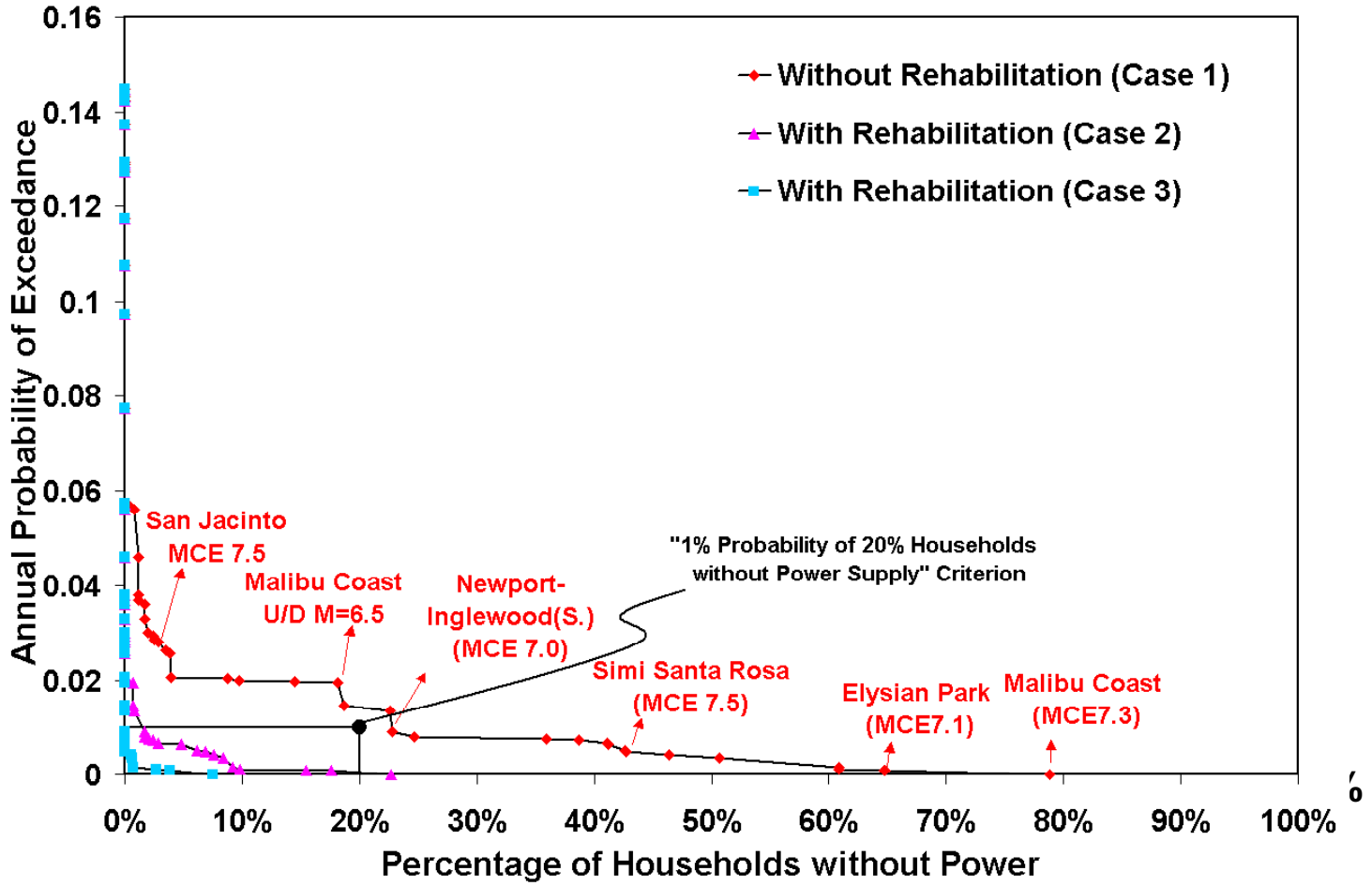
Circuit Breakers

Disconnect Switches

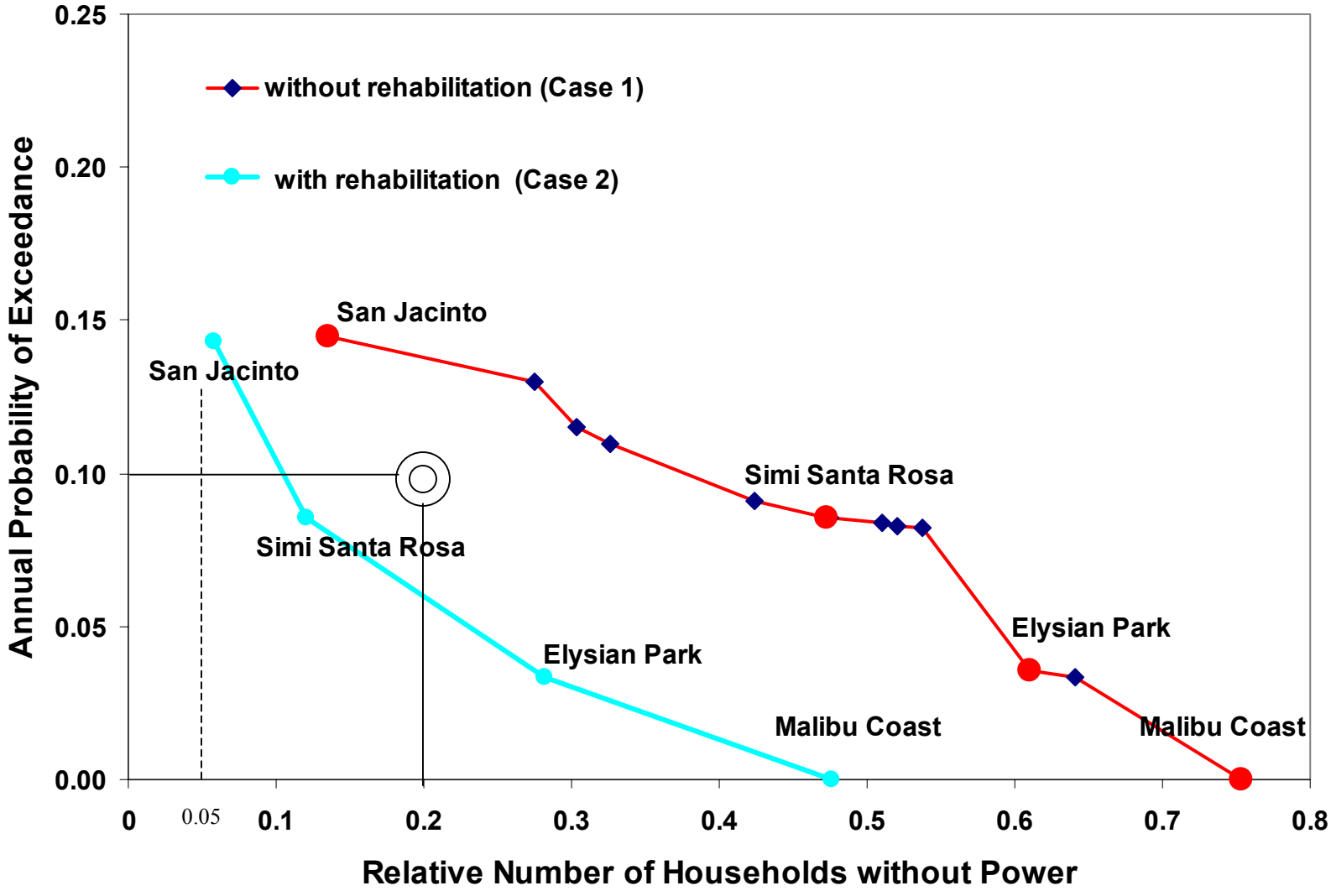
Risk Curves for Power Supply Reduction



