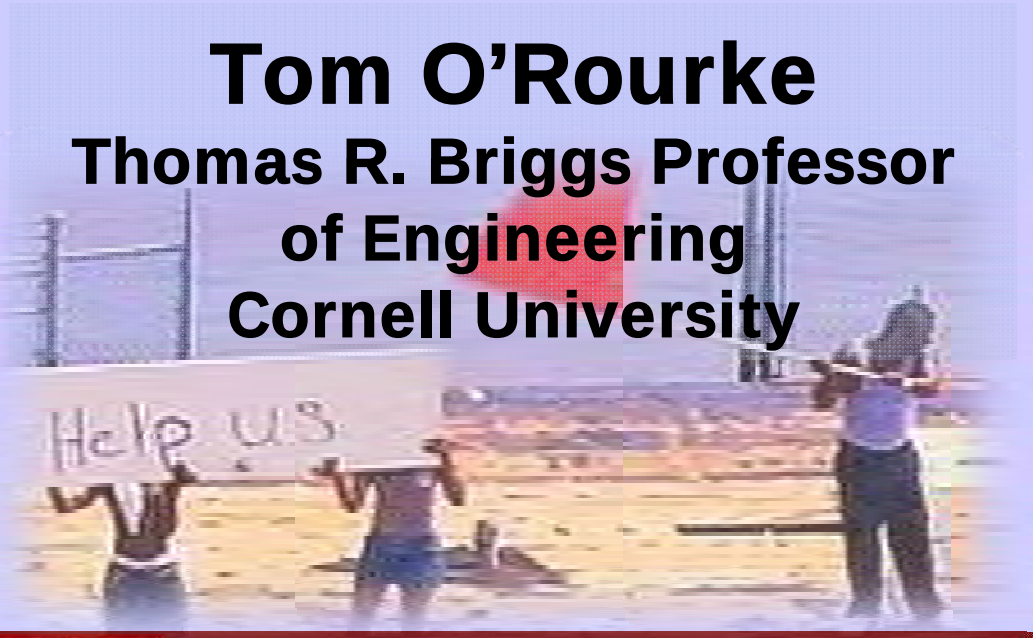
THE NEW NORMAL FOR NATURAL DISASTERS

Tom O'Rourke
Thomas R. Briggs Professor of Engineering
Cornell University



EERI Distinguished Lecture

TOPICS

- Tohoku Earthquake
- Canterbury EQ Sequence
- Hurricanes
  - New Orleans
  - New York City
- New Normal

TOPICS

- Tohoku Earthquake
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  - New Orleans
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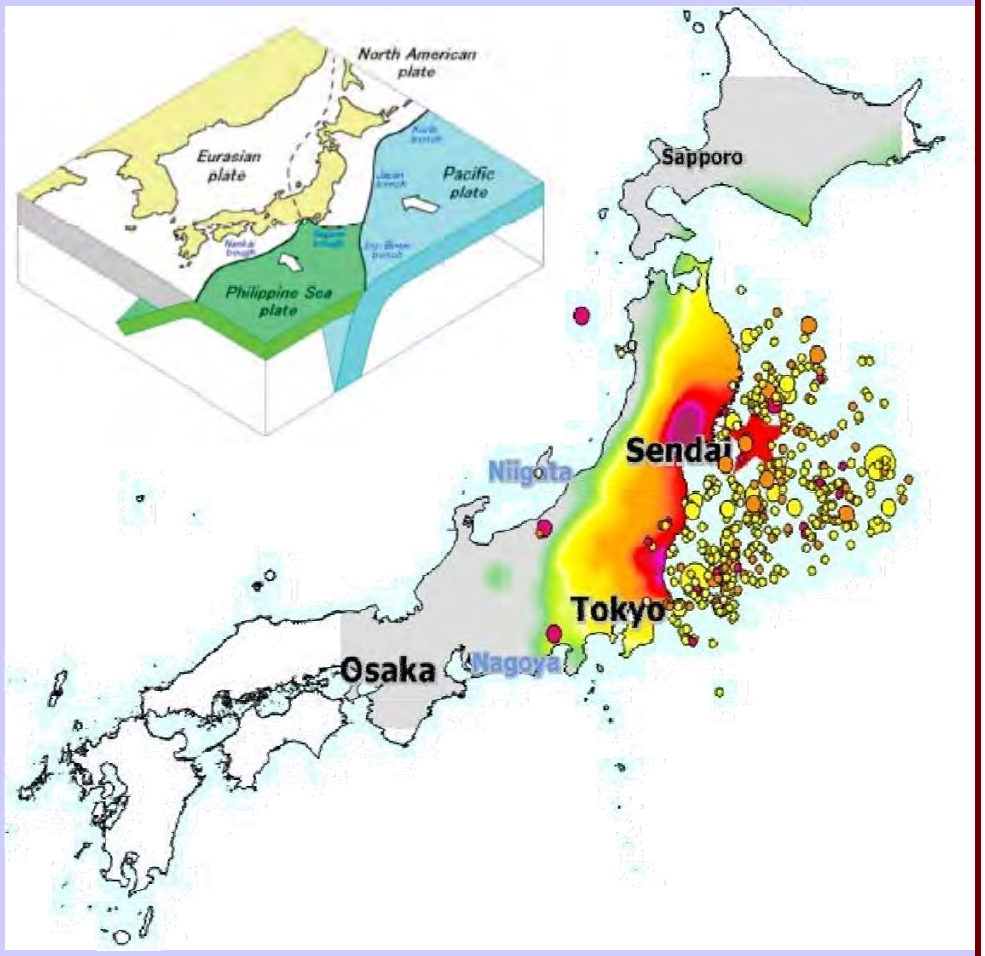
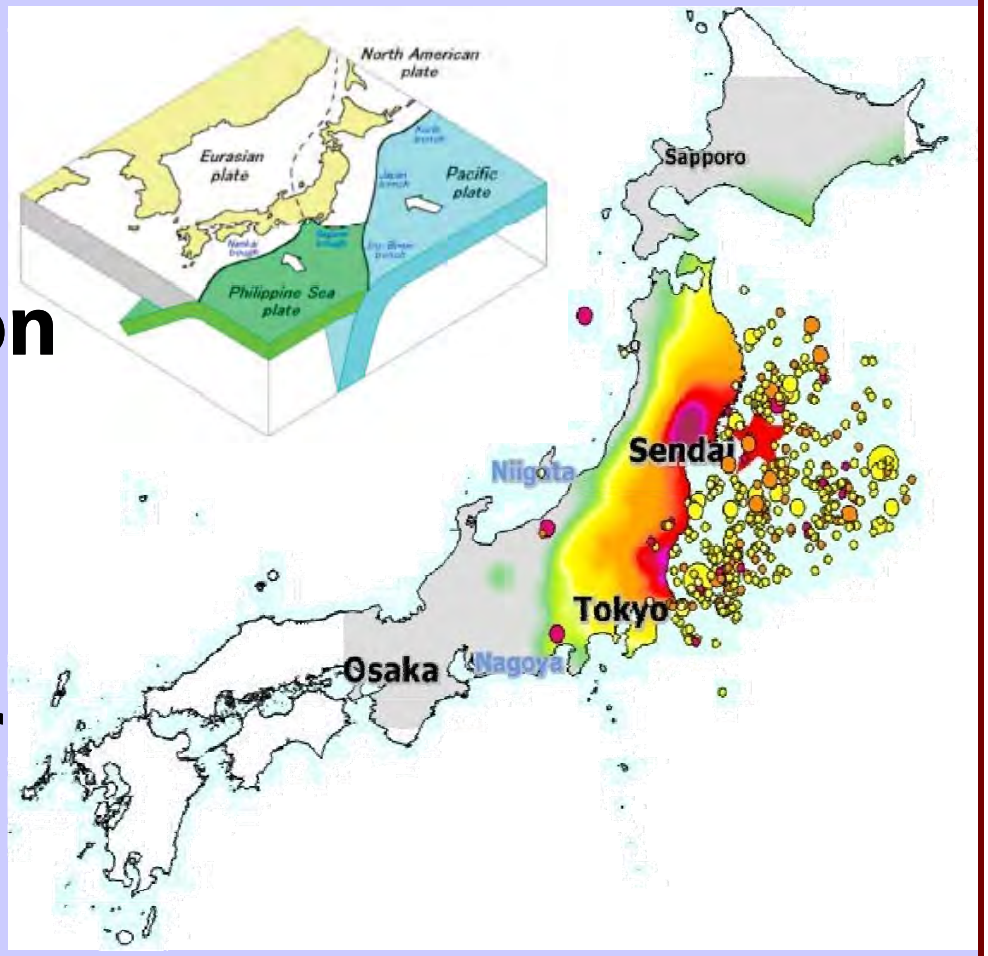
TOHOKU EARTHQUAKE

- 9.0 Mw (~ 4th Largest EQ Measured)
- 10-25 cm Shift in Earth's Axis
- 1000 x more power than 1995 Kobe EQ
- 600 million x more power than Hiroshima bomb



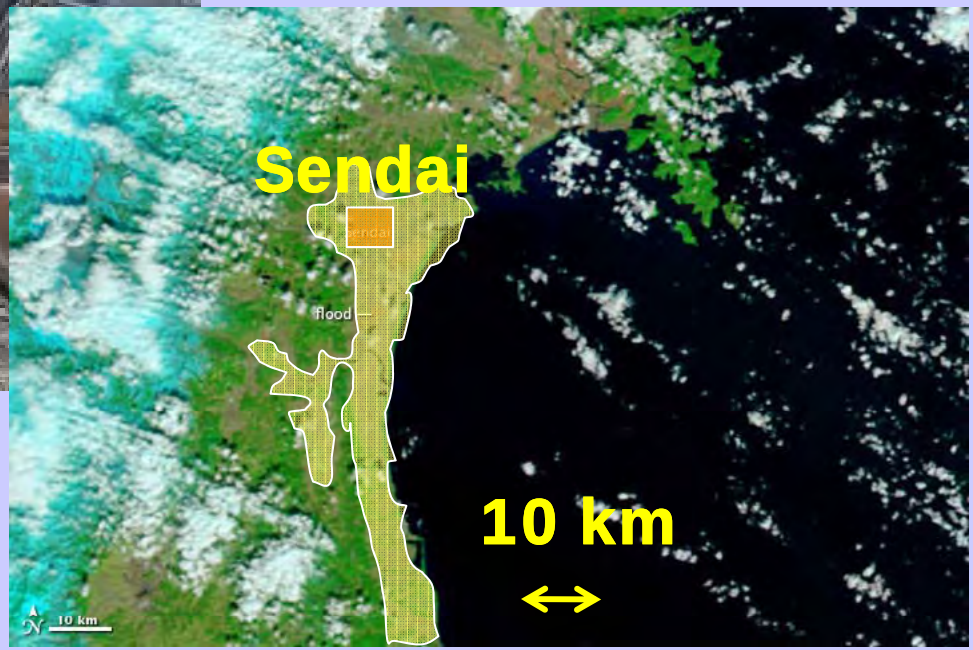
TOHOKU EARTHQUAKE

- 15,870 Deaths
- 2,814 Missing
- 129,225 Buildings Destroyed; > 1 Million Heavily Damaged
- $235 B Direct Losses
- ~ $620 B for Nuclear Decontamination & Decommissioning



TOHOKU TSUNAMI

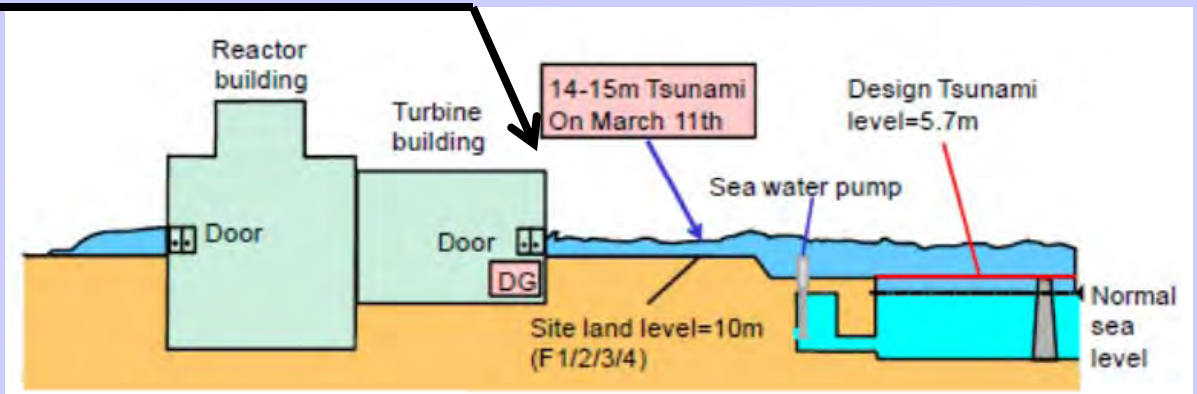
- Inundation = 561 km2
- Tsunami Heights = 3 to 7.3 m
- 50 km Run-up on Kitakami River



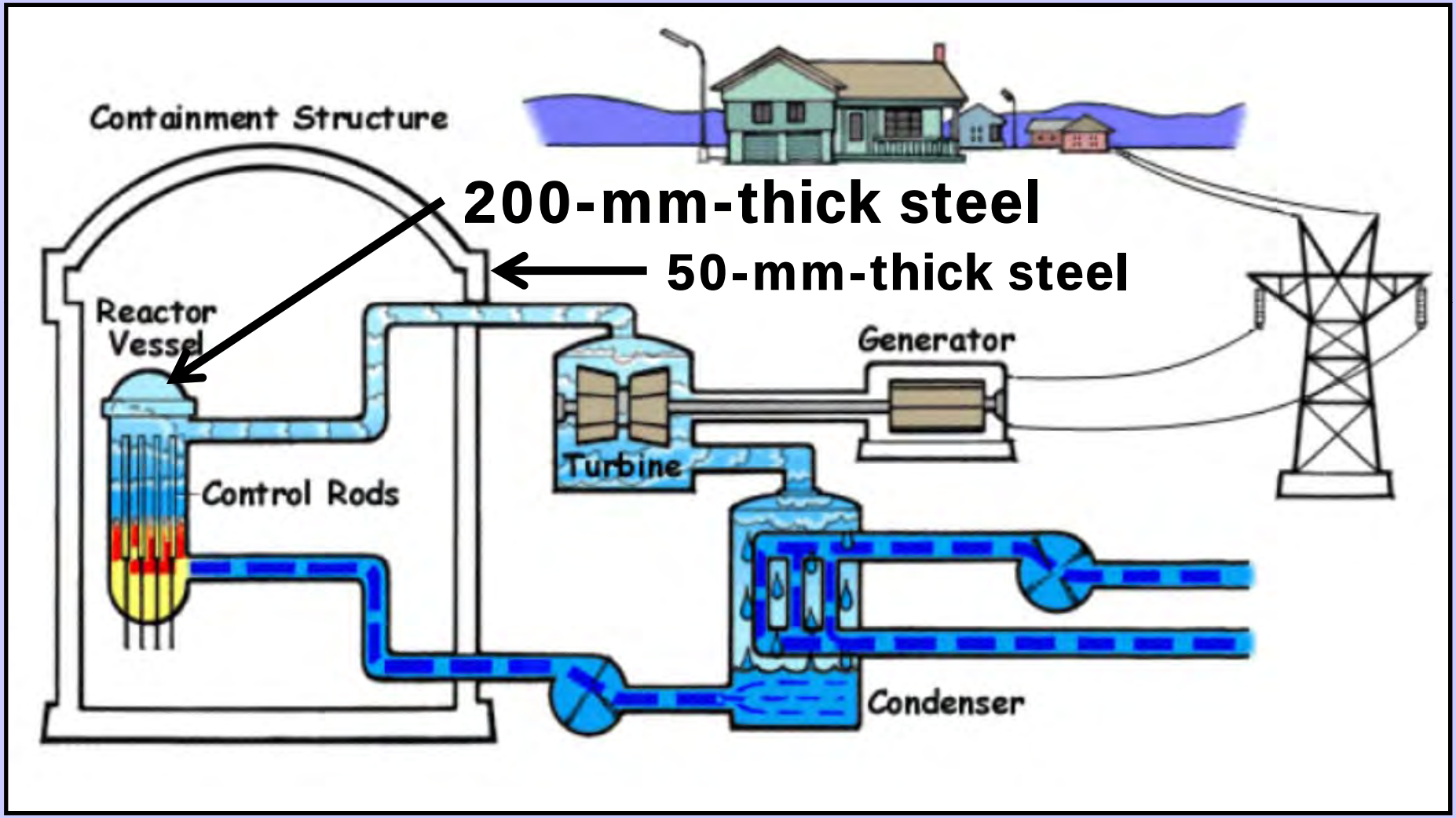
- 190 of 300 km Seawalls Heavily Damaged

