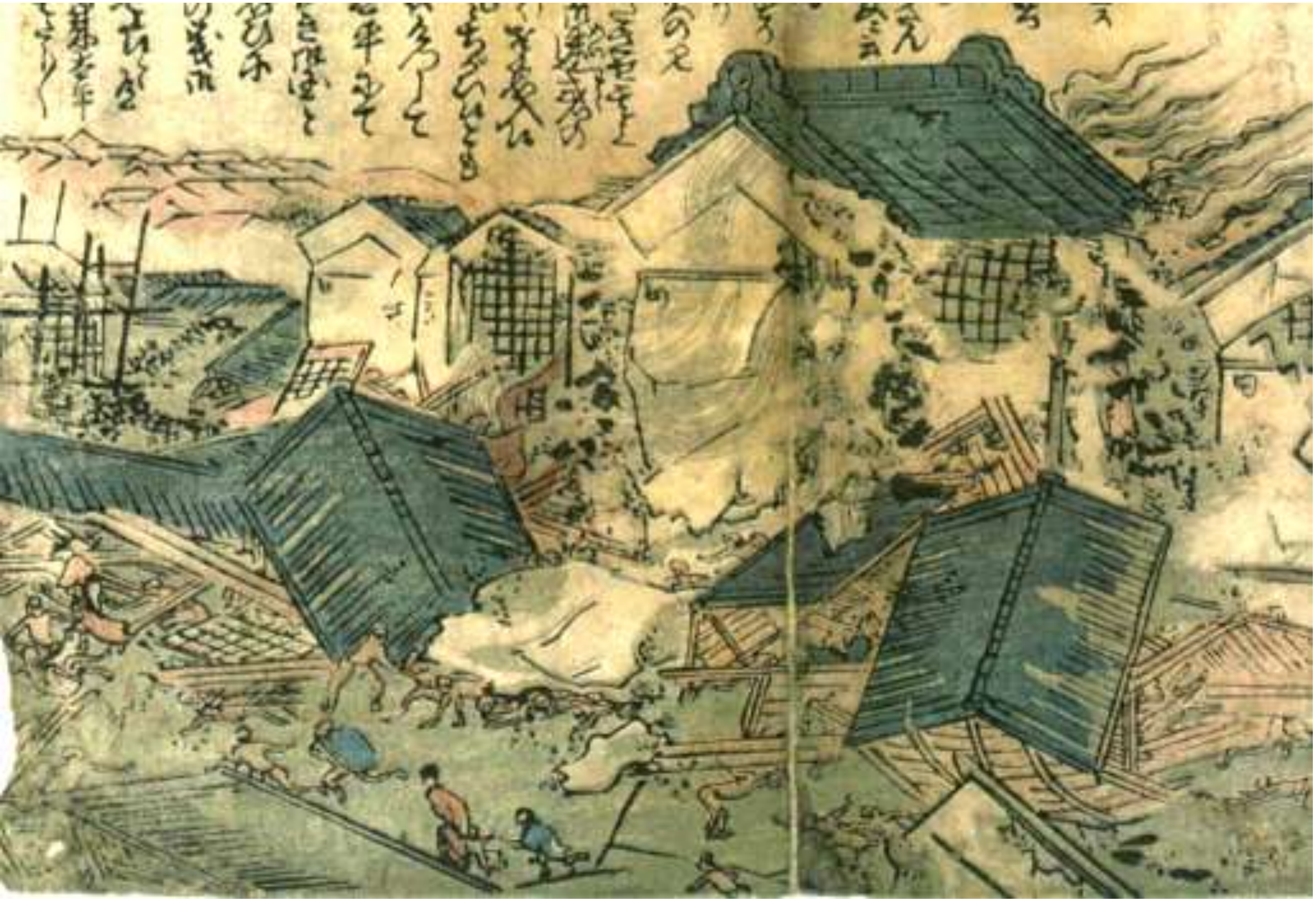
Assessing the Seismic Risk of Water Systems, Application of AWWA J-100



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PNWS AWWA, Bellevue, WA
April 29, 2015

Overview

- Introduction
- Seismicity and earthquake hazards
- Facility vulnerability
- System assessment
  - Portland
  - Seattle
- Restoration and resiliency
- Conclusions

Water System Seismic Risk Modeling

- Seismic risk assessment of water systems developed over last 25 years
- Pushed along by Loma Prieta 1989, Northridge, 1994, and Kobe 1995
- SVA's following 9/11
- 2011 Christchurch New Zealand and Japan/Tohoku - 40+ days water system outage
- Oregon Resilience Plan – February 2013 similar scenario based approach – focuses on Cascadia Subduction Zone scenario

AWWA J-100, Risk and Resilience Management of Water and Wastewater Systems

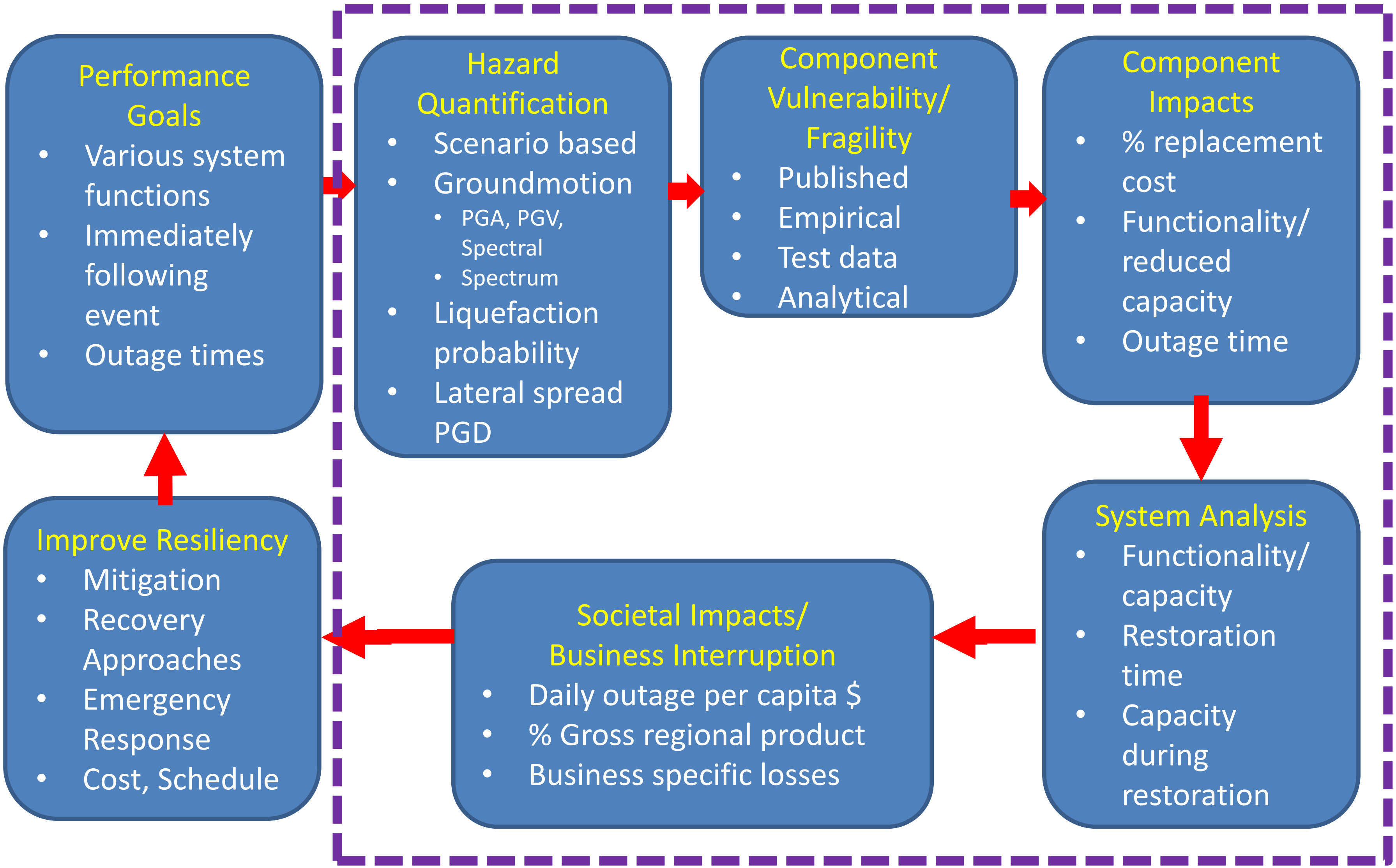
- Introduced in 2010
- Focus on security vulnerability with discussion on natural hazards
- 2016 version – Integrated Analysis of Natural Hazards, Nonmandatory Appendix 4
- Addresses earthquake, hurricane, tornado and flood, methodology applicable to all hazards