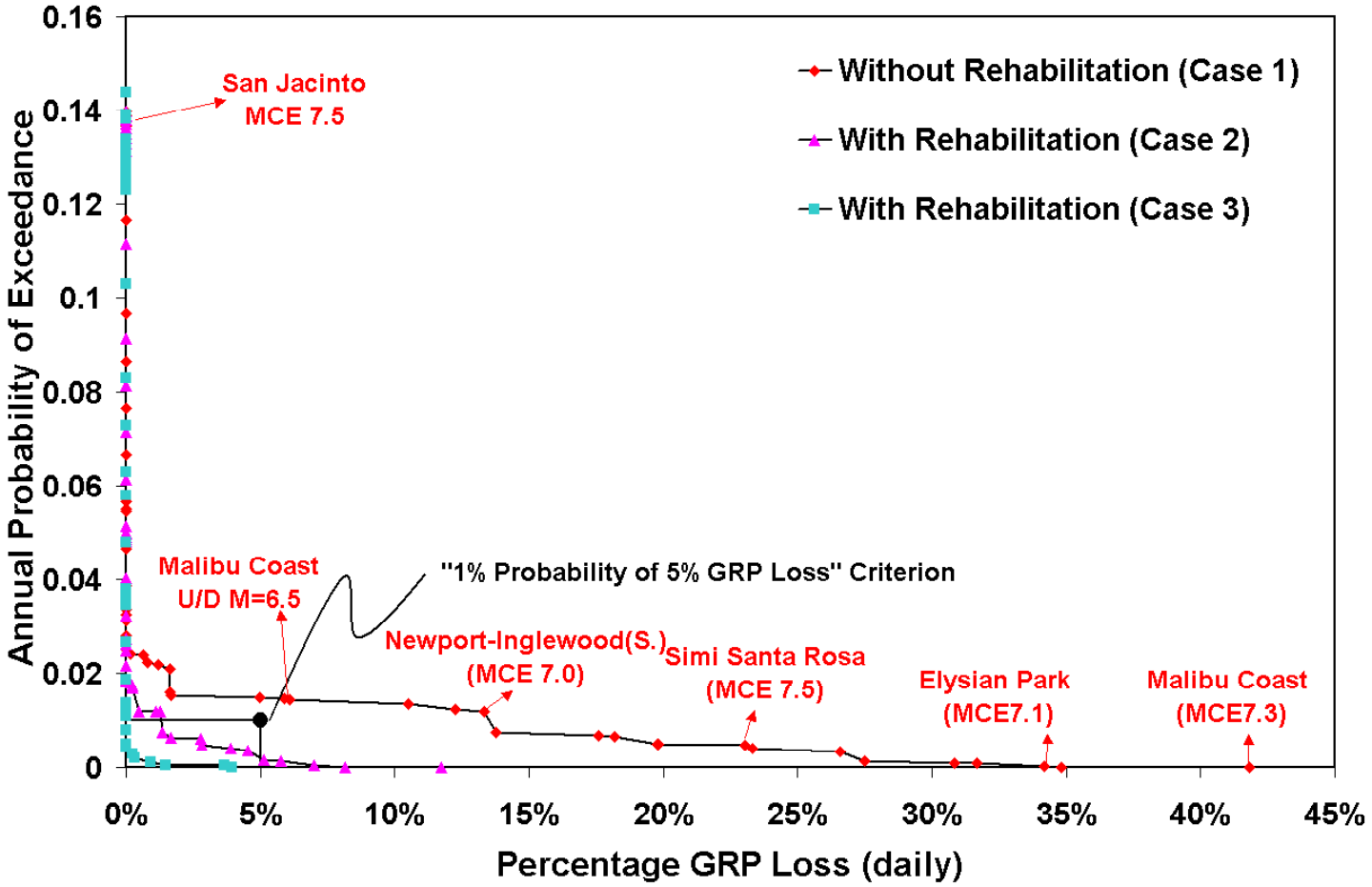
Risk Curves for Household Power Outage



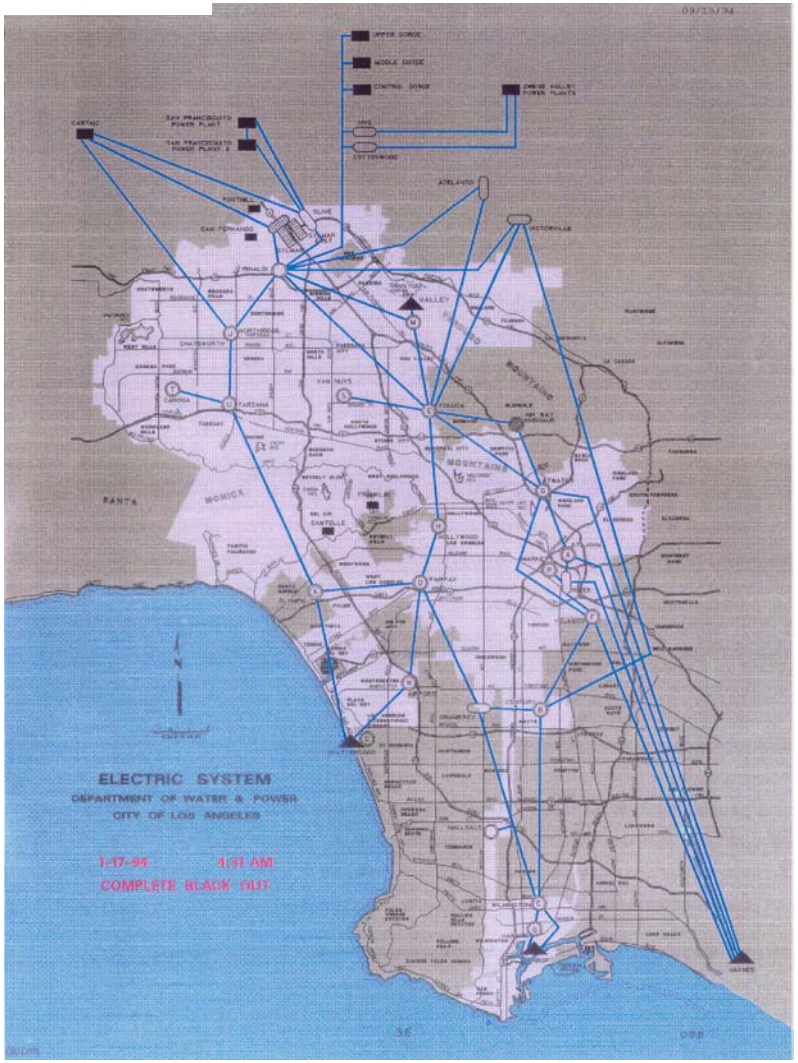
Seismic Risk Curves for LADWP Power Supply