FUKUSHIMA DAIICHI NUCLEAR PLANT

46-m-high splash

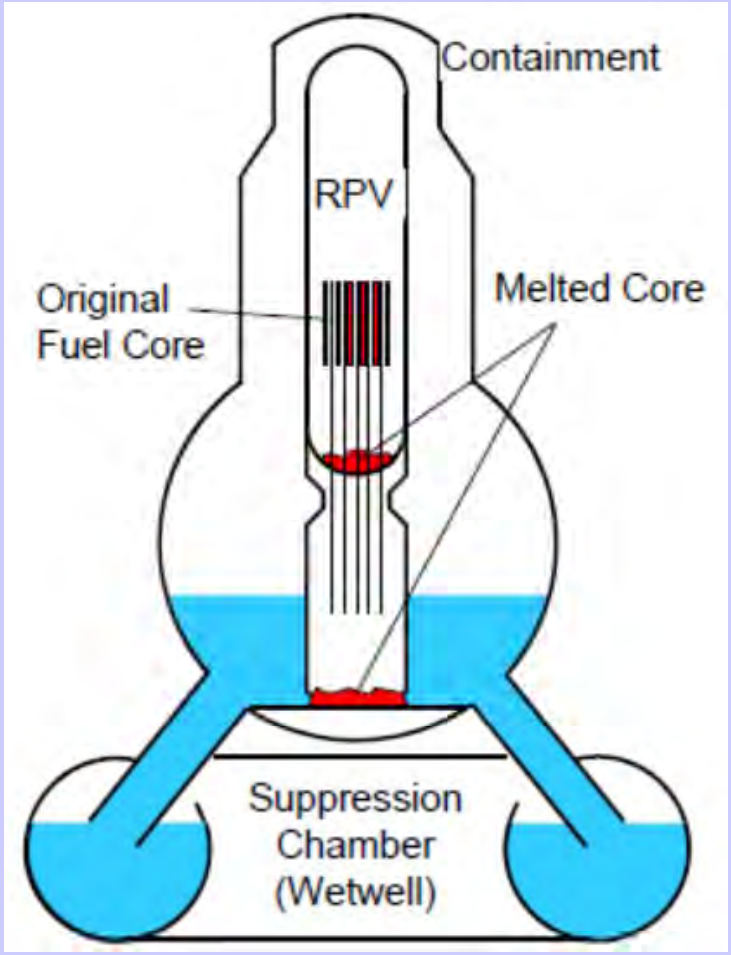


BOILING WATER REACTOR

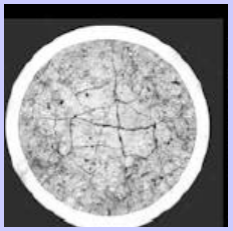


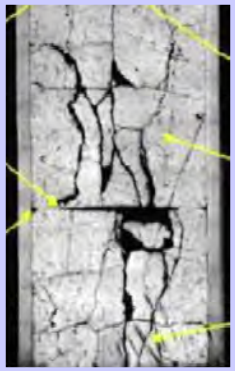
BOILING WATER REACTOR

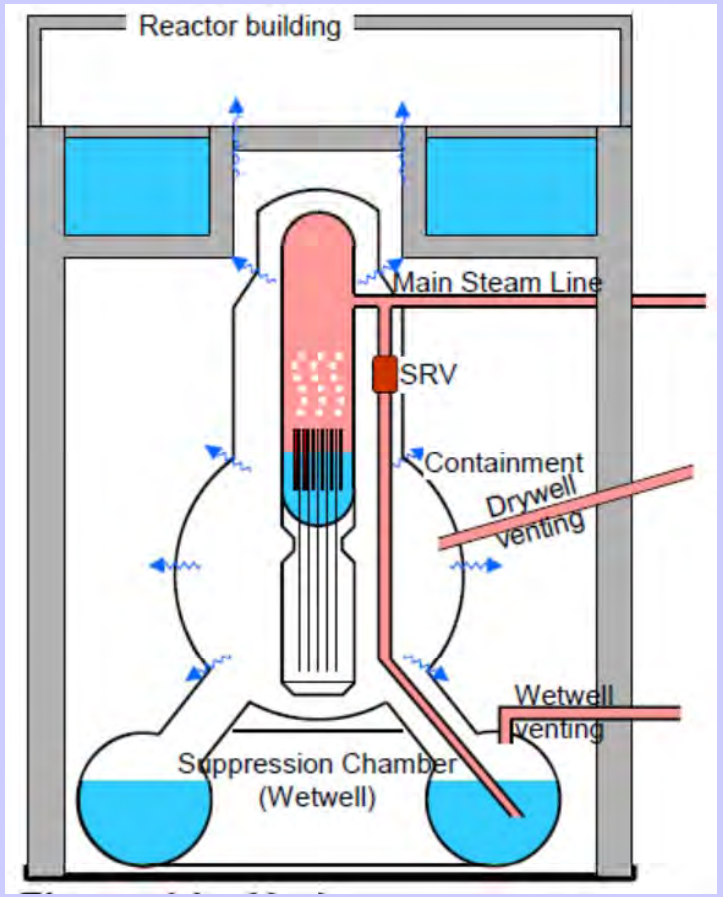
Zirconium cladding of fuel rods decomposes to generate hydrogen



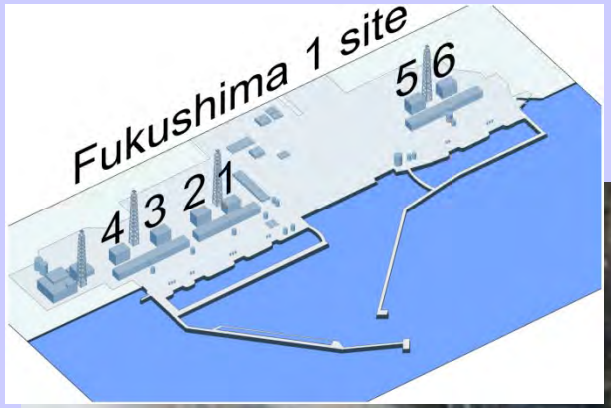
$$Zr + 2H_2O = ZrO_2 + 2H_2$$





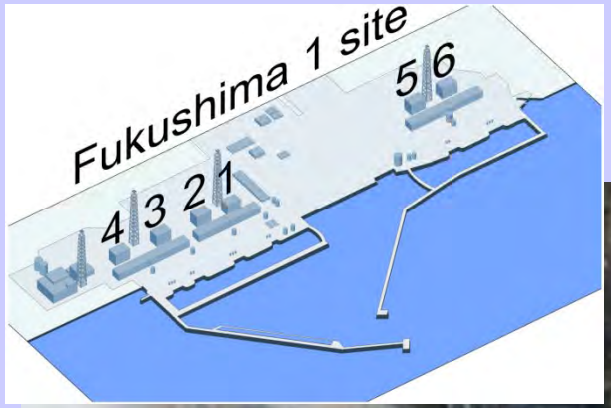


FUKUSHIMA DAIICHI NUCLEAR PLANT



- Electric power to plant lost, including steel tower failure
- Tsunami flooded all diesel generators (DGs) except one air-cooled DG at higher elevation
- Sea water cooling system destroyed

FUKUSHIMA DAIICHI NUCLEAR PLANT



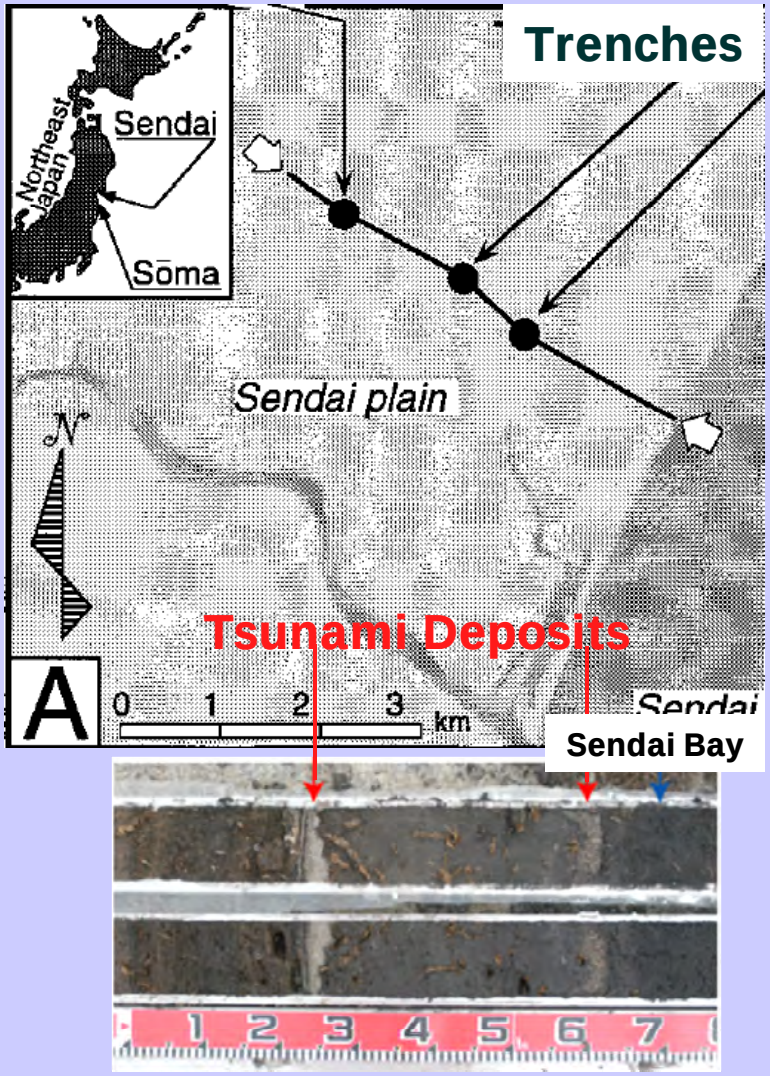
- **Partial meltdowns in Units 1, 2, & 3 in primary reactor pressure vessels (RPVs) and primary containment vessels (PCVs)**
- **Loss of cooling in Unit 4 spent fuel pool**
- **Hydrogen explosions at all 4 units**

FUKUSHIMA INDEPENDENT PANEL
(Hatamura Panel)

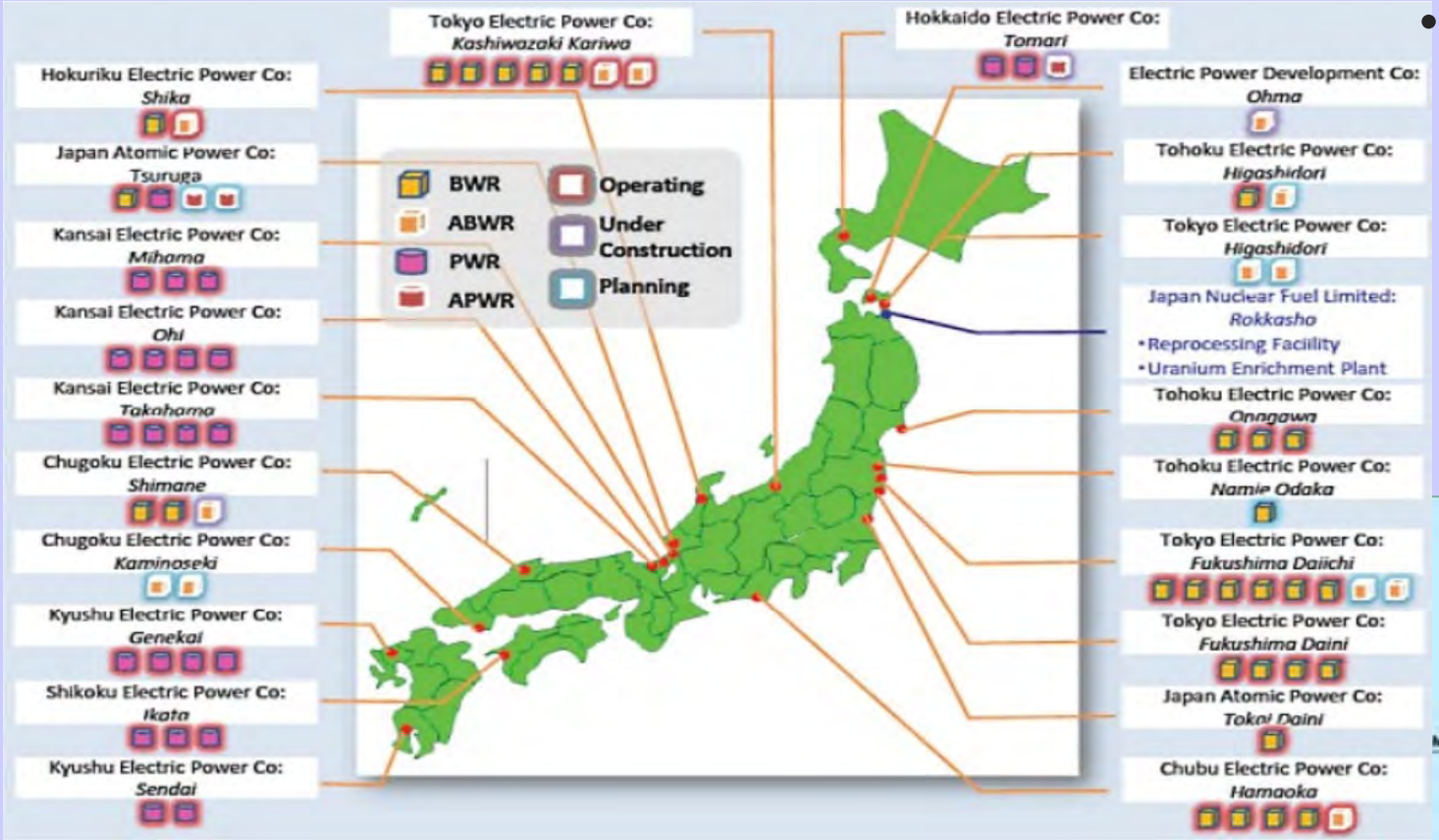
- Loss of Off-Site Emergency Center
- Failure to Delegate Authority
- Poor Coordination with Prime Minister's Office
- Errors in Use of Critical Equipment
- Inadequate Radiation Monitoring & Dissemination of Information
- Evacuation Mistakes

869 SANRIKU EQ AND TSUNAMI

- Trenches & Soil Coring Revealed Tsunami Deposits
- Sand Layers Between Peat Layers, Carbon Dating of Organics
- Historical Documents Confirm Tsunami
- Models Show ~ 8.4 Mw EQ
- Current Studies Suggest Tsunami Run-up > Extent of Sand Deposits
- ~1100 Yr. Recurrence



JAPAN'S NUCLEAR POWER PLANTS



- On 5 May 12 all 54 nuclear reactors down working, or 0 % of total nuclear; 1 reactor on line 1 July 12

- Japan imports 84 % of energy
- Nuclear reactors supplied ~ 30 % electricity
- Japan planned to increase to 40 % by 2017
- Nuclear was part of C02 reduction strategy

WORLDWIDE EFFECTS: NUCLEAR POWER

The New York Times

May 27, 2011

Officials in Germany Support Closing 7 Nuclear Plants

nuclear power plants in Germany that were
shima disaster in Japan are likely to be closed
ion Friday by state environment ministers.
ned, however, that without the seven plants
le coping with a failure in some part of the

orks to the limit of capacity," the Federal
ulates utilities, said in a report published

astern Germany, the state environment
he seven plants be closed. The decision
Merkel and her cabinet, which will

The New York Times

Switzerland Decides on Nuclear Phase-Out

By JAMES KANTER
Published: May 25, 2011

BRUSSELS — The Swiss government decided Wednesday to abandon plans to build new nuclear reactors, while European Union regulators agreed on a framework for stress-testing theirs, as repercussions from the disaster in Japan continue to ripple across Europe.

