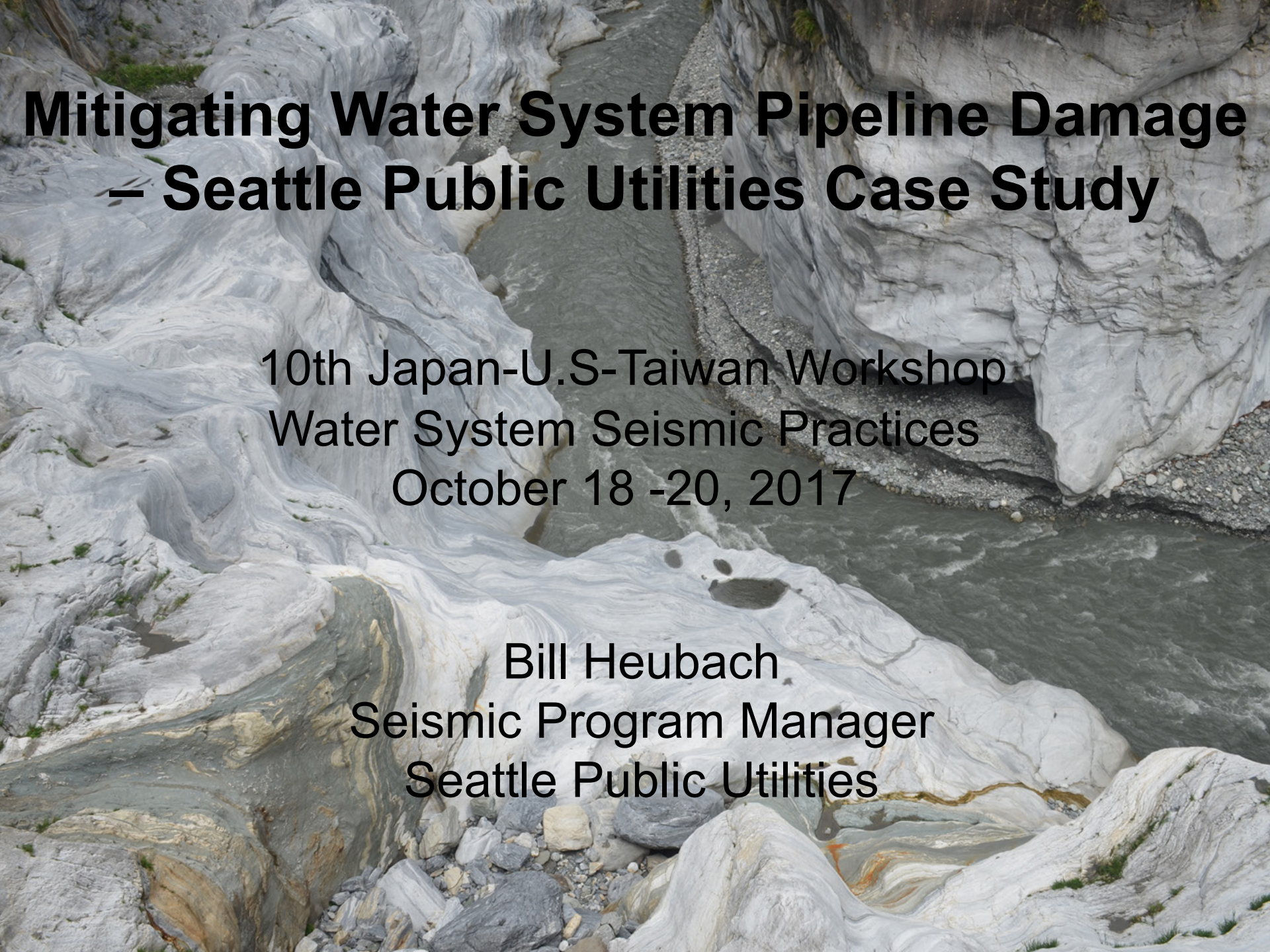
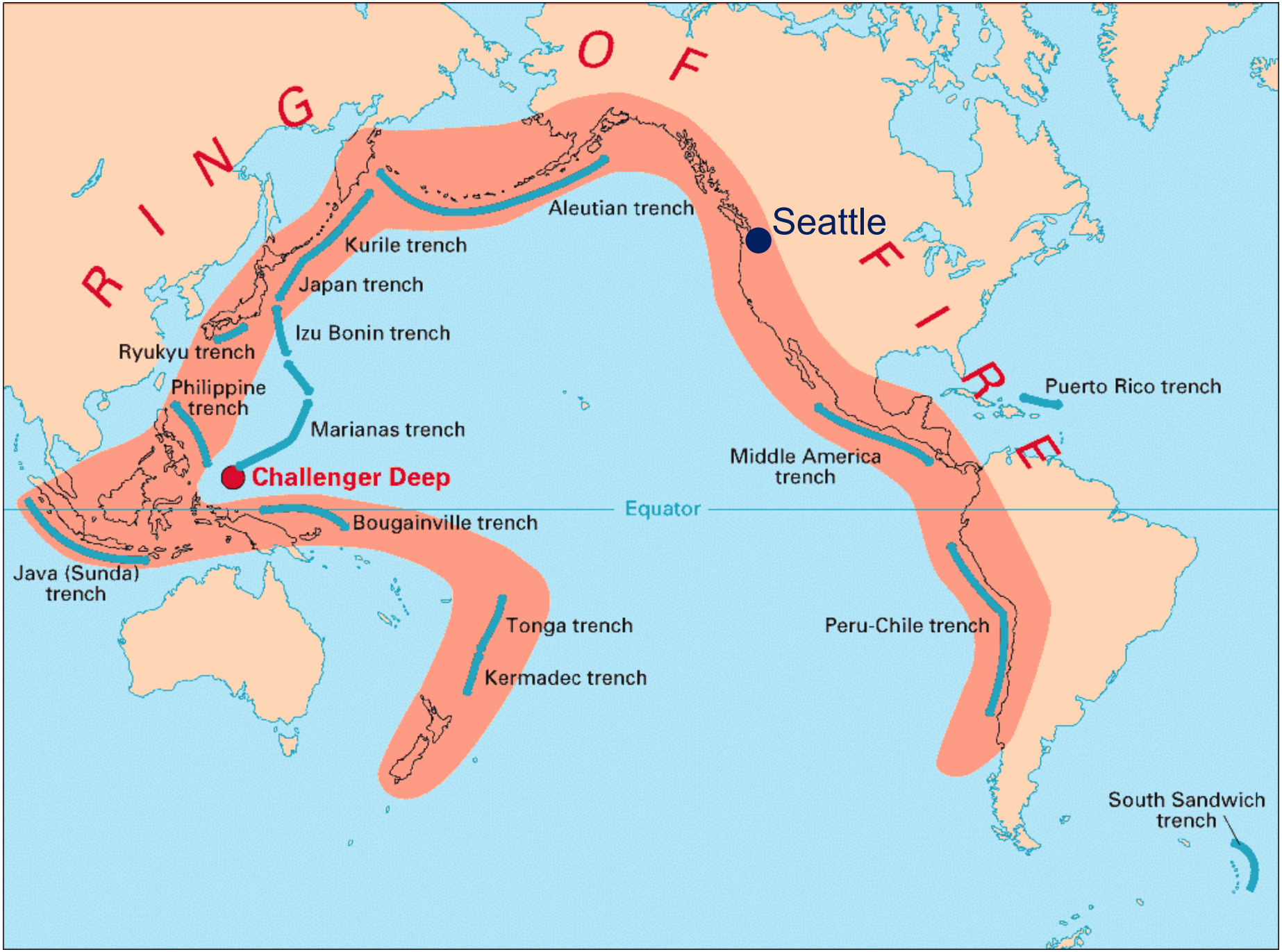


Mitigating Water System Pipeline Damage – Seattle Public Utilities Case Study

10th Japan-U.S-Taiwan Workshop
Water System Seismic Practices
October 18 -20, 2017