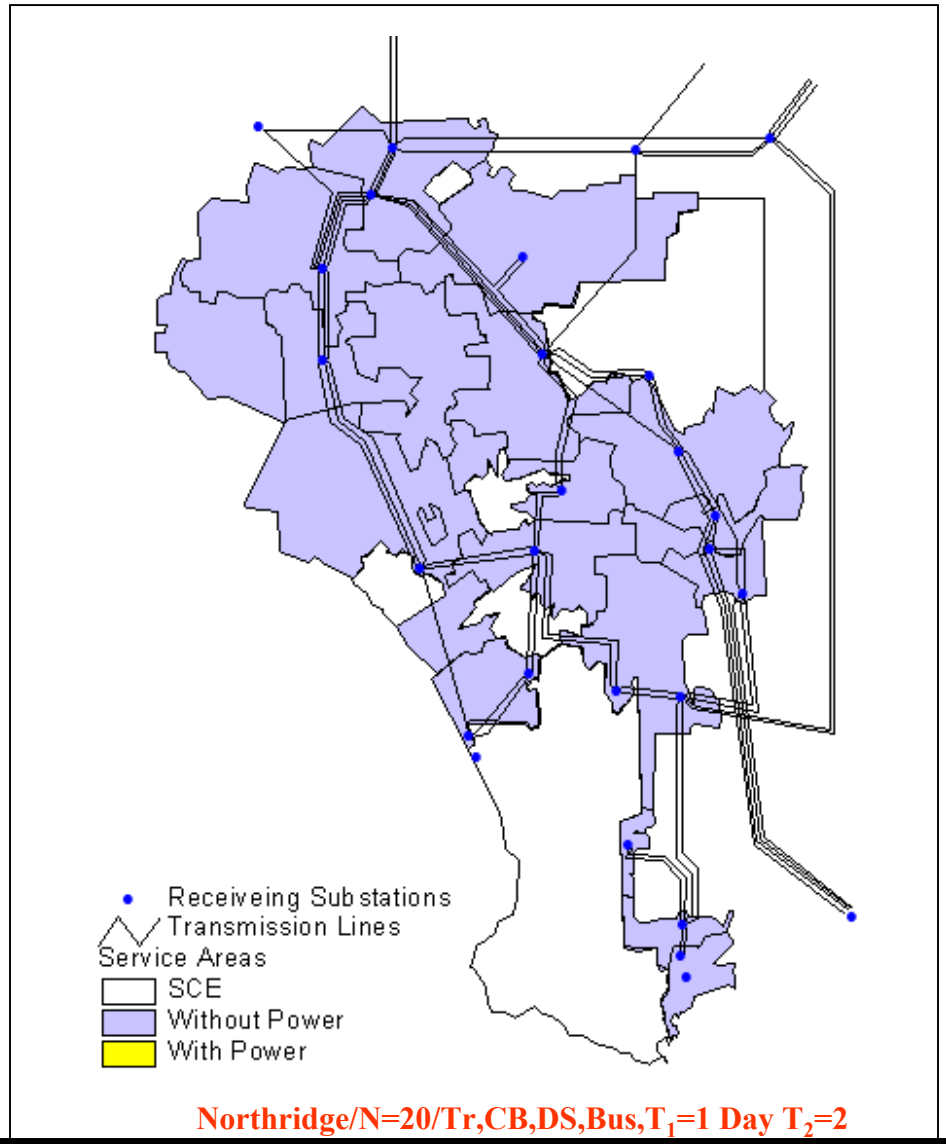
Risk Curve for Economic Loss



LADWP's Power Supply Immediately after Earthquake

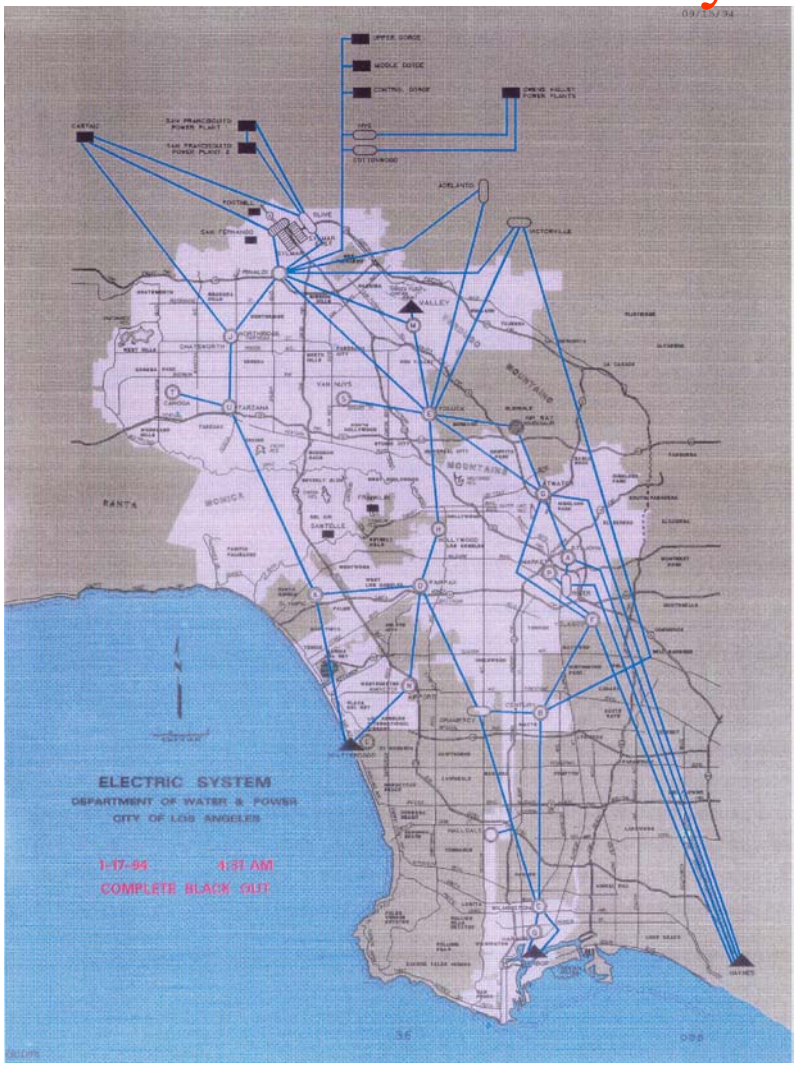


1-17-94 4:31AM

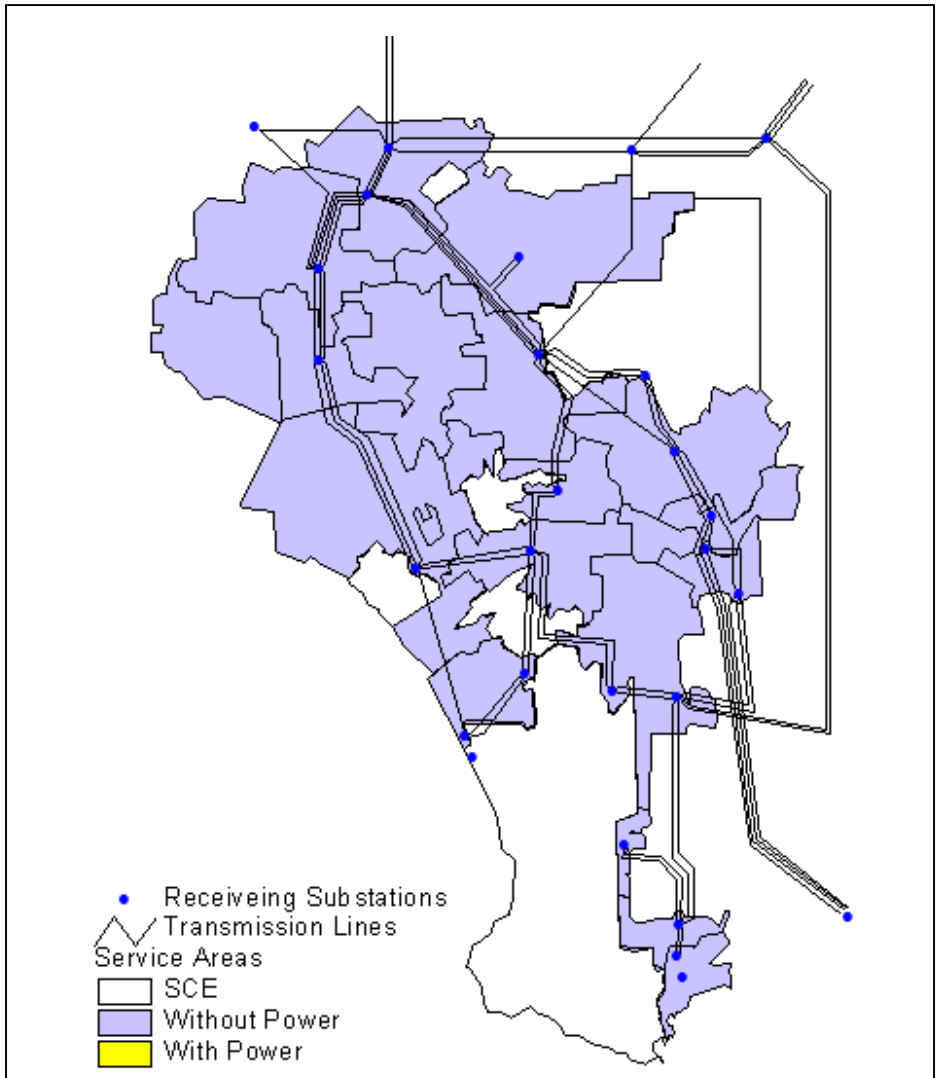


Northridge/N=20/Tr,CB,DS,Bus,T_1=1 Day T_2=2