Enlarge This Image

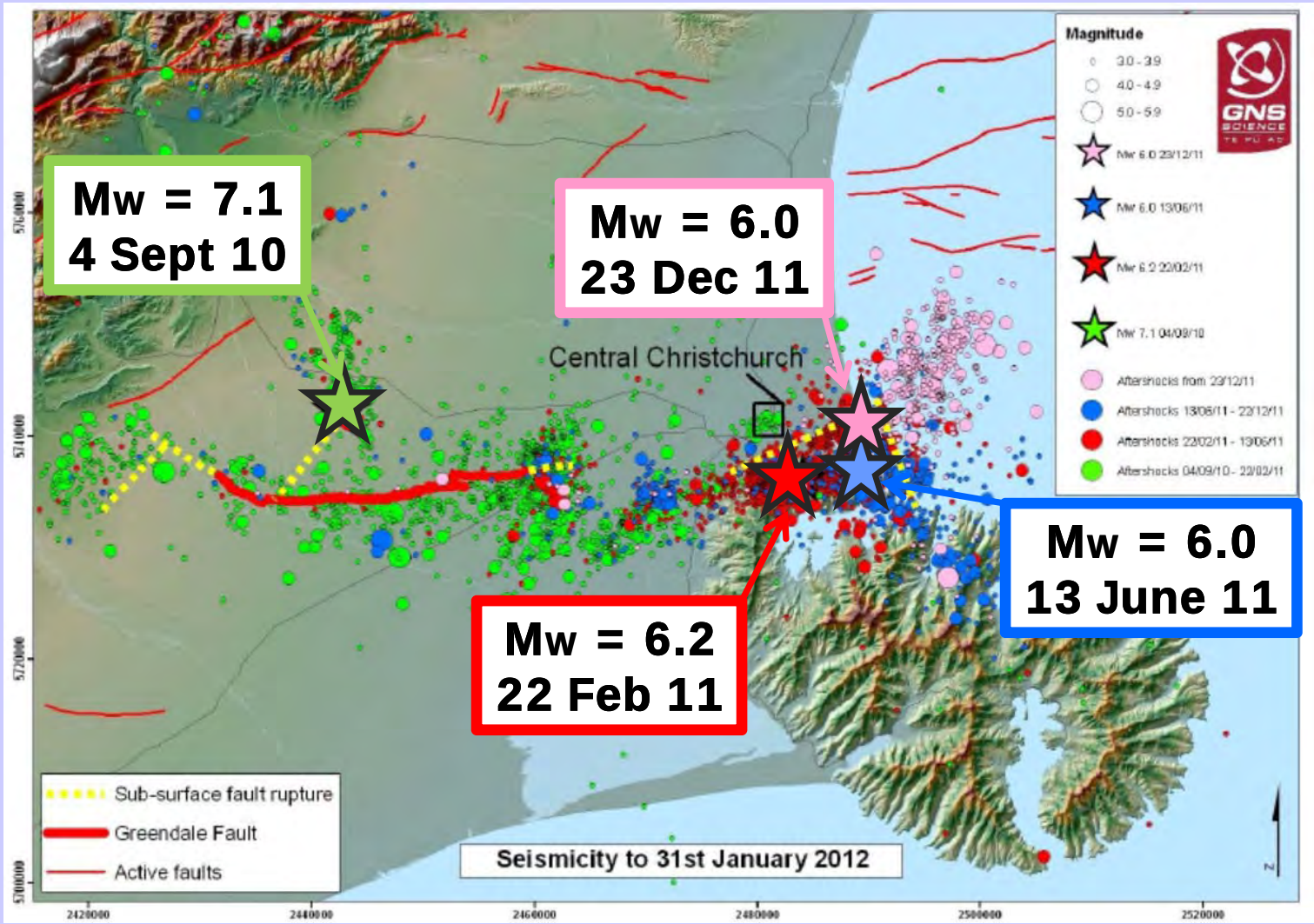
The Swiss Energy Minister Doris Leuthard had suspended the approvals process for three new reactors, pending a safety review, after the accident that struck the reactors at the Fukushima Daiichi plant in Japan after the earthquake and tsunami of March 11.

- **Germany to Close Out Nuclear Power (22.4% Electricity, 2010)**
- **Switzerland to Terminate Nuclear (40% Electricity, 2008)**
- **Italy Referendum (2011): > 94% Voters Oppose Plans to Resume Nuclear Power (abandoned 1980s)**

NEW ZEALAND

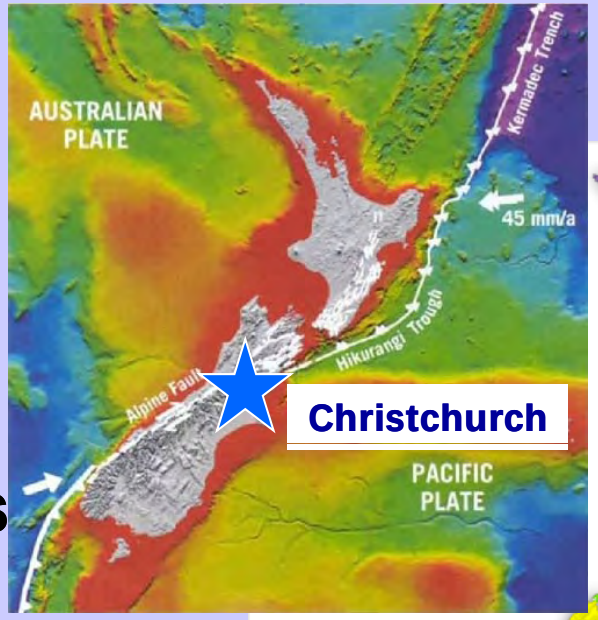
EERI Distinguished Lecture

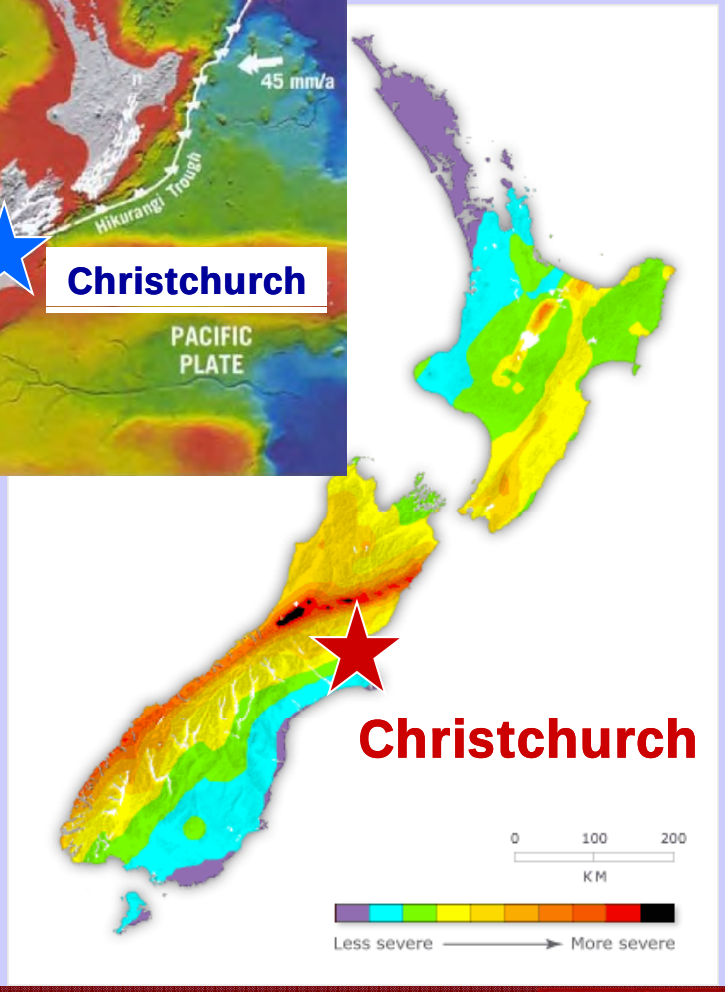
CANTERBURY EARTHQUAKE SEQUENCE



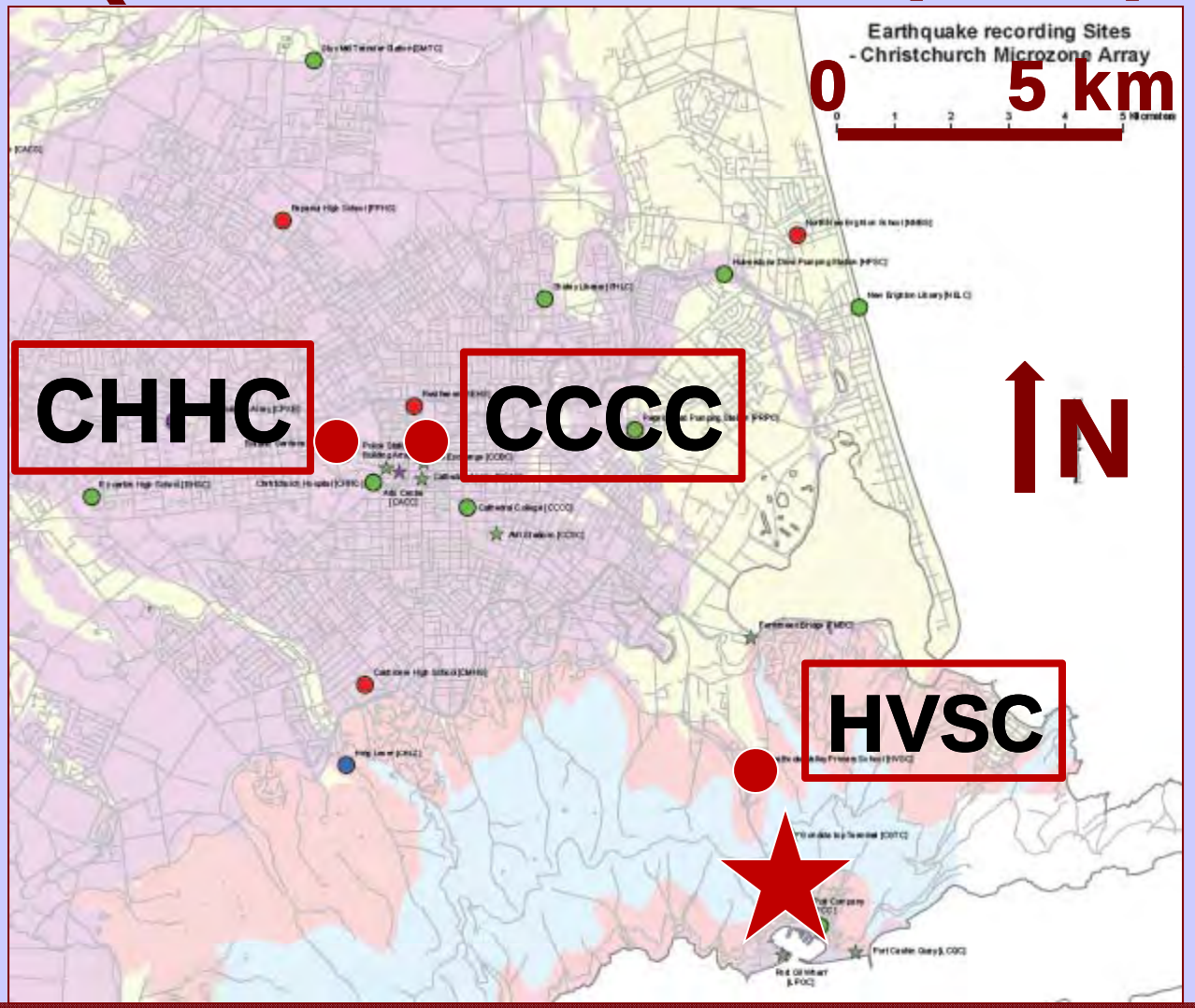
CANTERBURY EARTHQUAKE SEQUENCE

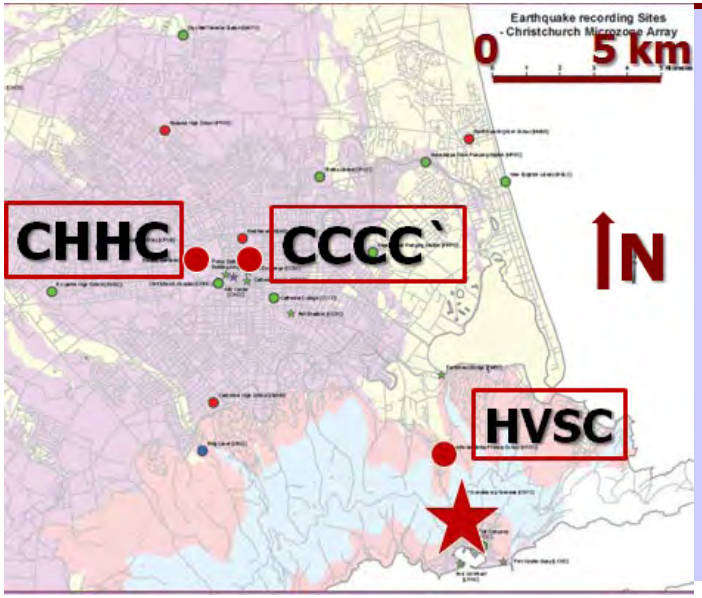
- ~ 190 Deaths
- CBD Destroyed
  - ~ 1800 CBD Bldgs. Demolished
  - ~ 55,000 Residences Damaged
- $25-30 B Direct Losses, >20 % GDP
- Massive Liquefaction & Infrastructure Damage



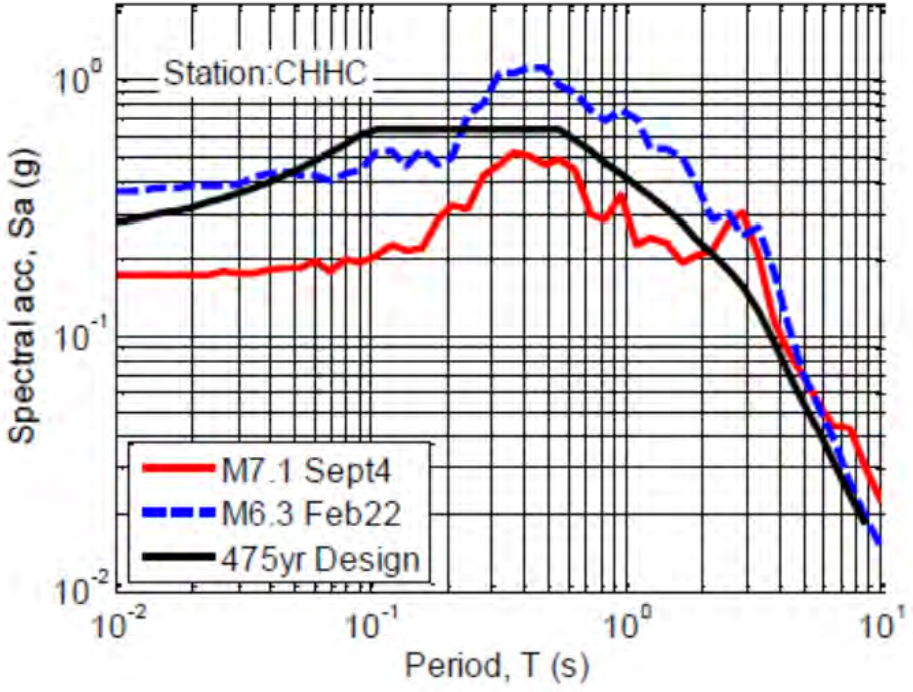


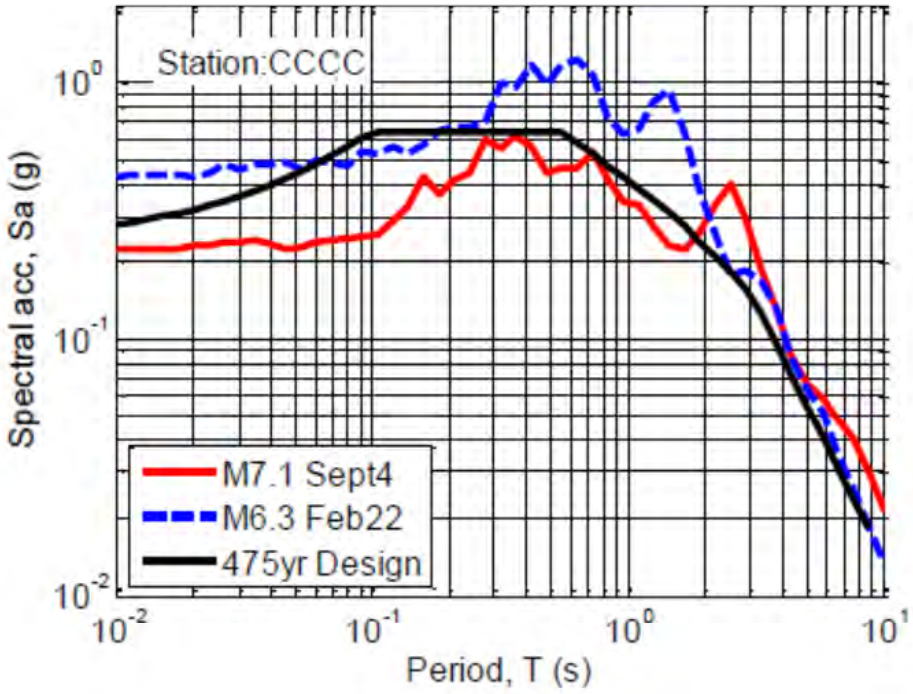
STRONG MOTION RECORDS
(Christchurch Earthquake)