Oregon Resilience Plan

System Function	Event Occurs	0-24 hours	1-3 days	3-7 days	1-2 weeks	2-4 weeks	1-3 months	3-6 monts	6-12 months
Potable water availalble at supply source		▲	●		◆			X	
Main transmission faciliites, pipes, pump stations and reservoirs operational		◆					X		
Water supply to critical facilities available		●	◆				X		
Water for fire suppression at key supply points		◆		X					
Water for fire suppression at fire hydrants				▲	●	◆			X
Water available at community distribution centers/points			●	◆	X				
Distribution system operational			▲	●	◆				X

Desired time to restore component to 80-90% operational	◆
Desired time to restore component to 50-60% operational	●
Desired time to restore component to 20-30% operational	▲
Current state (90% operational)	X

System Risk Analysis Methodology



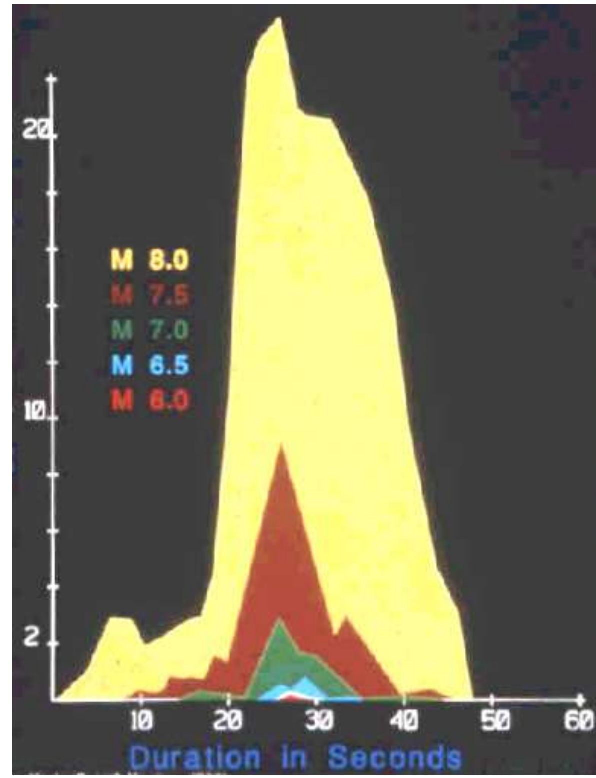
Risk Based

Risk = Frequency x Vulnerability x Consequence

- Frequency of hazard event
  - Probability of occurrence in 50 years 10%, 5%, 2%
  - Return period – 500, 1,000 or 2,500 years
  - Lower probability results in larger intensities
- Vulnerability when subjected given intensity
- Consequence of failure
  - Loss of function
  - Cost or repair
  - Cost resulting from outages

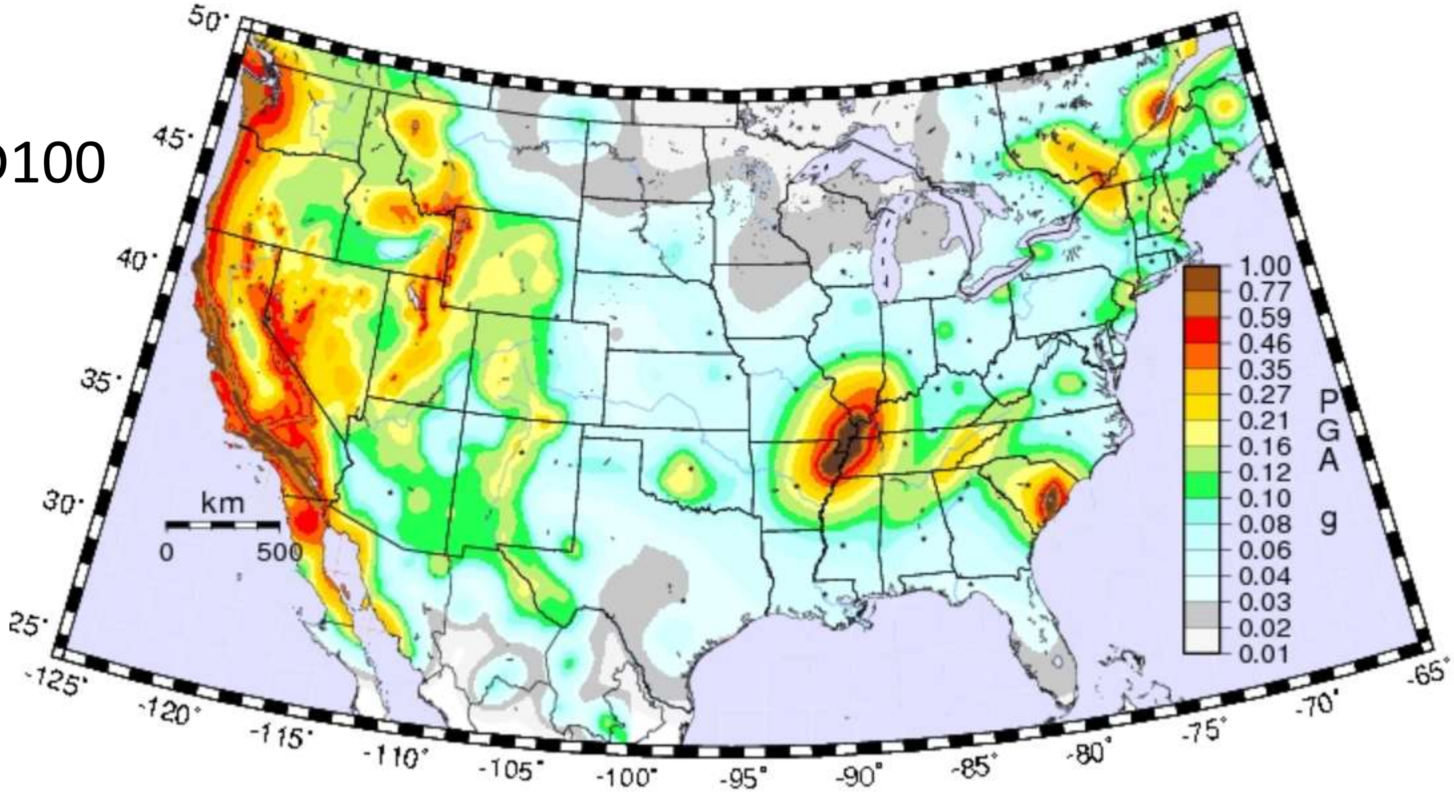
Earthquake Terminology

- Magnitude
  - Richter or Moment Magnitude
  - Measure of energy release
  - 32 times more energy for increase of 1
- Peak ground acceleration (PGA) % of gravity
- Permanent ground deformation (PGD) - inches