LADWP's Power Supply Immediately after Earthquake

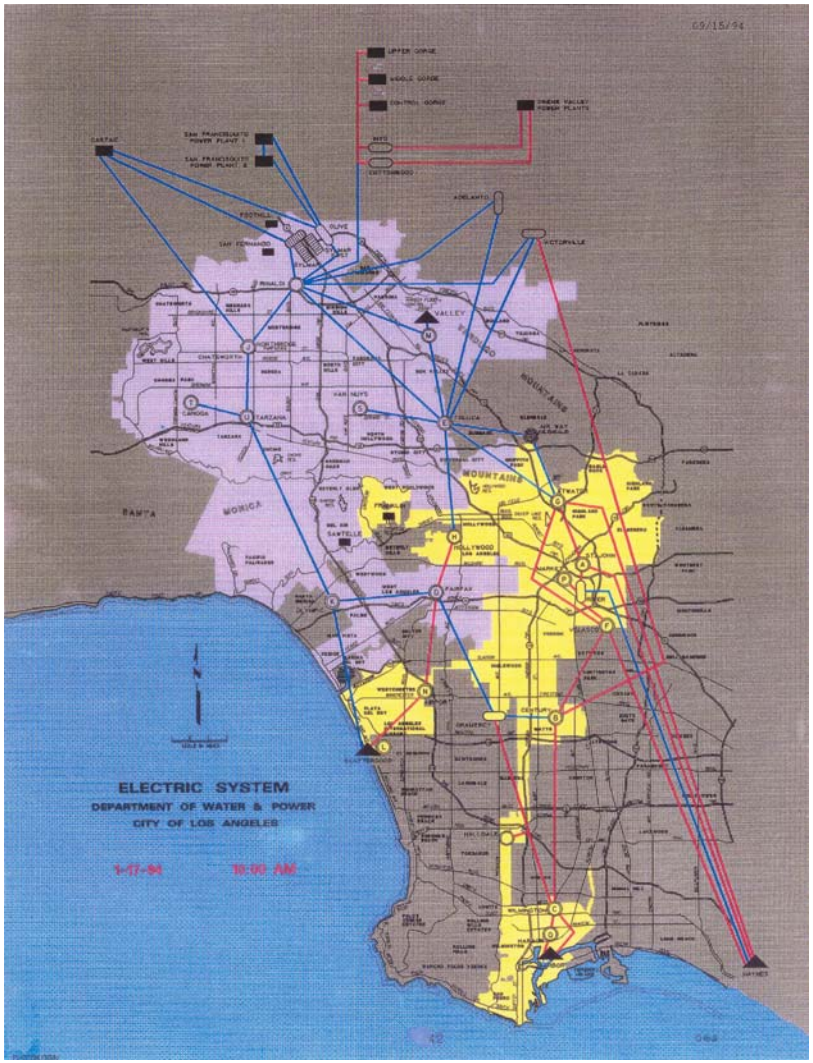


1-17-94 4:31AM

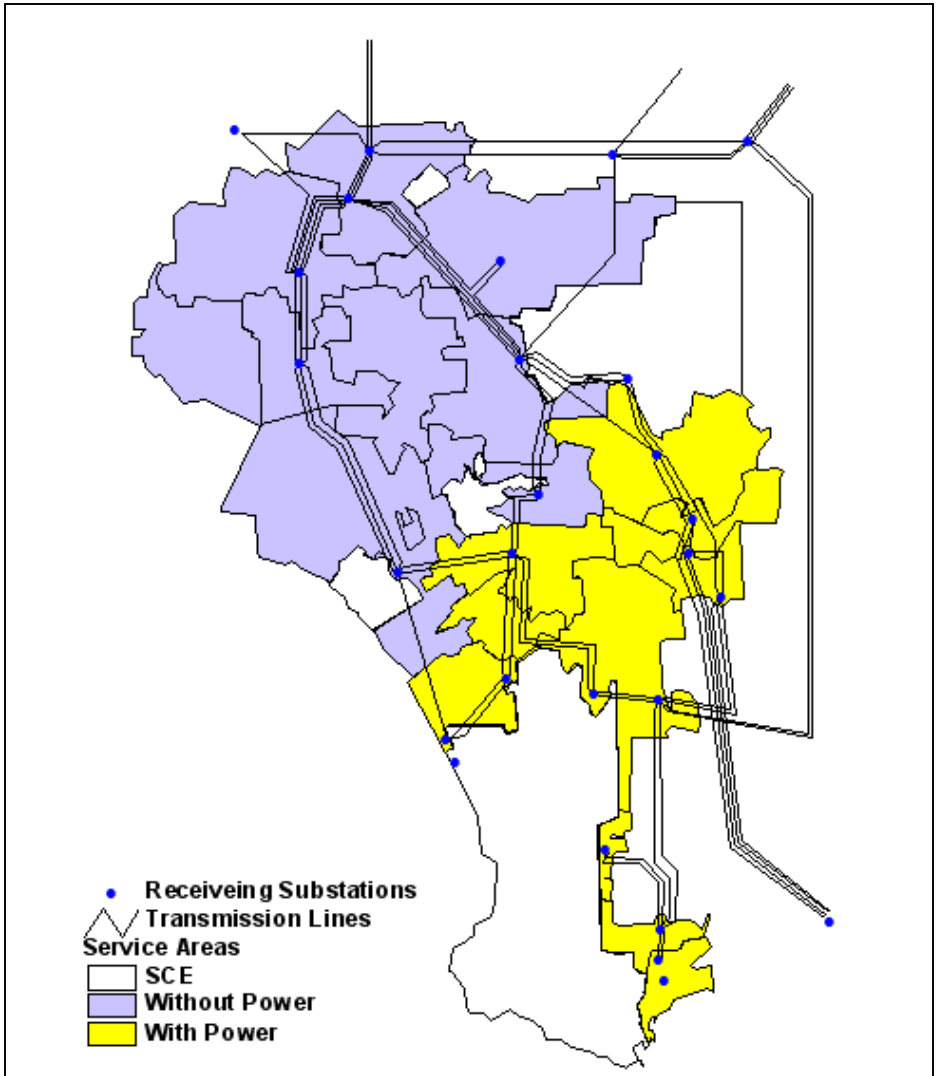


Northridge/N=20/Tr,CB,DS,Bus,T_1=1 Day T_2=2 Days

LADWP's Power Restoration
6 Hours after Earthquake

