Seismic Monitoring Advisory Committee Meeting

01 April 2018 to 30 September 2018 Reporting Period

Calpine Geothermal Visitors Center

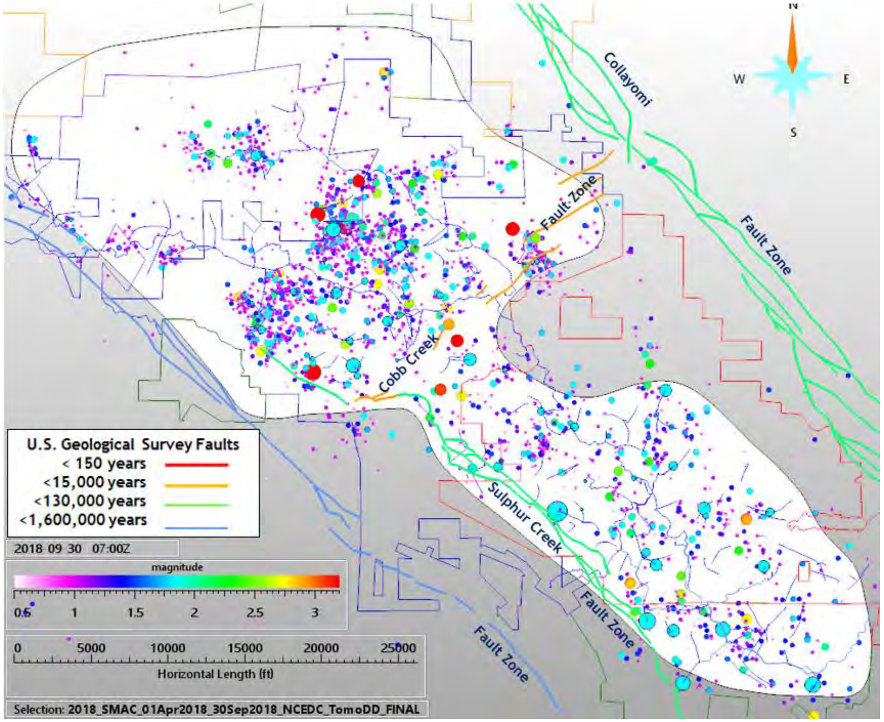
Middletown, California

13 November 2018

Craig Hartline   Senior Geophysicist   Calpine Corporation   The Geysers

Seismic Monitoring Advisory Committee Meeting
Calpine Presentation Agenda
Reporting Period: 01 April 2018 to 30 September 2018

- California Total Electrical Generation
- Status of Seismic Monitoring Networks
  - LBNL Seismic Monitoring Network
  - USGS / Northern California Seismic Network
  - Strong Motion Station
  - ShakeAlert USGS Earthquake Early Warning System
- Strong Motion Databases, Analysis and Equipment
- Yearly Field-wide Water Injection and Seismicity
- Fieldwide Seismicity Analysis
- Water Injection and Induced Seismicity Animations
- Community Hotline
- 3D Structural Model Building
  - Fault/Fracture Analysis
  - Compartmentalization
  - Water Injection Well Planning
- Additional Seismic Monitoring and Research



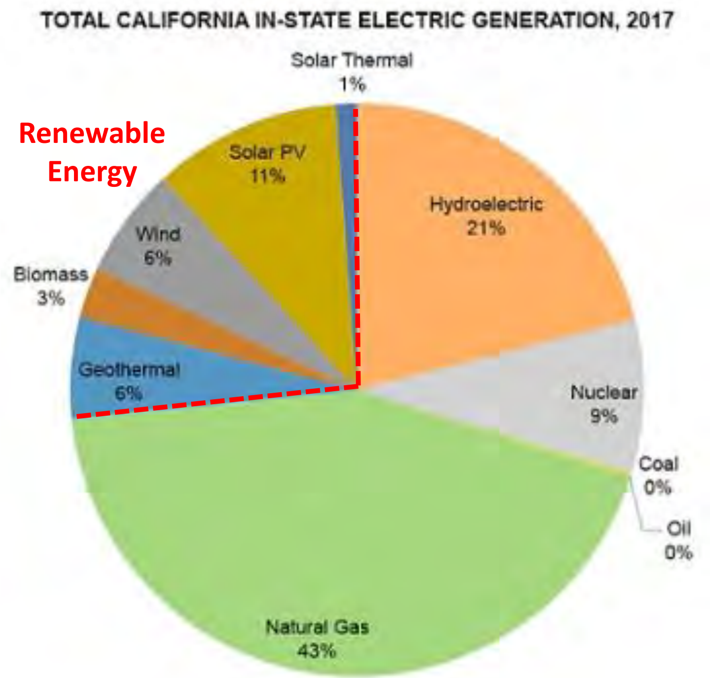
Seismic Monitoring Advisory Committee Meeting