Bill Heubach
Seismic Program Manager
Seattle Public Utilities

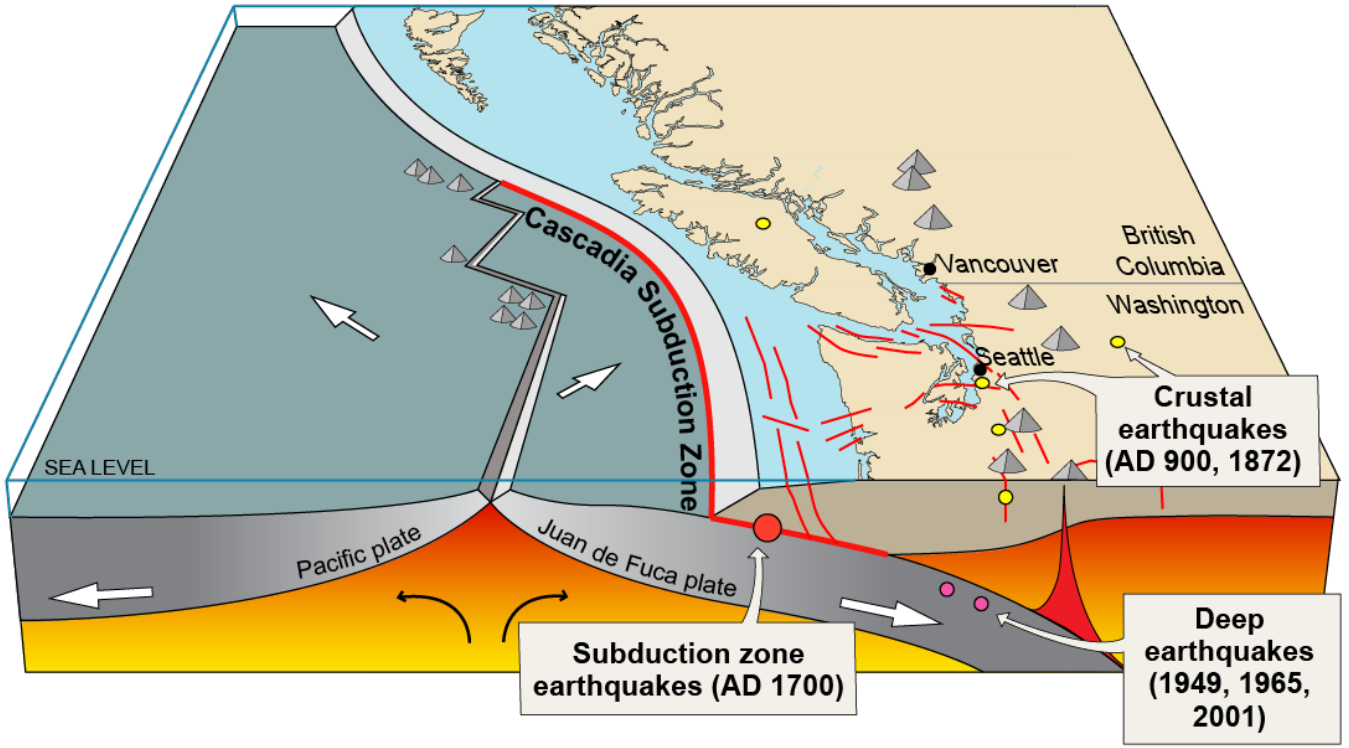

RING OF FIRE
Aleutian trench
Seattle
Kurile trench
Japan trench
Izu Bonin trench
Ryukyu trench
Philippine trench
Marianas trench
Challenger Deep
Puerto Rico trench
Middle America trench
Equator
Bougainville trench
Java (Sunda) trench
Tonga trench
Kermadec trench
Peru-Chile trench
South Sandwich trench

SPU System Overview

- Population Served: 1,400,000
- Average Daily Demand: 120 Million Gallons Per Day (450,000 Cubic Meters)
- Pipelines
  - Transmission: 200 Miles (350 Kilometers)
  - Distribution: 1700 Miles (2700 Kilometers)
- Storage Capacity – 300 Million Gallons (1,100,000 Cubic Meters)
- 16 Distribution System and 15 Transmission System Pump Stations

Pacific Northwest Earthquake Sources

(Washington State Department of Natural Resources and USGS)



Source	Max. Size	Recurrence
Subduction zone	M 9+	200–600 years
Deep Juan de Fuca plate	M 7+	30–50 years
Crustal faults	M 7+	Hundreds of years?

Volcano

Active crustal fault

Active plate boundary fault

*figure modified from USGS Cascadia earthquake graphics at http://geomaps.wr.usgs.gov/pacnw/pacnweq/index.html

Notable Seattle Seismic Events

- Historic
  - 900 – 930 A.D., M7 to M7.5 Seattle Fault
  - January 26, 1700, ~ M9 Cascadia Subduction
- Recent
  - 1949, M7.1 Olympia (Intraplate)
  - 1965, M6.5 Seattle-Tacoma (Intraplate)
  - 2001, M6.8 Nisqually (Intraplate)

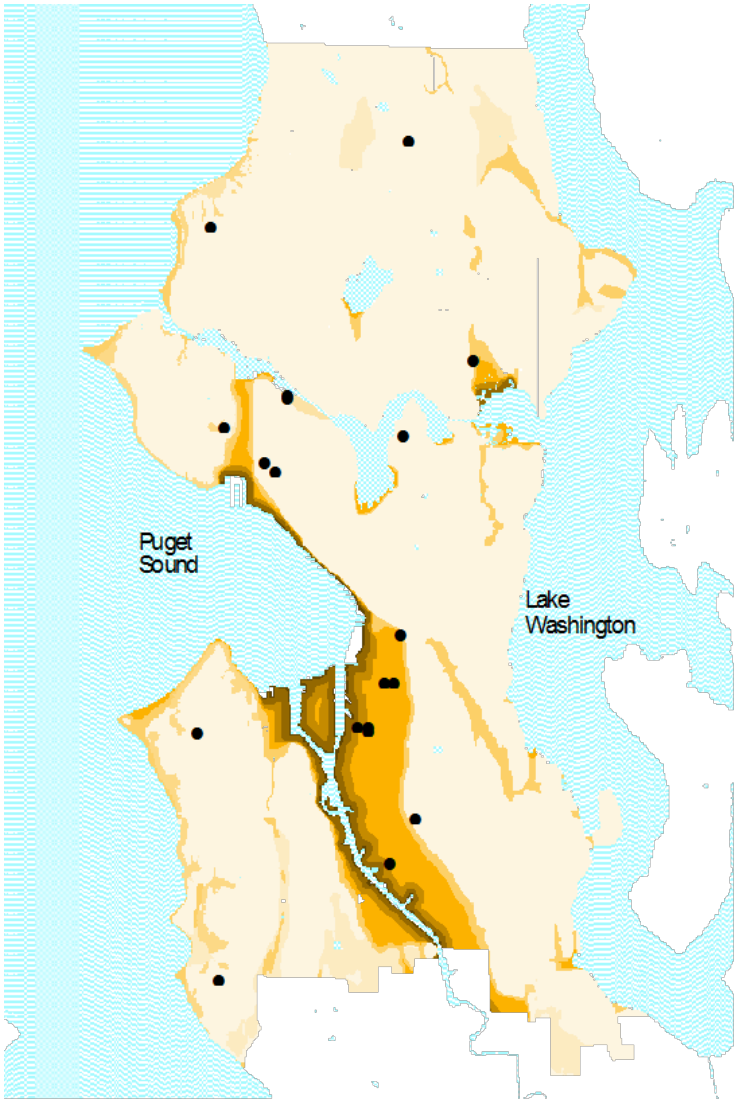
1965 M6.5 Seattle/Tacoma Earthquake Water System Damage

Standpipe Anchor Bolt Yielding

900 mm (36 inch) Concrete Cylinder Pipe Leak

500 mm (20 inch) Cast Iron Main Rupture

2001 M6.8 Nisqually Earthquake
Water System Damage - Pipelines



Pipeline Failure Locations

Liquefaction South of Downtown

2001 M6.8 Nisqually Earthquake
Water System Damage - Miscellaneous

Minor
Crack
Dam
Crack

Warehouse Nonstructural Damage

Landslide into Reservoir

Seattle Times: September 23, 2017

The latest in a long line of efforts to reduce death and destruction from future quakes got "zero funding and no additional staff time." Hence, earthquake drills in schools, for instance, get a higher priority rating than identifying school buildings at risk of collapse.

