Seismic Hazard Analysis along the State Water Project California Department of Water Resources

ATC-USGS NSHMP User-Needs Workshop
September 21-22, 2015
USGS Menlo Park

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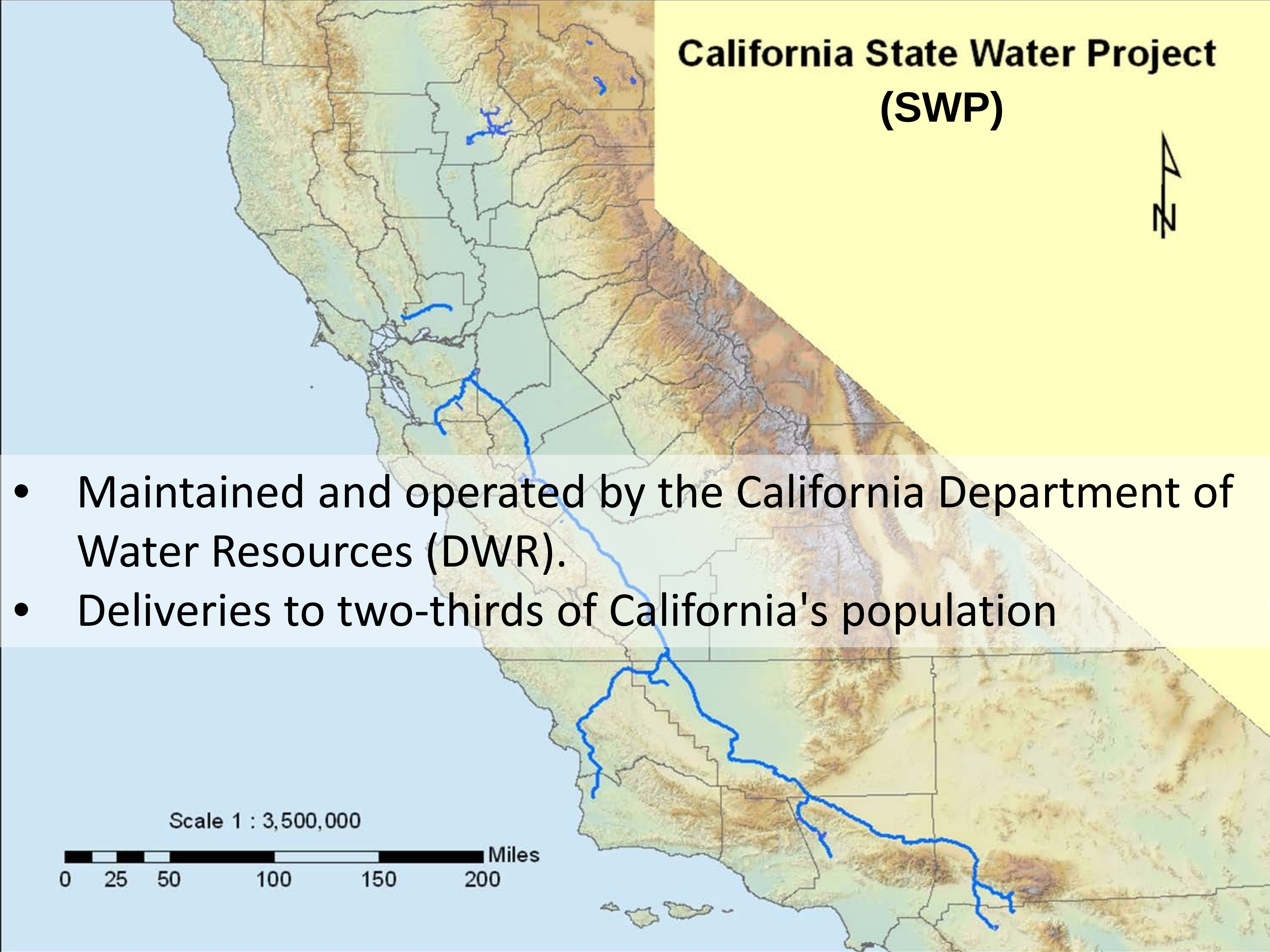
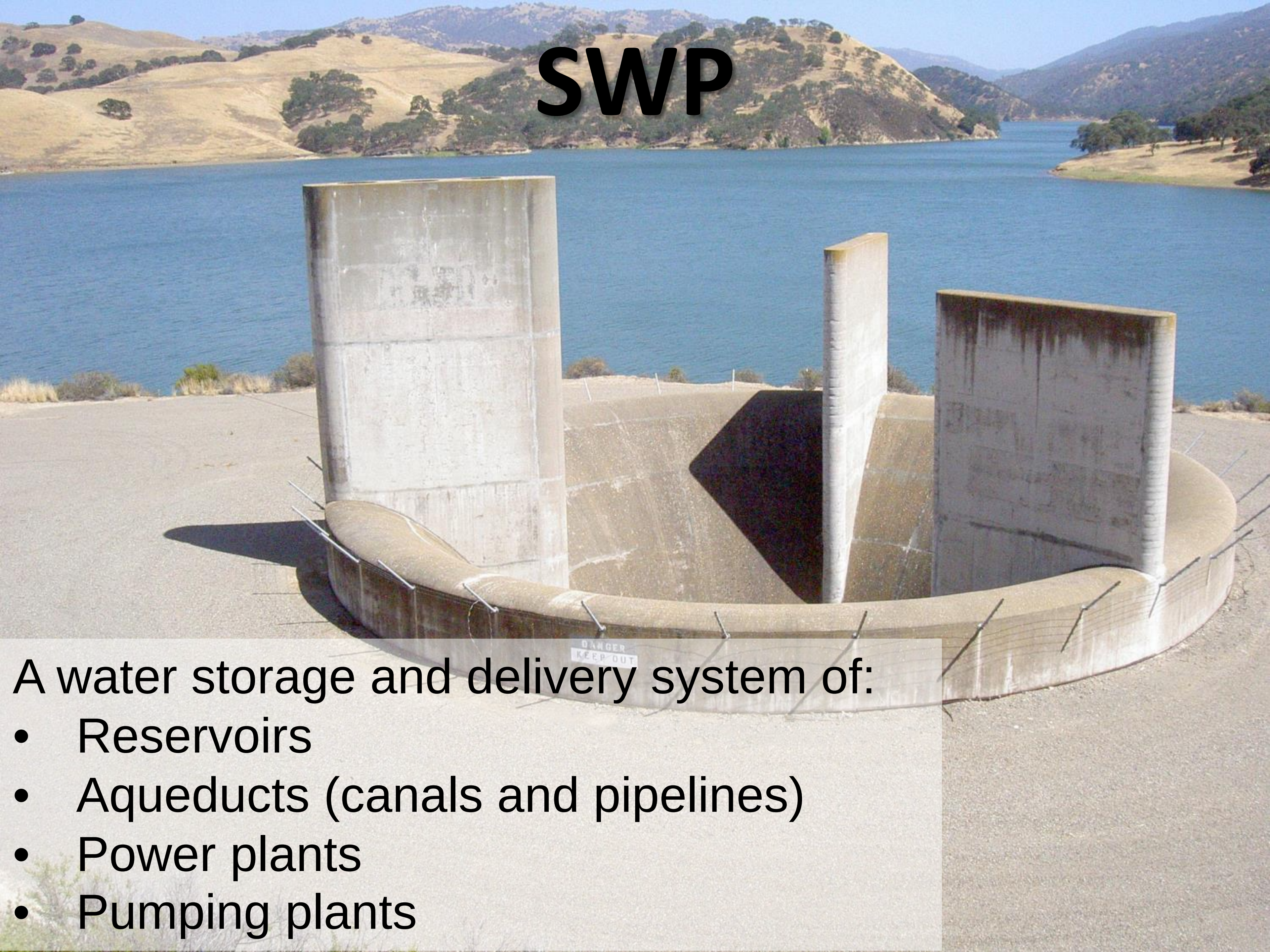
Division of Engineering
Geotechnical and Engineering Services Branch
Project Geology Section



- Maintained and operated by the California Department of Water Resources (DWR).
- Deliveries to two-thirds of California's population

SWP



A water storage and delivery system of:

- Reservoirs
- Aqueducts (canals and pipelines)
- Power plants
- Pumping plants

SWP

Main purpose:

- Store and distribute water to 29 urban and agricultural water suppliers (water contractors)
  - Northern California
  - San Francisco Bay Area
  - San Joaquin Valley
  - Central Coast
  - Southern California

SWP

Of the contracted water supply:

- 70 percent goes to urban users (about 25 million California's)
- 30 percent goes to agricultural users (about 750,000 acres of irrigated farmland)

SWP

The SWP is also operated to:

- Improve water quality in the Sacramento-San Joaquin River Delta
- Control Feather River flood waters
- Provide recreation, enhance fish and wildlife