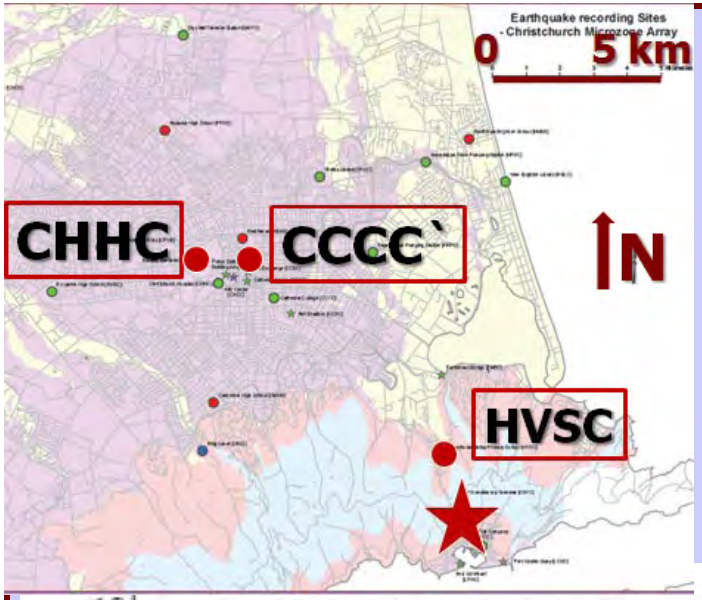




STRONG MOTION RECORDS







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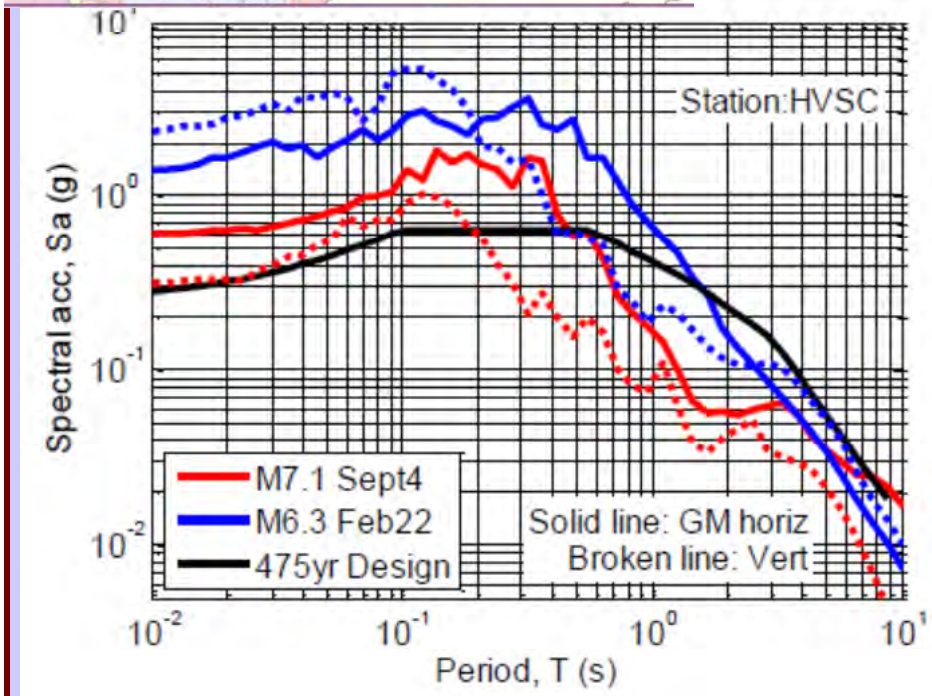
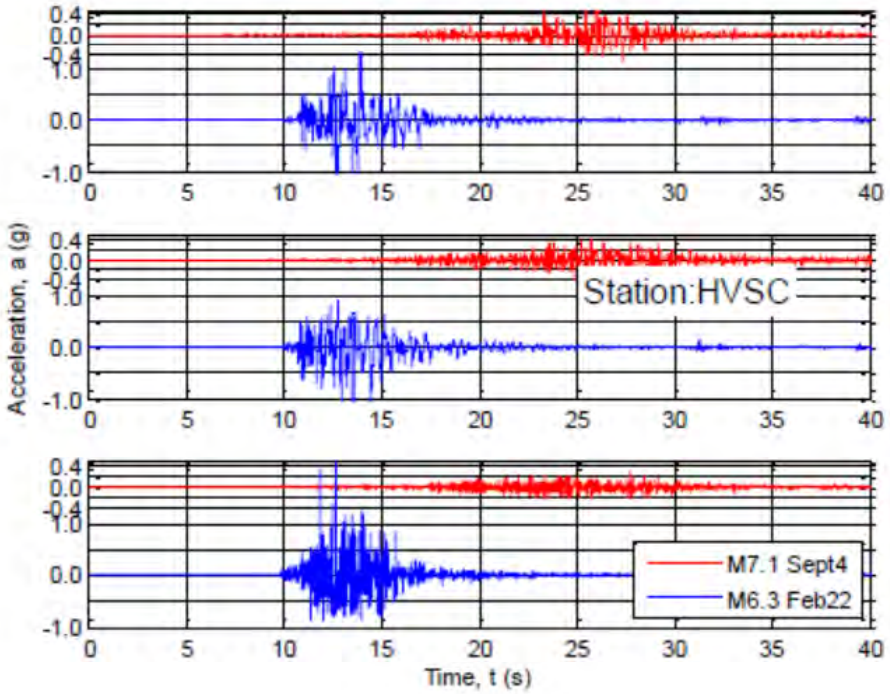
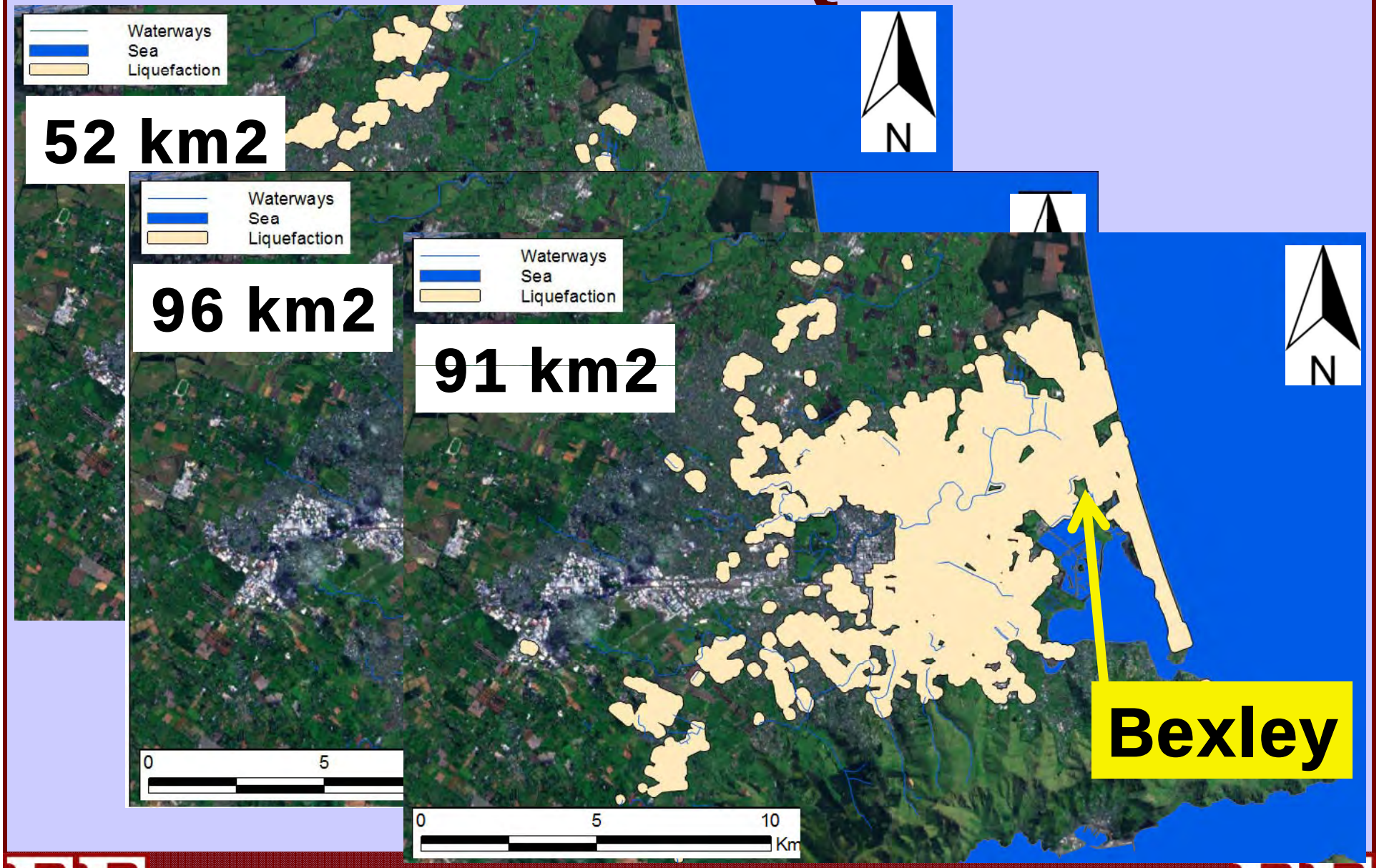




CHRISTCHURCH LIQUEFACTION



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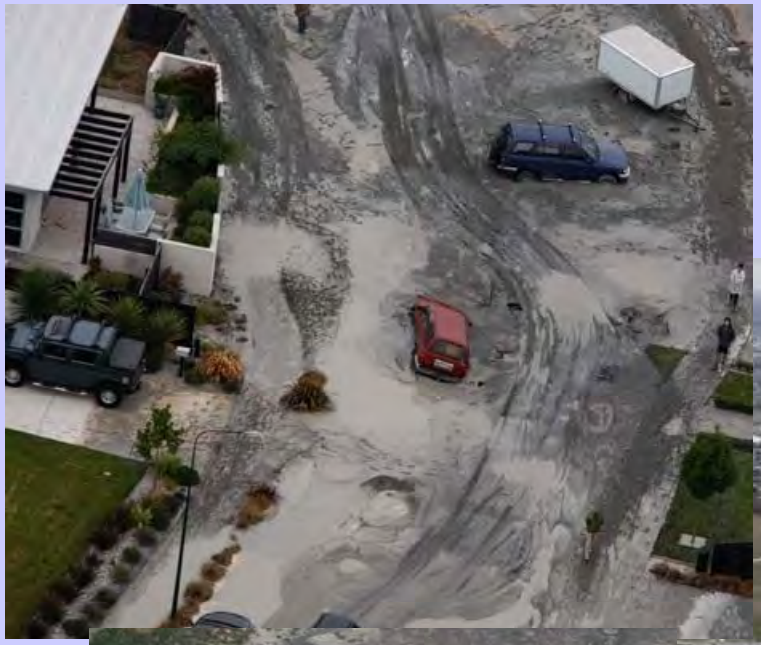
CHRISTCHURCH LIQUEFACTION



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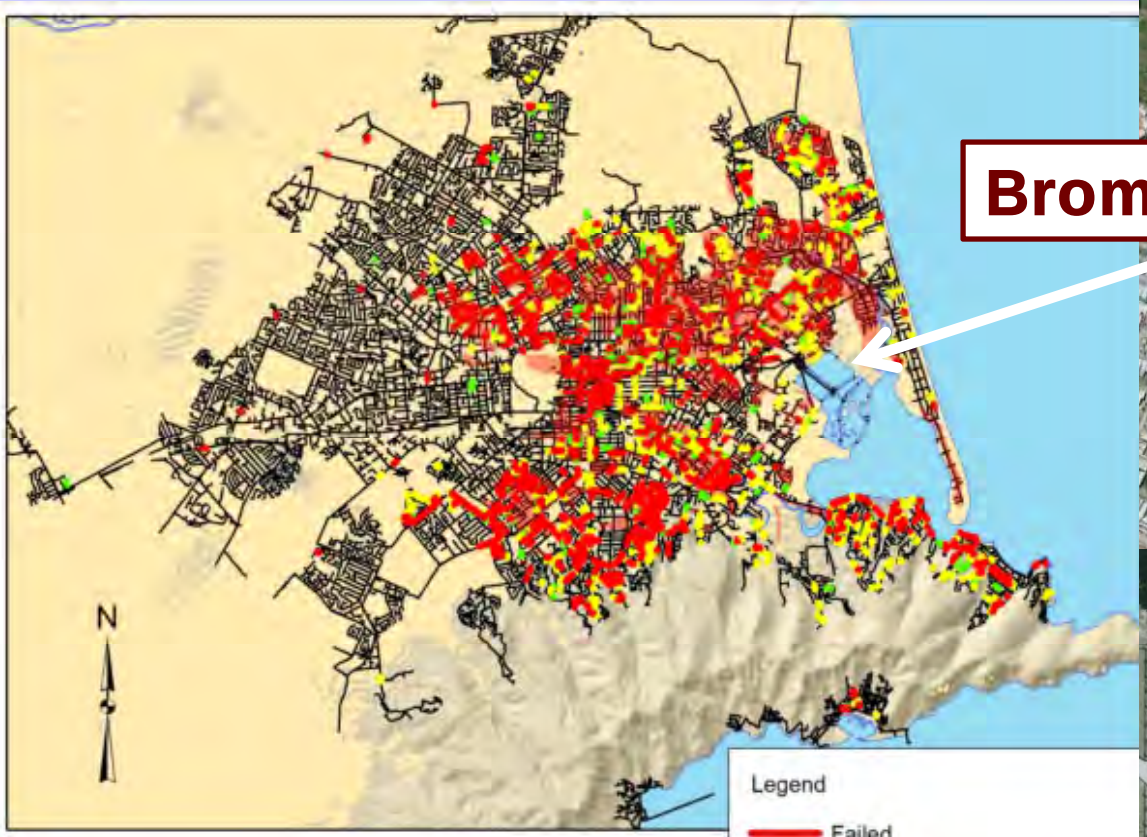
WASTEWATER SYSTEM



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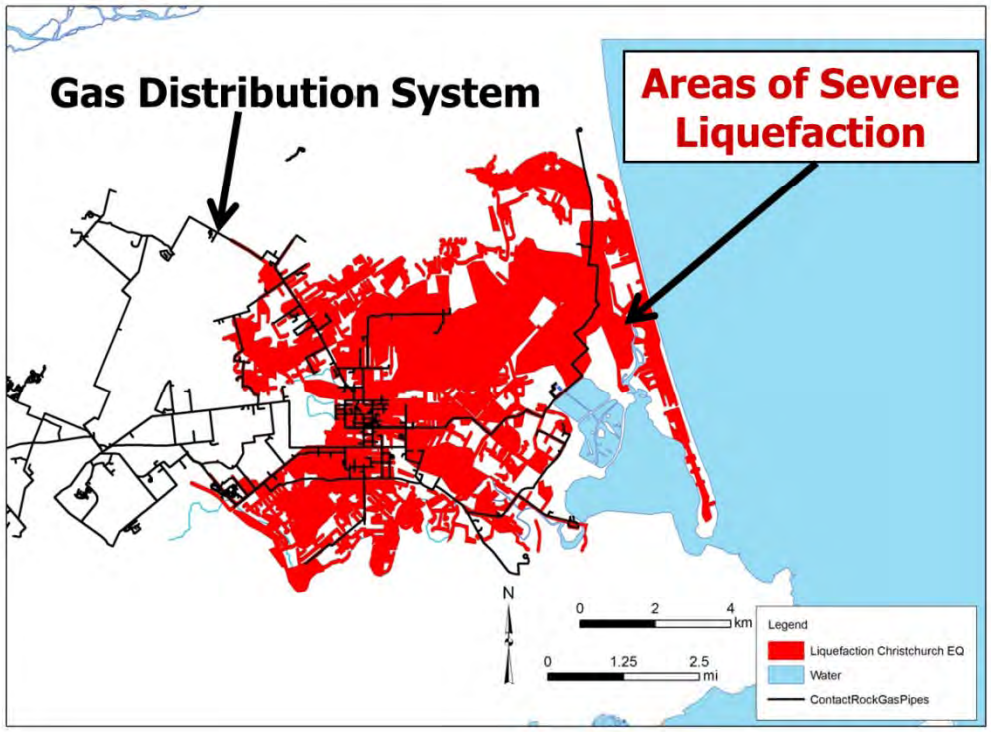
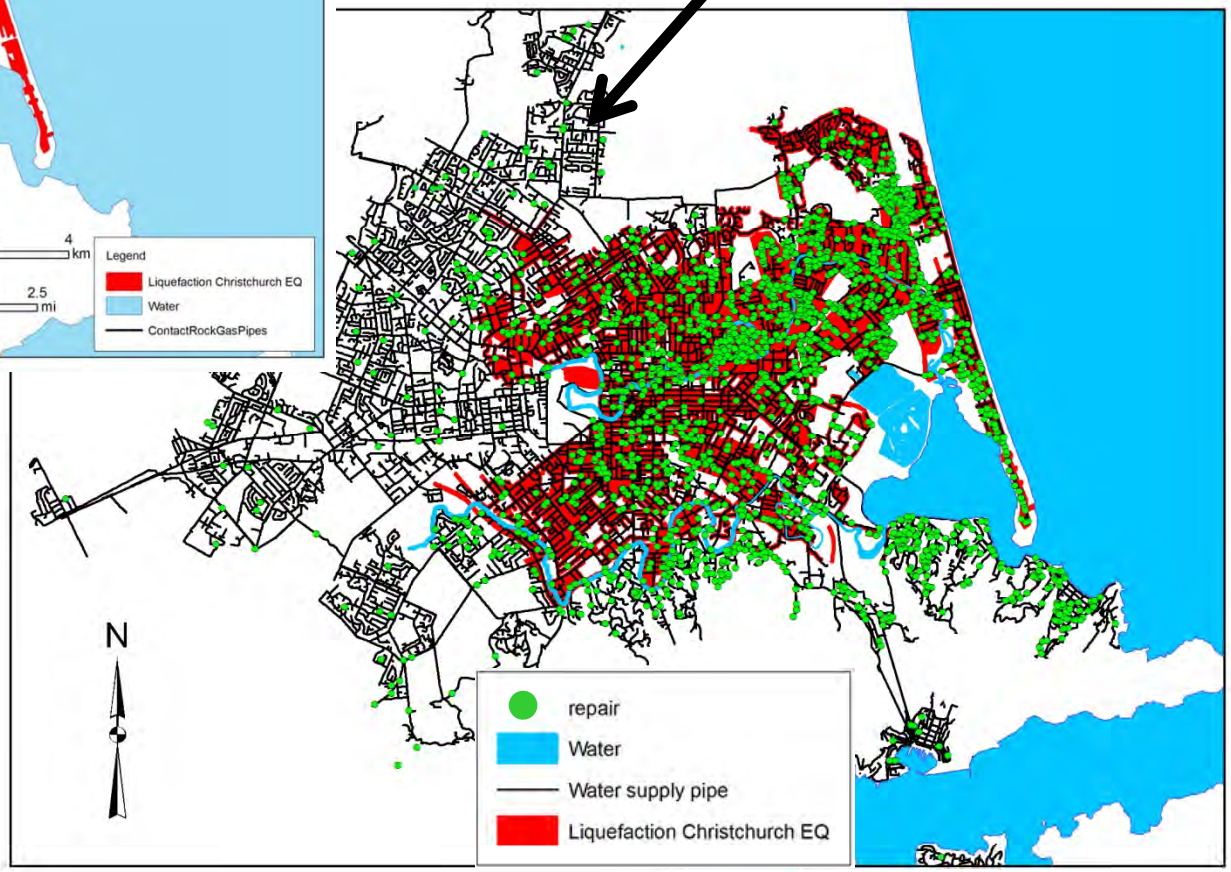