By Sandi Doughton and Daniel Gilbert

Seattle Times staff reporters

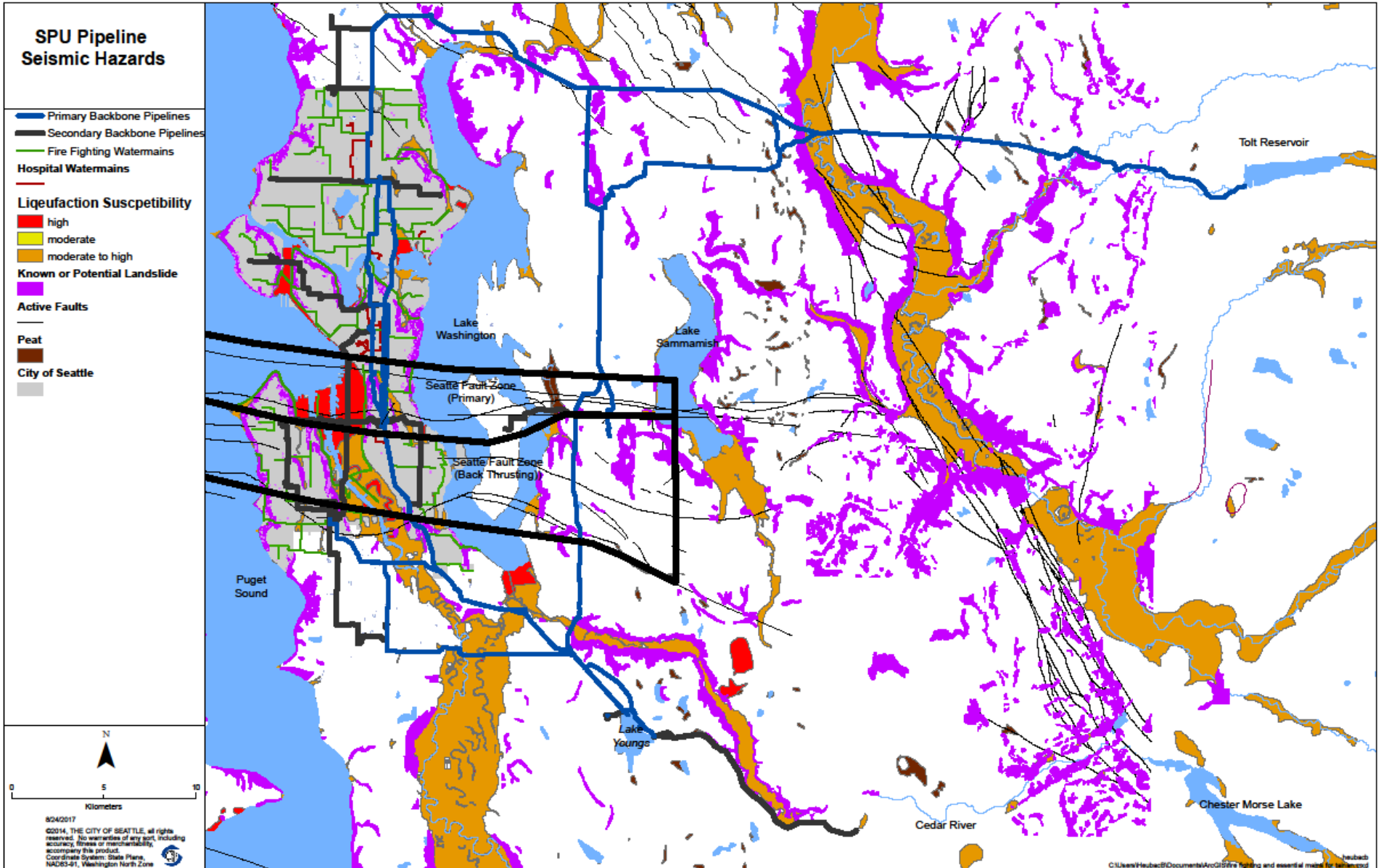
Ensure schools are seismically sound. Strengthen bridges and utilities against earthquakes. Build tsunami refuges on the coast.

Those recommendations have long topped the to-do list for protecting Washington from an inevitable, devastating quake. But they rank among the lowest priorities in a new report to Gov. Jay Inslee — because they are costly and difficult. Instead, the report from the governor's Resilient Washington Subcabinet favors actions that are easy and cheap.

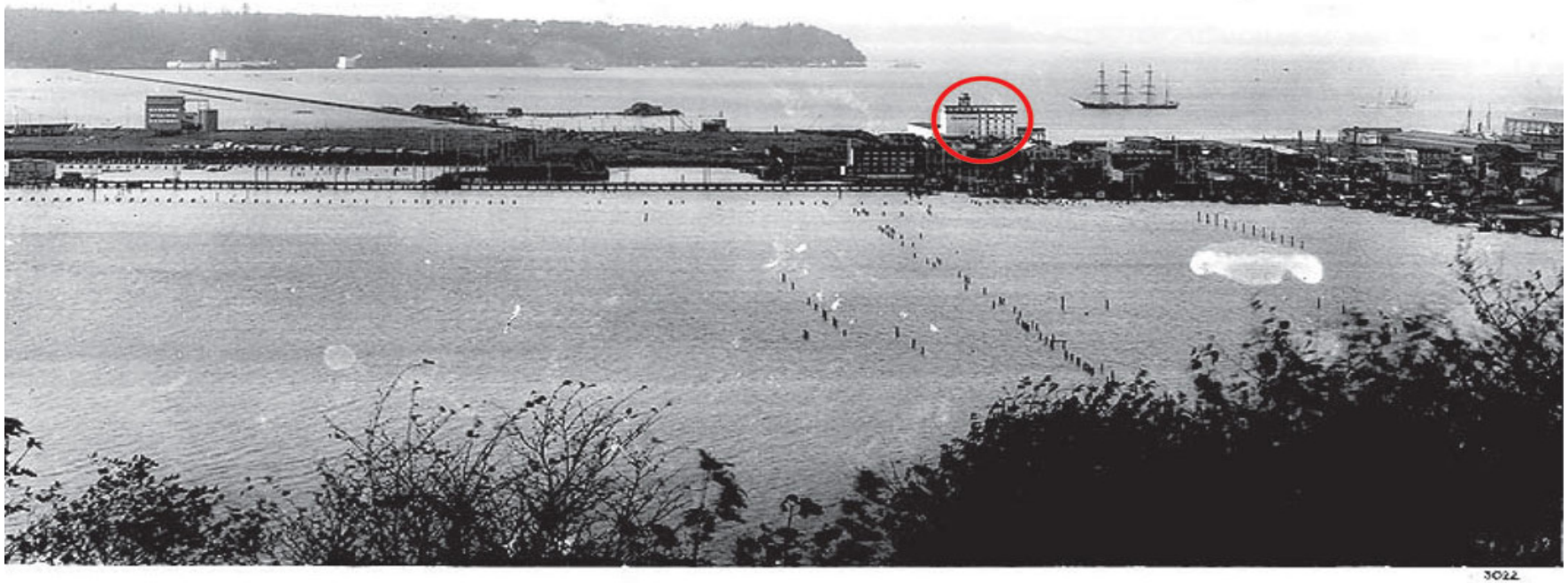
SPU Seismic Program Key Elements

- Assess Seismic Hazards
- Update Facility Vulnerability Assessments
- System Vulnerability Assessment
- Develop Performance Goals and Pipeline Standards
- Mitigation