SWP

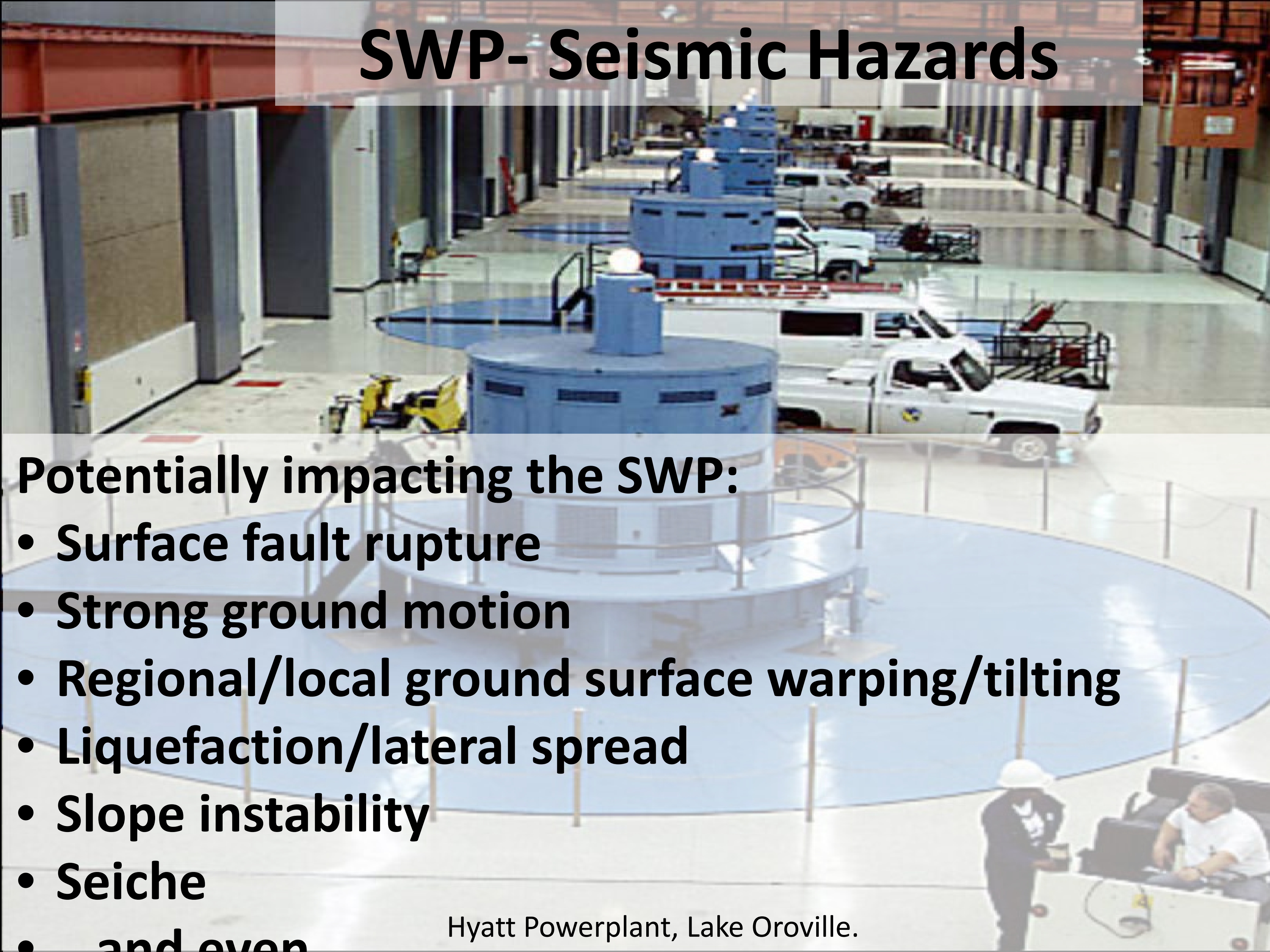
- Construction began in the late 1950’s into the 1970’s
- Subsequent facilities built in the 1980’s and 1990’s
- Additional phases continue today

SWP

Stretching from the Upper Feather River basin of Northern California in Plumas County to Perris Reservoir in Riverside County:

- 34 reservoirs
- 20 pumping plants
- 4 pumping-generating plants
- 5 hydroelectric power plants
- 701 miles of open canals, pipelines, and tunnels

SWP- Seismic Hazards

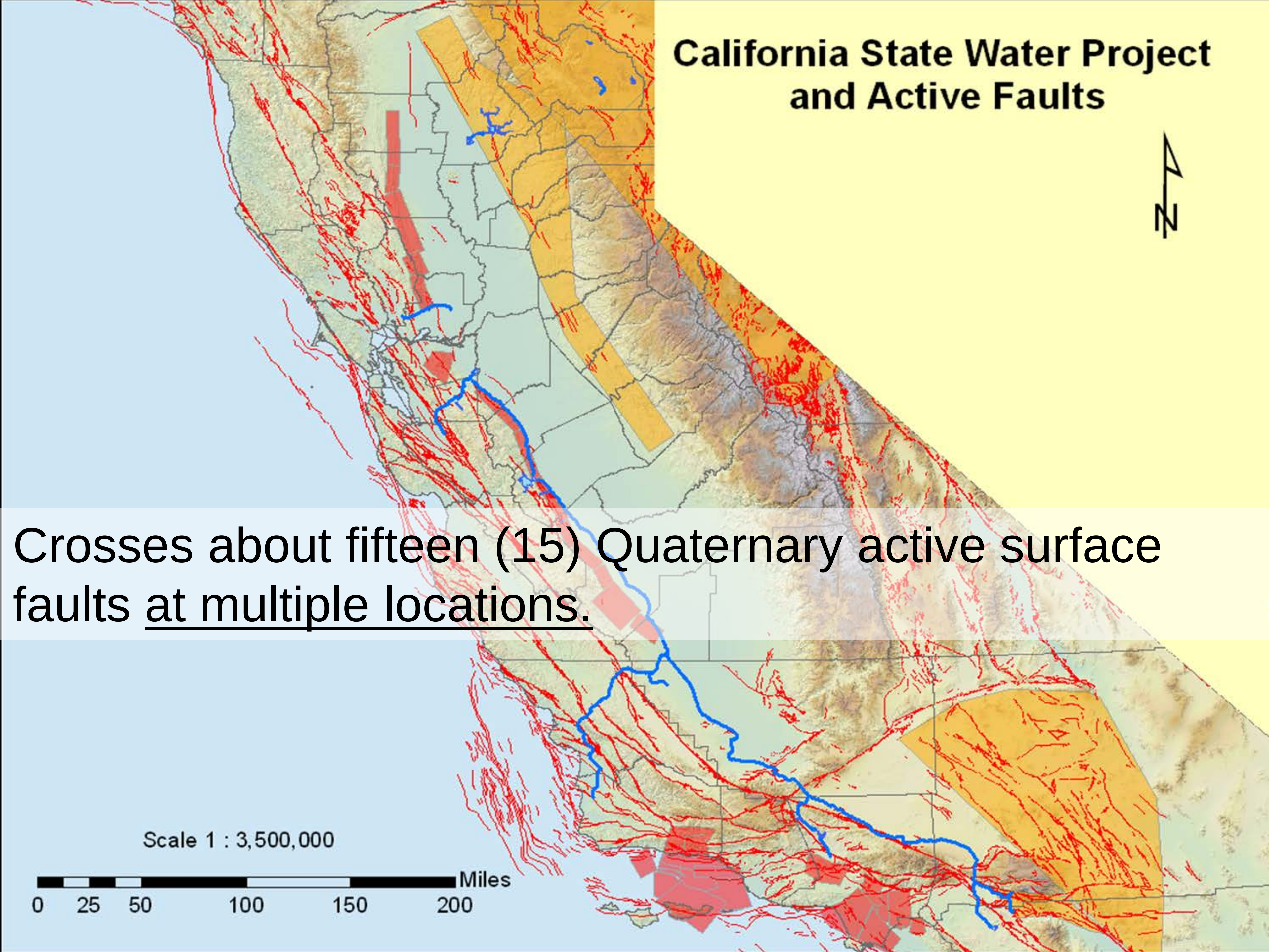


Hyatt Powerplant, Lake Oroville.

Potentially impacting the SWP:

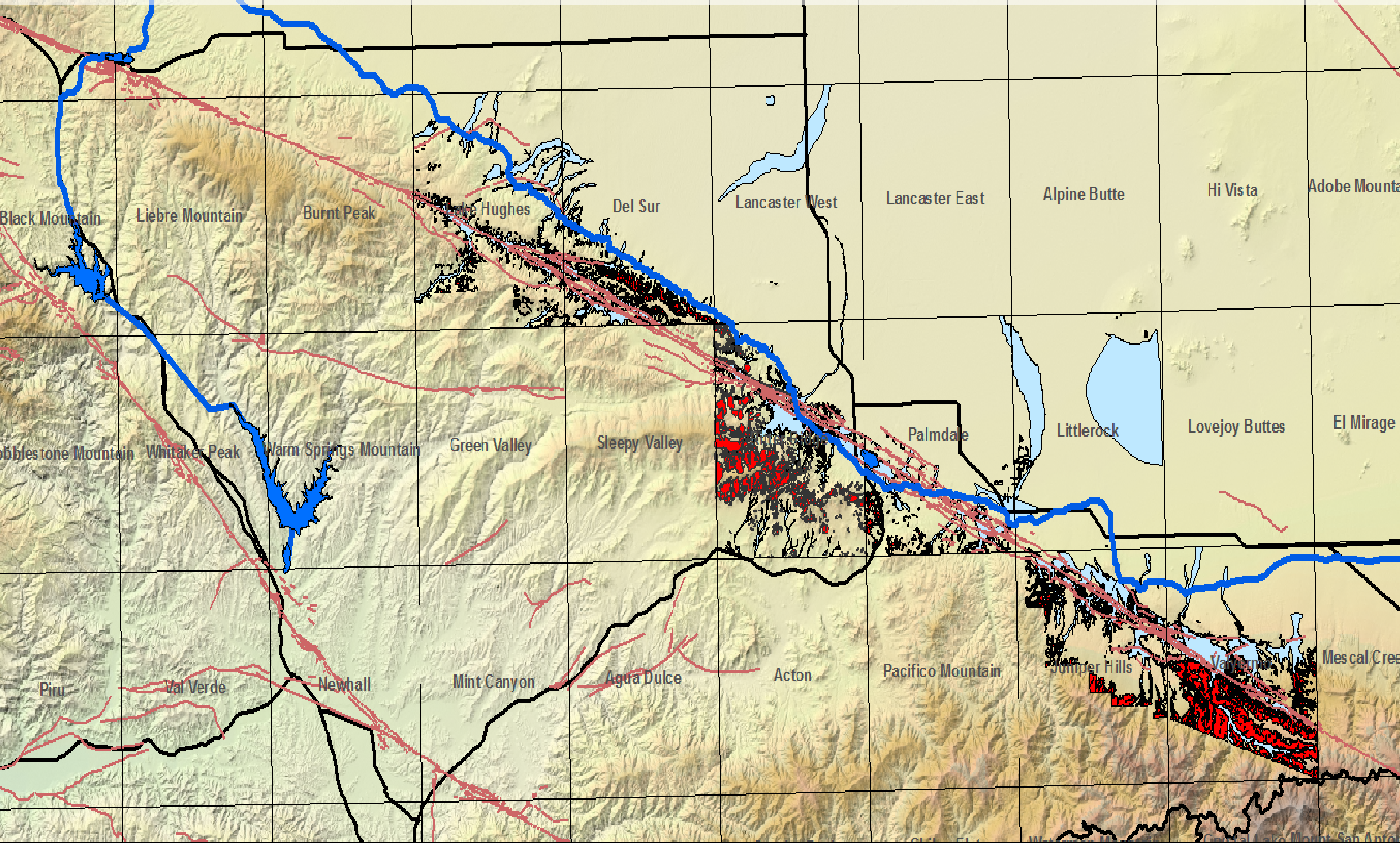
- **Surface fault rupture**
- **Strong ground motion**
- **Regional/local ground surface warping/tilting**
- **Liquefaction/lateral spread**
- **Slope instability**
- **Seiche**
- **…and even**

January 17, 1994 M6.7
Northridge earthquake



Crosses about fifteen (15) Quaternary active surface faults at multiple locations.