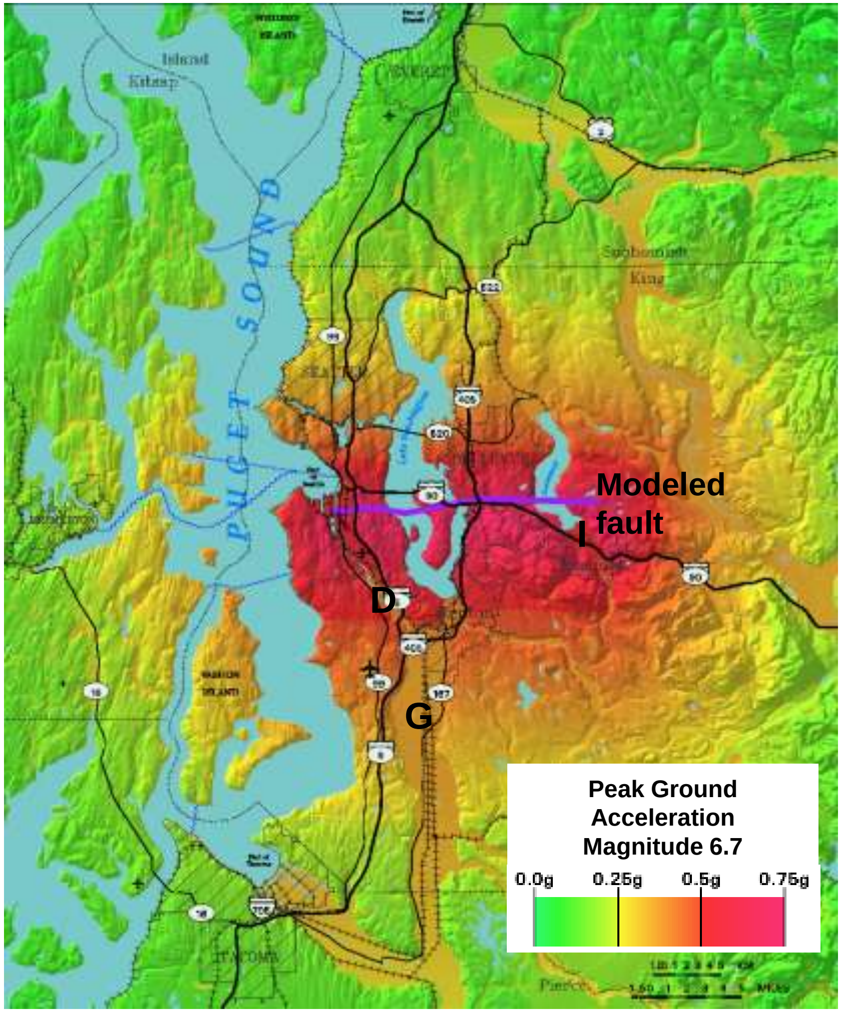


Probabilistic Hazard - Shaking

- USGS ground motions
  2% in 50 years
- IBC
- ASCE 7
- AWWA D100



Deterministic Hazard - Shaking



Seattle Fault, M6.7 Scenario

- Based on selected scenario with associated return period
- Maps estimated ground motions for a given event, not probabilistic ground motions
- Does not overestimate damage
- Shaking is calculated using attenuation relationships
- Recommend using multiple scenarios with range of return periods
- Scenarios available from the USGS

Earthquake Hazards

- Shaking
  - PGA, PGV, spectral
  - PGA – Northridge 80 x gravity
- Permanent Ground Deformation (PGD)
  - Tectonic uplift/subsidence
  - Fault offset
  - Settlement
  - Liquefaction
  - Lateral spread
  - Lurching
  - Landslide

Liquefaction

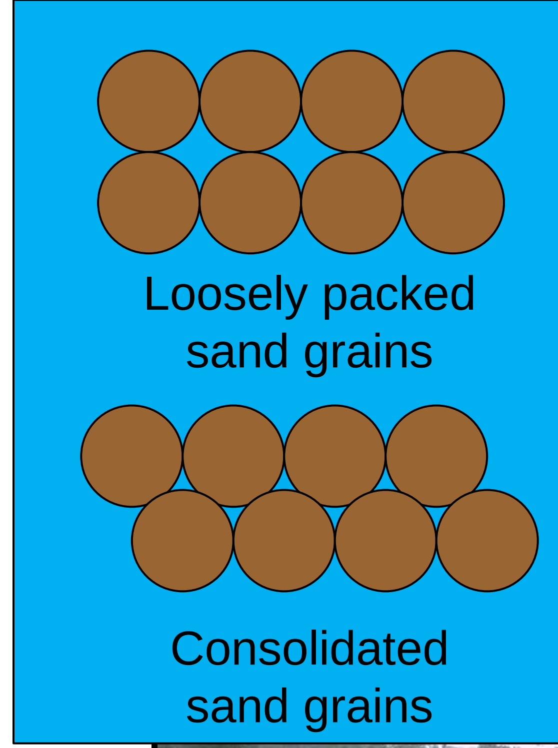
Costa Rica, 1991

Philippines, 1990

San Fernando Earthquake, 1971

Liquefaction

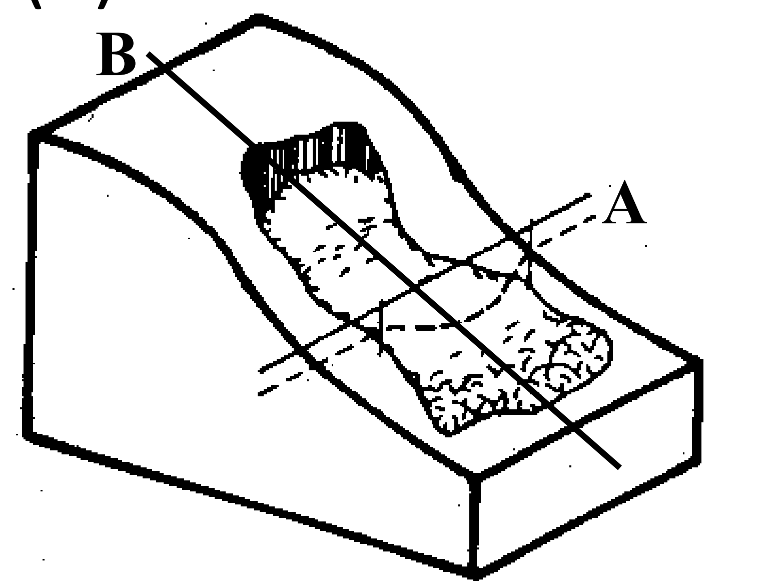
- Occurs due to shaking
- Soil particles consolidate squeezing out water
- Water pore water pressure increases reducing friction between soil particles
- Soil becomes a viscous liquid