Seattle Public Utilities Water System Seismic Hazard Map



The Recipe for Man-Made Liquefiable Soils - Sodo from Beacon Hill, 1901 and 1914



Magnitude 7 Seattle Fault Earthquake Ground Shaking Intensity

PGA ≤ 0.10 g

0.10 g< PGA ≤ 0.20 g

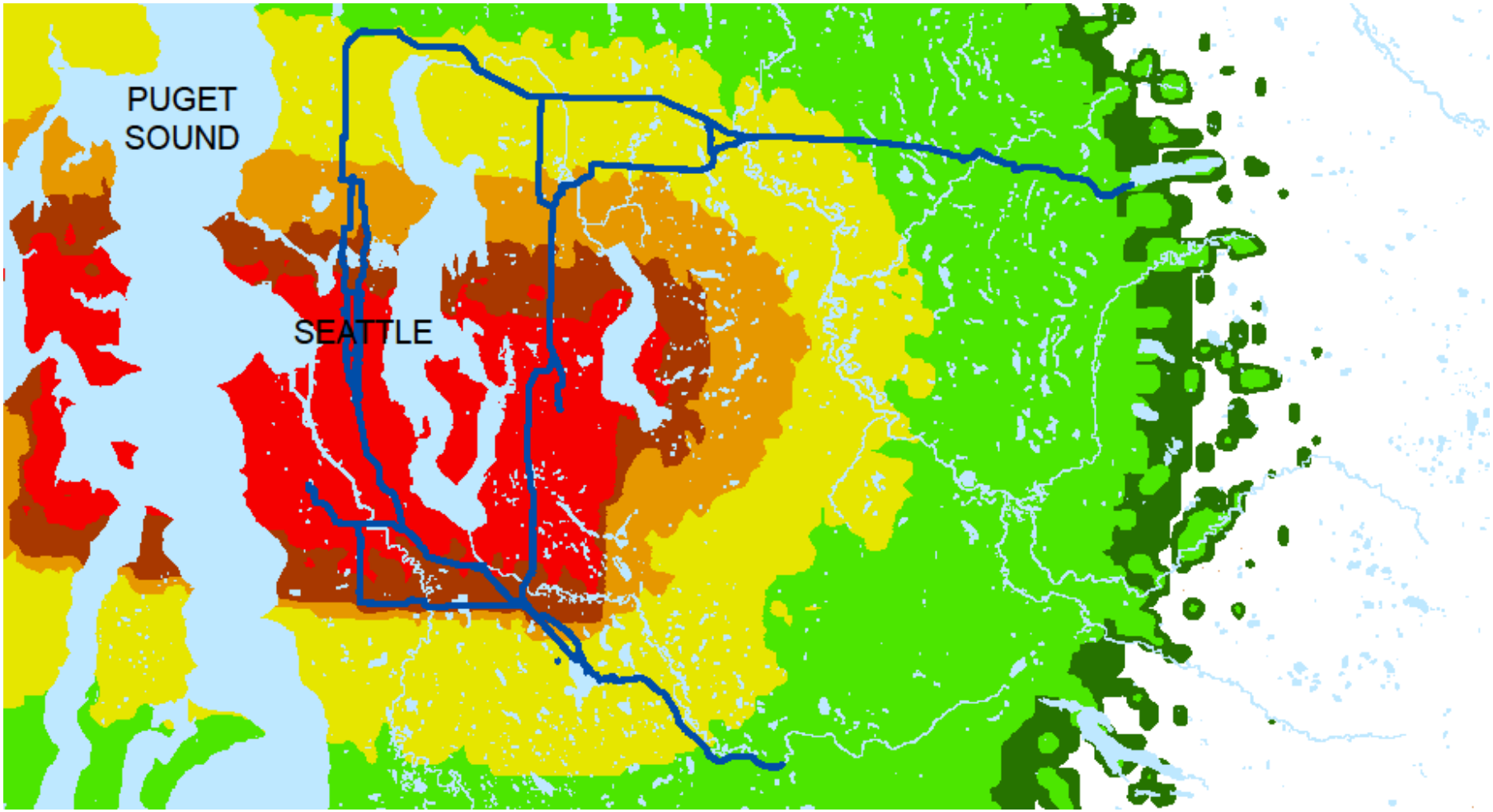
0.20 g< PGA ≤ 0.30 g

0.30 g< PGA ≤ 0.40 g

0.40 g< PGA ≤ 0.50 g

0.50 g< PGA

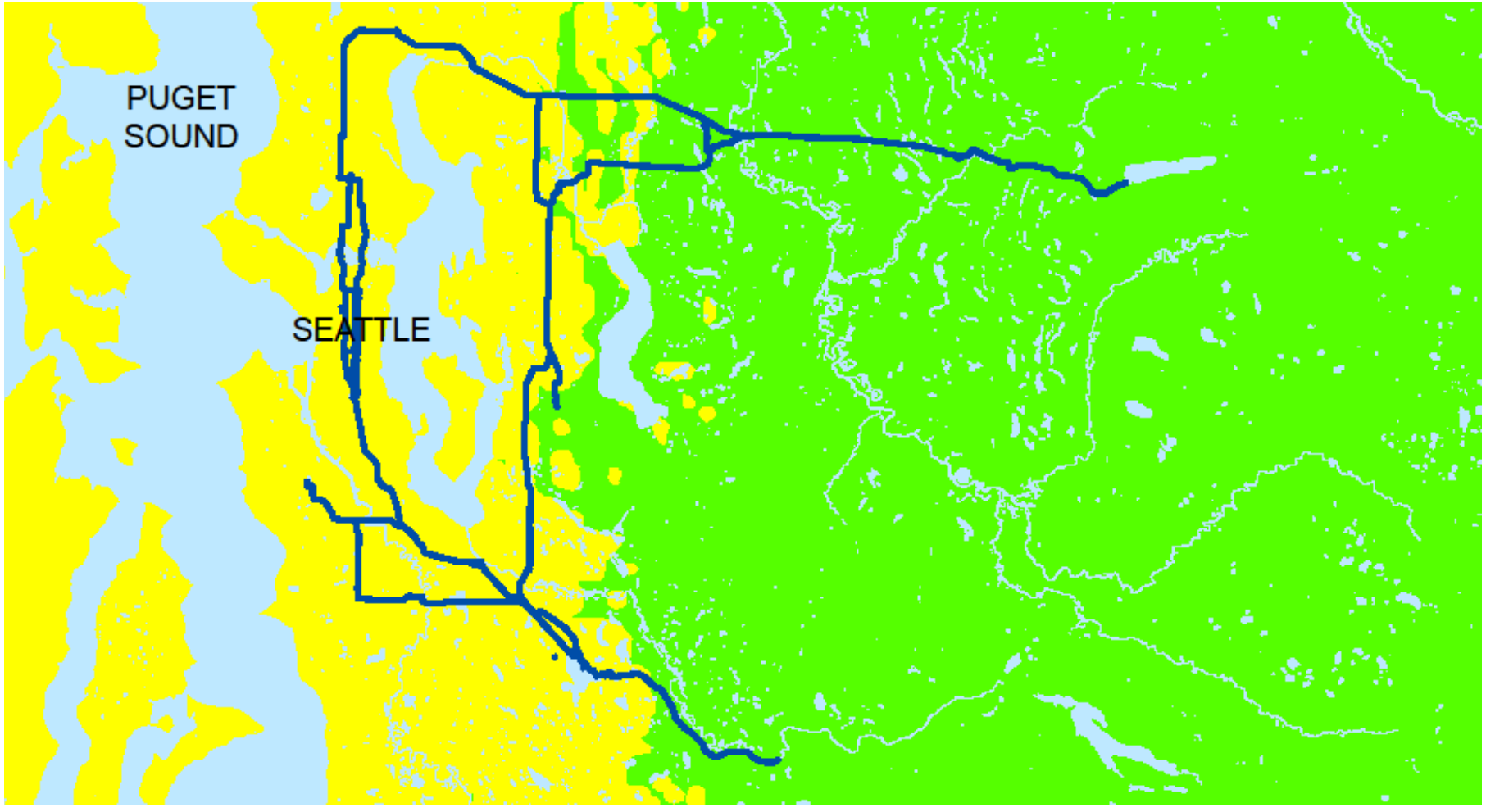
15 KILOMETERS



Magnitude 9 Cascadia Subduction Zone Ground Shaking Intensity

PGA ≤ 0.10 g	0.30 g< PGA ≤ 0.40 g
0.10 g< PGA ≤ 0.20 g	0.40 g< PGA ≤ 0.50 g
0.20 g< PGA ≤ 0.30 g	0.50 g< PGA