Water Distribution System



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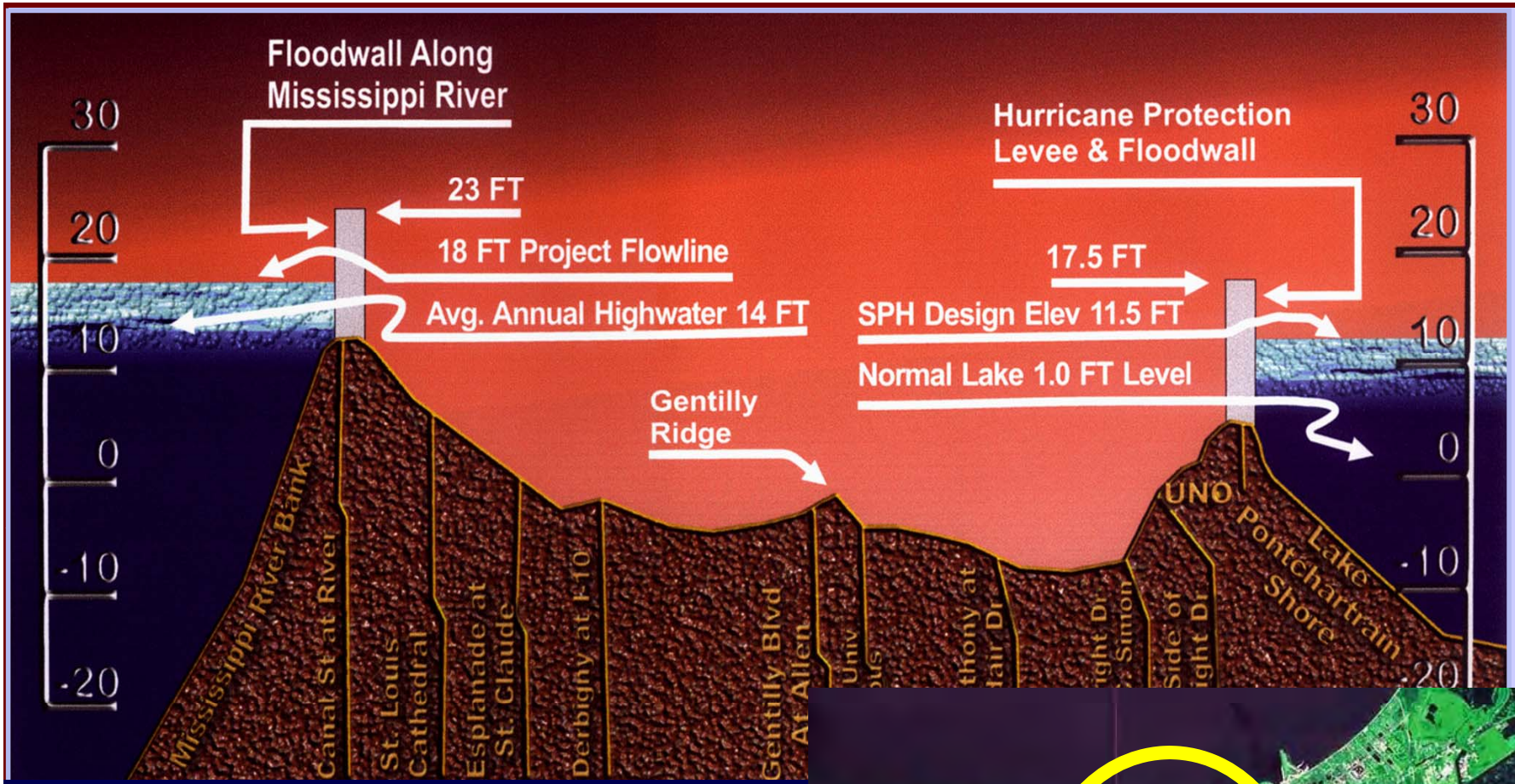
NEW ZEALAND INSURANCE

- ~80% Insurance Coverage Before Earthquakes
- After EQs, Renegotiation of Reinsurance
- Four-fold Increase in Insurance EQC Rates, with More Projected
- Termination of Local Authorities Protection Program (LAPP)

TOPICS

- Tohoku Earthquake
- Canterbury EQ Sequence
- **Hurricanes**
  - **New Orleans**
  - **New York City**
- New Normal


Mississippi River
New Orleans
Mississippi
Delta
25000 km2
Most Recent
Delta



New Orleans Elevation Cross-Section

Entergy (2006)

HURRICANE KATRINA

- Greatest U.S. Disaster
- 2000 Dead & Missing
- > $ 120 Billion Losses
- 80% New Orleans Flooded, 53 Days to Dewater
- Impacts on Gulf Offshore Infrastructure & Energy Delivery System

- Complete Failure of Hurricane Protection System
  - Hurricane Hazard
  - Incomplete Design & Construction
  - Poor Maintenance
  - I Walls & Foundations
  - Poor Preparation
  - Inadequate Response

EVOLUTION OF CONCEPT

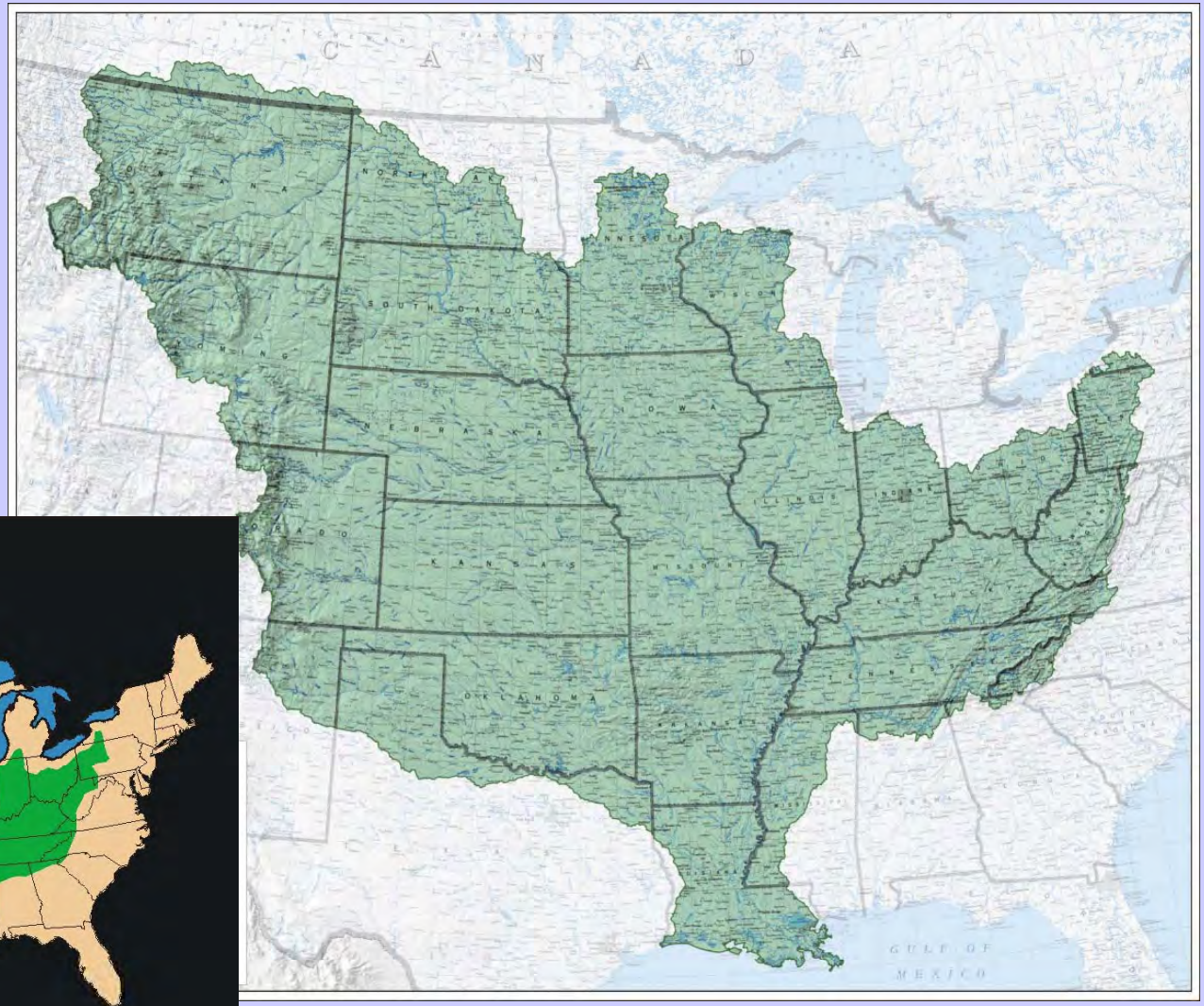
September 11:

- Protection of Critical Infrastructure

Hurricane Katrina:

- Resilient Communities

Mississippi River Drains 41% of US



65 Kilo-tonnes/s
1927, ’37. ‘73

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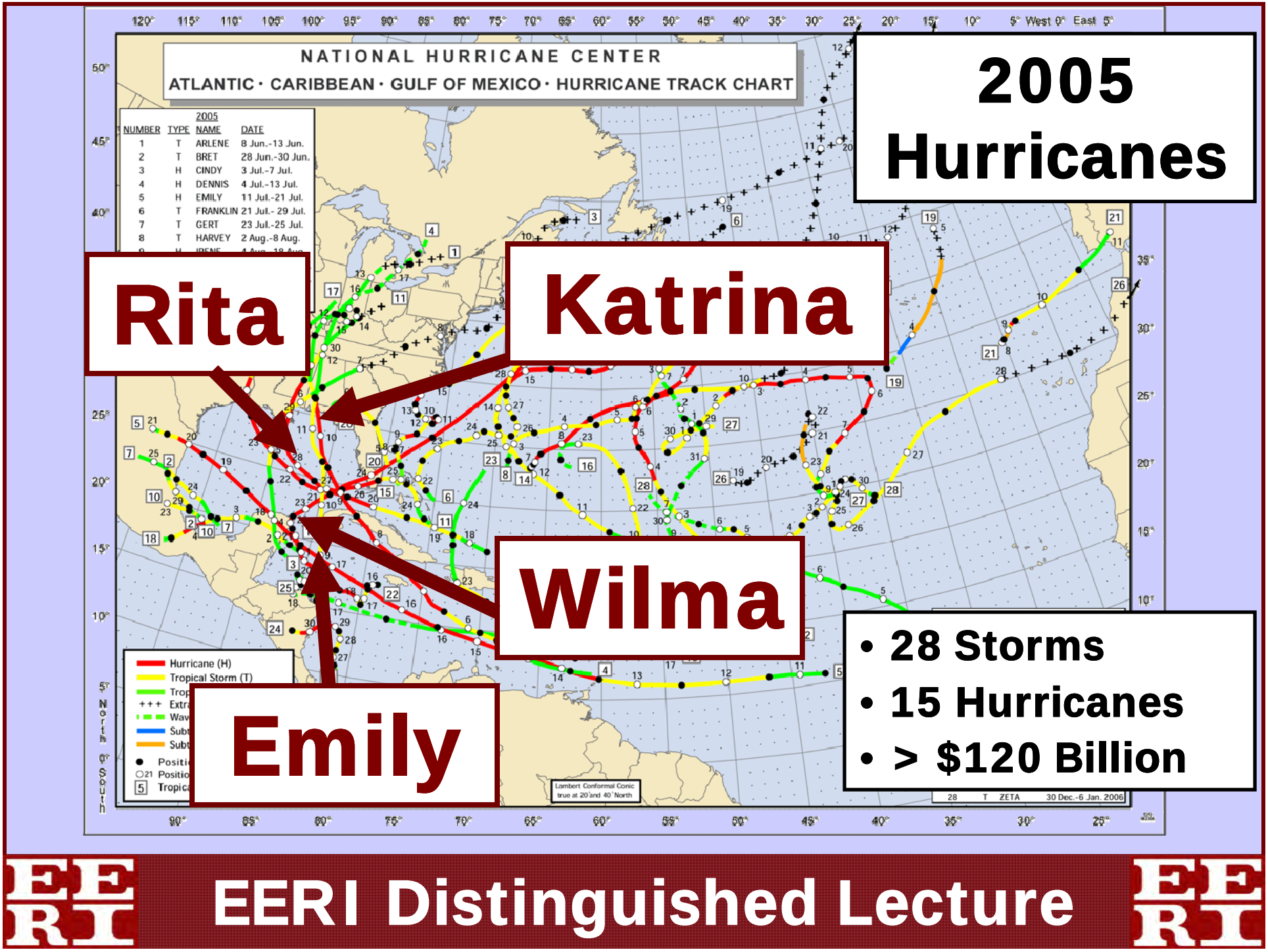
100 km2, 1-2m Deep per Year