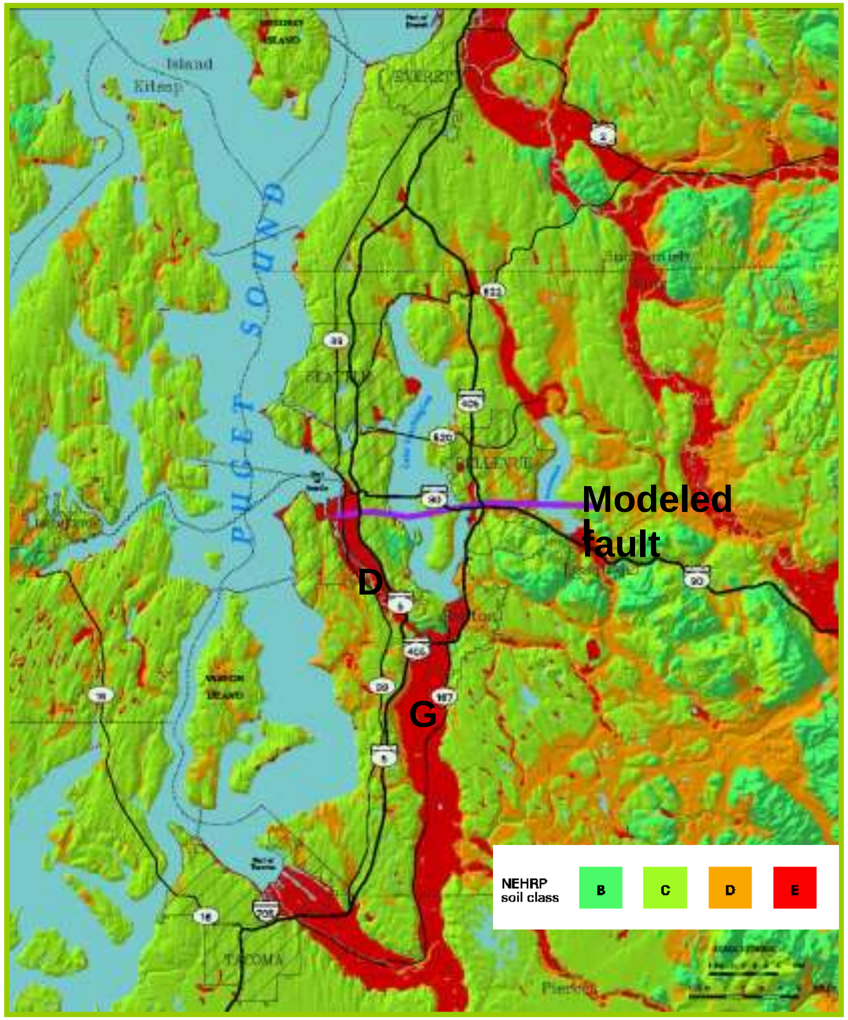
Costa Rica, 1991

Liquefaction – Lateral Spread

- Movement is perpendicular to pipe (A)
  - Pipe can accommodate some bending
  - Segmented pipe will separate at joints, shear and bend
- Movement parallel to pipe (B)
  - Segmented pipe will pull apart at one end, and crush at the other



Hazard - Mapping



- Liquefaction susceptibility and landslide mapping often available from the state, DNR, DOGAMI, etc
- PGD mapping is not available

Component Vulnerability

- Assess each system facility
- Estimate actual performance for scenario
- Understand damage state
  - Likelihood of Failure
  - Functionality
  - Recovery
  - Recovery cost
- For specific earthquake
- For hazards

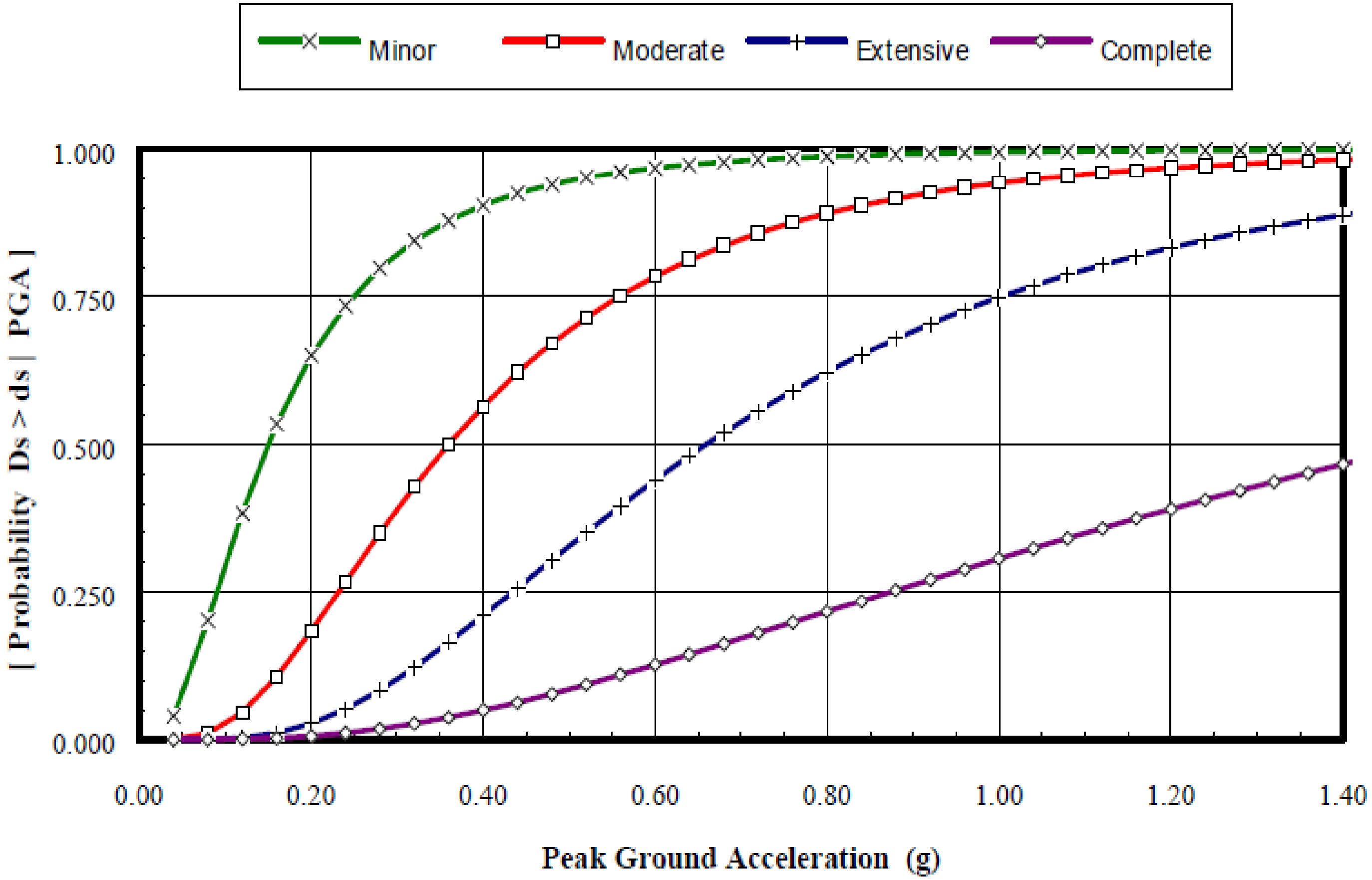
Buckled Steel Tank. Northridge Earthquake, 1994

Resources for Developing Fragilities

- HAZUS - FEMA
- ASCE Technical Council on Lifeline Earthquake Engineering
- American Lifelines Alliance
- MCEER, MAE, PEER Centers of Excellence