California Total Electrical Generation and In-State Electrical Generation

2017 Total System Electric Generation in Gigawatt Hours

Fuel Type	California In-State Generation (GWh)	Percent of California In-State Generation	Northwest Imports (GWh)	Southwest Imports (GWh)	California Energy Mix (GWh)	California Power Mix
Coal	302	0.15%	409	11,364	12,075	4.13%
Large Hydro	36,920	17.89%	4,531	1,536	42,987	14.72%
Natural Gas	89,564	43.40%	46	8,705	98,315	33.67%
Nuclear	17,925	8.69%	0	8,594	26,519	9.08%
Oil	33	0.02%	0	0	33	0.01%
Other (Petroleum Coke/Waste Heat)	409	0.20%	0	0	409	0.14%
Renewables	61,183	29.65%	12,502	10,999	84,684	29.00%
Biomass	5,827	2.82%	1,015	32	6,874	2.35%
Geothermal	11,745	5.69%	23	937	12,705	4.35%
Small Hydro	6,413	3.11%	1,449	5	7,867	2.70%
Solar	24,331	11.79%	0	5,465	29,796	10.20%
Wind	12,867	6.24%	10,015	4,560	27,442	9.40%
Unspecified Sources of Power	N/A	N/A	22,385	4,632	27,017	9.25%
Total	206,336	100.00%	39,873	45,830	292,039	100.00%

https://www.energy.ca.gov/almanac/electricity_data/total_system_power.html



http://www.conservation.ca.gov/dog/geothermal
Division of Oil, Gas and Geothermal Resources

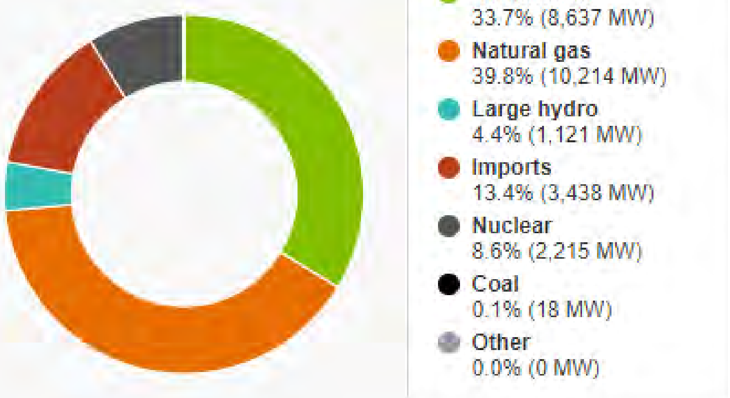
In 2017, California geothermal produced 11.7 terawatt-hours (TWh) of electricity, including Calpine Geysers yearly production of nearly 6.0 terawatt-hours (TWh). With an additional 0.7 TWh of imported geothermal power, this is nearly 6 percent of California's total system power.

Seismic Monitoring Advisory Committee Meeting

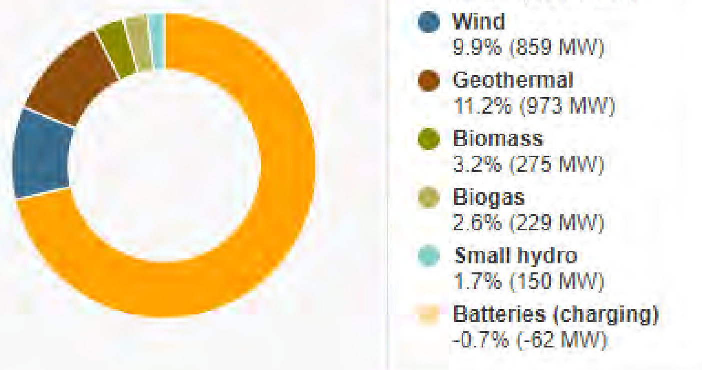
California ISO Electrical Power Sources
Snapshot at 15:10 on 12 November 2018

25,670 MW	8,637 MW	6,213 MW	859 MW
Current demand	Current renewables	Current solar	Current wind

Current supply AS OF 15:10



Current renewables AS OF 15:10



* California Independent System Operator http://www.caiso.com/TodaysOutlook/Pages/supply.aspx

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California ISO Electrical Power Sources on 11 November 2018

RENEWABLES WATCH | California ISO

For Operating Day: **Sunday, November 11, 2018**

The Renewables Watch provides important information about actual renewable production within the ISO grid as California movestoward a 33 percent renewable generation portfolio. The information provided is as accurate as can be delivered in a daily format. It is unverifed raw data and is not intended to be used as the basis for operational or financial decisions.