200 Million Tonnes of Sediment/Yr.



2005 Hurricanes

Rita

Katrina

Wilma

Emily

- **28 Storms**
- **15 Hurricanes**
- **> $120 Billion**

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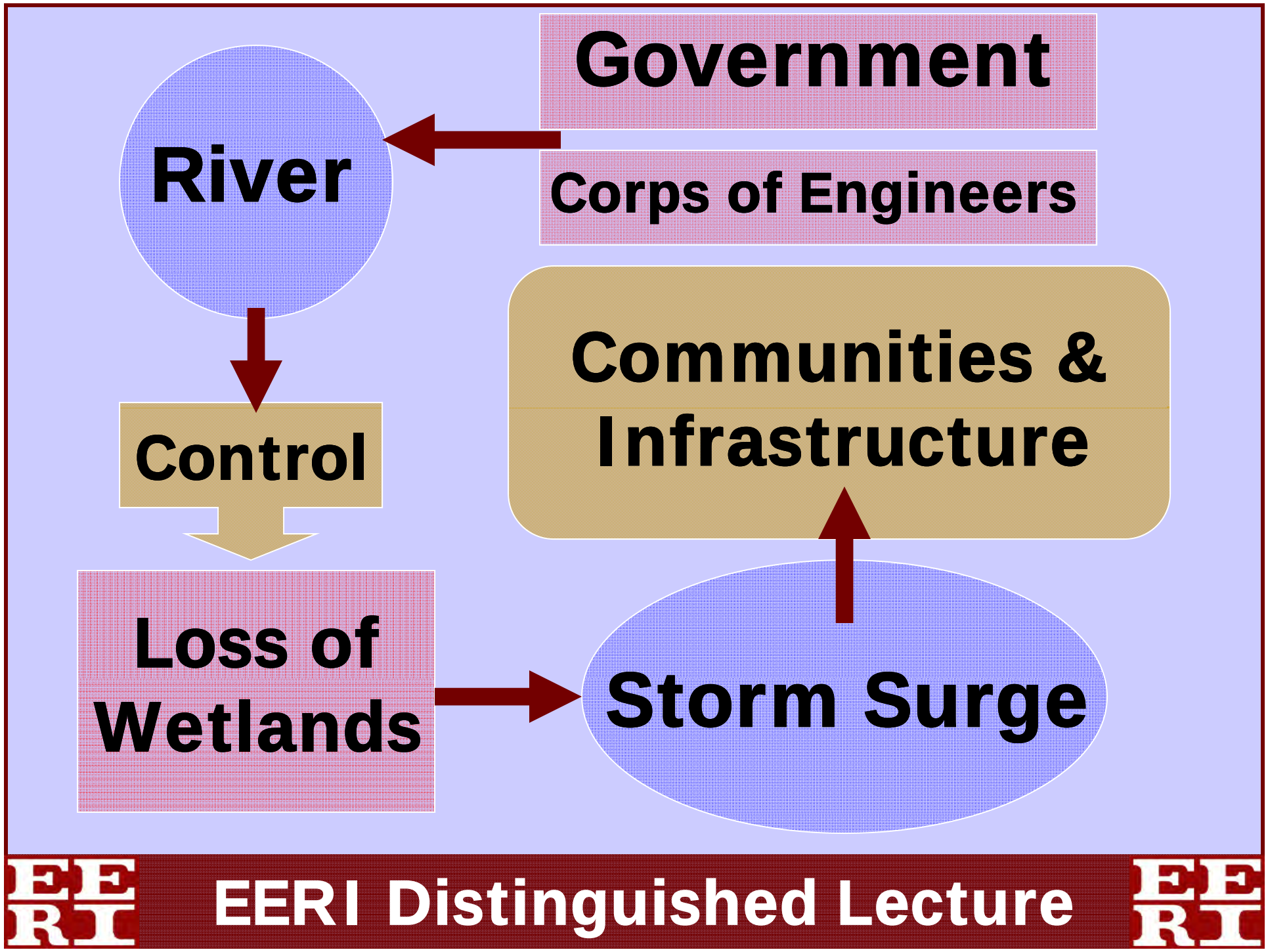
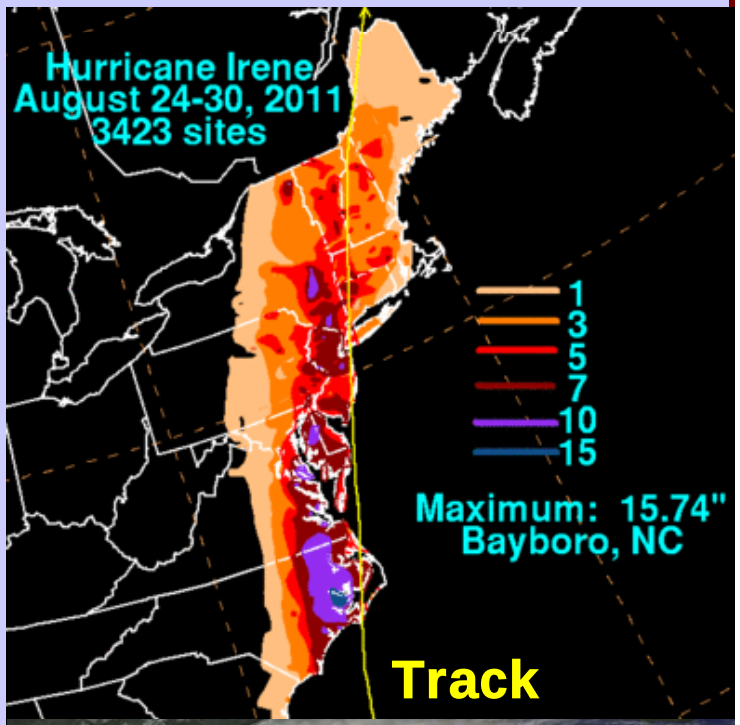

Government
River
Corps of Engineers
Communities &
Infrastructure
Control
Loss of
Wetlands
Storm Surge

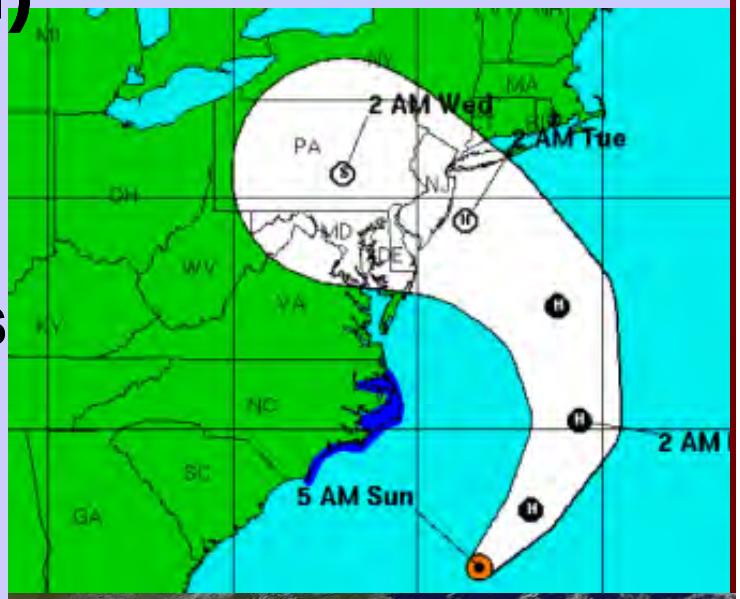
HURRICANE IRENE

- 56 Killed
- $10-15 Billion Direct Losses
- 7.4 Million Homes & Businesses Without Power
- NYC Evacuation & Shutdown of MTA & Public Transportation
- Record Flooding
- Near Miss

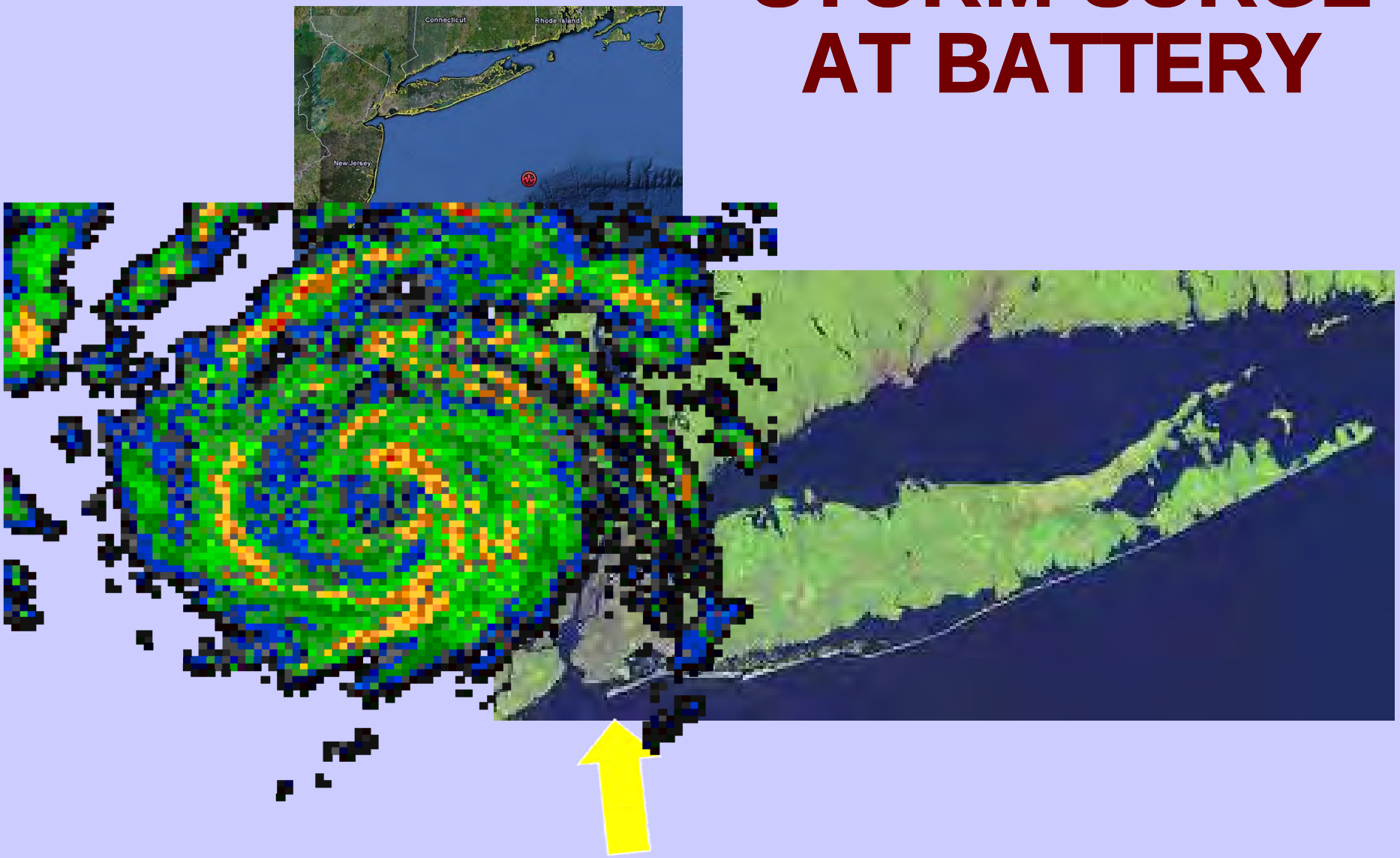


HURRICANE SANDY

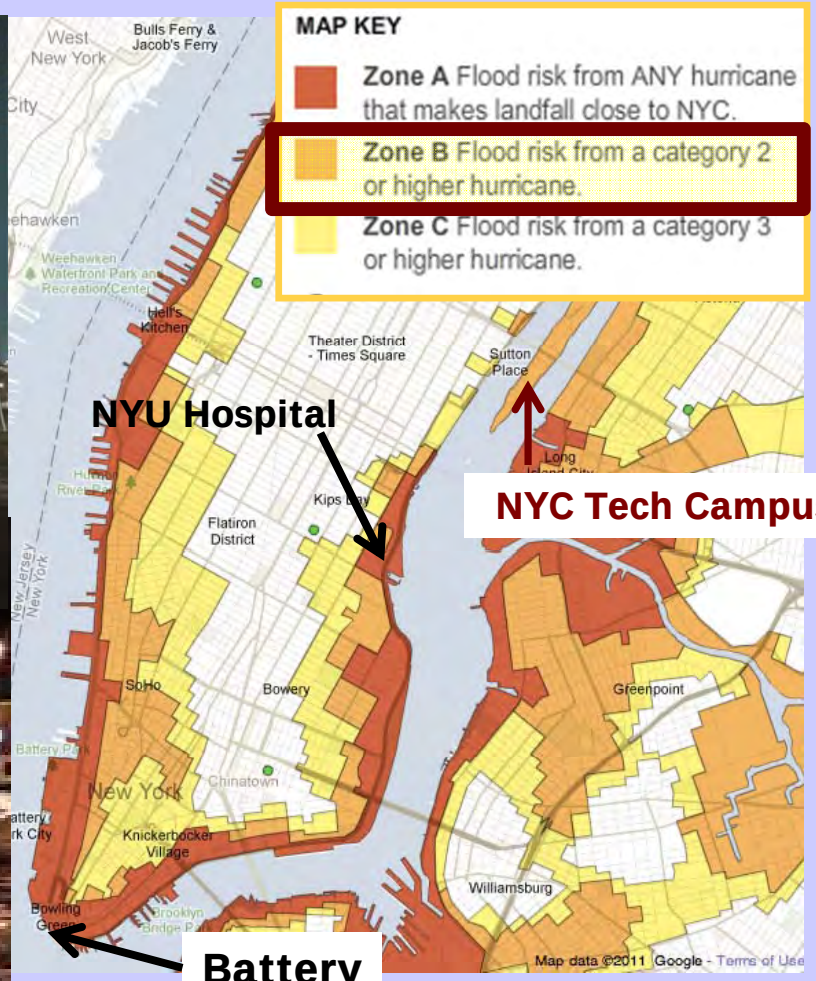
- > 120 Killed US (~70 Carribean)
- > $60 Billion Property and Business Losses
- 8.5 Million Homes & Businesses Without Power
- NYC Evacuation & Shutdown of MTA & Public Transport
- Wall Street Shut 2 Days
- Record Flooding (Surge)
- Direct Hit



STORM SURGE AT BATTERY



NEW YORK CITY HURRICANE FLOOD ZONES



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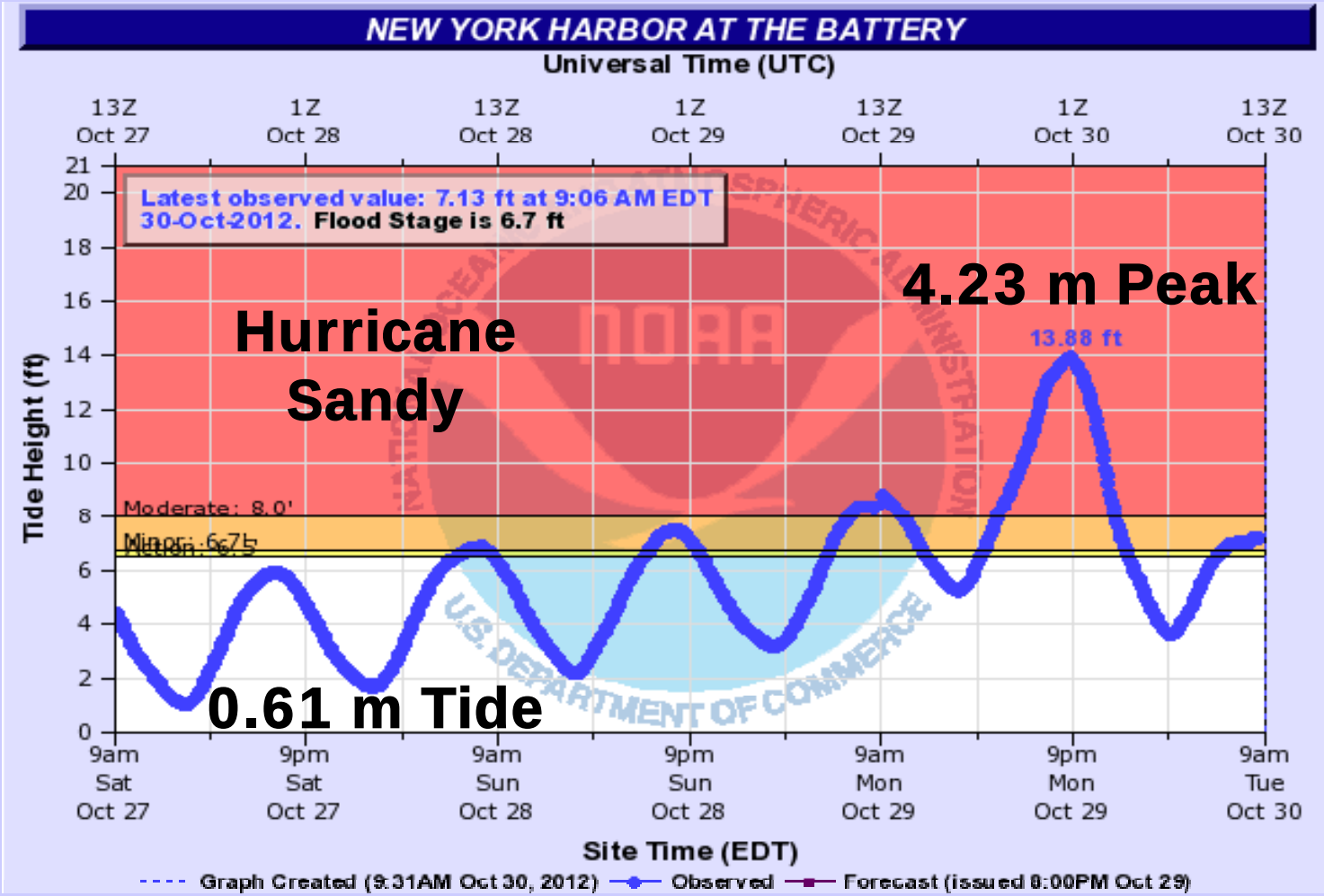
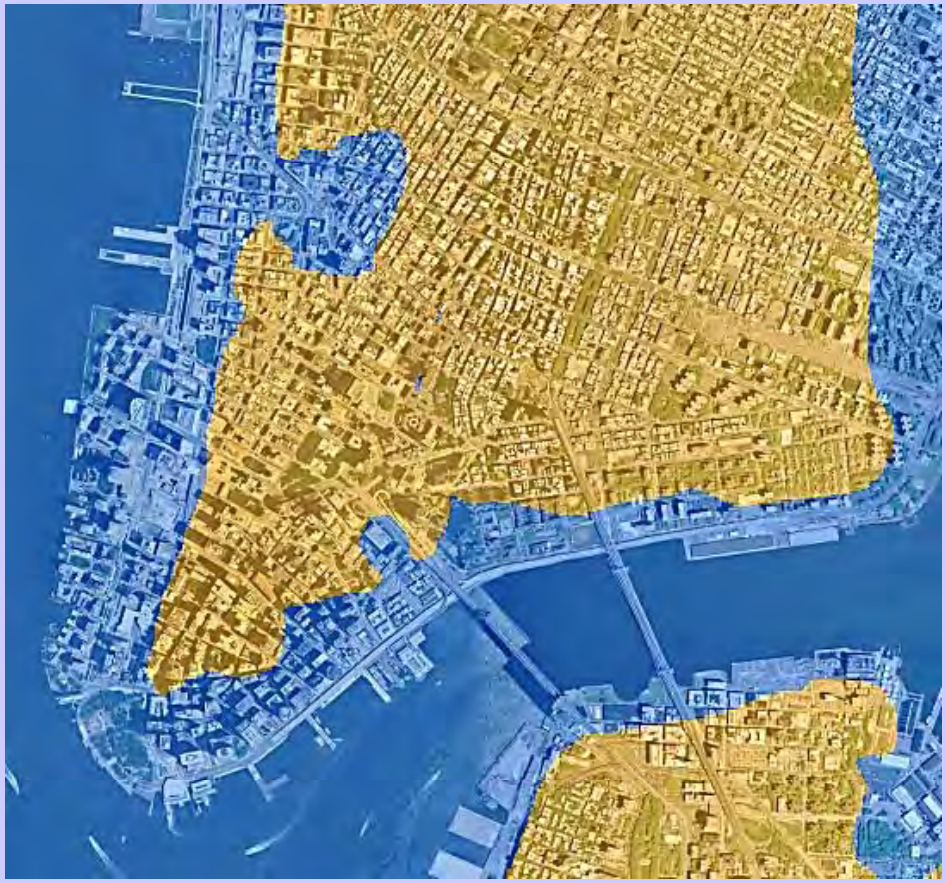
STORM WATER AT BATTERY