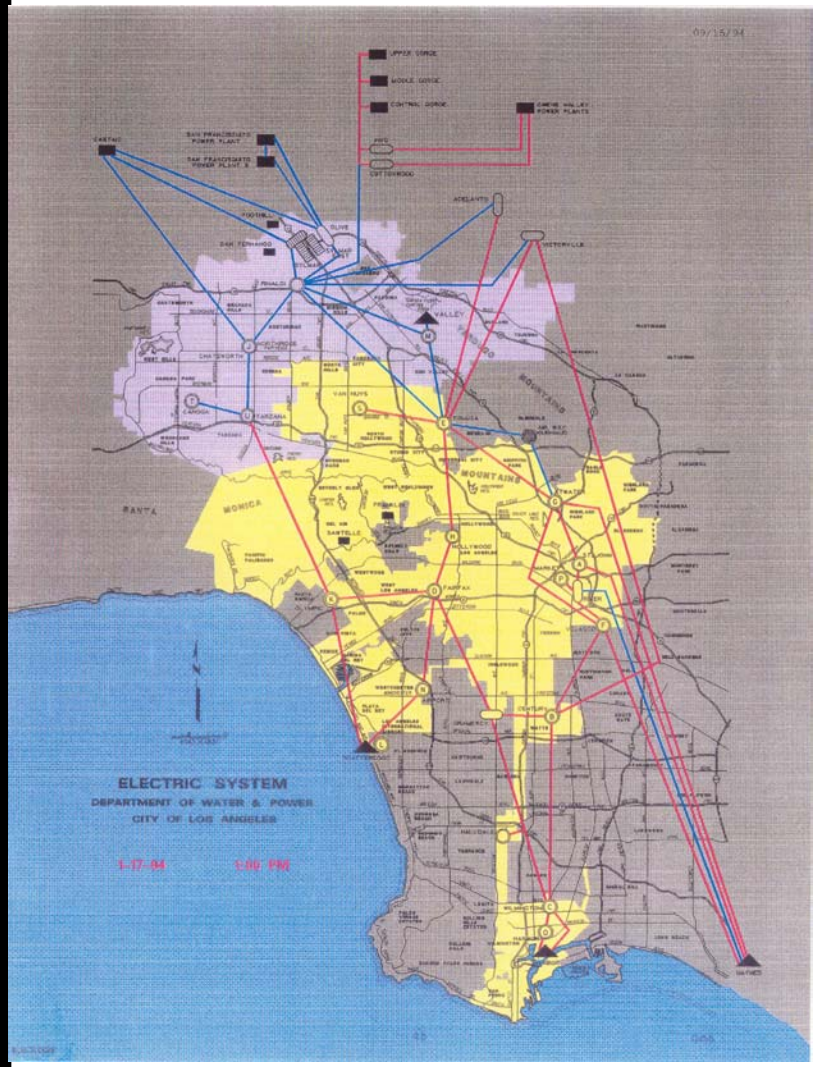


1-17-94 10:00 AM

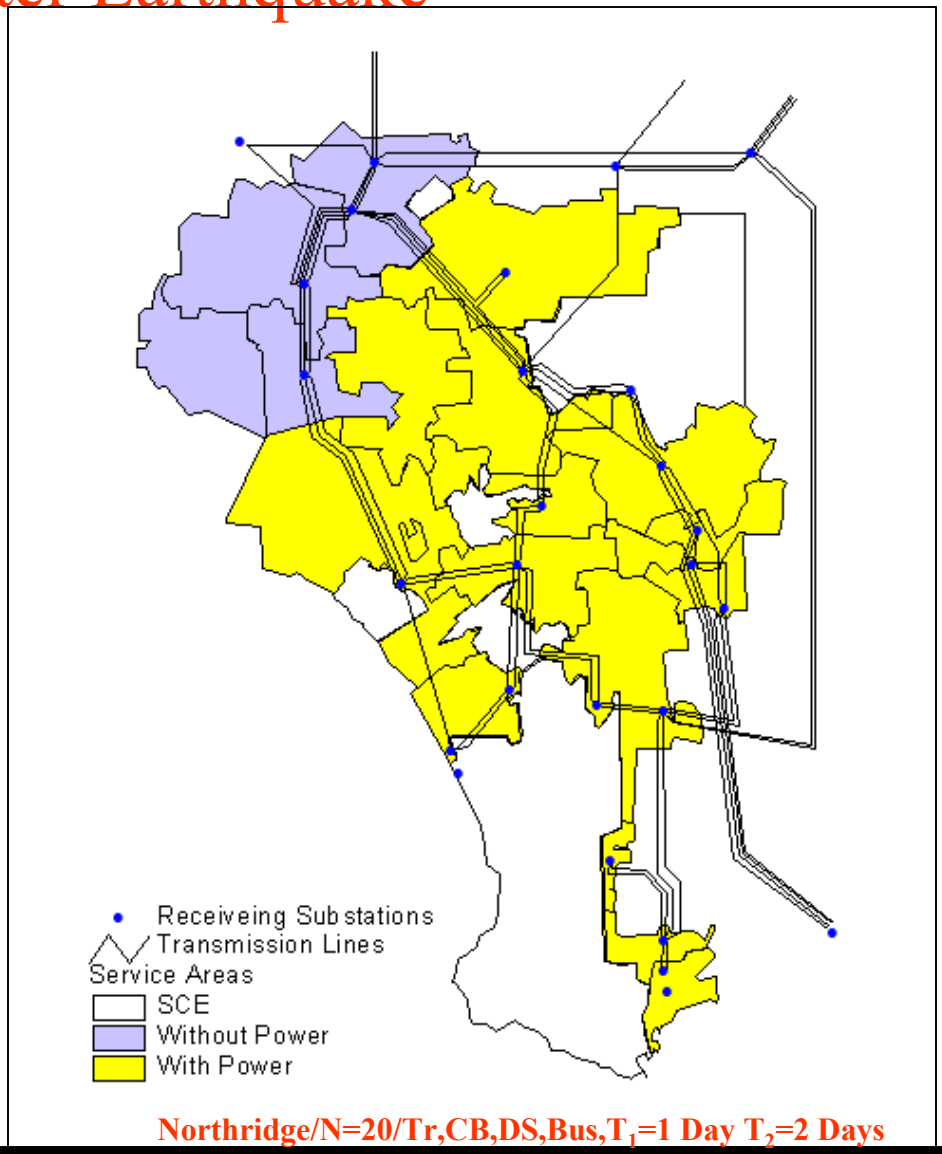


Northridge/N=20/Tr,CB,DS,Bus,T_1=1 Day T_2=2 Days

LADWP's Power Restoration
12 Hours after Earthquake

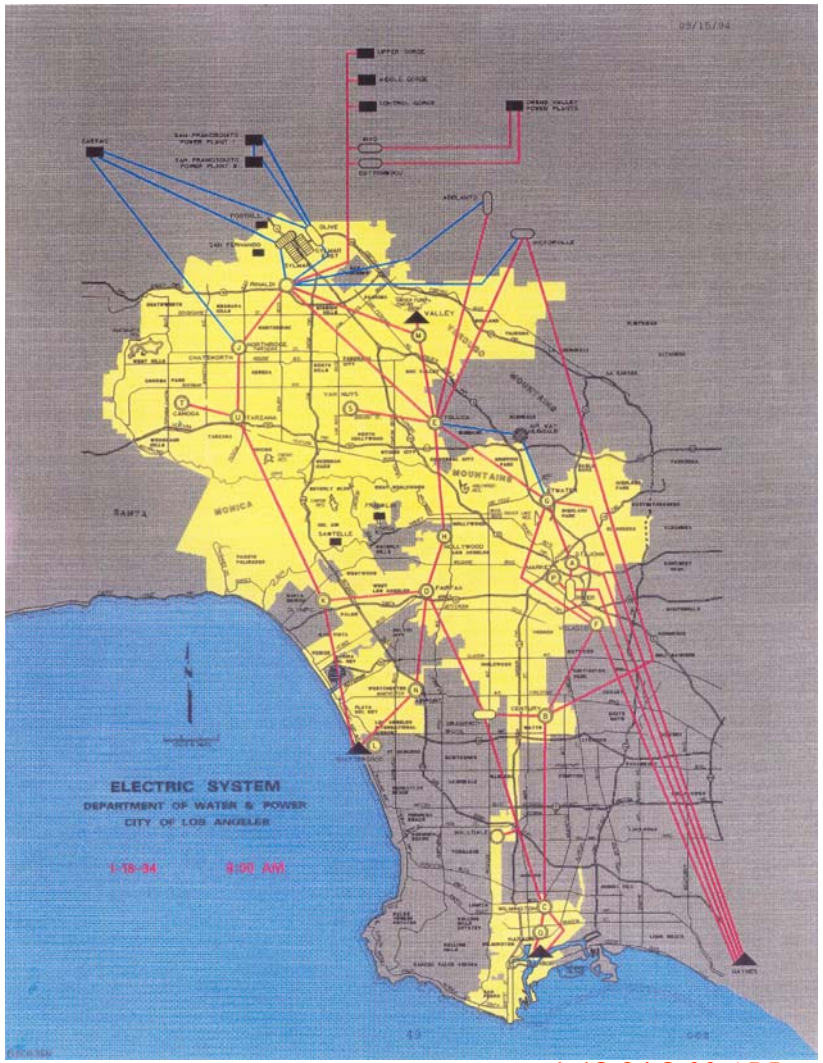


1-17-94 1:00 PM

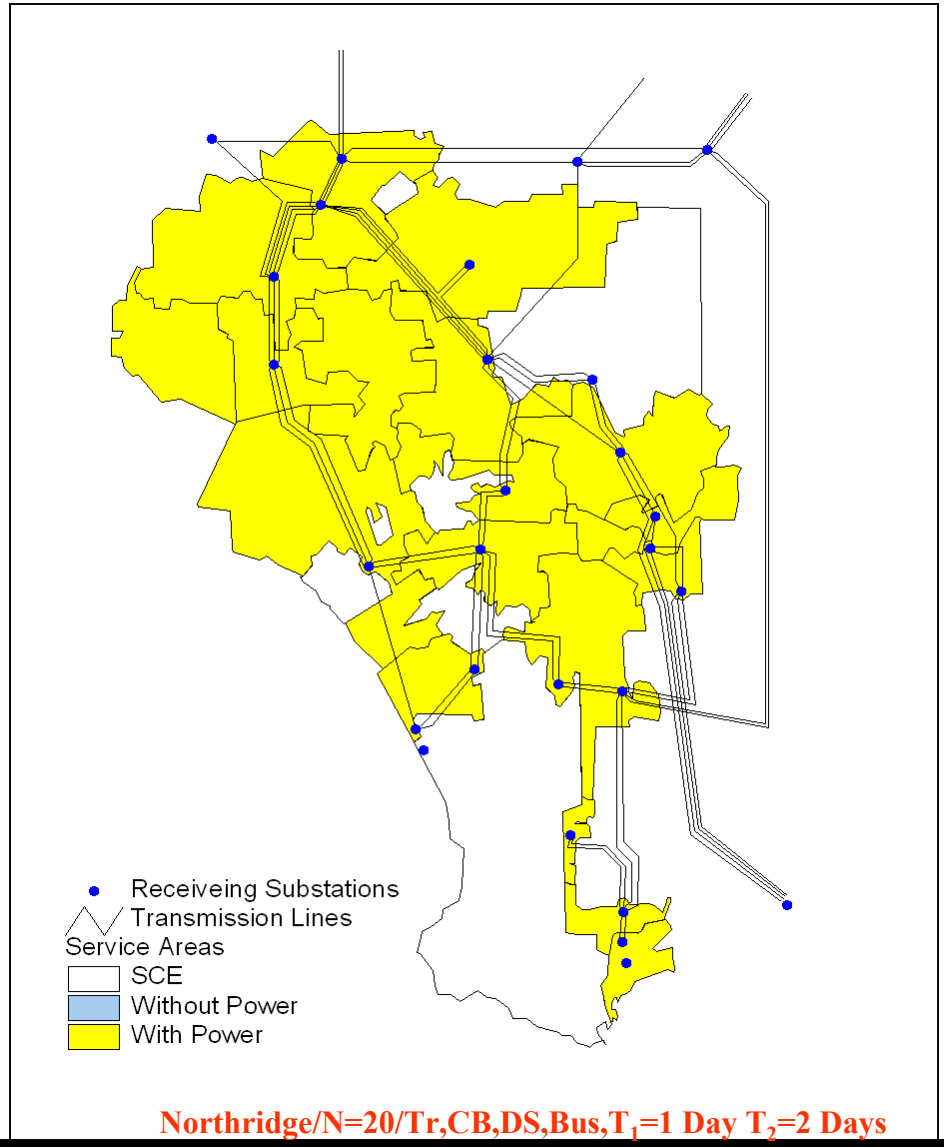