Burst cast iron pipe. Kobe 1995

Fragility Curves from HAZUS

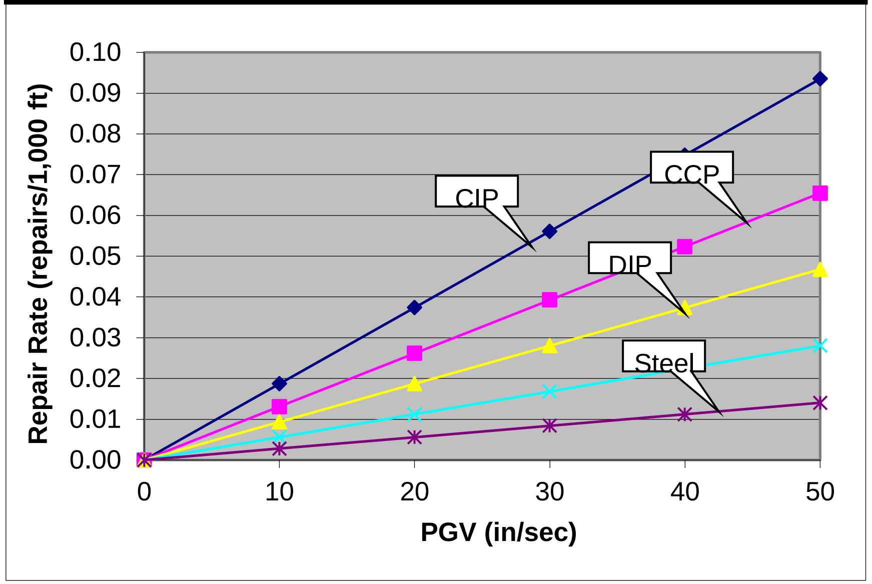


Fragility Curve Development

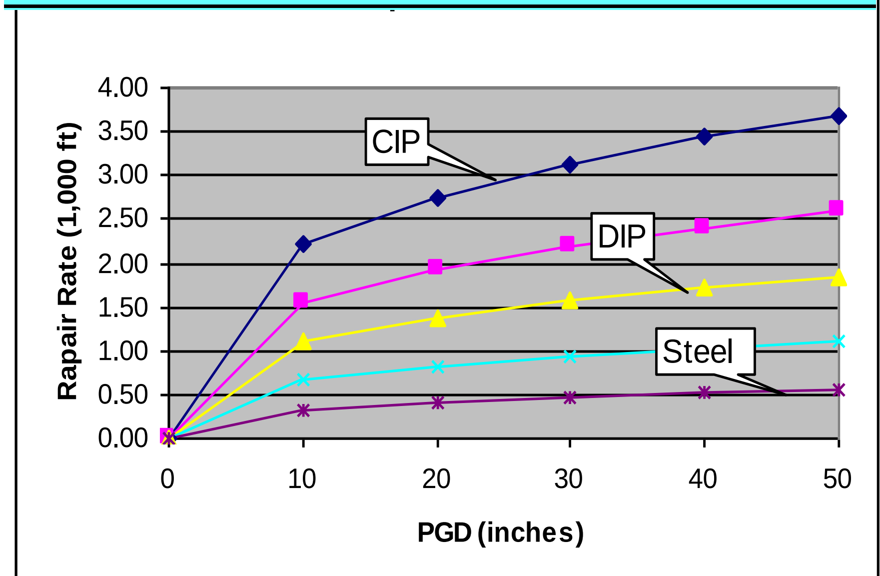
- Date of design/building code
  - E.g. – improvements following 1971 San Fernando
  - Progression of AWWA D100 seismic requirements
- Seismic zone designed to
  - Oregon increased in early 1990s
- Analysis
  - Capacity/demand ratios
  - Estimate damage when exceeded

Burst Wire-Wrapped Tank, Purissima Hills, Loma Prieta, 1989

Repair Rate/1000 feet = $K_1 * (0.00187) * PGV$



Repair Rate/1000 feet = $K_2 * (1.06) * PGD^{0.319}$



ALA Pipeline Damage Relationships

- Using GIS, pipelines are overlaid on hazard layers
- PGV is "related" to pipe
- PGD is "related" to pipe in liquefaction areas
- Pipe breaks and leaks can be calculated within GIS
- Breaks and leaks can be calculated by pressure zone

ALA Pipe Damage Relationships K Values

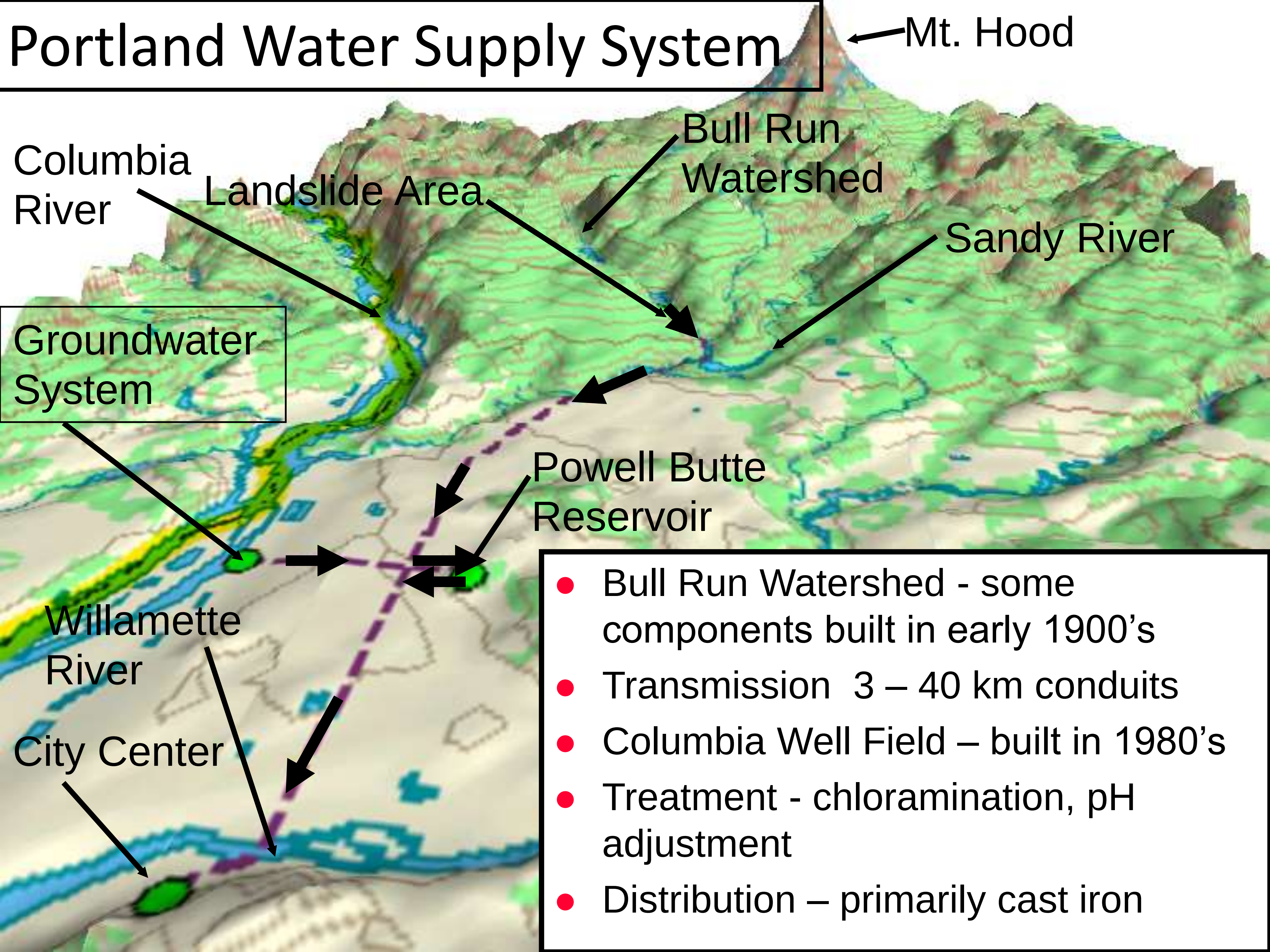
Material	Joint Type	Soils	Diameter	K_1	K_2
Cast iron	Cement	All	Small	1.00	1.00
Cast iron	Cement	Corrosive	Small	1.40	
Cast iron	Cement	Non-corrosive	Small	0.70	
Cast iron	Rubber gasket	All	Small	0.80	0.80
Cast iron	Mechanical restrained				0.70
Welded steel	Lap-Arc Welded	All	Small	0.60	
Welded steel	Lap-Arc Welded	Corrosive	Small	0.90	
Welded steel	Lap-Arc Welded	Non-corrosive	Small	0.30	
Welded steel	Lap-Arc Welded	All	Large	0.15	0.15
Welded steel	Rubber gasket	All	Small	0.70	0.70
Welded steel	Screwed	All	Small	1.30	
Welded steel	Riveted	All	Small	1.30	
Asbestos Cement	Rubber gasket	All	Small	0.50	0.8
Asbestos Cement	Cement	All	Small	1.00	1.00
Concrete w/Stl Cyl.	Lap-Arc Welded	All	Large	0.70	0.60
Concrete w/Stl Cyl.	Cement	All	Large	1.00	1.00
Concrete w/Stl Cyl.	Rubber gasket	All	Large	0.80	0.70
PVC – C900, C905	Rubber gasket	All	Small	0.50	0.80
➡ PVC – C909 (1)	Restrained	All	Small	0.15	
Ductile Iron	Rubber gasket	All	Small	0.50	0.50
➡ Ductile iron (1)	Restrained joint	All	Small	0.25	
➡ Ductile iron (1)	Seismic joint	All	Small	0.15	
➡ HDPE (1) – C906	Fused	All	Small	0.15	