Renewables Production

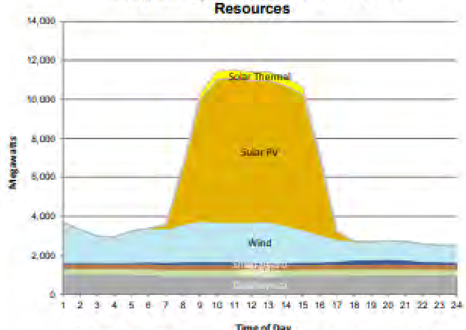
24-Hour Renewables Production

Renewable Resources	Peak Production Time	Peak Production (MW)	Daily Production (MWh)
Solar Thermal	10:27	451	3,308
Solar	14:06	7,493	57,152
Wind	12:28	2,196	35,658
Small Hydro	19:20	275	3,892
Biogas	9:50	235	5,561
Biomass	19:00	320	7,380
Geothermal	5:36	1,016	23,395
Total Renewables			**136,346**

Total 24-Hour System Demand (MWh): *524,155*

This table gives numeric values related to the production from the various types of renewable resources for the reporting day. All values are hourly average unless otherwise stated. Peak Production is an average over one minute. The total renewable production in megawatt-hours is compared to the total energy demand for the ISO system for the day.

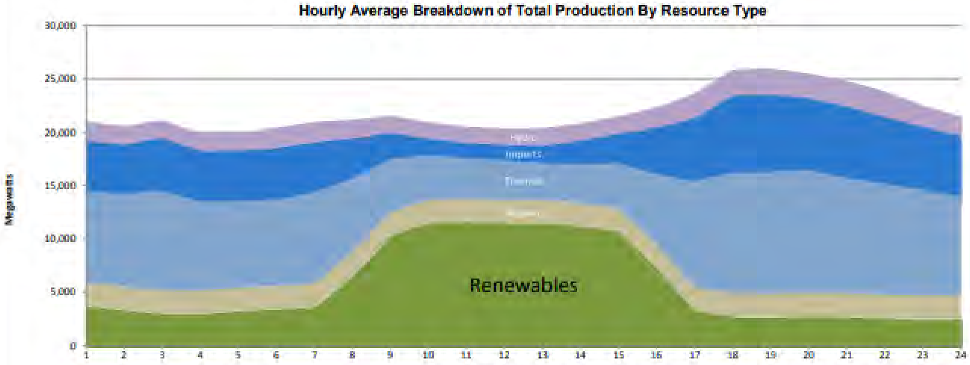
Hourly Average Breakdown of Renewable Resources



This graph shows the production of various types of renewable generation across the day.

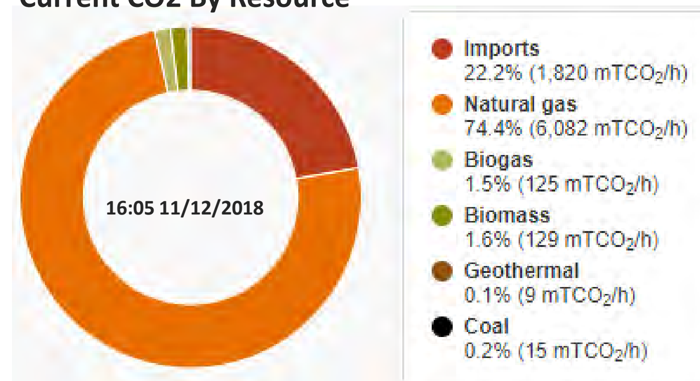
System Peak Demand (MW) 26,146
*one minute average
Time: 17:51

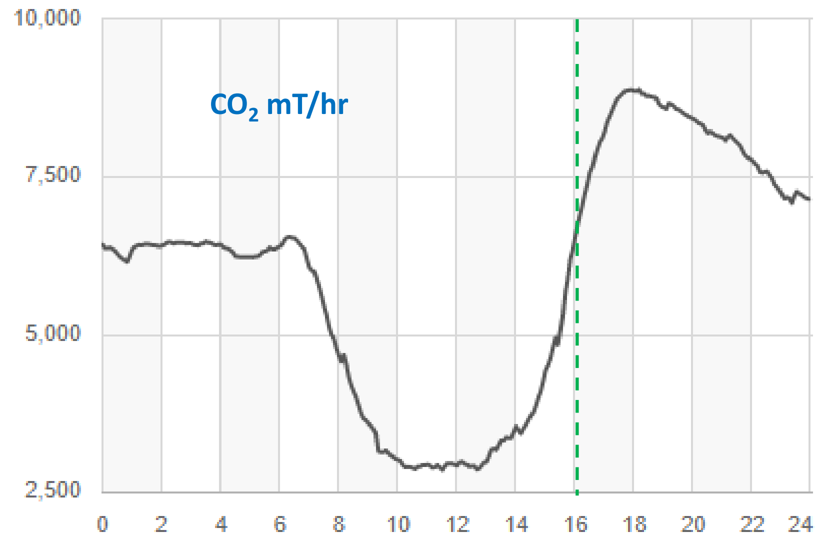
Hourly Average Breakdown of Total Production By Resource Type