Most notably near Palmdale along the “East Branch” of the SWP where the canal runs parallel and on-top-of the San Andreas fault zone for about 18 kilometers.



About 240 km of the California Aqueduct lies on the hanging wall of the Great Valley blind thrust fault system

SWP- Facilities

Facilities have been built to withstand considerable ground motions (dams), secondary effects (liquefaction) were not originally specifically designed for (leaking canals)…

SWP- Facilities and “SEERG”

To better address seismic deficiencies, identify vulnerability, and to improve water delivery reliability, DWR management created SEERG in 2008.

SWP-Dams, Subject to Regulations

As dam owners/operators of both power generating and non-power generating facilities, DWR is regulated by DSOD and FERC.

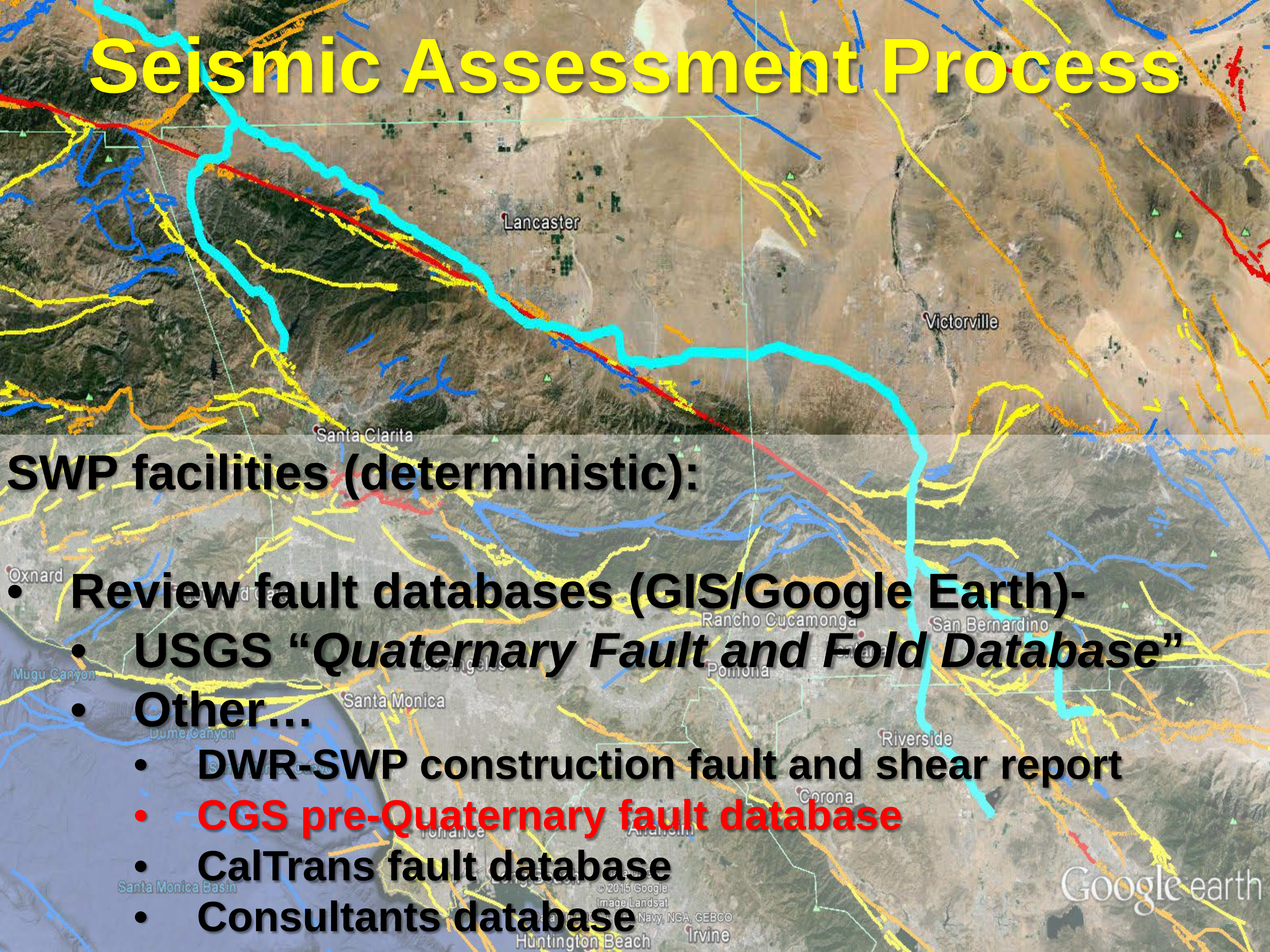
We therefore operate in <u>both</u> a *deterministic* and *probabilistic* environment.

Forces conservatism….

Seismic Assessment…

- Always based on engineer’s needs
  - Dams and appurtenant structures = *mostly* deterministic analysis
  - Existing facilities outside of regulatory authority = probabilistic analysis
  - Newer facility design and upgrades = *towards* performance based

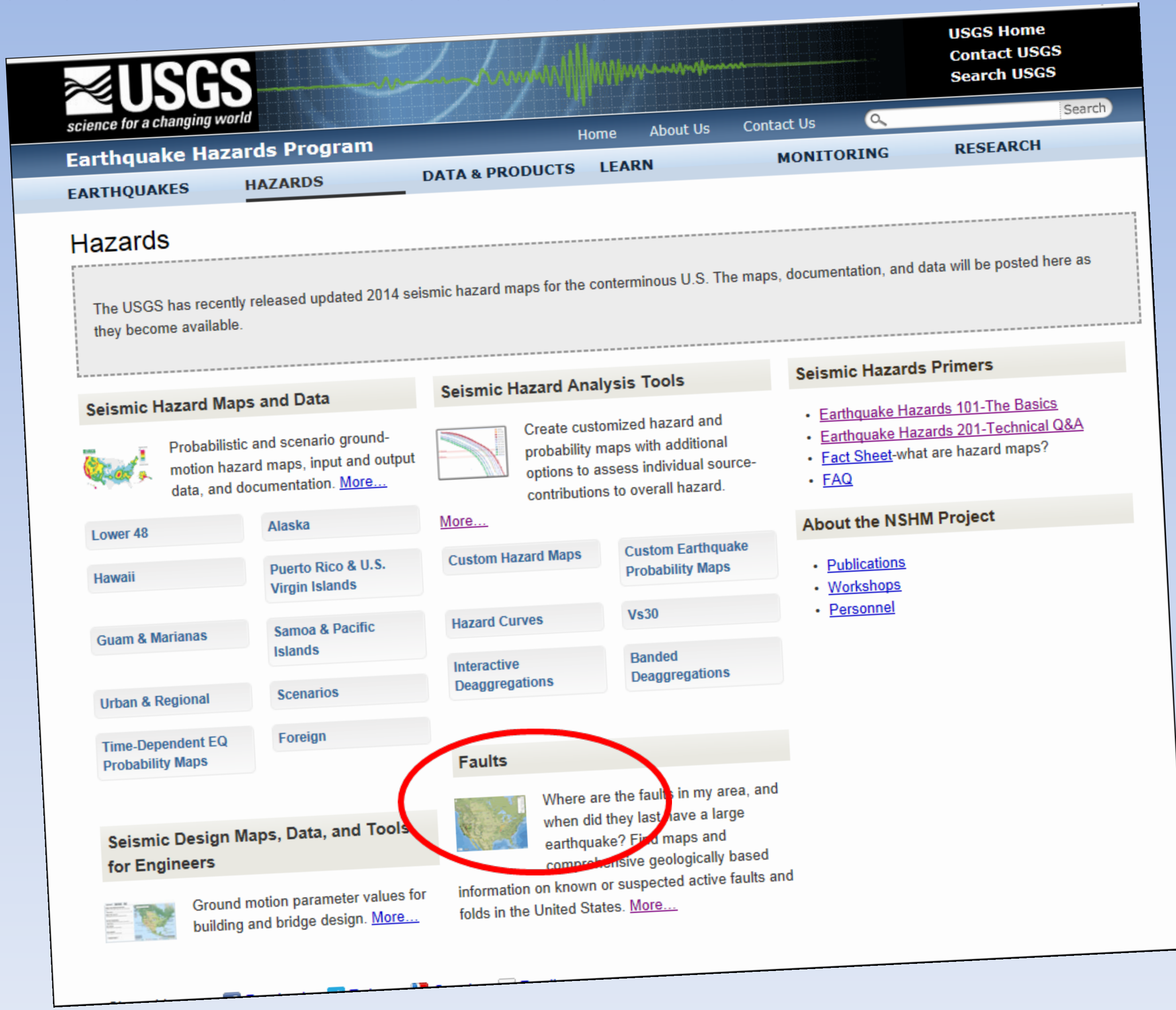
Seismic Assessment Process



SWP facilities (deterministic):

- **Review fault databases (GIS/Google Earth)-**
  - **USGS "*Quaternary Fault and Fold Database*"**
  - **Other…**
    - **DWR-SWP construction fault and shear report**
    - **CGS pre-Quaternary fault database**
    - **CalTrans fault database**
    - **Consultants database**

Seismic Assessment Process



Quaternary Faults in Google Earth

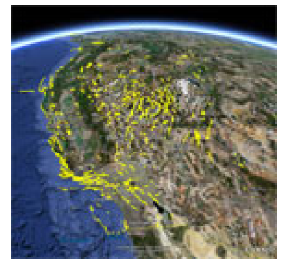
Faults are classified by age of last known movement.