Northridge/N=20/Tr,CB,DS,Bus,T_1=1 Day T_2=2 Days

LADWP's Power Restoratione
24 Hour after Earthquake

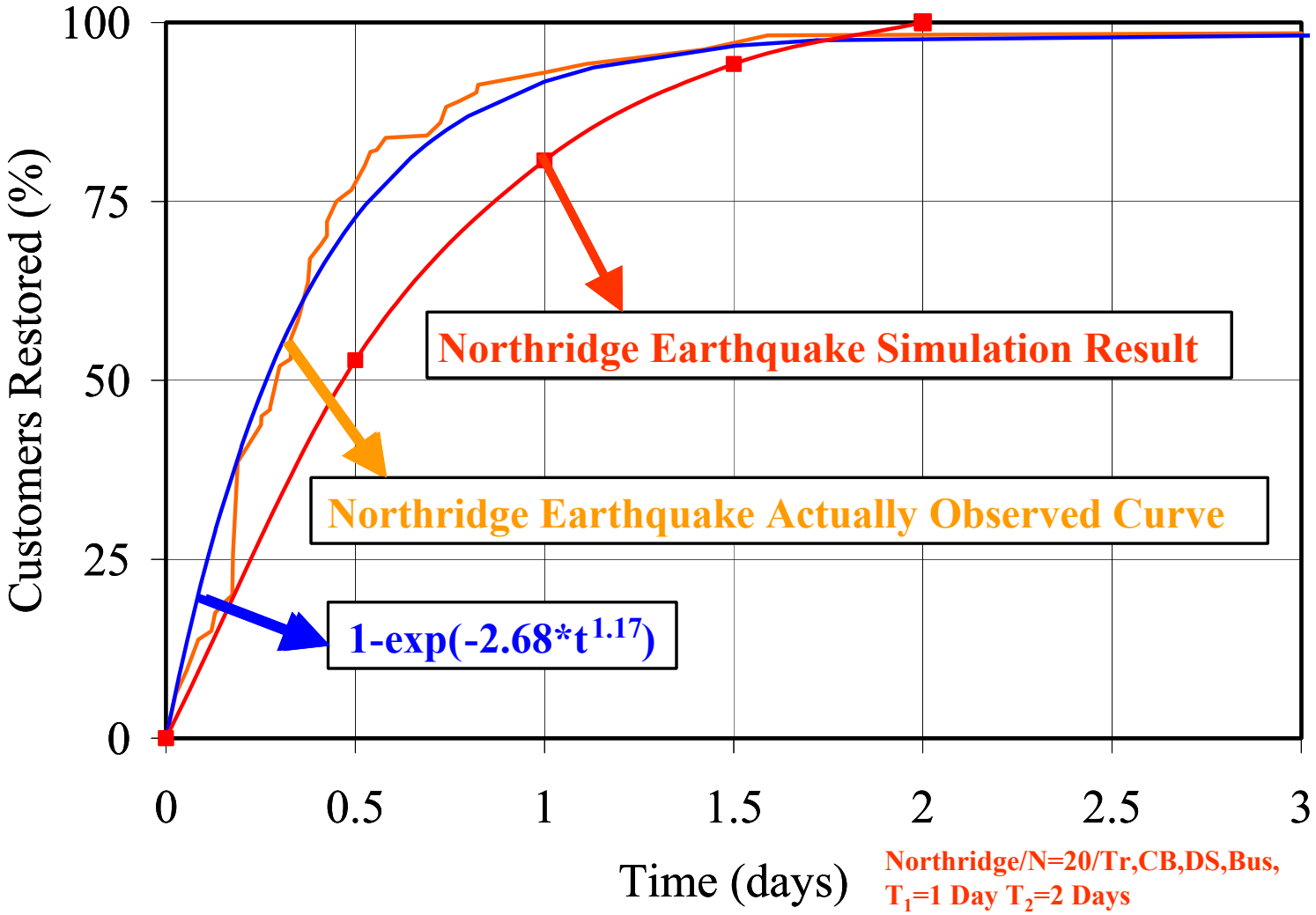


1-18-94 8:00 AM



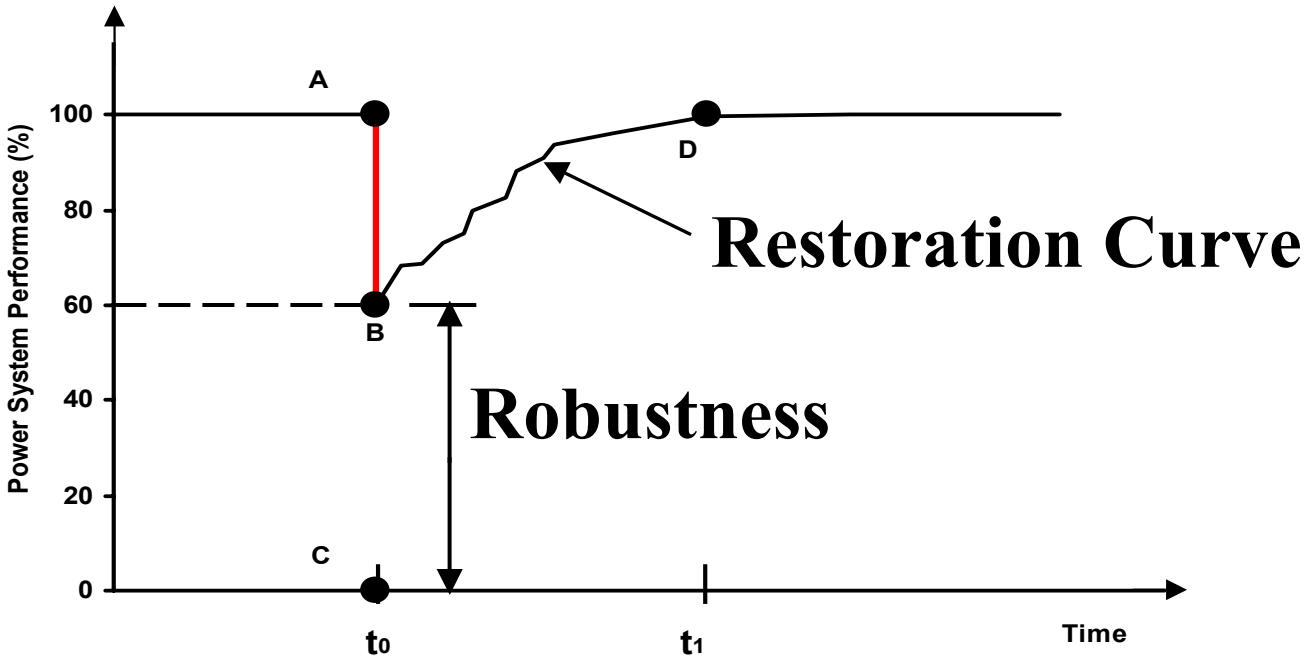
Northridge/N=20/Tr,CB,DS,Bus,T_1=1 Day T_2=2 Days