*** California Independent System Operator**
http://content.caiso.com/green/renewrpt/DailyRenewablesWatch.pdf

Current CO2 By Resource





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Calpine Geysers Greenhouse Gas Equivalence

Approximate CO_2 Emission Reduction From 6 Terawatt-Hour Yearly Production

Power

6 Terawatt = 6e+9 Kilowatt

Formula multiply the power value by 1e+9

If You Have Energy Data | If You Have Emissions Data

6000000000 kilowatt-hours of electricity

Calculate

https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

Equivalency Results How are they calculated?

The sum of the greenhouse gas emissions you entered above is of Carbon Dioxide Equivalent. This is equivalent to: 4,465,302 Metric Tons

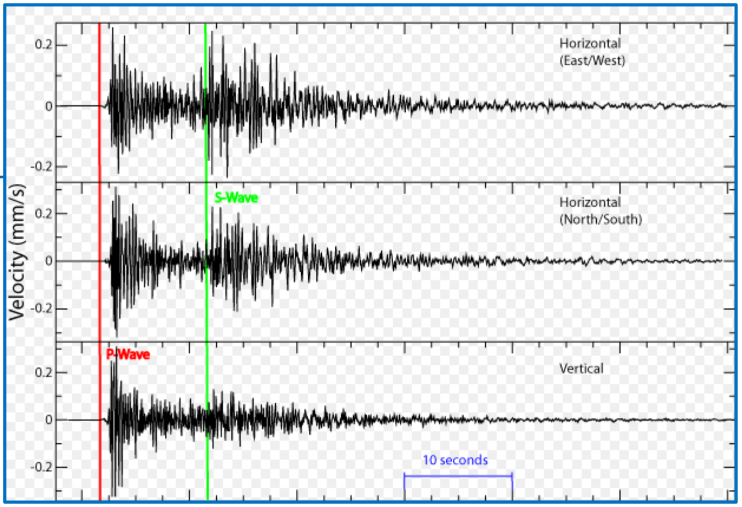
Greenhouse gas emissions from

- 956,167 Passenger vehicles driven for one year -or-
- 10,944,367,647 Miles driven by an average passenger vehicle -or-
- 1,555,854 Tons of waste recycled instead of landfilled -or-
- 222,486 Garbage trucks of waste recycled instead of landfilled

CO_2 emissions from

- 502,453,246 gallons of gasoline consumed -or-
- 4,885,450,766 Pounds of coal burned -or-
- 59,112 tanker trucks' worth of gasoline -or-
- 482,162 homes' energy use for one year -or-
- 1,131 Wind turbines running for a year -or-
- 669,260 homes' electricity use for one year -or-

Seismic Monitoring Advisory Committee Meeting
Status of Seismic Monitoring Networks



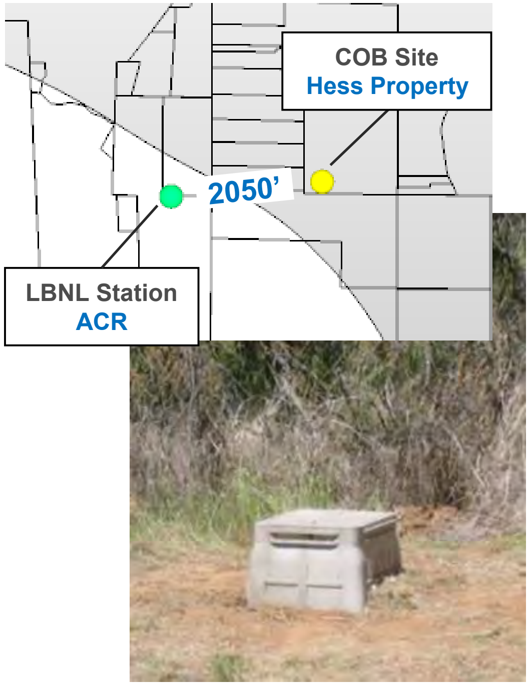
LBNL Seismic Monitoring Network
- Fully Functional

USGS / Northern California Seismic Network
- Fully Functional

Strong Motion Stations - Concerns Discussed on Following Slides
- Anderson Springs
  Community Center Strong Motion ADS2
- Anderson Springs
  Engels Strong Motion ESM
- Cobb
  Alder Creek Strong Motion ASR