Historic

Most recent, known movement less than about 150 years

Holocene to Latest Pleistocene

Younger than 15,000 years

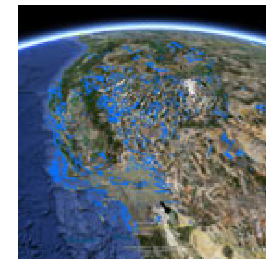


Late Quaternary

Younger than 130,000 years

Mid to Late Quaternary

Younger than 750,000 years



Quaternary

Younger than 1,600,000 years

Download all 5 layers as a .zip file.

Tips

- Faults are colored coded for ...
- As you ho... color as the fault.

... can click a link for the database of information about that fault.

... get the text box to open.

... an also access a fault through the Google Earth table of contents. Open the folder for the correct age, find the fault name in the list, and double click the name. Google Earth will "fly" to the fault you selected.

Google Earth software enables you to zoom in beyond the level of accuracy provided in these data layers. Fault traces are depicted at their mapped location on the surface. Most faults dip one way or another at depth, and their location must be modeled or inferred from geologic evidence. Fault dip information is included for each fault within the application.

```
QUATERNARY FAULT GIS FILES
--------------------------------------------------------------
These files were updated on November 3rd, 2010 with the most recent version of the Quaternary Faults features.  They are updated periodically with no set update times.
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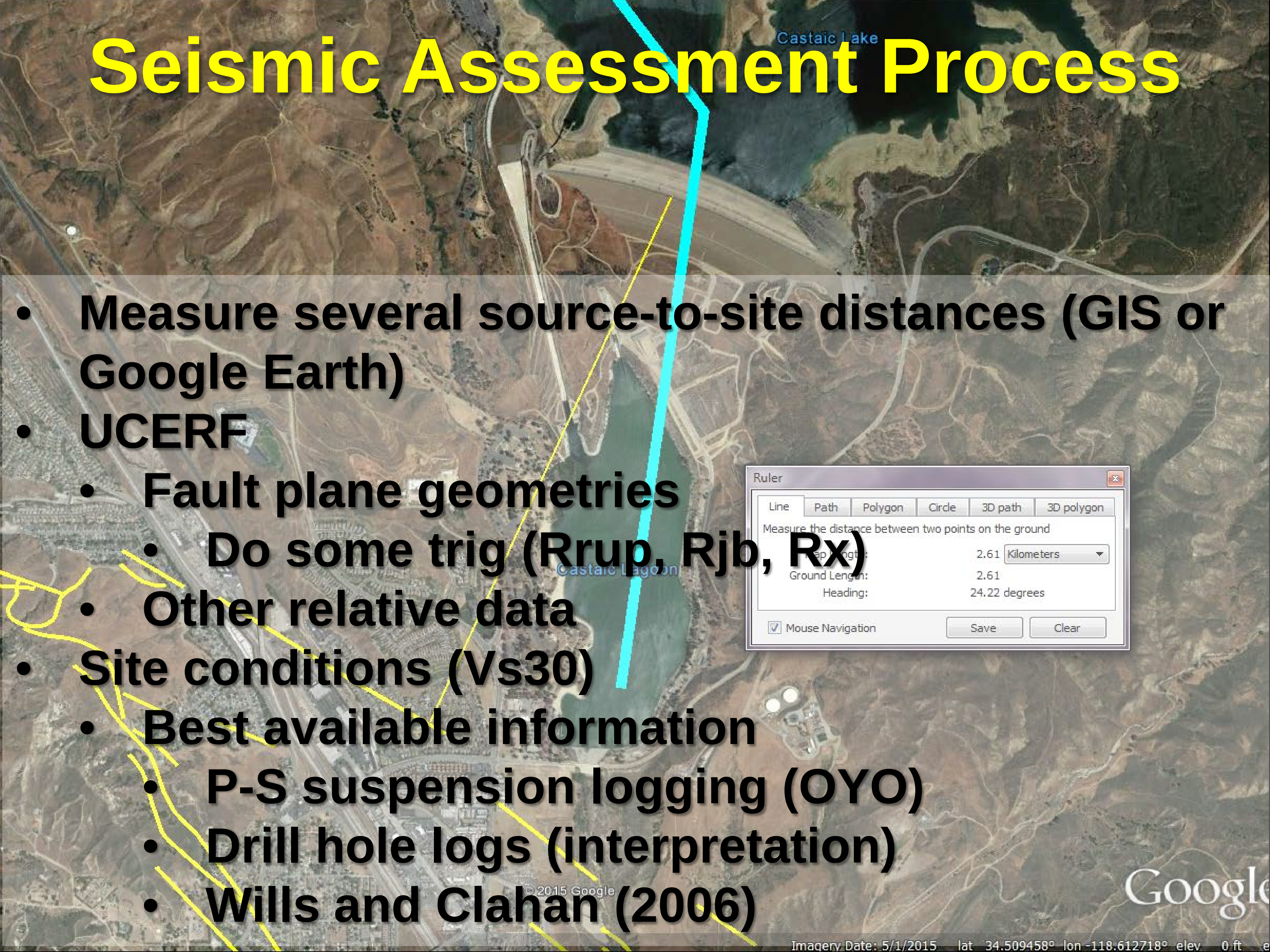
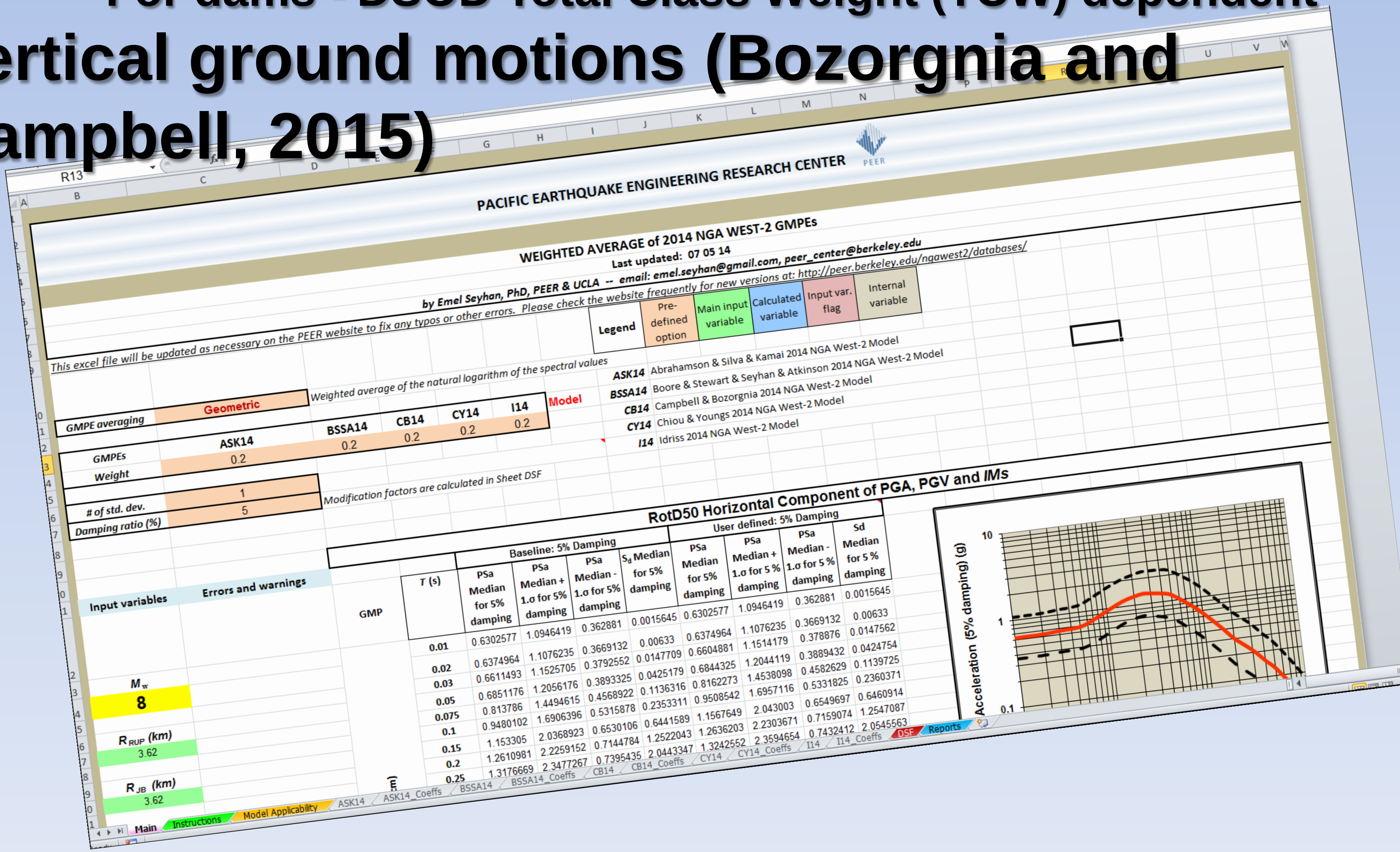
Seismic Assessment Process



- Measure several source-to-site distances (GIS or Google Earth)
- UCERF
  - Fault plane geometries
    - Do some trig (Rrup, Rjb, Rx)
  - Other relative data
- Site conditions (Vs30)
  - Best available information
    - P-S suspension logging (OYO)
    - Drill hole logs (interpretation)
    - Wills and Clahan (2006)

Seismic Assessment Process

- **PEER NGA-West 2 GMPE spreadsheet calculator**
  - **50th, (67th), and 84th percentiles**
    - **For dams - DSOD Total Class Weight (TCW) dependent**
- **Vertical ground motions (Bozorgnia and Campbell, 2015)**



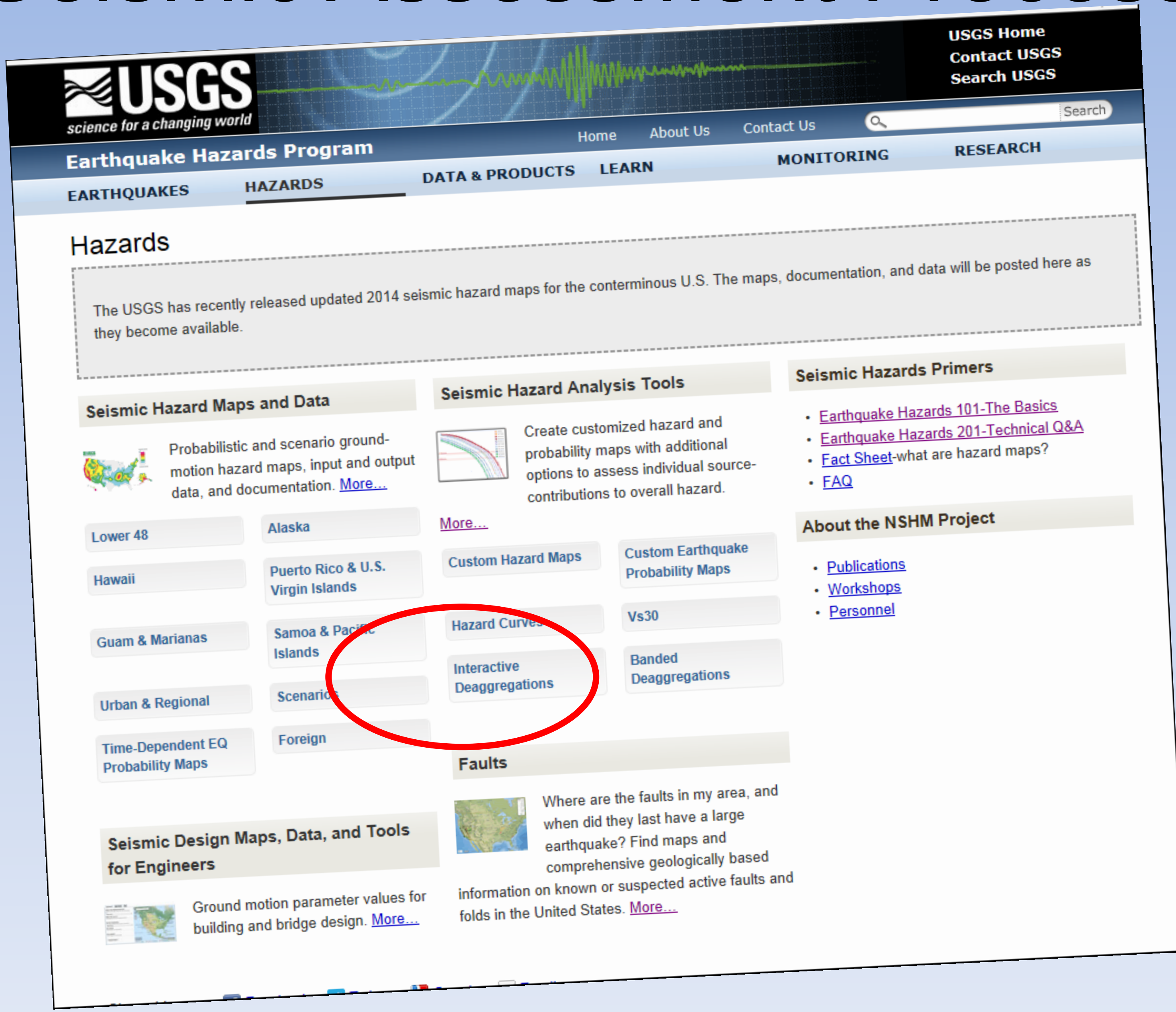
Seismic Assessment Process

- **Directivity (*waiting for PEER model*)**
- **Arias Intensity**
- **Significant Duration**
- **Estimate earthquake magnitude, fault slip displacement (Wells and Coppersmith, 1994)***
  - **21 years of additional data available**

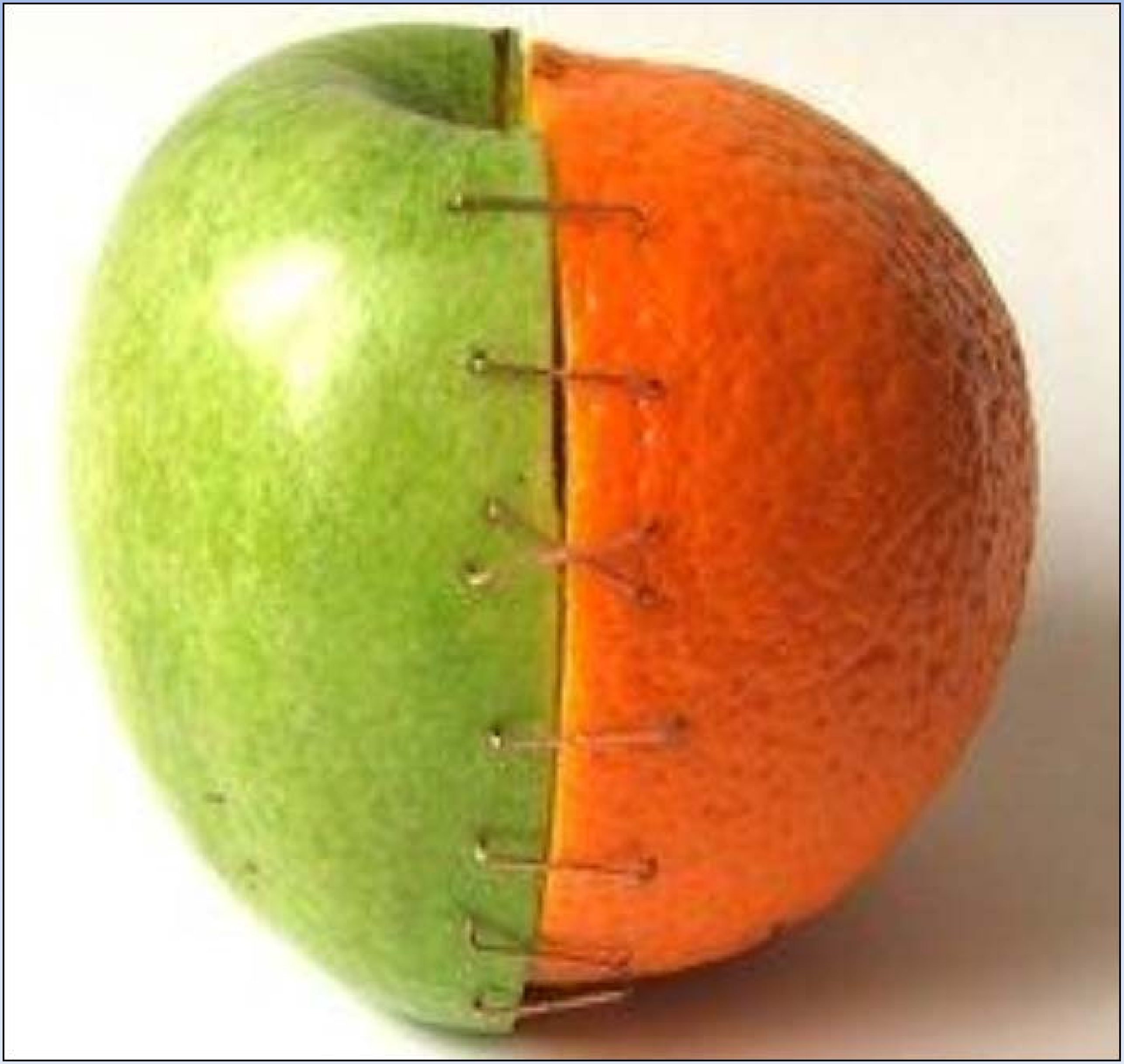
Seismic Assessment Process

- **Other data sources (general work)**
  - **OpenSHA**
  - **Real-Time Double-Difference (Hypocenter) Locations (DD-corr) for northern California** **(Website developed and maintained by Felix Waldhauser and Ben Engebreth at LDEO, Columbia University).**
  - **SCEC SoCal DD-corr catalog and fault database**
  - ***Center for Engineering Strong Motion Data*** ***(http://www.strongmotioncenter.org/)***

Seismic Assessment Process



Seismic Assessment Process



USGS Hazard Curve for Determining Return Periods of PGA Estimates Compared with Deterministic Estimates