LADWP's Power System Customers Restored versus Time



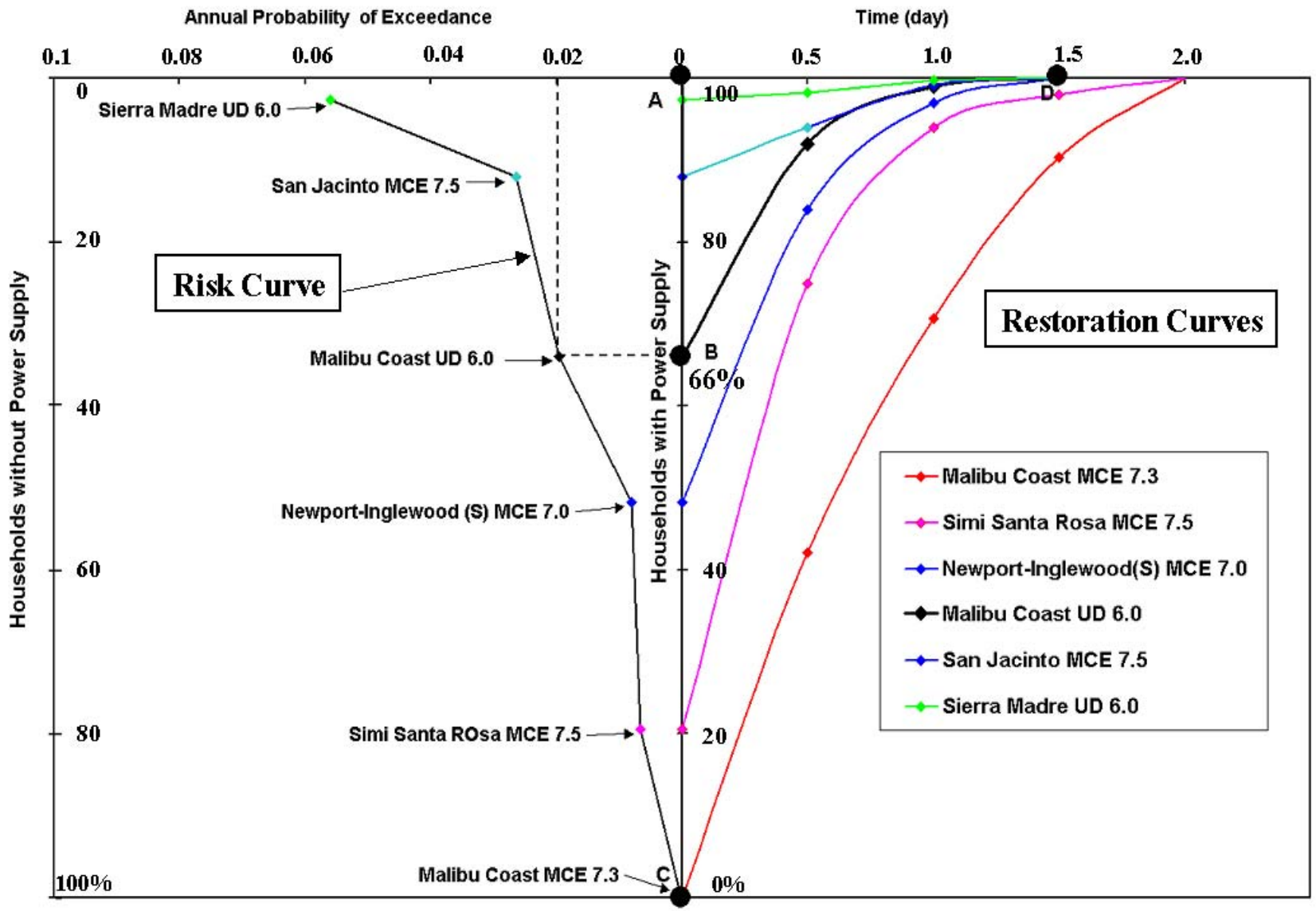
Seismic Resilience of Power System

(Unique to Each Earthquake)



t_0 = Time at which an earthquake occurs

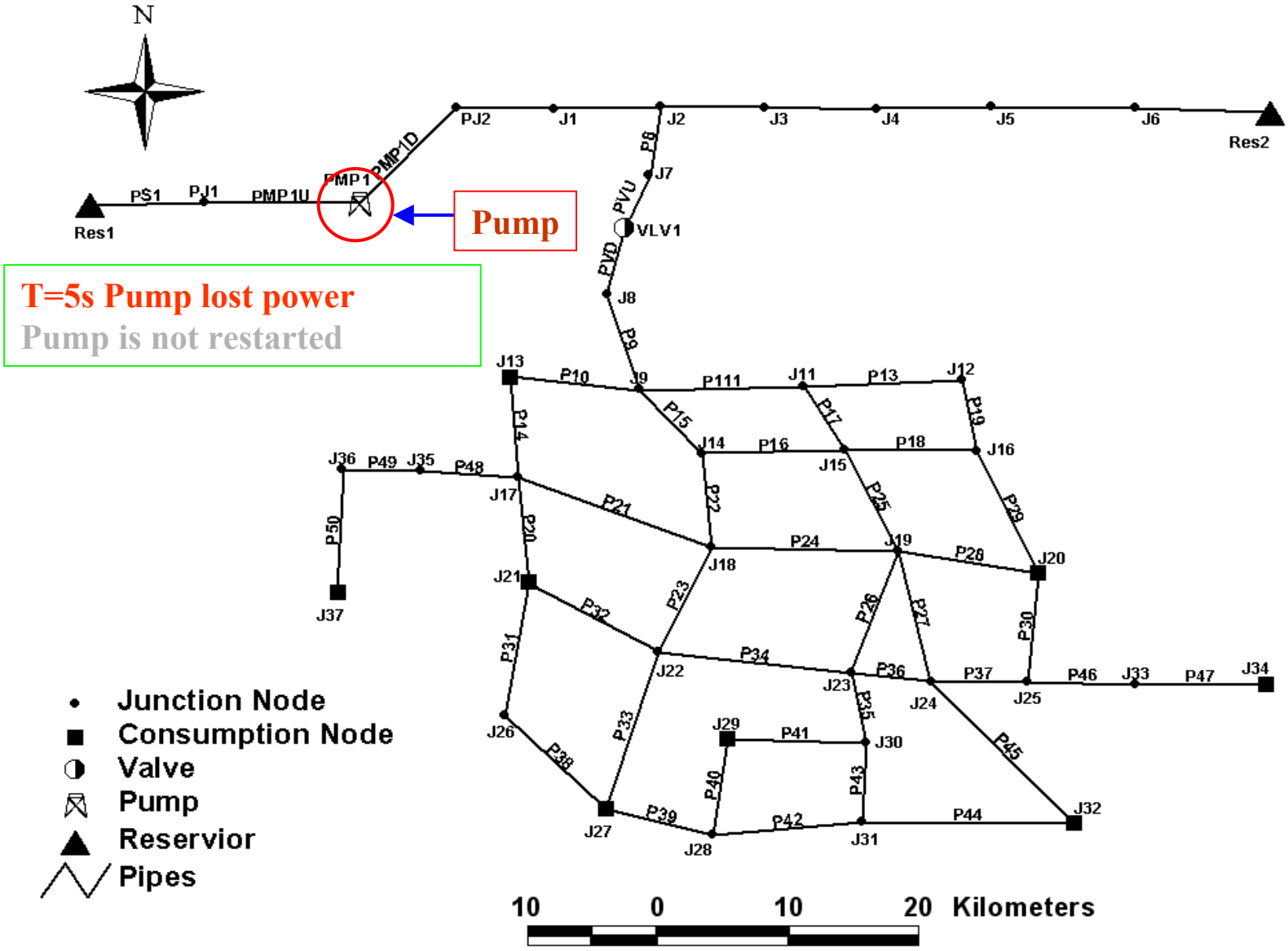
t_1 = Time at which power performance is restored 100%


Annual Probability of Exceedance
0.1
0.08
0.06
0.04
0.02
0
Households without Power Supply
0
20
40
60
80
100%
Sierra Madre UD 6.0
San Jacinto MCE 7.5
Risk Curve
Malibu Coast UD 6.0
Newport-Inglewood (S) MCE 7.0
Simi Santa ROsa MCE 7.5
Malibu Coast MCE 7.3
C
Time (day)
0
0.5
1.0
1.5
2.0
A
D
B
66%
Households with Power Supply
100
80
40
20
0%
Restoration Curves
Malibu Coast MCE 7.3
Simi Santa Rosa MCE 7.5
Newport-Inglewood(S) MCE 7.0
Malibu Coast UD 6.0
San Jacinto MCE 7.5
Sierra Madre UD 6.0

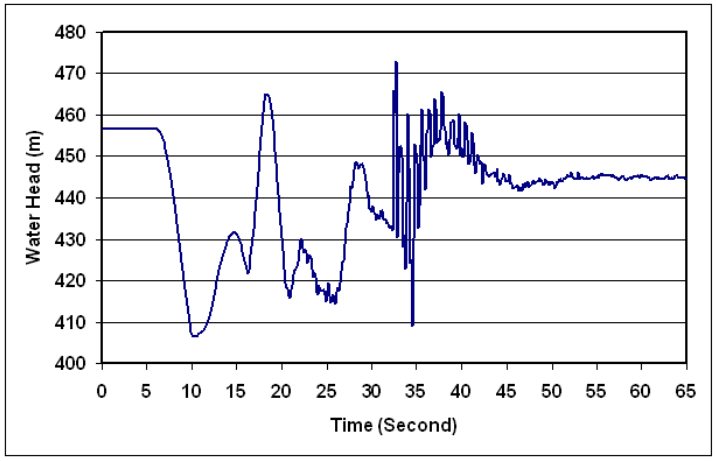
- System Interaction

  - Transient Behavior of Water Delivery Network under Sudden Blackout

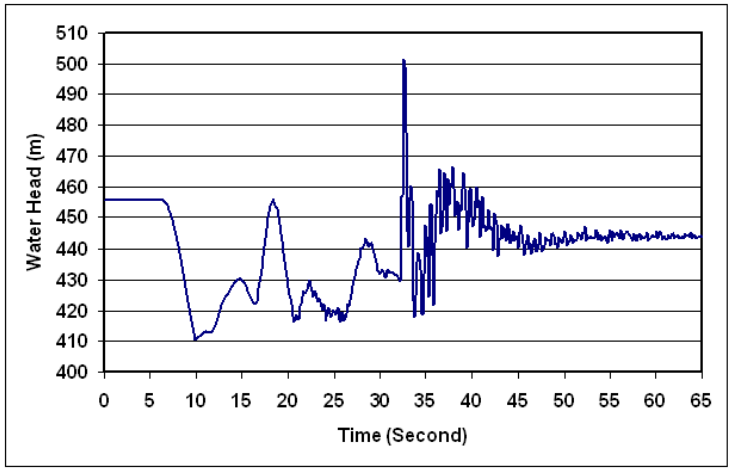
Hydraulic Analysis Results: Pump Loses Power