Engels Strong Motion ESM

Alder Creek Strong Motion ASR



Seismic Monitoring Advisory Committee Meeting

Status of Seismic Monitoring Networks

Strong Motion Data Access

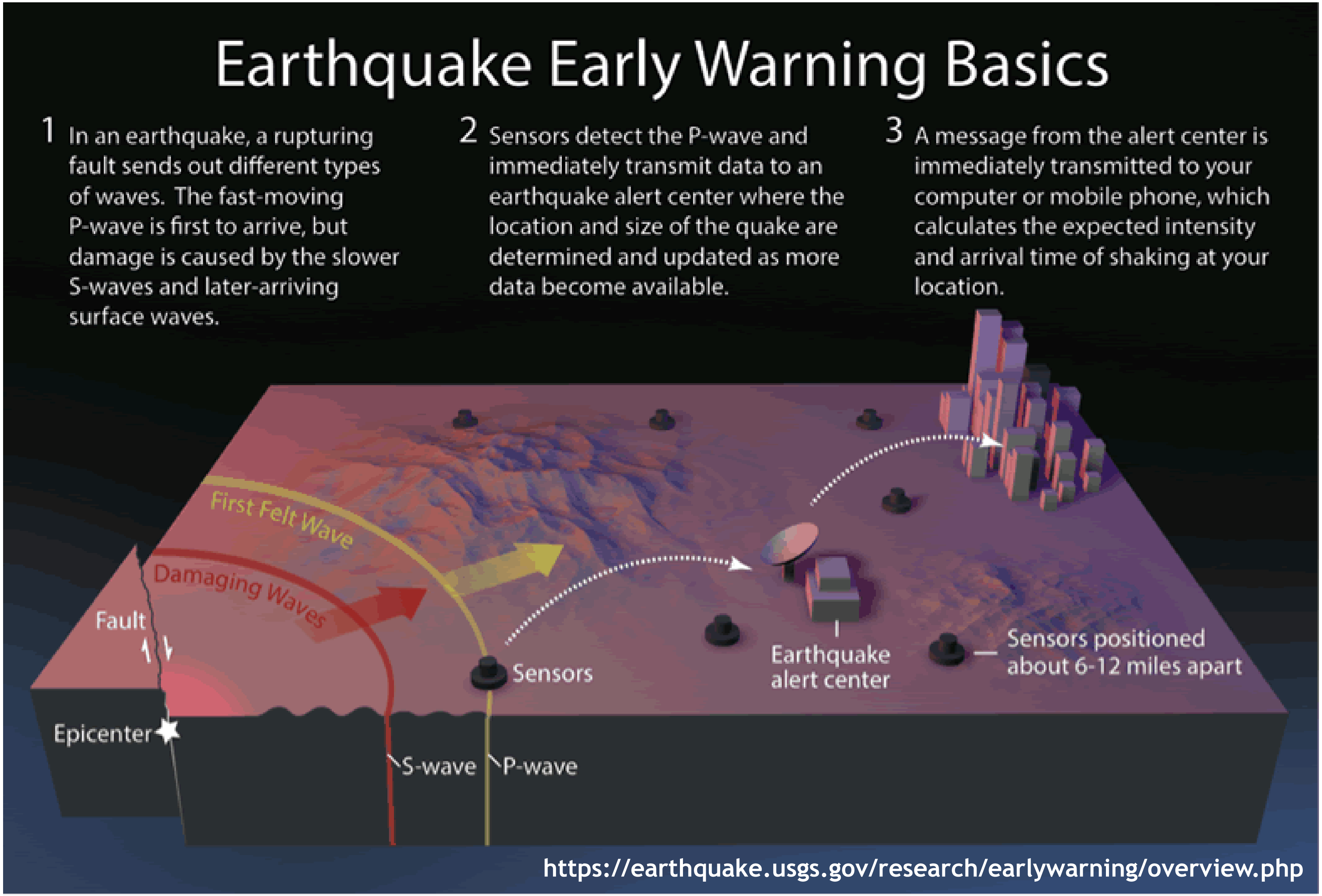
The United States Geological Survey and Lawrence Berkeley National Laboratory have for decades provided many services of significant value to the operators of The Geysers geothermal field including:

- seismic monitoring network equipment installation
- seismic event monitoring
- seismic data transfer, analysis and archival
- collaborative seismic research
- oversight and guidance concerning induced seismicity

For the United States Geological Survey, recent budget restrictions and project reprioritization, including earthquake early warning system research, have resulted in limited resources available for activities associated with The Geysers geothermal field.

Recent United States Geological Survey retirements with no backfilling of positions has resulted in no assigned seismologists to support The Geysers strong motion monitoring programs, including database maintenance and updates.