Developed at 108, 224, 475, 975, 2475, and 4975 year Return Periods from the following authors: Chiou-Youngs, Boore-Atkinson, and Campbell-Bozorgnia (2008)

Dam:	Bethany
Location:	Dam Crest
County:	Alameda
Latitude (deg):	37.780
Longitude (deg):	-121.608
Date:	11/5/2012
Author:	D.F. Hoirup Jr.

DSHA Parameters

Fault Name:	Midway
M_{max}:	6.90
R_{rup} (km):	0.86
Slip Rate (mm/yr):	0.2
Vs30 (m/s)	490

USGS Hazard Curve Parameters

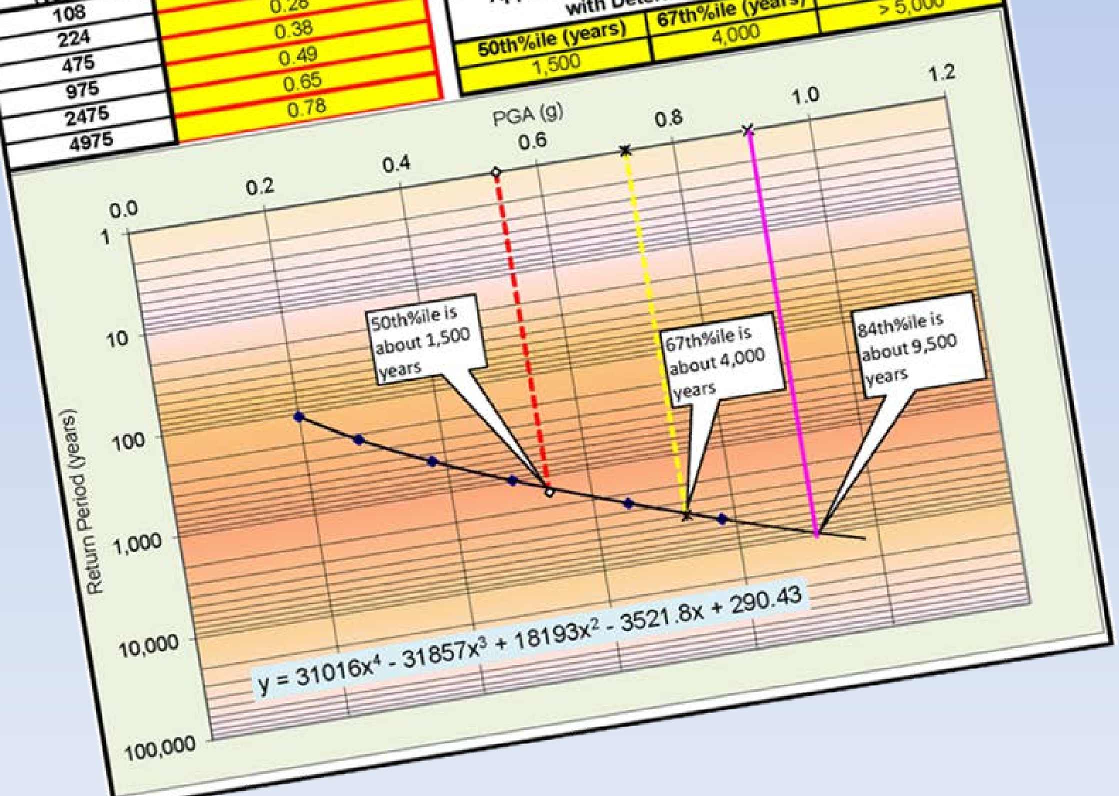
Exceedance Return Periods (years)	Corresponding PGA (g)
108	0.20
224	0.28
475	0.38
975	0.49
2475	0.65
4975	0.78

[illegible] Attenuation Model Ground Motion

PGA 50%ile (g)	PGA 67%ile (g)	PGA 84%ile (g)
0.54	0.73	0.91
μ	$\mu + ½\sigma$	$\mu + \sigma$

Approximate USGS Return Period Corresponding with Deterministic Ground Motion

50th%ile (years)	67th%ile (years)	84th%ile (years)
1,500	4,000	> 5,000



Seismic Assessment Process

State of California
California Natural Resources Agency
DEPARTMENT OF WATER RESOURCES
Division of Engineering

DEL VALLE DAM
FAULTING AND SEISMICITY REANALYSIS

Alameda County

Project Geology Report No. 40-13-29

November 2012

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Table 1 Del Valle Dam Significant Faults, Parameters, and PGA Used in NGA Calculations.

Fault Name/ Activity	Moment Magnitude (Mw)	Slip Rate (mm/yr)	Distance (km)			Type	Dip Angle (degrees), Dip Direction	Rupture Rake (degrees)	Rupture Width (km)	Weighted Average of NGA Relationships Peak Ground Acceleration (g) (5% damping) Horizontal		
			Rrup	Rjb	Rx (+/-)					50th%ile	67th%ile	84th%ile
Pleasanton-Verona-Williams (A)	6.8	<0.2	2.57	0.0	3.0	Thrust	~59, East	90	19.8	0.61	0.84	1.06
Las Positas (A)	6.3	<1.0	2.94	2.94	2.94	Strike-slip	90	0	17.0	0.36	0.50	0.64
Greenville (A)	7.0	~2.0	9.93	9.93	9.93	Strike-slip	90	180	17.0	0.24	0.34	0.42
Great Valley Segment 7 (A)	6.9	~1.5	18.96	16.71	23.53	Thrust (blind)	15, West	90	7.6	0.23	0.31	0.40
Calaveras (A)	7.0	6.0	11.17	11.17	11.17	Strike-slip	90	180	13.0	0.23	0.31	0.39
Hayward-Rodgers Creek (A)	7.3	9.0	20.12	20.12	20.12	Strike-slip	90	180	12.0	0.16	0.22	0.28
San Andreas (A)	8.0	~20.0	49.53	49.53	49.53	Strike-slip	90	180	~14	0.11	0.15	0.19

Notes:
1. A=active fault, per DSOD criteria. Fault has ruptured within last 35,000 years.
2. CA (not applicable in this report) = conditionally active fault, per DSOD criteria. Fault ruptured within the Quaternary period, but its displacement history during the last 35,000 years is unknown.
3. To preserve space, "Percentile" is abbreviated as "%ile" on this table.
4. Slip rates listed as less than 1.0 mm/yr are an approximation.
5. San Andreas fault parameters are based on the Peninsula and Santa Cruz Mountains strands.

Report for our engineers for their calculations, and for our Director's Safety Review Board

Suggestions to NSHMP

Issue:

Not all Quaternary faults (surface) appear to be included in the USGS Quaternary fault database (Grizzly Valley fault, Plumas County). *Last update of fault database (GIS/Google Earth files) was November 3, 2010.*

Suggestion:

Form workgroup (USGS, CGS, DWR, CalTrans, others...)