➡ Added since ALA published

System Assessment

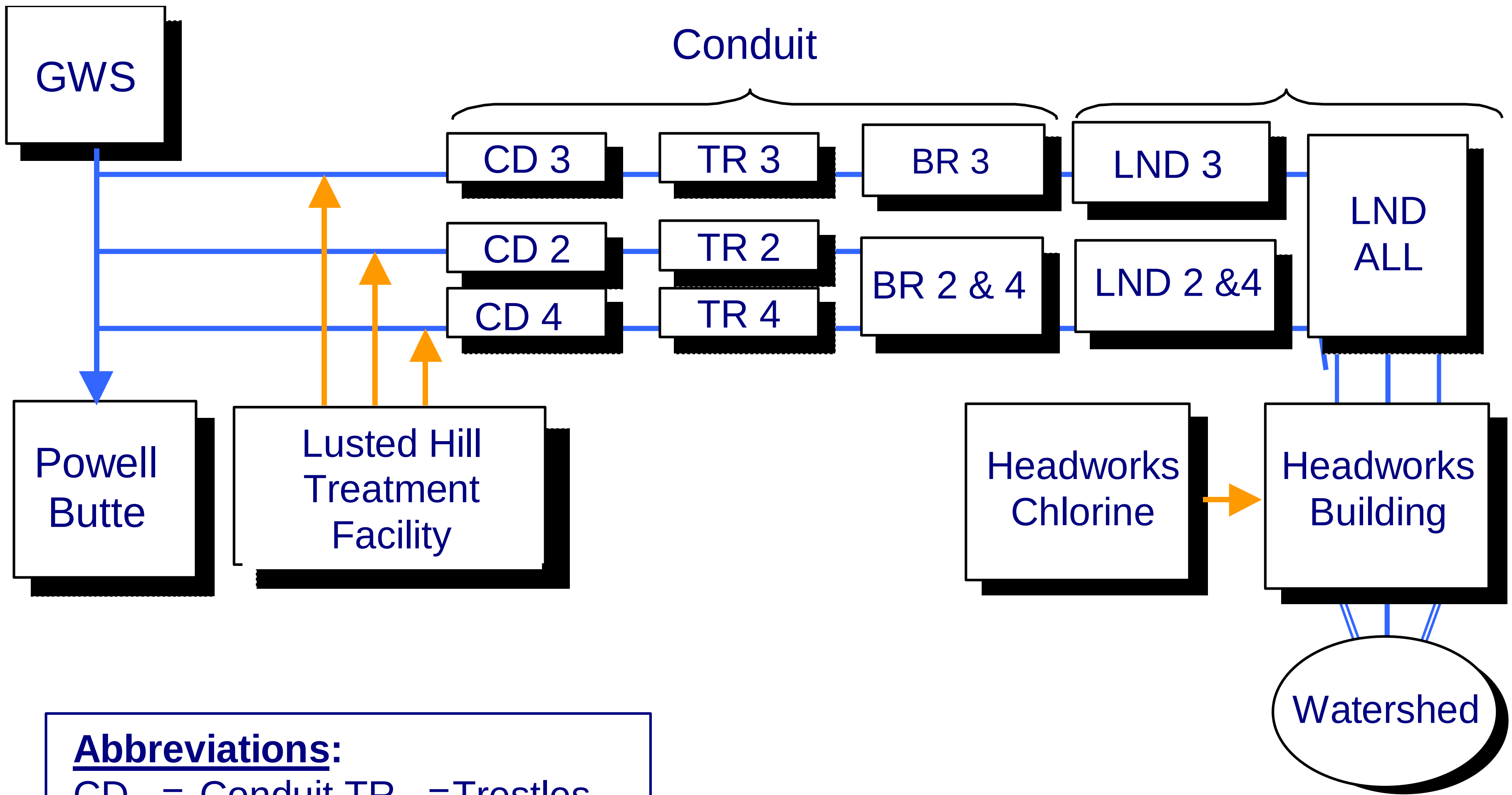
- Workshop setting – experts
  - GIS showing facility and pipeline functionality
- Connectivity model/system probabilistic assessment – spreadsheet
- Hydraulic model
  - EPANET
  - Academic models
  - Negative pressure issues with many pipe failures

Portland Water Supply System



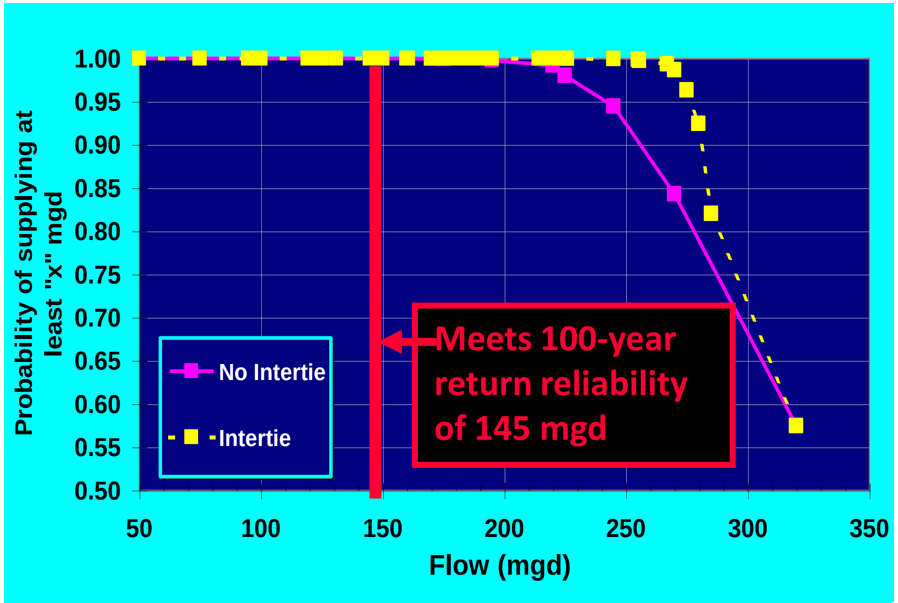
- Bull Run Watershed - some components built in early 1900's
- Transmission 3 – 40 km conduits
- Columbia Well Field – built in 1980's
- Treatment - chloramination, pH adjustment
- Distribution – primarily cast iron