15 KILOMETERS



Vertical Liquefaction Displacement Model

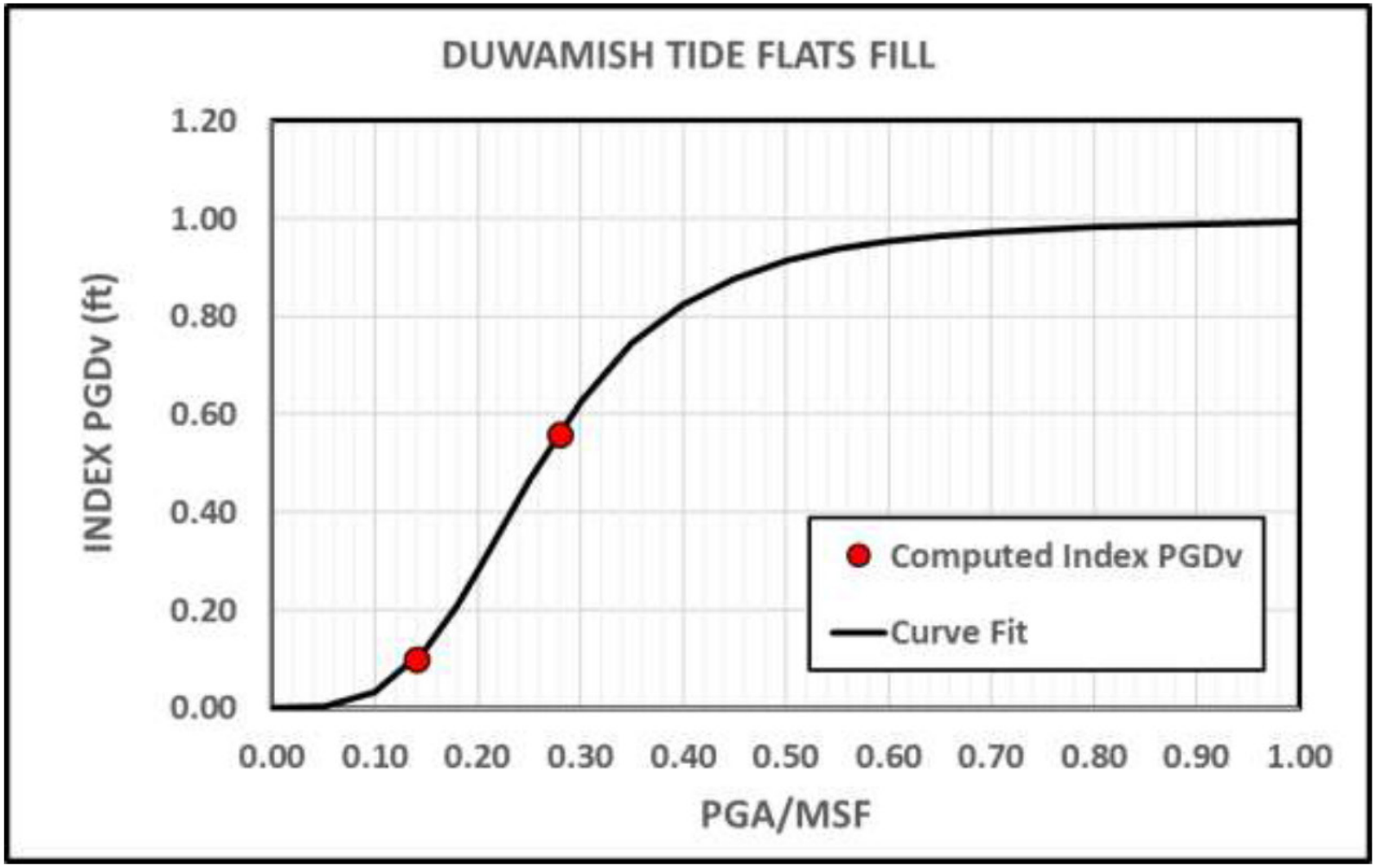


Figure 1: Trend of post-liquefaction settlement versus the duration-normalized ground motion for sandy fill placed in the Duwamish Tide Flat area.

(New Albion, 2017)