USGS Earthquake Early Warning System
ShakeAlert



Seismic Monitoring Advisory Committee Meeting
USGS Earthquake Early Warning System
ShakeAlert

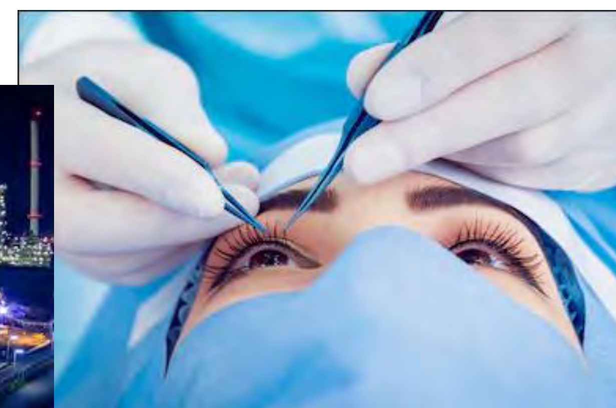
Earthquake Early Warning Systems Around the World

Earthquake Early Warning systems are operational in several countries around the world, including Mexico, Japan, Turkey, Romania, China, Italy, and Taiwan. All of these systems rapidly detect earthquakes and track their evolution to provide warnings of pending ground shaking.

Discussion of Early Warning Systems

• Mexico City has a system that warns of strong shaking from large earthquakes that occur off of the country's coast. The system consists of a series of sensors located along the coast that detect shaking from a large earthquake and rapidly determine the location and magnitude. Since Mexico City is located several hundred miles from the main plate boundary they can receive up to a minute or more of warning of the impending shaking for subduction zone earthquakes, and warning times are shorter for earthquakes that occur closer to the city. This system has been in operation since 1991.

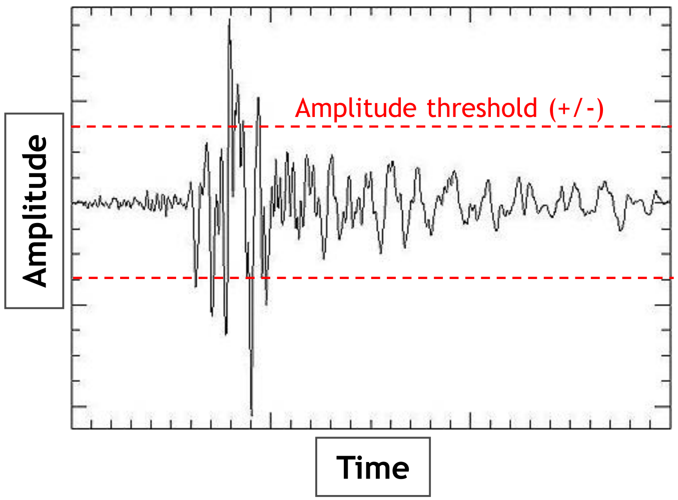
• Japan currently has the most sophisticated early warning systems in the world. The warnings were initially developed for use in slowing and stopping high-speed (300 km/hr) trains prior to strong shaking. The success of that program in addition to the devastating effects of the 1995 Kobe earthquake paved the way for building a nationwide early warning system. Japan has built a dense network of seismic instruments to rapidly detect earthquakes. They have been issuing public warnings since 2007.