Maintain existing fault database, update GIS/Google Earth files, or create *new* fault database that captures all faults. Allow **registered users** to upload new fault information/data to supplement the existing database search results…

Interactive Fault Map
Database Search
Fault Data Used in Hazard Maps
Background
Contributors

Database Search

Complete Report for Green Valley fault (Class A) No. 37

Compiled in cooperation with the California Geological Survey

citation for this record: Bryant, W.A., and Cluett, S.E., compilers, 2002, Fault number 37, Green Valley fault, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, http://earthquakes.usgs.gov/hazards/qfaults, accessed 09/20/2015 02:13 PM.

Synopsis	Holocene active dextral strike-slip fault. The Green Valley fault, which is the easternmost strike-slip fault of larger San Andreas system in the San Francisco Bay area, is characterized by aseismic creep and has been monitored by Galehouse (1992 #5333; 1999 #5500) since 1984. Detailed reconnaissance-level mapping exists for most of the fault as are geologic and geomorphic data (Weaver, 1949 #5317; Sims and others, 1973 #5263; Dooley, 1973 #5331; Bryant, 1982 #5327; 1992 #5328; Frizzell and Brown, l976 #5332). Several site-specific studies in compliance with Alquist-Priolo Act (Hart and Bryant, 1997 #4856) have documented the location and approximate time of the most recent faulting. Preliminary data from the Lopes Ranch paleoseismic site [37-1] indicates that the Green Valley fault has produced multiple surface-rupturing events in the past 2.7 ka and has minimum late Holocene dextral slip rate of 3.8 mm/yr to 4.8 mm/yr (Baldwin and Lienkaemper, 1999 #5325).
Name comments	Fault first mapped, but not named, by Lawson (1908 #4969). Wood (1916 #5259) named it the Suisun fault, whereas the southern part of fault was referred to as the Mt. Diablo Thrust by Tolman (1931 #5322). Weaver (1949 #5317) used the name Green Valley fault, which currently is the more commonly used name. The fault extends from Wooden Valley south to Suisun Bay. Location of the fault north of Wooden Valley is conjectural, although a linear zone of seismicity suggests a northward subsurface continuation of the fault zone. Baldwin and others (1998 #5324) reported that the apparent termination of the Green Valley fault at Wooden Valley may indicate a transfer of some amount of dextral slip west across contractional structures in the Howell Mountains and northward onto the Maacama fault [30]. **Section:** **Fault ID Comments:** Refers to number 154 (Green Valley fault) of Jennings (1994 #2878) and number C4 (Green Valley fault) of Working Group on Northern California Earthquake Potential (1996 #1216).
County(s) and State(s)	NAPA COUNTY, CALIFORNIA SOLANO COUNTY, CALIFORNIA
Physiographic	PACIFIC BORDER

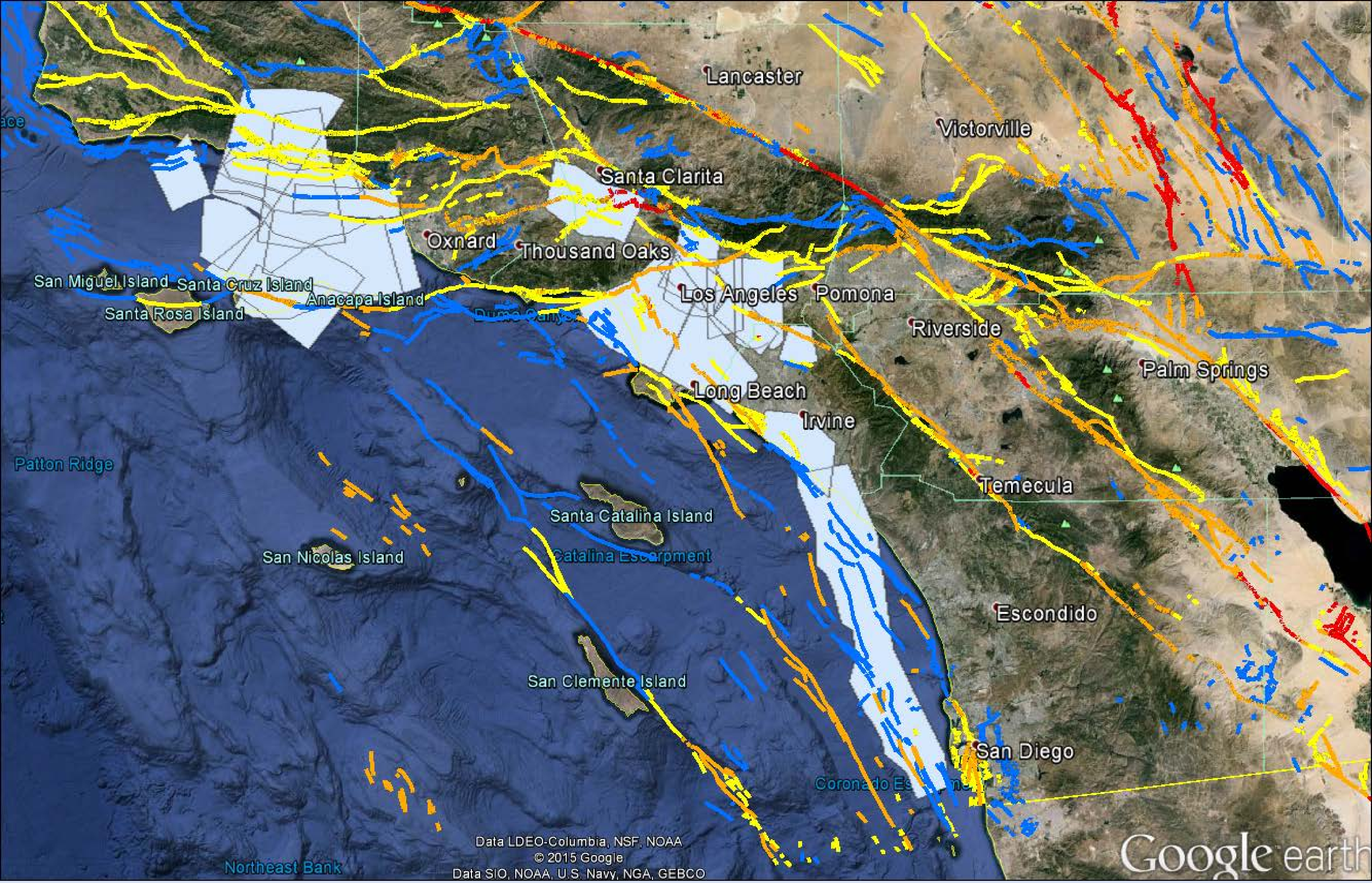
Suggestions to NSHMP

Issue:

The USGS Quaternary fault database does not include *blind thrust faults* as GIS or Google Earth files. Other means must be used to apply estimated earthquake source-to-site distances required in the NGA calculator.