Horizontal Liquefaction Displacement Model

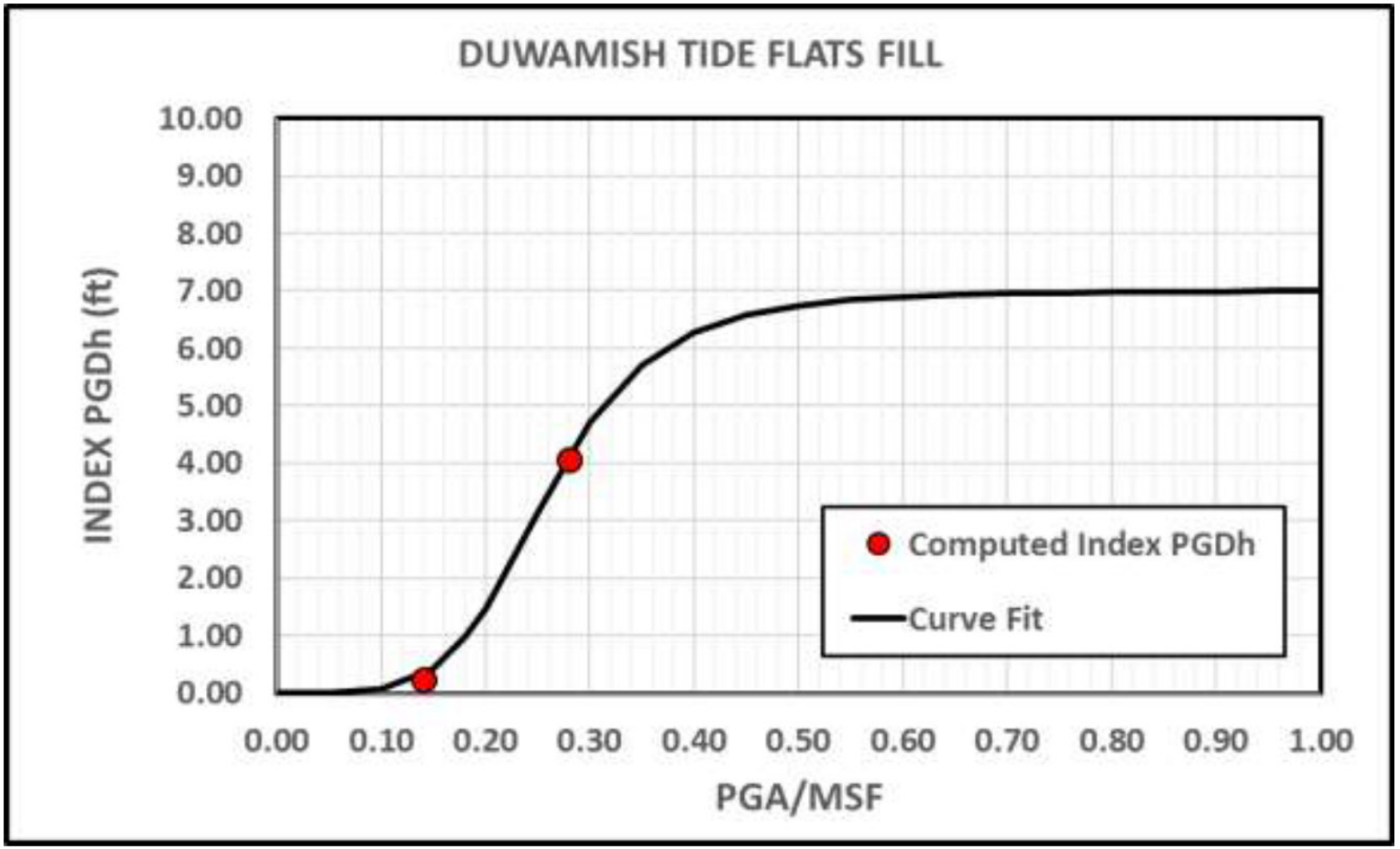
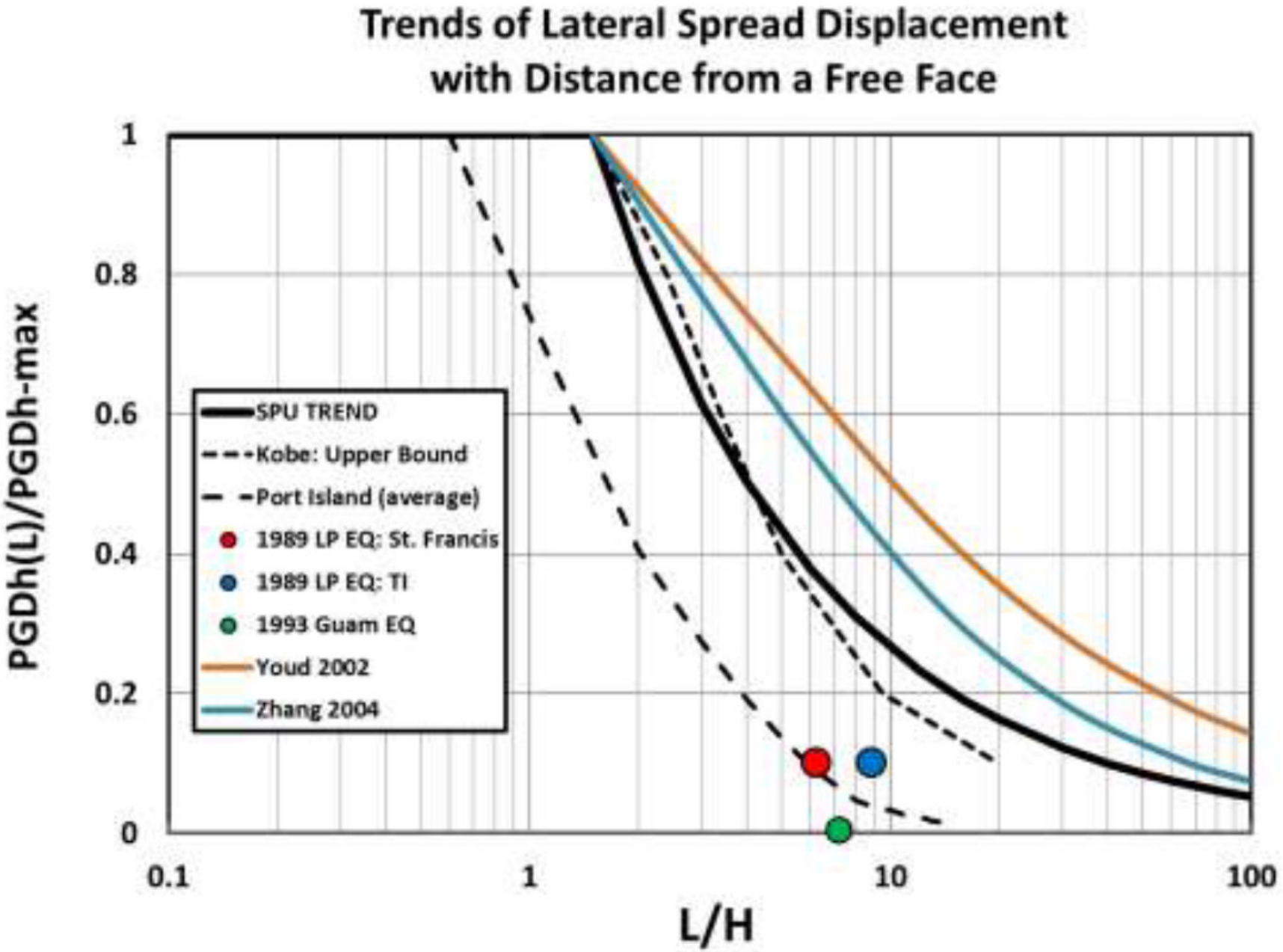
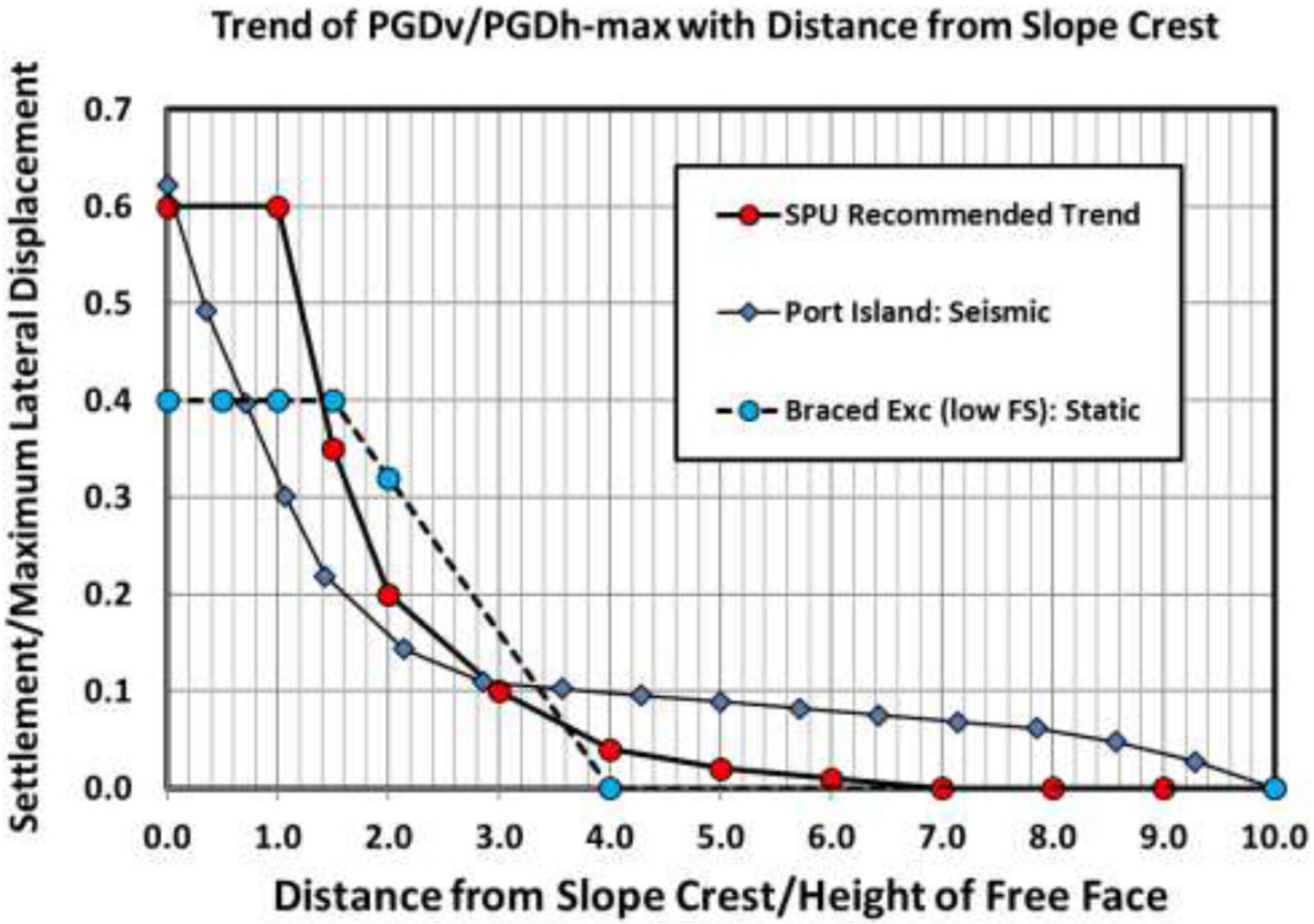


Figure 2: Trend of lateral spreading displacement versus the duration-normalized ground motion for sandy fill placed in the Duwamish Tide Flat area.

(New Albion, 2017)

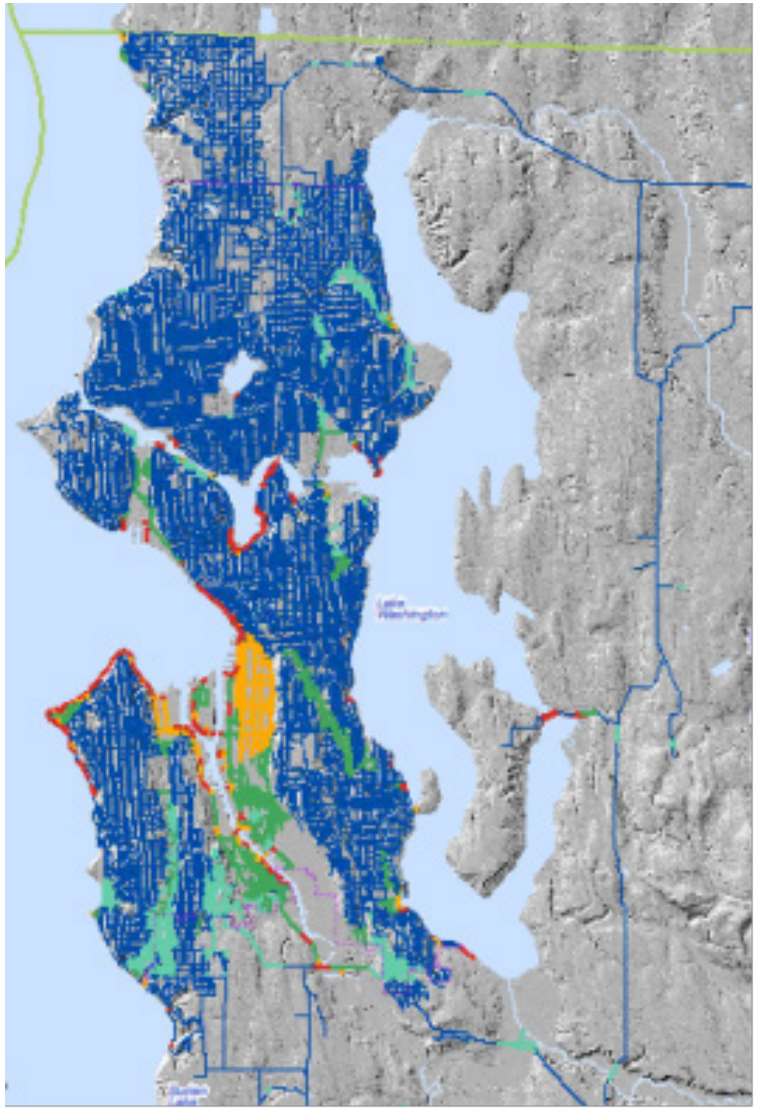


(New Albion, 2017)