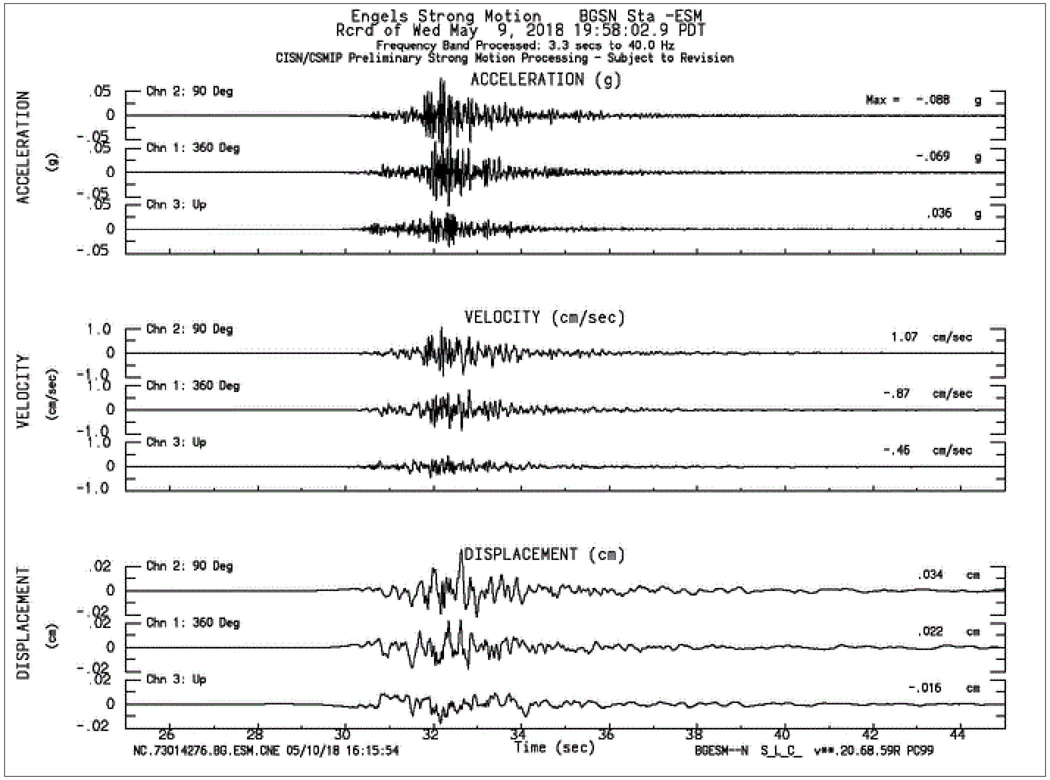


Seismic Monitoring Advisory Committee Meeting
Status of Seismic Monitoring Networks
Strong Motion Data Access

Calpine Corporation is coordinating and funding software development* due to strong motion data access limitations with an end 2018 target for completion.

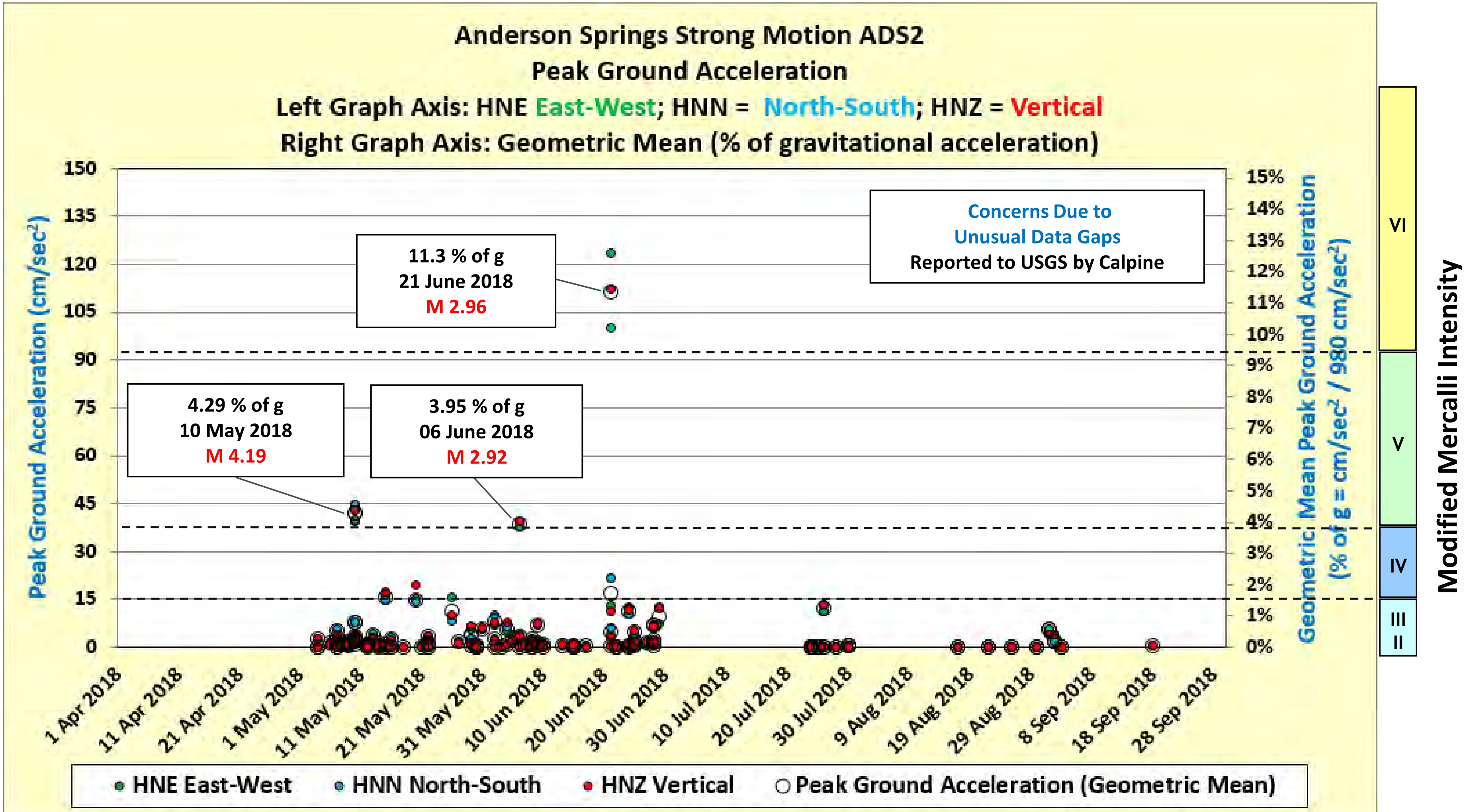
Seismic waveforms with significant amplitude excursions indicate significant ground motion. Software algorithms are being developed and calibrated to identify, isolate and properly represent significant amplitude excursions as (1) peak ground acceleration values, (2) peak ground velocity values, and (3) peak ground displacement values, which will be stored in an online database.