Suggestion:

Include blind faults into the GIS/Google Earth files… (Mt. Diablo, Great Valley Segments (1-14), Off/On shore Santa Barbara-Ventura, Northridge, Off/On shore Los Angeles and San Diego).



Lancaster
Victorville
Santa Clarita
Oxnard
Thousand Oaks
San Miguel Island
Santa Cruz Island
Anacapa Island
Santa Rosa Island
Los Angeles
Pomona
Riverside
Palm Springs
Long Beach
Irvine
Patton Ridge
Temecula
Santa Catalina Island
San Nicolas Island
Escondido
San Clemente Island
San Diego
Northeast Bank
Data LDEO-Columbia, NSF, NOAA
© 2015 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth

Suggestions to NSHMP

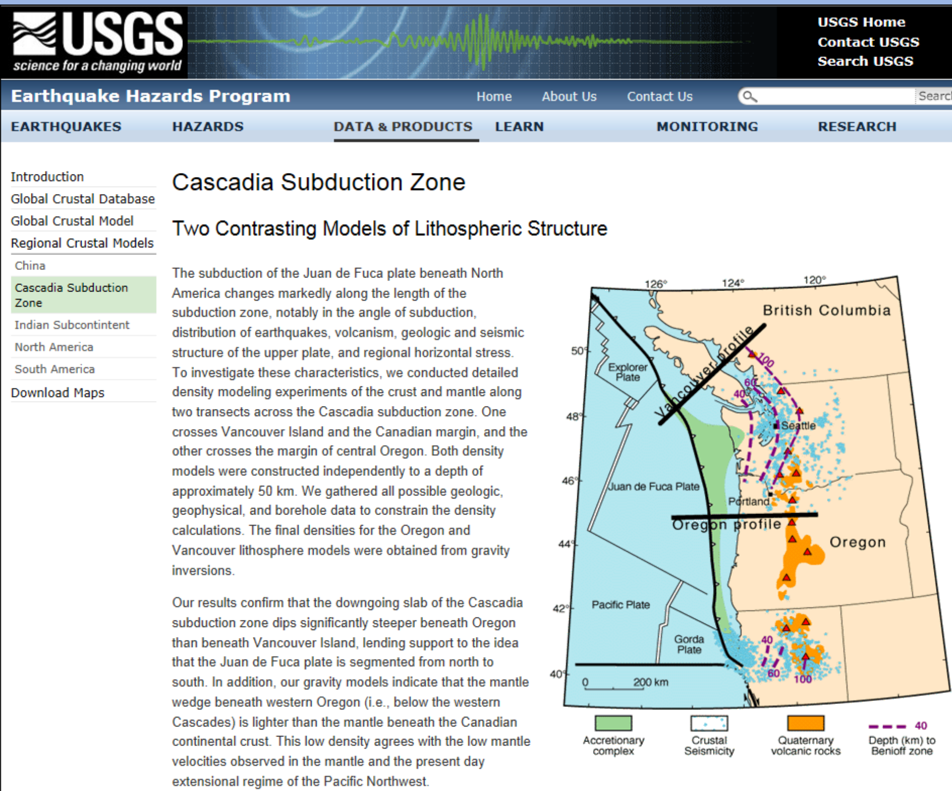
Issue:

Information and tools for Cascadia Subduction Zone (California). Low population, *lots* of infrastructure and lifelines.

Suggestion:

Include California specific fault parameters/geometry. Web based ground motion tools (interactive deterministic). NGA-W2 not available for CSZ event.

Art Frankel model…? (Rui Chen, CGS)



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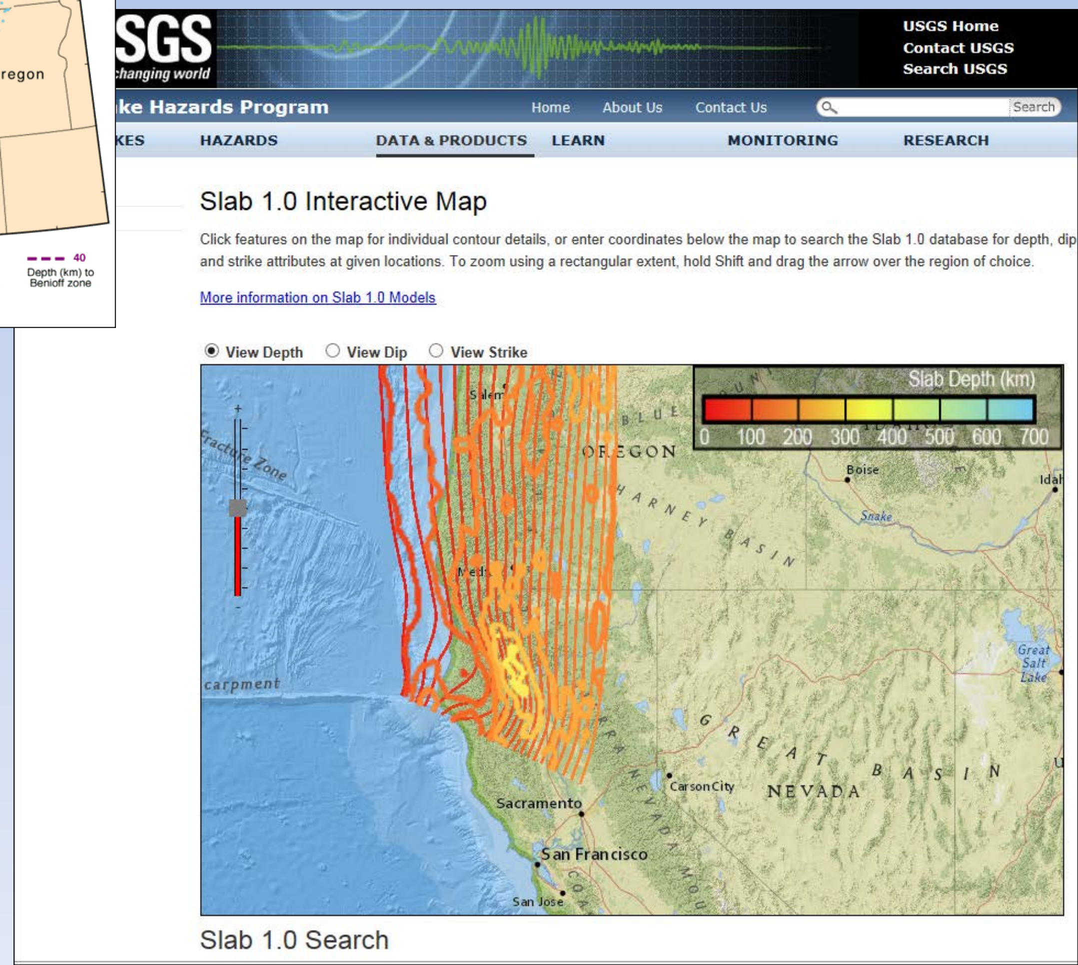
Introduction
Global Crustal Database
Global Crustal Model
Regional Crustal Models
China
Cascadia Subduction Zone
Indian Subcontintent
North America
South America
Download Maps

Cascadia Subduction Zone

Two Contrasting Models of Lithospheric Structure

The subduction of the Juan de Fuca plate beneath North America changes markedly along the length of the subduction zone, notably in the angle of subduction, distribution of earthquakes, volcanism, geologic and seismic structure of the upper plate, and regional horizontal stress. To investigate these characteristics, we conducted detailed density modeling experiments of the crust and mantle along two transects across the Cascadia subduction zone. One crosses Vancouver Island and the Canadian margin, and the other crosses the margin of central Oregon. Both density models were constructed independently to a depth of approximately 50 km. We gathered all possible geologic, geophysical, and borehole data to constrain the density calculations. The final densities for the Oregon and Vancouver lithosphere models were obtained from gravity inversions.

Our results confirm that the downgoing slab of the Cascadia subduction zone dips significantly steeper beneath Oregon than beneath Vancouver Island, lending support to the idea that the Juan de Fuca plate is segmented from north to south. In addition, our gravity models indicate that the mantle wedge beneath western Oregon (i.e., below the western Cascades) is lighter than the mantle beneath the Canadian continental crust. This low density agrees with the low mantle velocities observed in the mantle and the present day extensional regime of the Pacific Northwest.



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Slab 1.0 Interactive Map

Click features on the map for individual contour details, or enter coordinates below the map to search the Slab 1.0 database for depth, dip and strike attributes at given locations. To zoom using a rectangular extent, hold Shift and drag the arrow over the region of choice.