4.23 m
- 0.61 m
~ 3.62 m
Surge

HURRICANE SANDY INNUNDATION

HURRICANE SANDY INNUNDATION



HURRICANE SANDY INNUNDATION

Flooded Tunnels

- 7 Subway Tunnels
- Brooklyn Battery
- Midtown Tunnel
- PATH Tunnels
- Holland Tunnel

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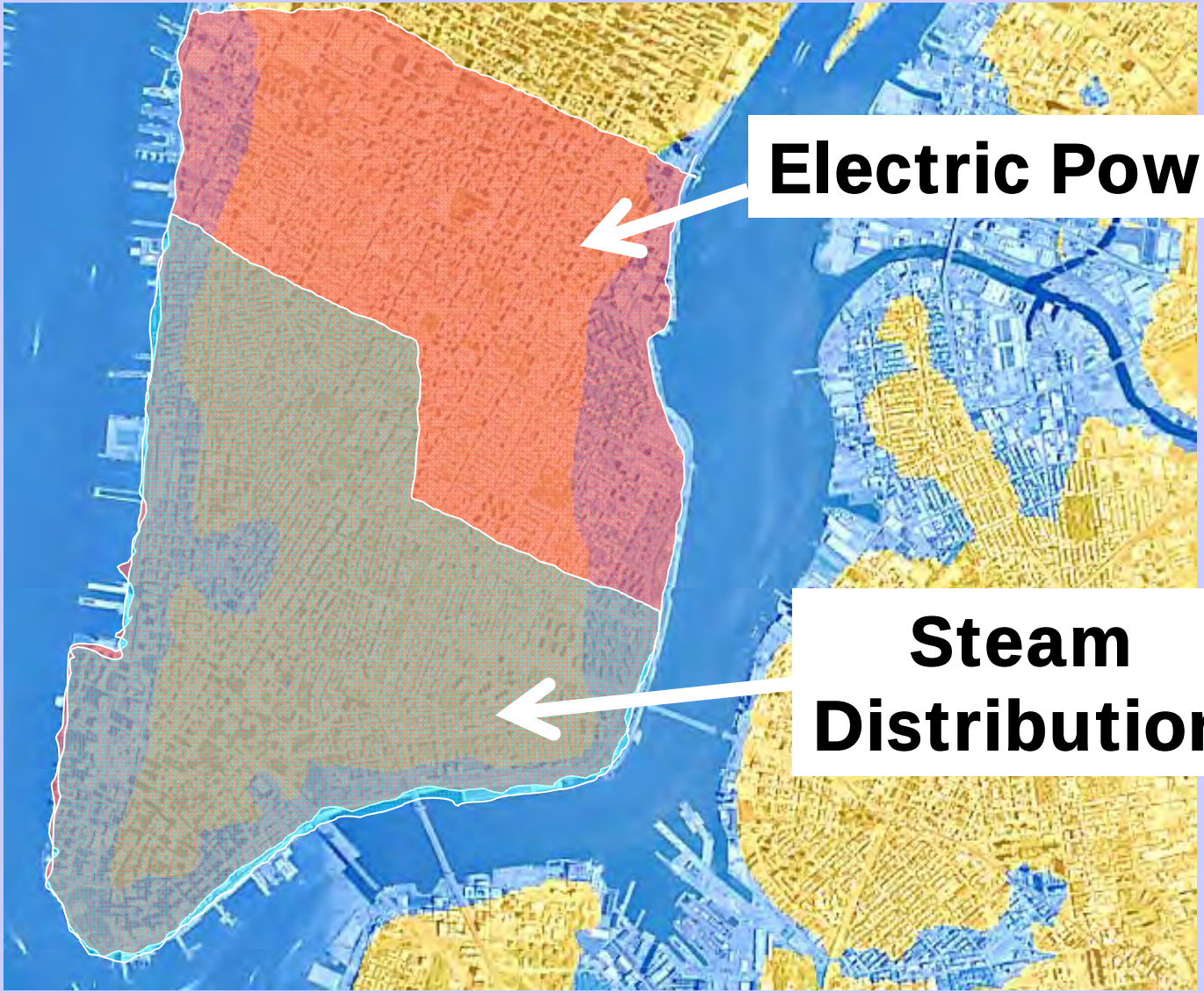
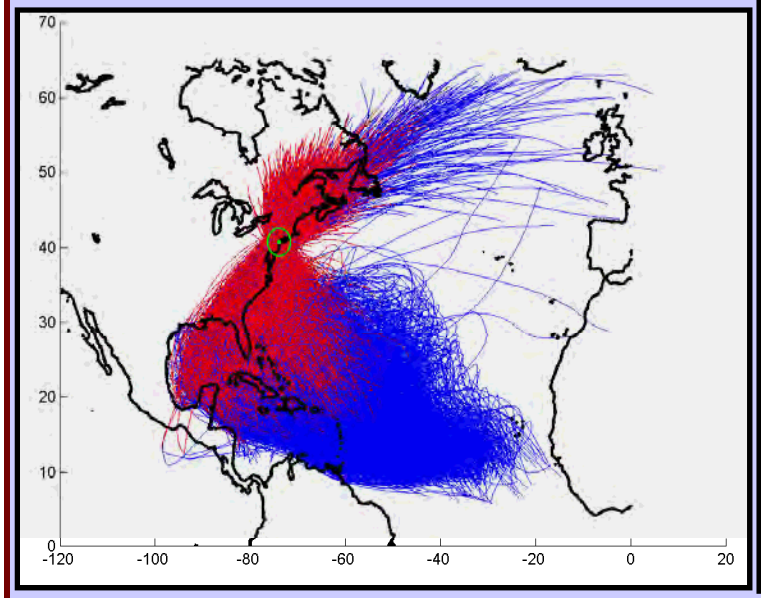
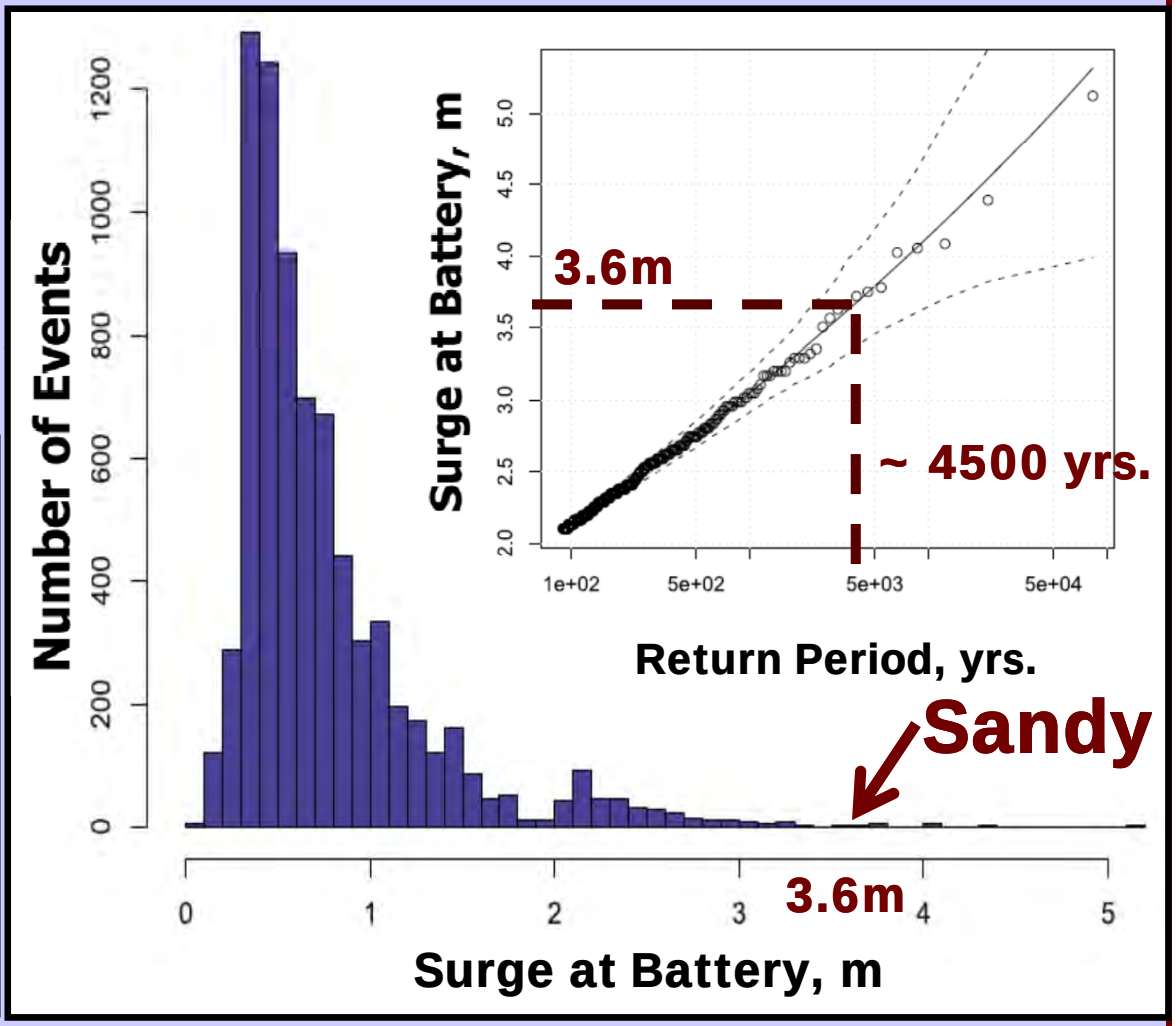
HURRICANE SANDY INNUNDATION



HURRICANE SIMULATION (Lin et al. , 2010)

- **Simulated 7555 Storm Tracks Within 200 km of Battery**
- **Hydrodynamic Models: SLOSH and ADCIRC**



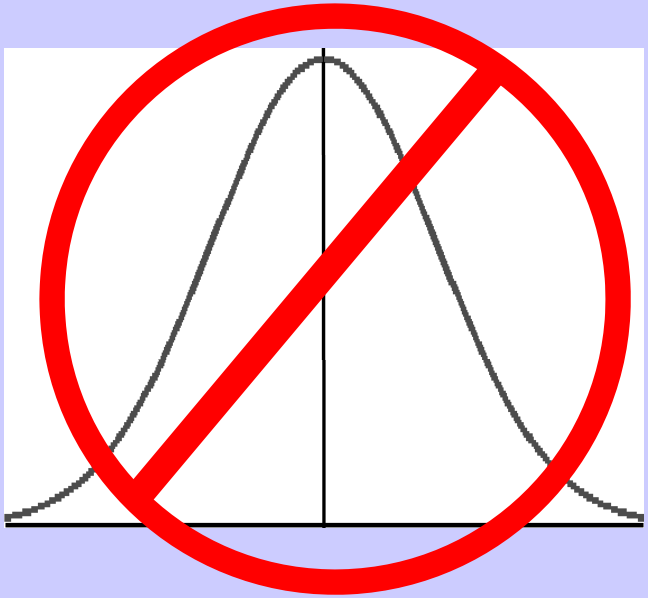


TOPICS

- Tohoku Earthquake
- Canterbury EQ Sequence
- Hurricanes
  - New Orleans
  - New York City
- **New Normal**

OBSERVATIONS

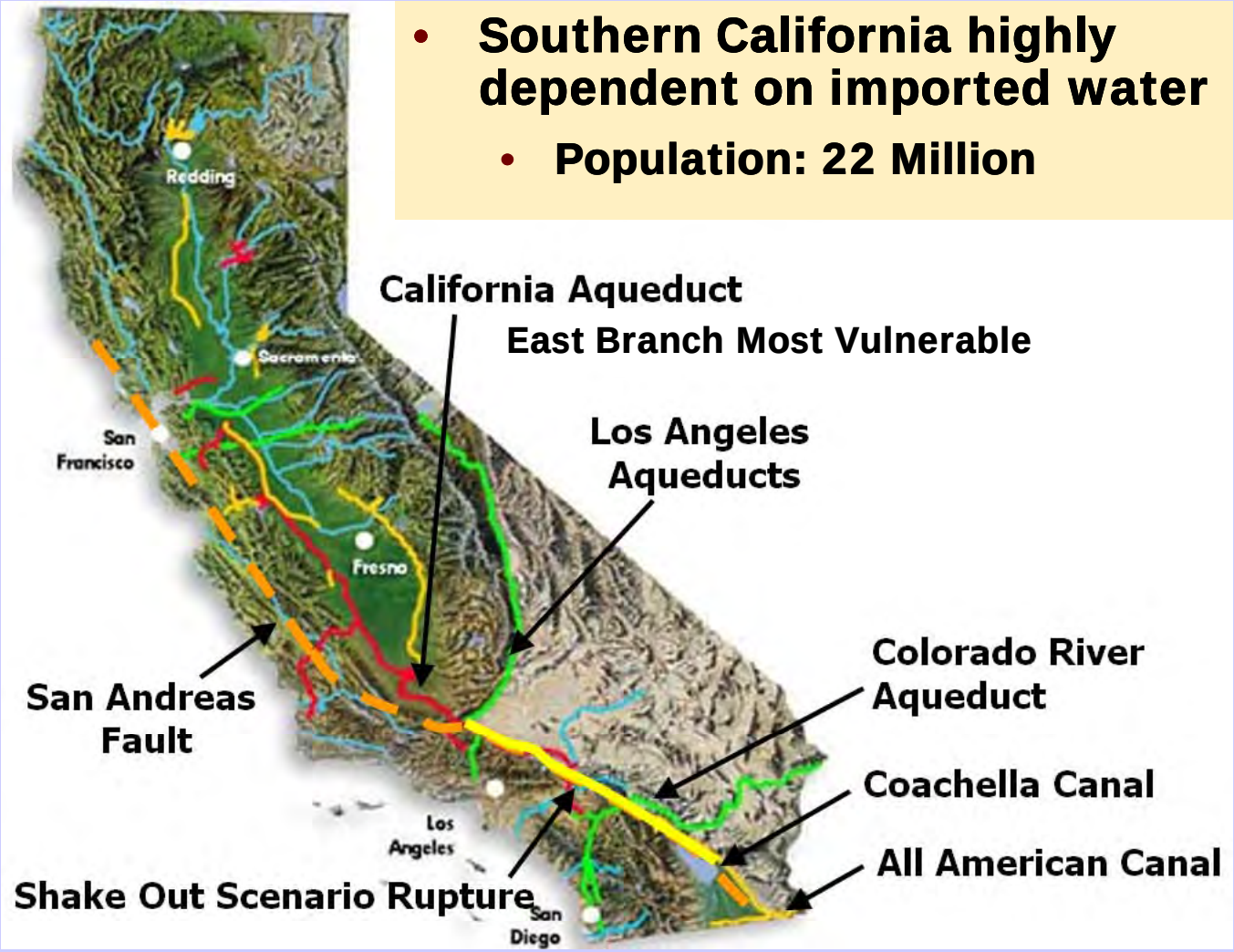
- **Anything But Normal**
  - **Target nuclear failure probability ≈ 1x 10-6/yr**
  - **5 major nuclear releases in 14,000 reactor years = 3x 10-4/yr**
  - **Probability tails control**
- **Problems Compounded by Institutional Constraints, Politics, Lack of Perspective, & Dysfunction**