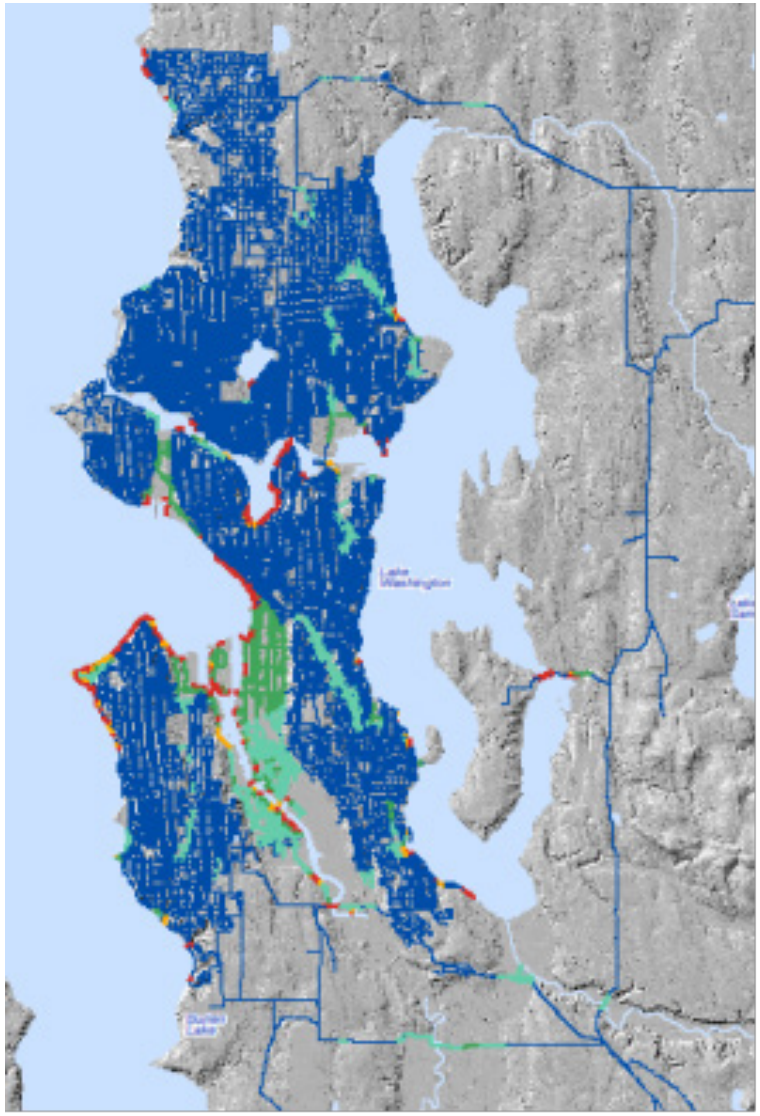
(New Albion, 2017)

Permanent Ground Displacement



M7 Seattle Fault Scenario

- 0 to 1 in (0 to 25mm)
- 1 to 6 in (25 to 150 mm)
- 6 to 12 in (150 to 300 mm)
- 12 to 18 in (300 to 450 mm)
- 18 to 120 in (450 to 3000 mm)



M9 Cascadia Subduction Scenario

Facility Vulnerability Assessments

- ASCE 41-13
- FEMA 154
- AWWA D-100, D-103, D-110, D-115
- ASCE 7-10
- ACI 350, 350.3

Distribution Pipeline Vulnerability Assessments – American Lifeline Alliance Models

- $RR_{PGV} = K_1 \times 0.00187 \times PGV$
- $RR_{PGD} = K_2 \times 1.06 \times PGD^{0.319}$

RR_{PGV} = number of repairs per 1000 feet (305 meters) caused by seismic wave propagation effects

K_1 = constant dependent on the pipe material and joint system

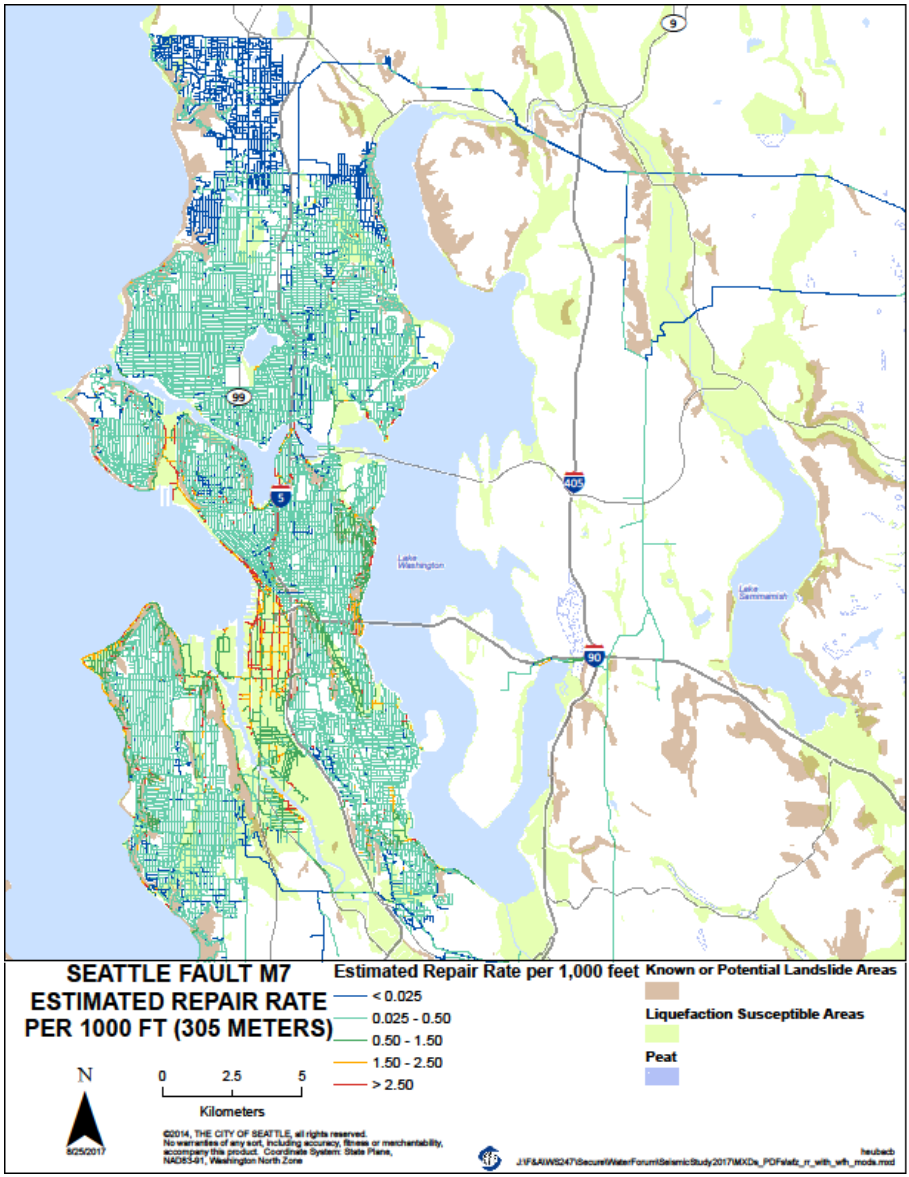
PGV = the peak ground velocity expressed in inches per second

RR_{PGD} = number of repairs per 1000 feet (305 meters) caused by permanent ground displacement effects