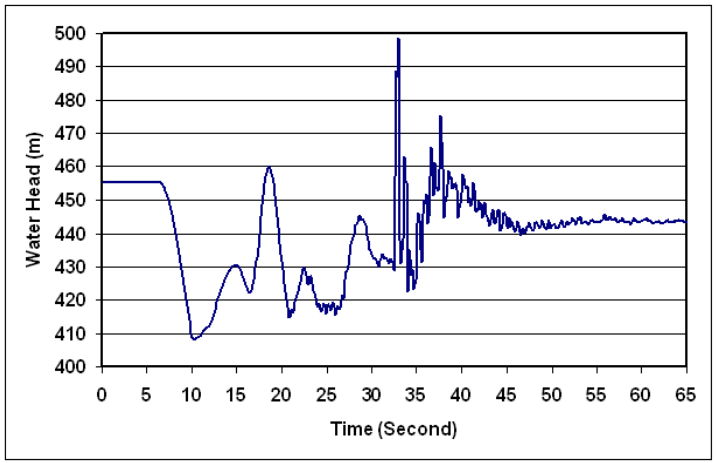
Nodal Water Head Time Histories; Emergency Power Fails



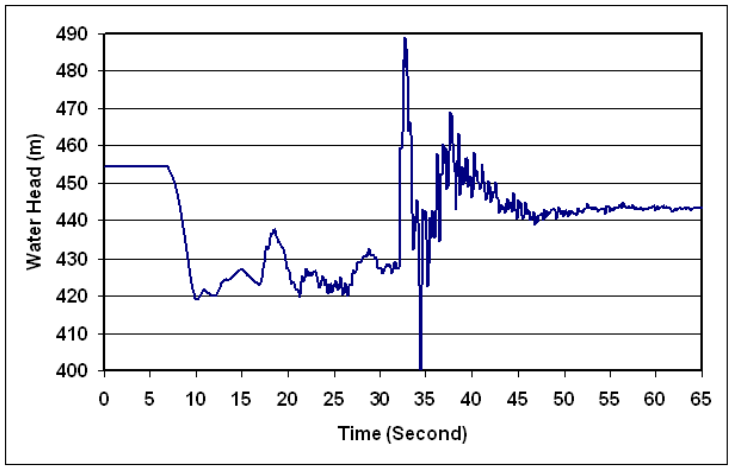
J9



J11

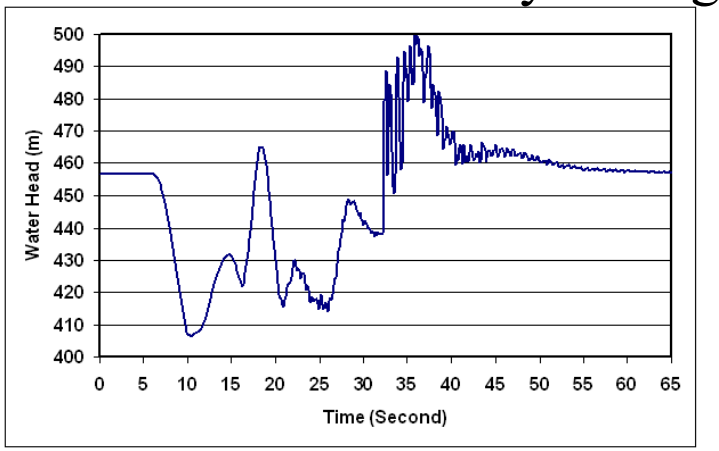


J13

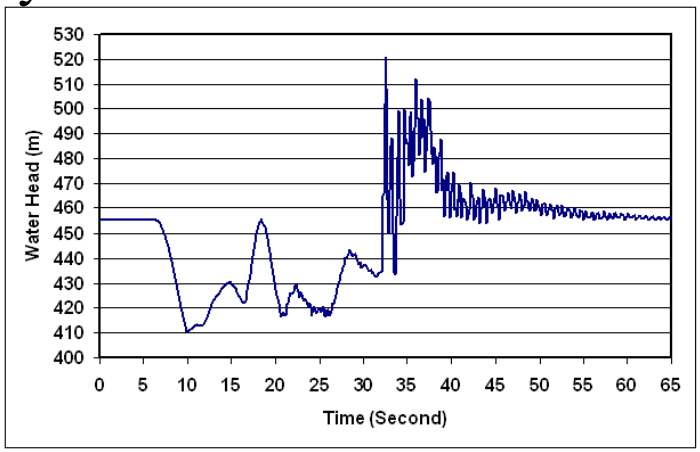


J20

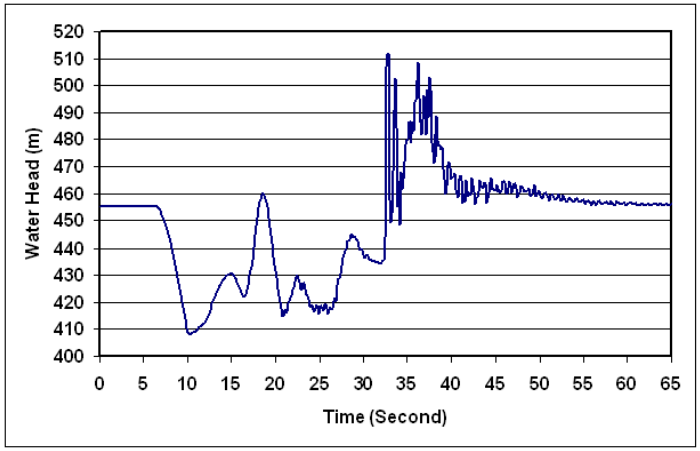
Nodal Water Head Time Histories; Pump Restarts at t=25 sec by Emergency Power



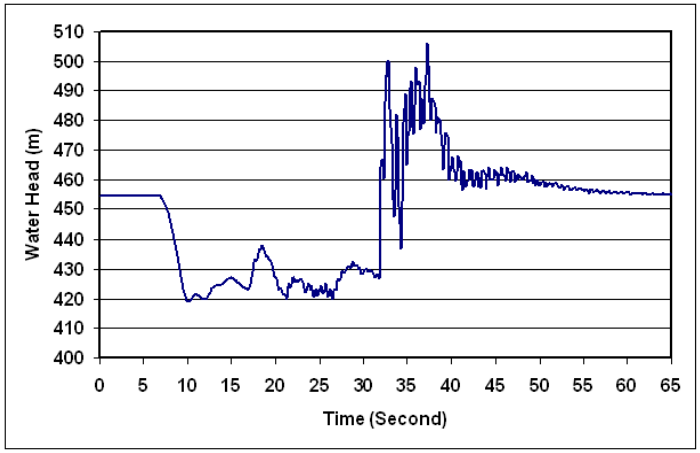
J9



J11



J13



J20

Conclsions

Power Systms

- ARE Fragile under Extreme Events

Human and technological errors, natural hazards including weather conditions

- Exhibit Cascading Effect quickly over a Vast Area
- Affect All Other Lifelines
- Have Good Emergency Repair Records even under Extreme Event, But
- Requires Substantial Expenditure for Full Recovery

Collaborative Research

- Is Urged between Industry and University on Power System Reliability Under Natural Hazards
- That currently exist Between MCEER and LADWP, SCE and MLGW should be expanded in scope

Acknowledgements

- National Science Foundation Grant EEC9701471 through the MCEER and NSF Grant CMS-0112665.

- Technical Contribution by Mr. R. Tognazzini and Mr. J. Mochizuki of LADWP and Professor T.C. Cheng and Dr. X. Jin, University of Southern California.