Portland Supply System Schematic/ Spreadsheet Connectivity Analysis

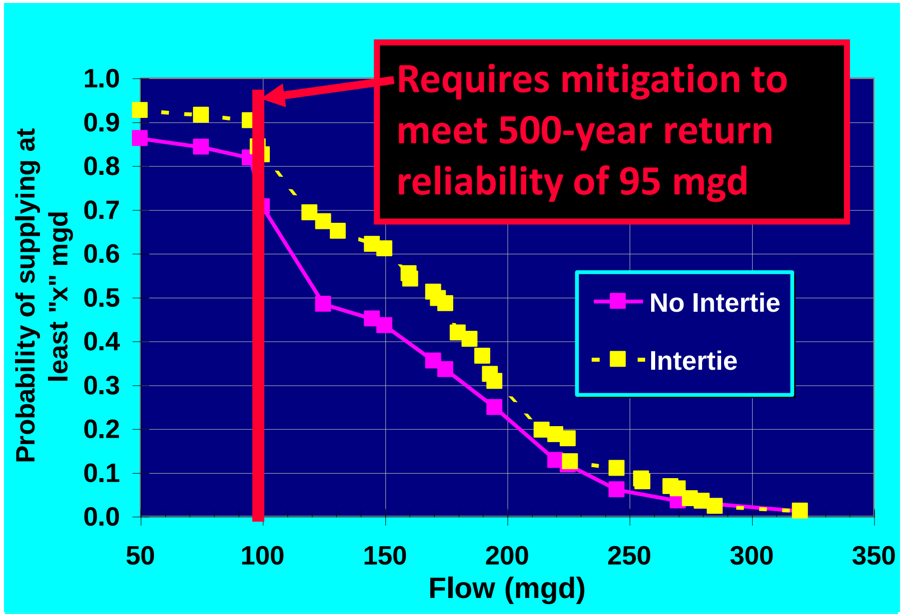


Abbreviations:
CD = Conduit TR =Trestles
BR = Bridges LND =Landslide

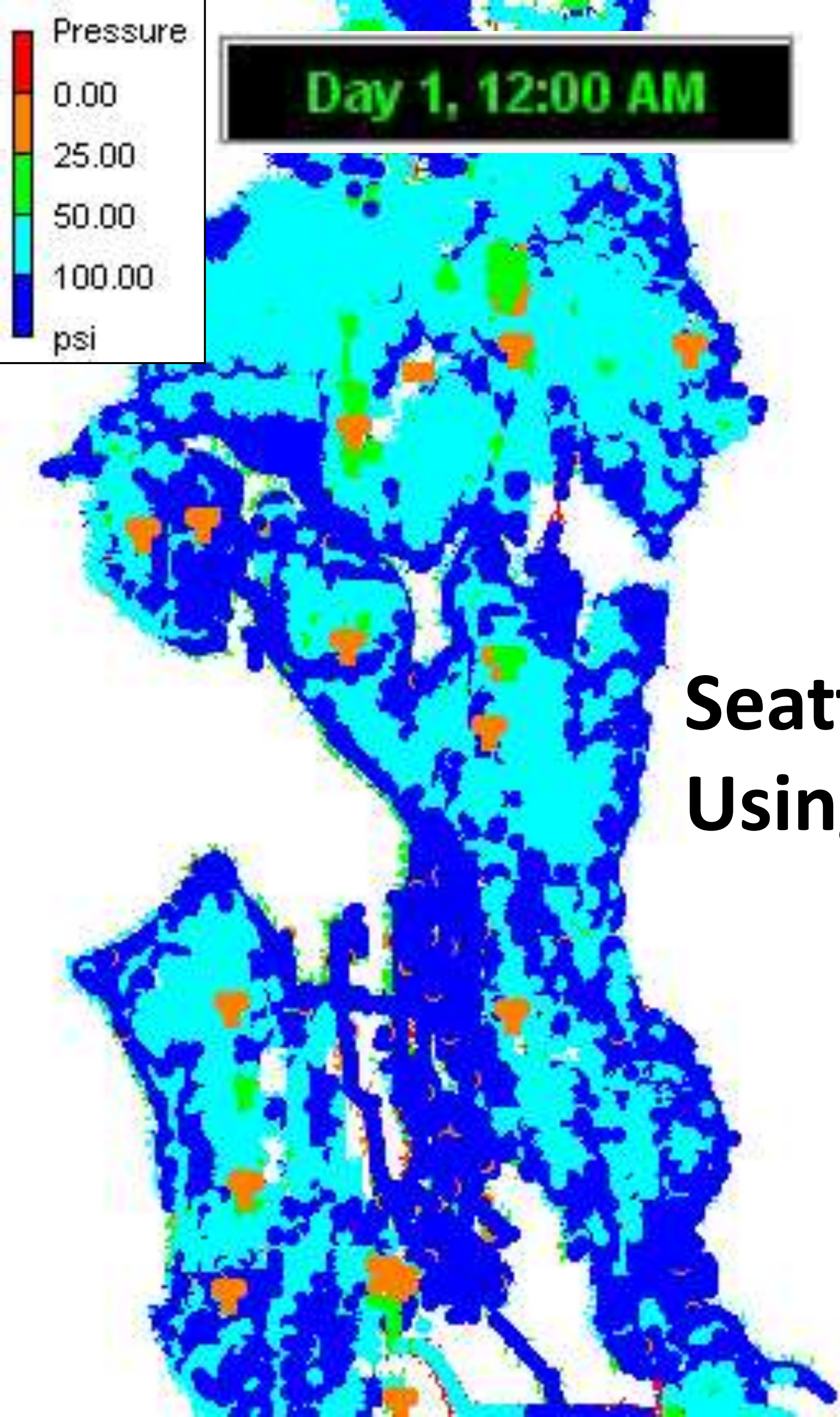
Portland Earthquake Reliability



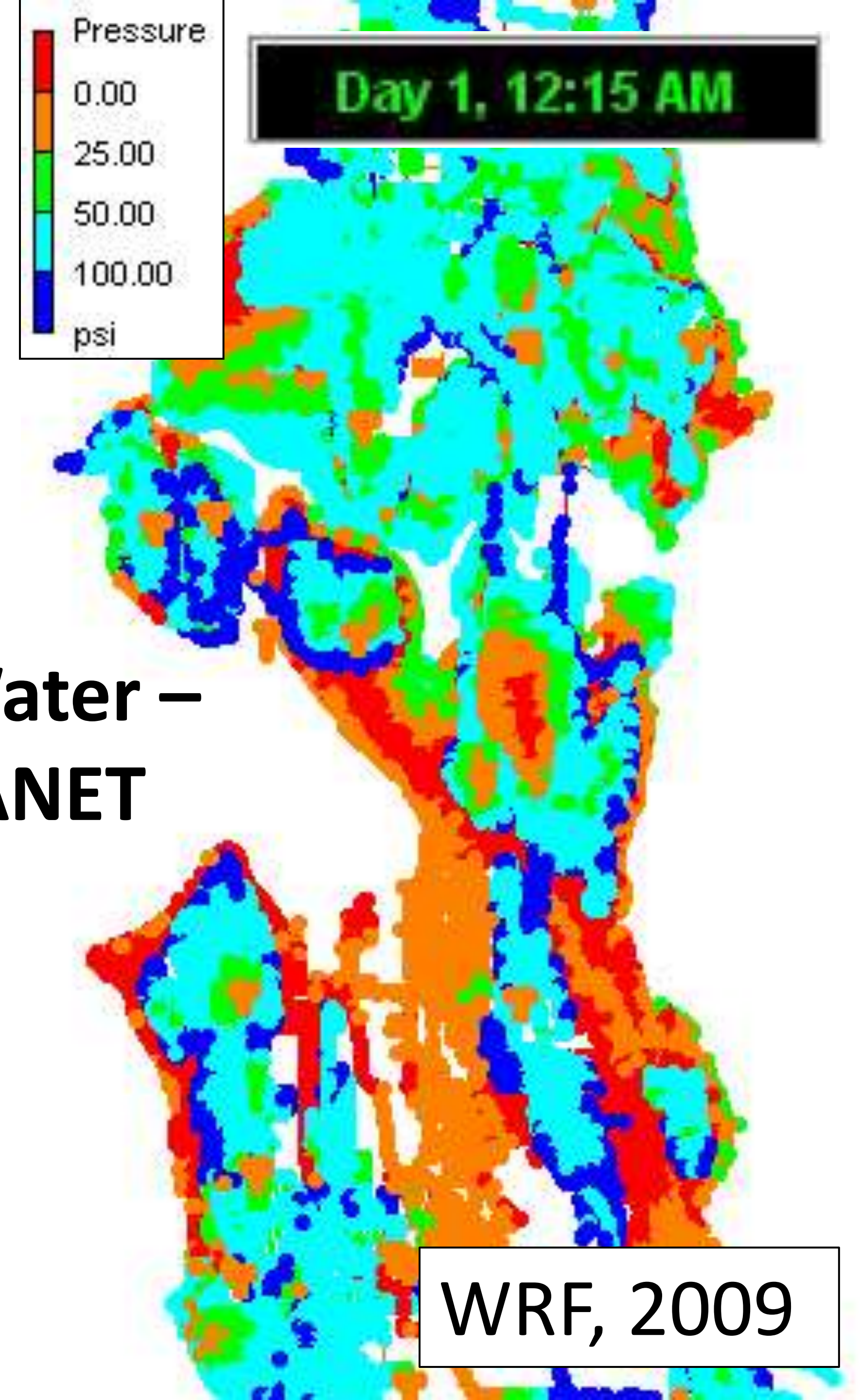
Supply System Reliability, 100-Year Return Earthquake