More information on Slab 1.0 Models

View Depth | View Dip | View Strike

Slab 1.0 Search

ESRI ArcGIS, 3D Analyst, (ArcScene) model of the CSZ…

Suggestions to NSHMP

Issue:

CGS publishes the “Fault Activity Map of California” that includes pre-Quaternary faults.

Suggestion:

Update and revise the existing pre-Quaternary fault database with best available informtion.

Create a web-based pre-Quaternary fault database, similar to the Quaternary fault database with GIS and Google Earth files.

Suggestions to NSHMP

Issue:
Directivity (PEER)
Arias Intensity
Significant Duration
Estimate earthquake magnitude, fault slip displacement (Wells and Coppersmith, 1994)*

Suggestion:
An interactive website where the user can input their parameters and retrieve results.

Suggestions to NSHMP *(Overview)*

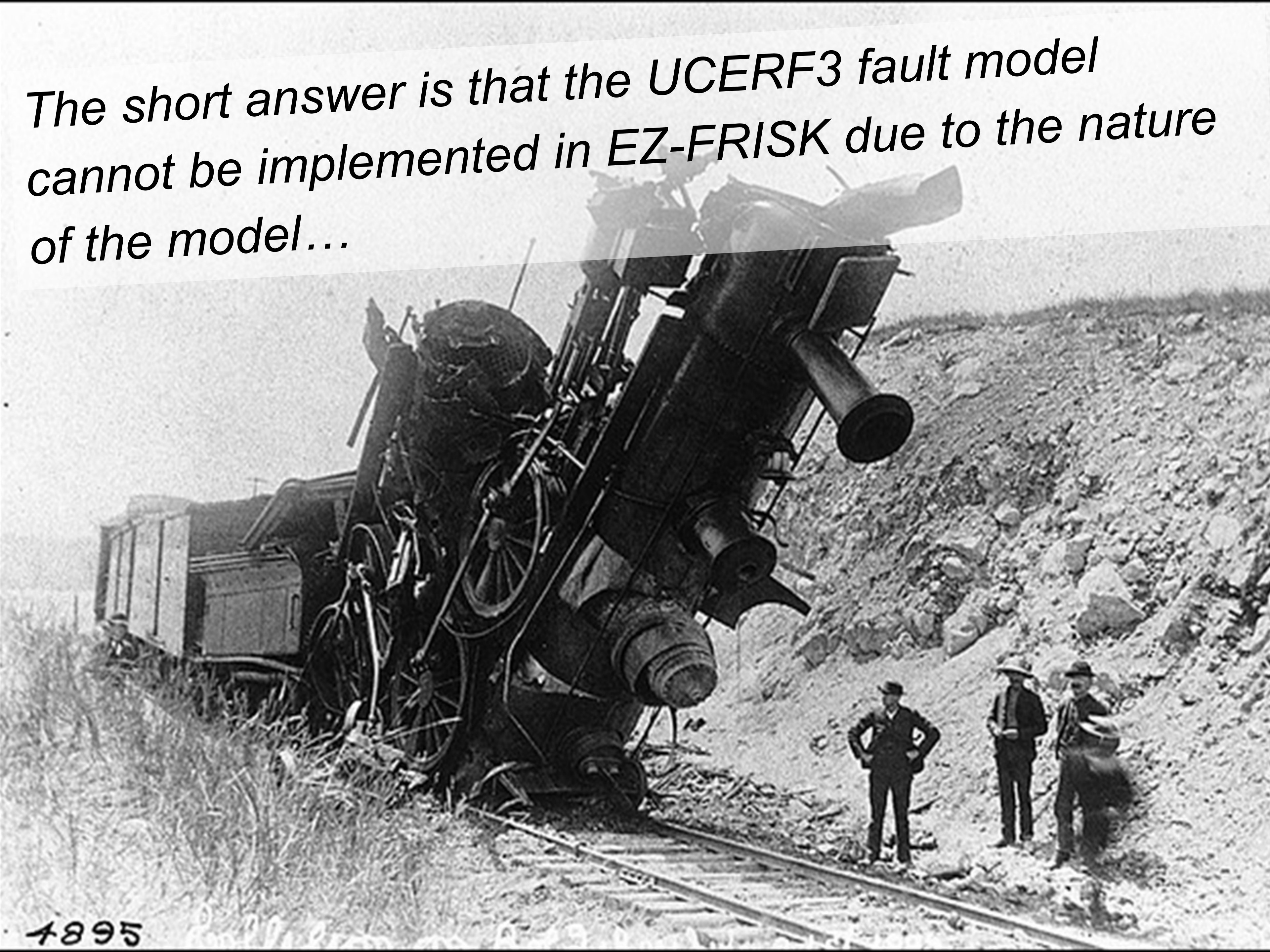
- Interactive probabilistic seismic hazard information is available from the USGS National Seismic Hazard Mapping Project (*and we like it!*)
- Similar interactive deterministic seismic hazard information and tools would be useful.

Comments from DWR Engineers (SEERG)

Our comments/concerns are related to the ability of commercially available seismic hazard software to implement the UCERF3 model. We believe that not only users of commercial software but users of in-house software will have the same concerns.

The following is the response received from Risk Engineering, Inc. when we asked them when to expect their implementation of UCERF3 into EZFrisk...

The short answer is that the UCERF3 fault model cannot be implemented in EZ-FRISK due to the nature of the model…



Risk Engineering, Inc. has developed and applied (to a SSHAC II-level project in CA) a methodology for performing moment balancing, however, <u>it cannot be performed for arbitrary site coordinates as definition of the control faults is judgment-based and will be dependent on the site location.</u>

As such, it cannot be part of the USGS 2014 model implementation that we are preparing for EZ-FRISK.

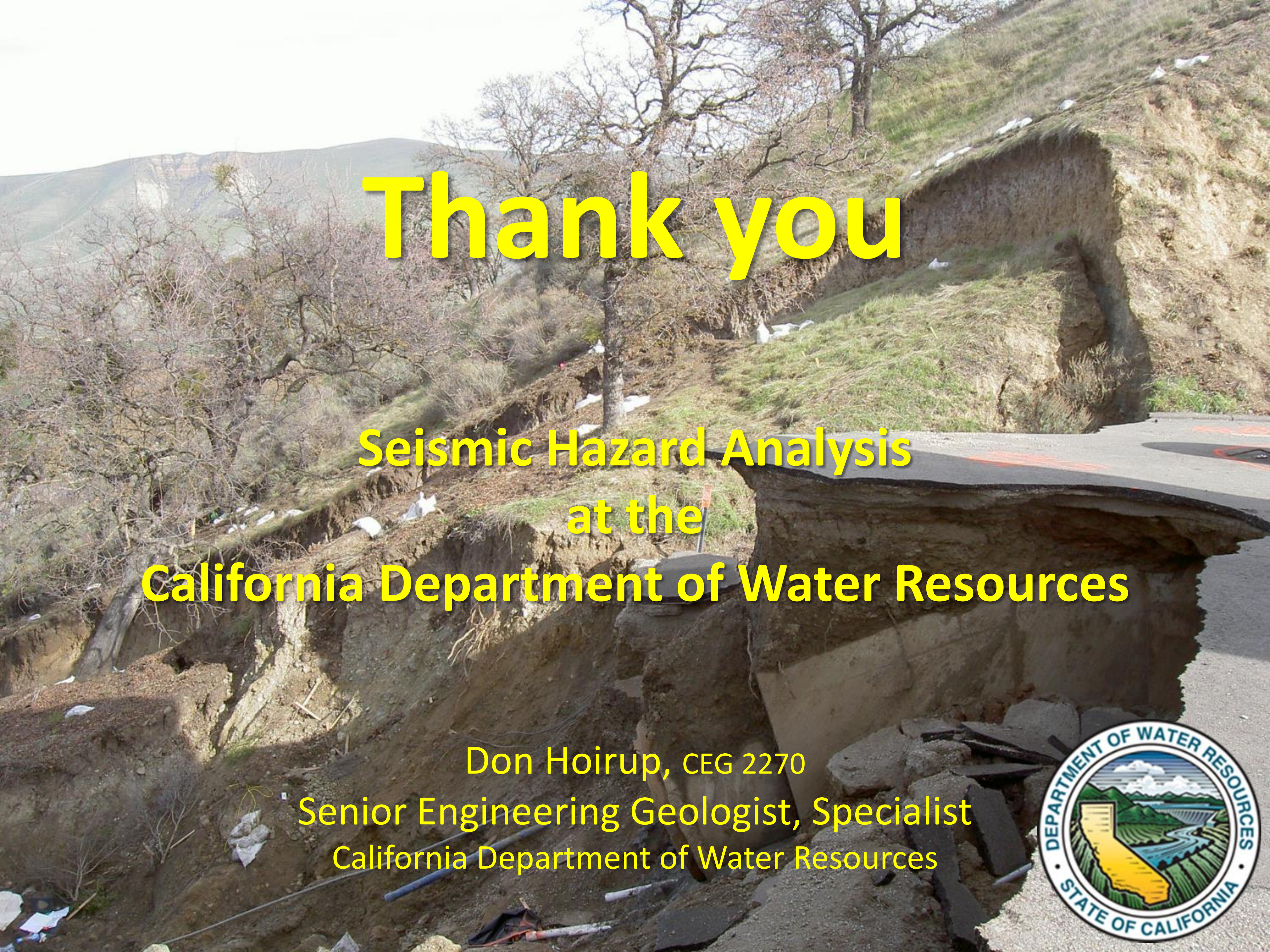
Comments from DWR Engineers/Geo's (SEERG)

If we will no longer be able to use EZFrisk to perform PSHA/DSHA using the UCERF3 model then our "user needs" for consideration by the NSHMP would be having the ability to:

- Perform PSHA/DSHA using UCERF3
- Select period(s) for spectral output
- Select various output (horizontal/vertical acceleration, max rotated component of horizontal acceleration, Arias Intensity, CAV, etc…)

Comments from DWR Engineers/Geo's (SEERG)

- Customize UHS return period
- Select (or exclude) seismic sources
- Use any or all NGA-West2 GMPEs (weights)
- Customize inputs to the various NGA (Vs30, Z1, Z2.5, etc.)
- Include directivity
- Deaggregate the hazard
- Perform Conditional Mean Spectra



Thank you

Seismic Hazard Analysis at the California Department of Water Resources

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