NEW NORMAL

- Too Big To Fail
  - Reassess Risk Related to Critical Infrastructure
  - Reassess & Identify *Critical* Infrastructure
- Local Coalitions
  - Coalitions to Protect Critical Infrastructure Too Big to Fail
- Punctuated Resilience

SOUTHERN CALIFORNIA WATER SUPPLY



- **Southern California highly dependent on imported water**
  - **Population: 22 Million**

70% Imported Water:

- **California Aqueduct**
- **Los Angeles Aqueducts**
- **Colorado River Aqueduct**

30 % Ground Water

SHAKEOUT SCENARIO

7.8 M_W San Andreas Fault Earthquake

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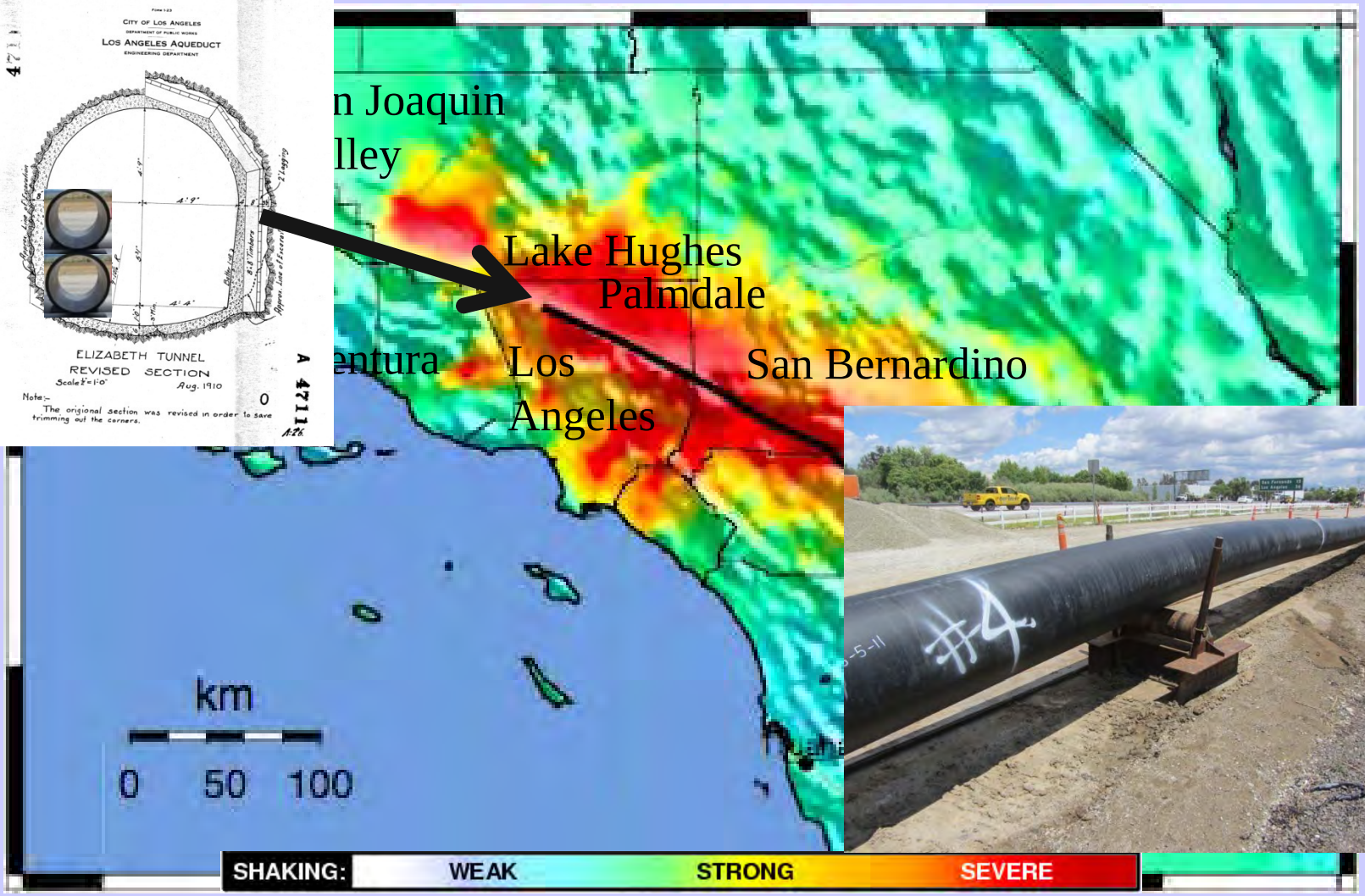
SOUTHERN CALIFORNIA WATER SUPPLY (after Davis, 2010)

- CA Aqueduct (CA DWR)
  - 49 billion m3/yr
  - Faulting Rupture in >15 places
- LA Aqueducts (LADWP)
  - 390 million m3/yr
  - Elizabeth Tunnel
- Colorado River Aqueduct (MWD)
  - 900 million m3/yr
  - Multiple fault ruptures & ~ 4 m uplift

LOS ANGELES AQUEDUCTS

- **3.3m Horizontal Fault Displacement**
- **2.9m Wide Elizabeth Tunnel**
  - **Cuts off tunnel**

LA WATER SUPPLY CROSSES SAN ANDREAS FAULT



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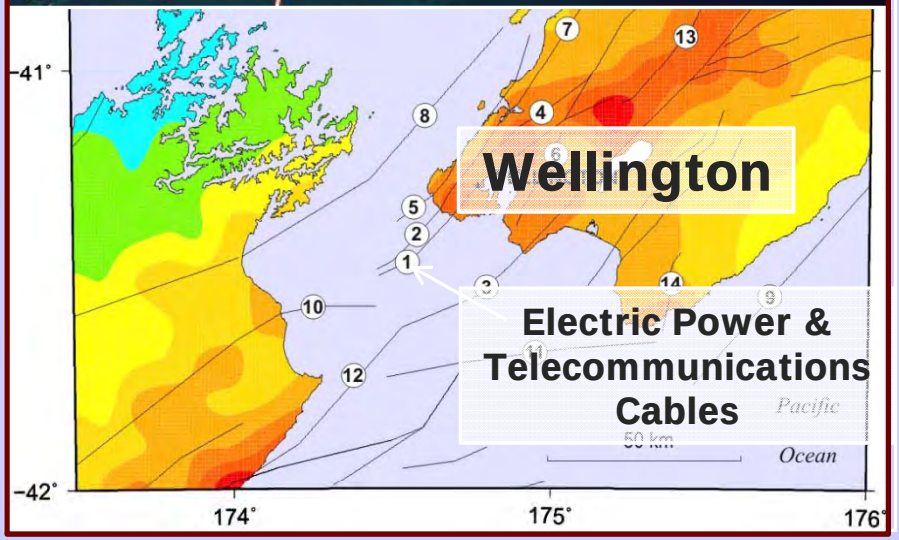
WELLINGTON SEISMIC RISK

- **Urgent Need to Apply Christchurch Lessons**
  - **Harbor Facilities**
  - **Water Supply**
  - **Fire Hazards**
  - **Major Highways**
  - **Electric Power System**
  - **Telecommunications**
  - **National Government**



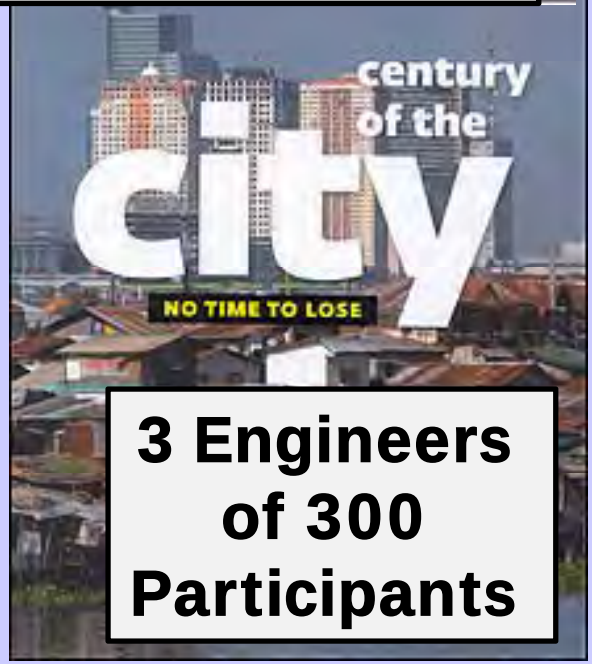
CRITICAL INFRASTRUCTURE PROJECTS

- Southern California Water Supply
- Sacramento River Delta Flood Protection System
- San Francisco Fire Protection System & Auxiliary Water Supply
- New York City Water Supply
- New Madrid Zone Transportation & Liquid Fuel Lifelines
- Mississippi Delta Flood Management

MULTIDSICIPLINARY DIALOGUE

No Engineers of 28 Speakers

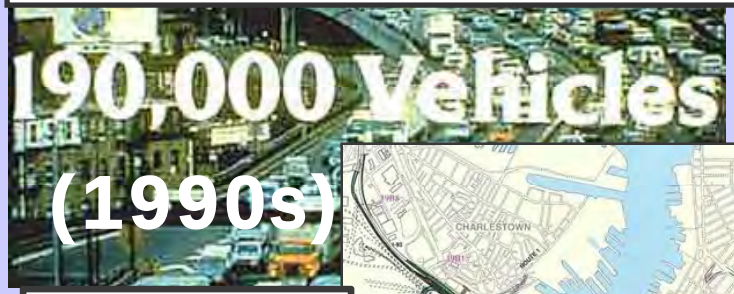
< 10 % Engineers



3 Engineers of 300 Participants

INFRASTRUCTURE FINANCING

Boston Central Artery/Tunnel

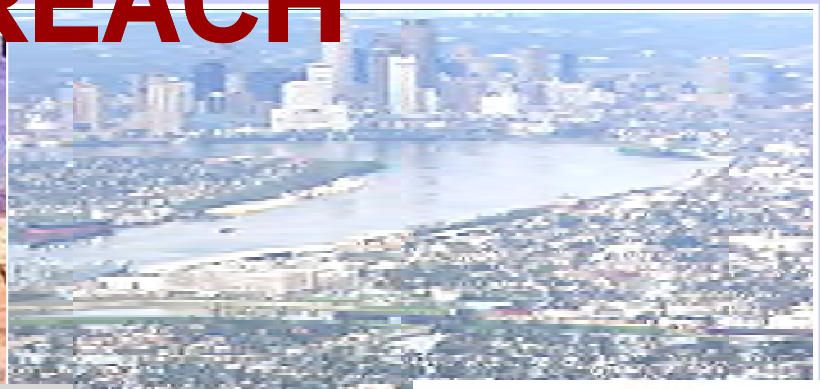


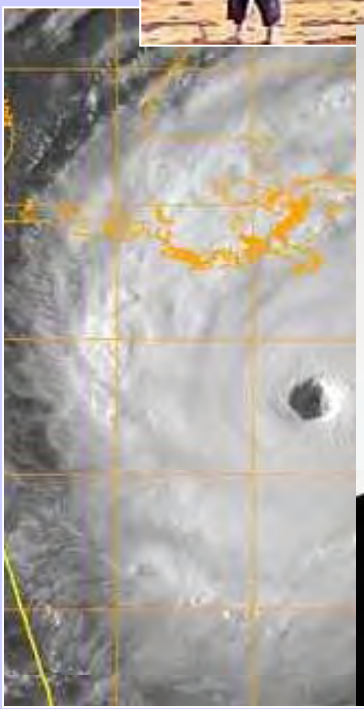
- $ 2.8 B (1982)
- $ 6.0 B (1996)
- $14.8 B (2007)

Access to Region's Core ARC Project

- $ 8.7 B among Federal & state governments
- *Canceled*

LEADERSHIP & PUBLIC OUTREACH





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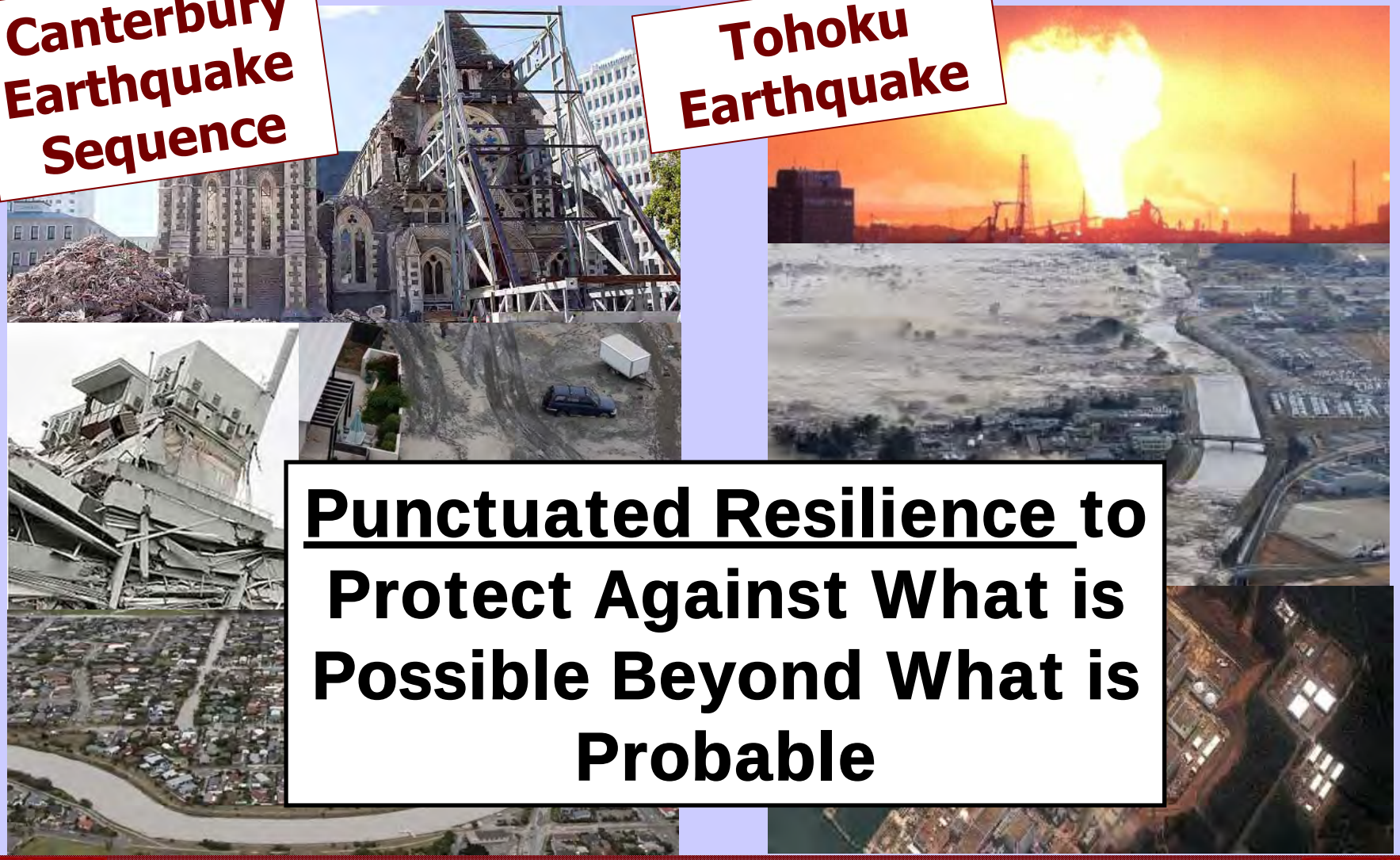
NEW NORMAL FOR NATURAL DISASTERS

Canterbury Earthquake Sequence

Tohoku Earthquake



<u>Punctuated Resilience</u> to Protect Against What is Possible Beyond What is Probable

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