Supply System Reliability, 500-Year Return Earthquake



Seattle Water – Using EPANET

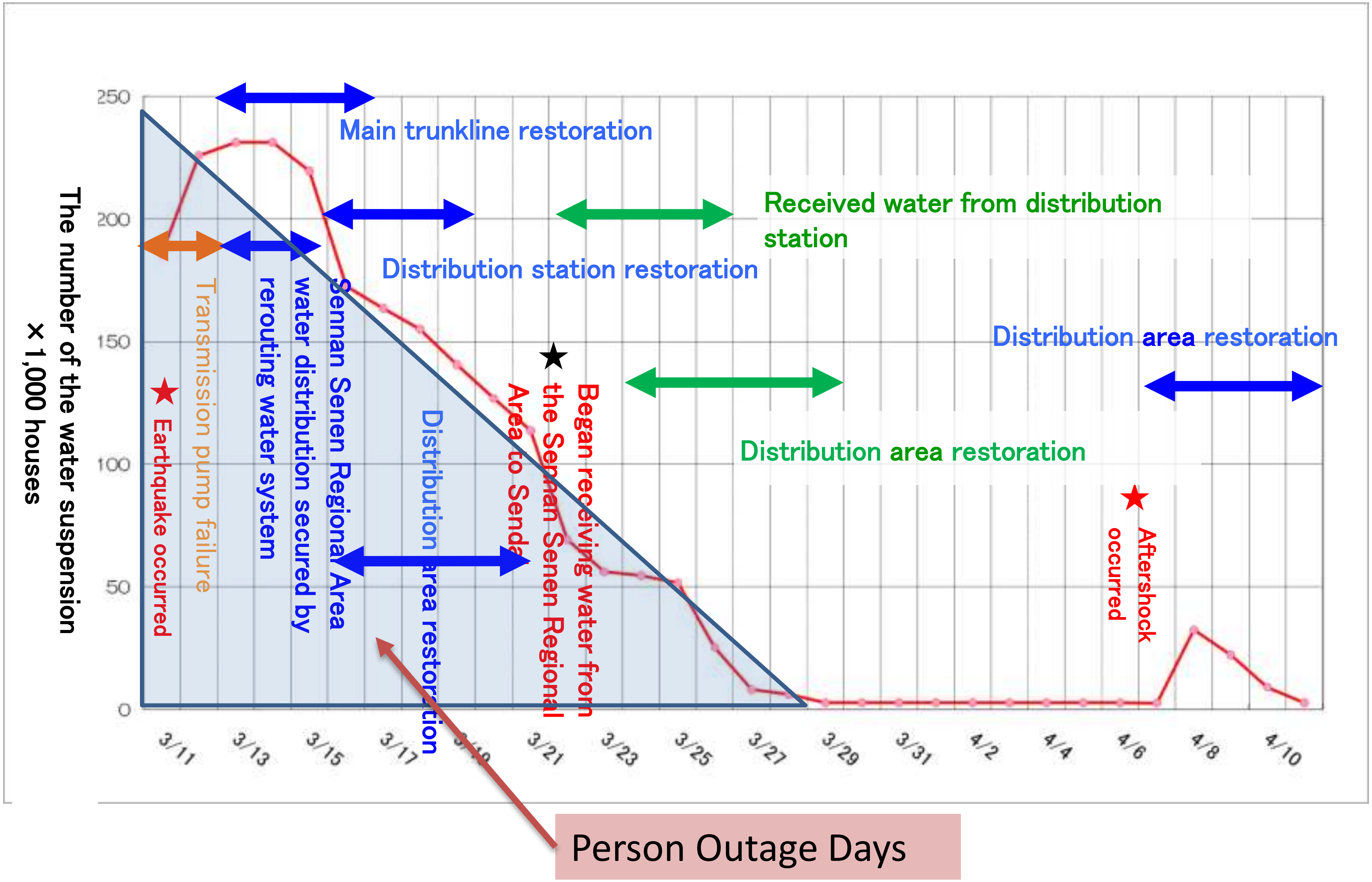


WRF, 2009

Restoration Calculations

- Start with damage estimate of facilities and pipelines
- Identify which are required to restore service
- Estimate repair crews available – structures, equipment, large diameter pipe, distribution pipe
  - Internal, Contractors, Mutual aid
- Estimate repair rate/crew
- Develop repair sequence
  - Restore the most people the fastest
  - Restore critical services – hospitals, industries etc.
- Calculate
  - Restoration days (by pressure zone)
  - Restoration time line
  - Person outage days (by pressure zone)

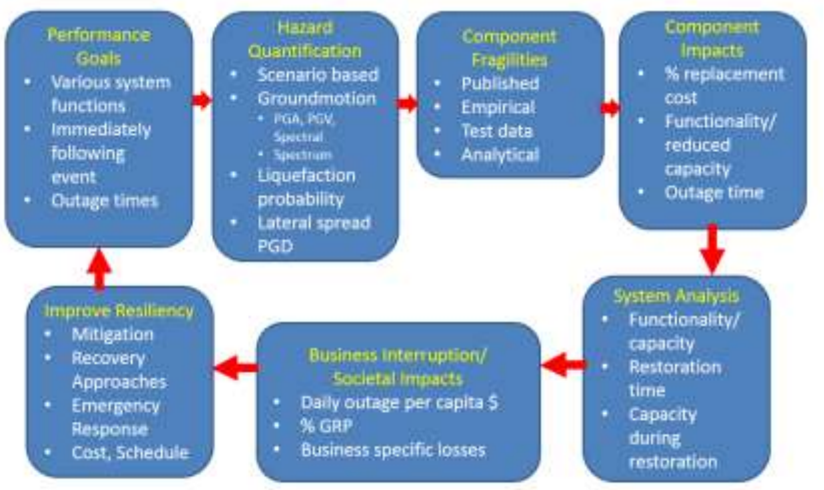
Water Restoration Timeline - Sendai



Improve Resiliency

- Upgrade or replace deficient facilities and pipe
- Enhance restoration procedures
- Emergency response
- Develop costs and implementation schedule

- Loop back to reevaluate performance levels



Where's it Being Used ?

Variations of this scenario-based methodology are being widely used in the Pacific Northwest:

- Portland (Oregon Resilience Plan)
- Sammamish Plateau W&S
- Tacoma
- Tualatin Valley WD (Oregon Resilience Plan)
- Seattle – near future

Conclusions

- AWWA J-100 effective tool for assessing system resilience
- Risk Based
- Components
  - Performance Goals
  - Hazards
  - Vulnerability/Fragility –Parameters
  - System Analysis
  - Societal Impacts and Business Interruption
  - Improve Resilience

Tohoku Earthquake
Japan 2011

Questions ?

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Kanigawa WTP,
Tohoku Earthquake
Japan 2011