K_2 = constant dependent on the pipe material and joint system

PGD = the permanent ground displacement expressed in inches

K_1 and K_2 range from 0.15 for ductile pipe to 1.4 for brittle pipe



Distribution Pipeline Vulnerability Assessments – High Level Assessment at Multiple Sites

Assessment Findings

TRANSMISSION PIPELINES
Lake Youngs Aqueduct
Overall (entire alignment)
Landsburg Park
Lake Youngs Supply Line 4
Overall (entire alignment)
Lake Peterson Swamp
Unstable slope near Highway 18
Hays Creek Gravel Pit
Lake Youngs Supply Line 5
Overall (entire alignment)
Honey Creek Aluvial Area
Lake Peterson Swamp
Unstable slope near Highway 18
Lake Youngs Bypass Line 4
Overall (entire alignment)
Lake Youngs Bypass Line 5
Overall (entire alignment)
North shore of Lake Youngs
Lake Youngs Tunnel
Overall (entire alignment)
Cedar River Pipeline No. 1
Overall (entire alignment)
Molasses Creek
Ginger Creek
Renton/Black River
South Seattle liquefaction area
MLK slide areas
I-90 liquefaction area
Cedar River Pipeline No. 2/ 430 Pipeline
Overall (entire alignment)
Molassess Creek
Ginger Creek
Renton/Black River
South Seattle liquefaction area
MLK slide areas
I-90 liquefaction area

BURIED AND/OR CONCRETE RESERVOIRS
Beacon
Bitter Lake
Eastside Reservoir
Lake Forest Park Reservoir
Lake Youngs Clearwells
Lincoln
Magnolia
Maple Leaf
Myrtle
Riverton Heights
Roosevelt Resevoir
Soos Reservoirs
Tolt Clearwell
View Ridge
Volunteer Park
West Seattle

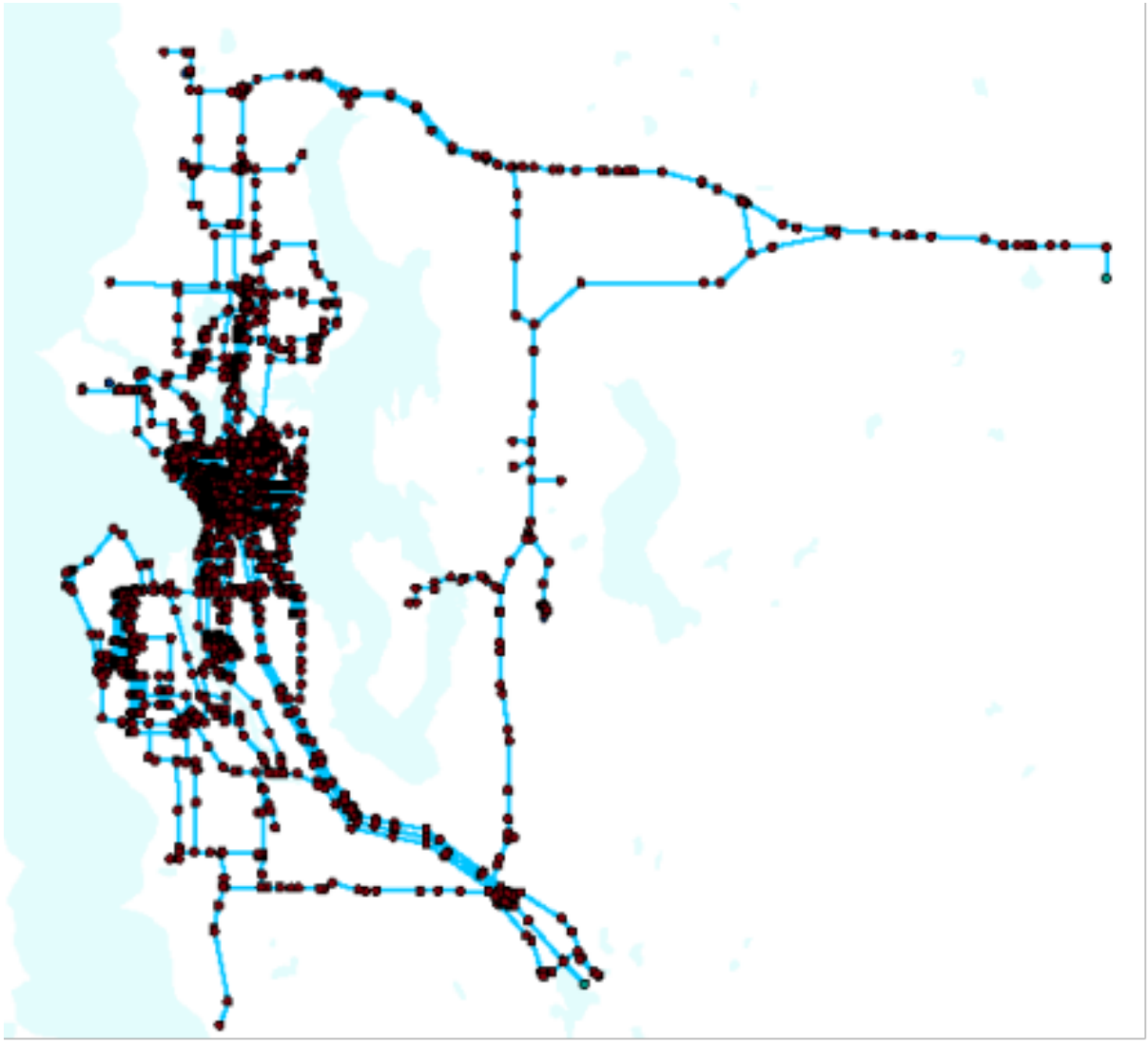
PUMP STATIONS AND OTHER BUILDINGS
Augusta PS and Gatehouse
Beacon Gate House
Beacon Valve
Bitter Lake PS
Bothell Way PS
Boulevard Park Well
Broadway PS
Burien PS
Control Works
Dayton Avenue PS
Eastgate PS
Fairwood PS
First Hill
Foy
Green Lake PS
Highland Park
Interbay PS
Lake Forest Park Chlorination
Lake Forest Park PS
Lake Hills PS
Lake Youngs Pump Station
Landsburg Screen House
Landsburg Tunnel Gate House
Lincoln GH/PS
LY Treatment Operation Bldg
LY Treatment Ozone Bldg
LY Treatment Raw Water PS
LY Treatment UV and Bldg

STEEL TANKS
Beverly Park
Charleston
Control Works
Foy
Landsburg Tank
Magnolia Bluff Elevated
Myrtle Elevated No. 2
Queen Anne Standpipe
Richmond Highlands
Trenton
Volunteer Park Standpipe

Pressure Zone	Failures
AU550	7.02
BA484	15.70
BA484-260	2.52
BA484-270	0.46
BA484-405	0.65
BE460	47.64
BL509	12.10
DA660	0.59
FH530	1.02
MG330	39.47
MG480	16.83
MG480-260	10.12
ML430	82.58
ML550	9.28
NO326	99.25
OH510	0.41
QA530	62.38
QA580	2.62
RH550	0.00
RH590	18.17
RH590-210	0.61
RH590-290	1.85
RH590-430	1.82
RH590-434	0.03
RH590-480	0.04
SH550	2.99
SK500	10.67
SO326	1293.69

System Assessment/Hydraulic Modeling

- “Skeletonized” EPANet System Model
- Pipeline Breaks Modeled with Emitters



Key Findings

- Pipeline Vulnerability Is the Critical Issue
  - Possible Loss of Both Major Supplies
  - Over 1000 Distribution Pipeline Breaks
- Most Large (40,000 M^3, 10 MG) Reservoirs OK
- Most Pump Stations OK
- Several Highly Vulnerable "Vertical" Facilities

Mitigation

- Seismic-Resistant Transmission Pipeline (20 to 50 year time frame)
- Earthquake-Resistant Pipe (50 to 100 year time frame)
  - Pipelines Subject to Permanent Ground Displacement
  - Transmission, Backbone and Essential/Critical Pipelines
- Continuation of Critical Facility Upgrades (tanks, pump stations, etc., 20 year time frame)
- Isolation and Control (10 year time frame)
  - Reservoirs
  - Distribution System
- Emergency Preparedness and Response Planning Augmentation (10 year time frame)
  - Stockpiling Resources Needed to Respond
  - Emergency Drinking Water Supply

QUESTIONS?