* With Ramsey Haught (LBNL contractor) and subcontractor Steve Jarpe (Jarpe Data Systems)

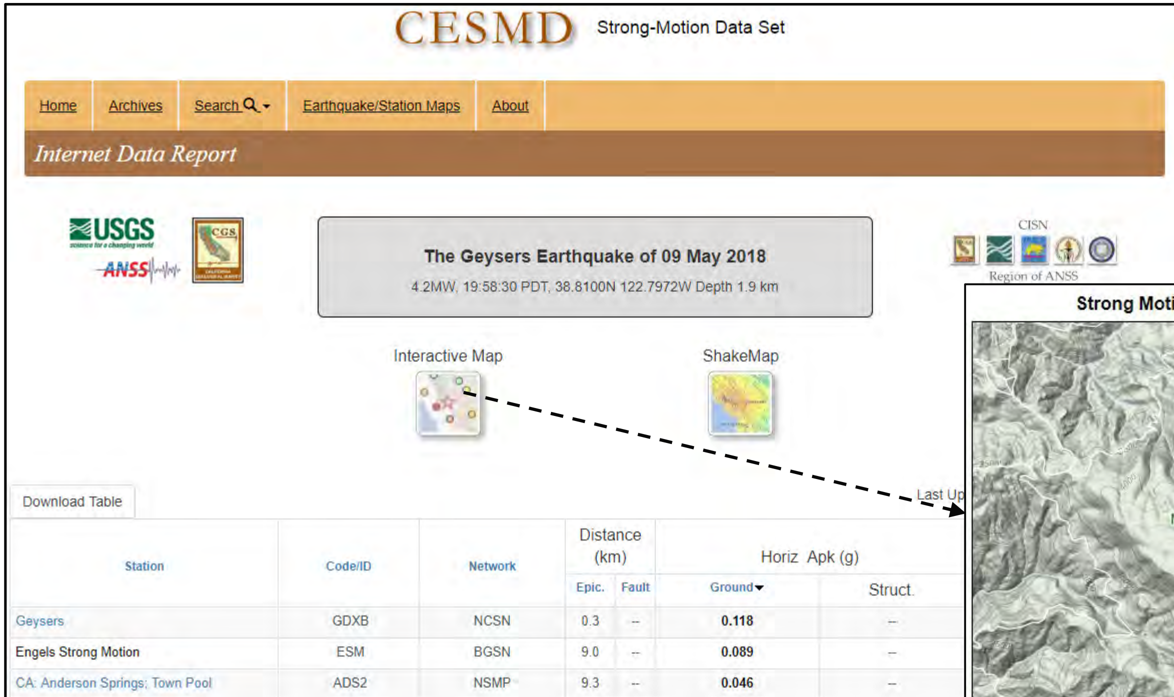
Seismic Monitoring Advisory Committee Meeting
Anderson Springs Strong Motion Station ADS2



Perceived Shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	None	None	None	Very Light	Light	Moderate	Mod/Heavy	Heavy	Very Heavy
Peak Acceleration (% of g)	< 0.17	0.17 - 1.4	1.4 - 3.9	3.9 - 9.2	9.2 - 18.0	18.0 - 34.0	34.0 - 65.0	65.0 - 124.0	> 124.0
Peak Velocity (cm/sec)	< 0.10	0.1 - 1.1	1.1 - 3.4	3.4 - 8.1	8.1 - 16.0	16.0 - 31.0	31.0 - 60.0	60.0 - 116.0	> 116.0
Modified Mercalli Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X

Seismic Monitoring Advisory Committee Meeting
Center for Engineering Strong Motion Data
Engels Strong Motion ESM Data For 09 May 2018 Magnitude 4.2 Seismic Event

The Engels Strong Motion station data is transferred by radio telemetry via the LBNL seismic monitoring network and accessible at the Center for Engineering Strong Motion Data*, a cooperative effort of the United States Geological Survey, California Geological Survey and the Advanced National Seismic System.



Station	Code/ID	Network	Distance (km) Epic.	Fault	Horiz. Apk (g) Ground	Struct.
Geysers	GDXB	NCSN	0.3	--	0.118	--
Engels Strong Motion	ESM	BGSN	9.0	--	0.089	--
CA: Anderson Springs; Town Pool	ADS2	NSMP	9.3	--	0.046	--

Center for Engineering Strong Motion Data

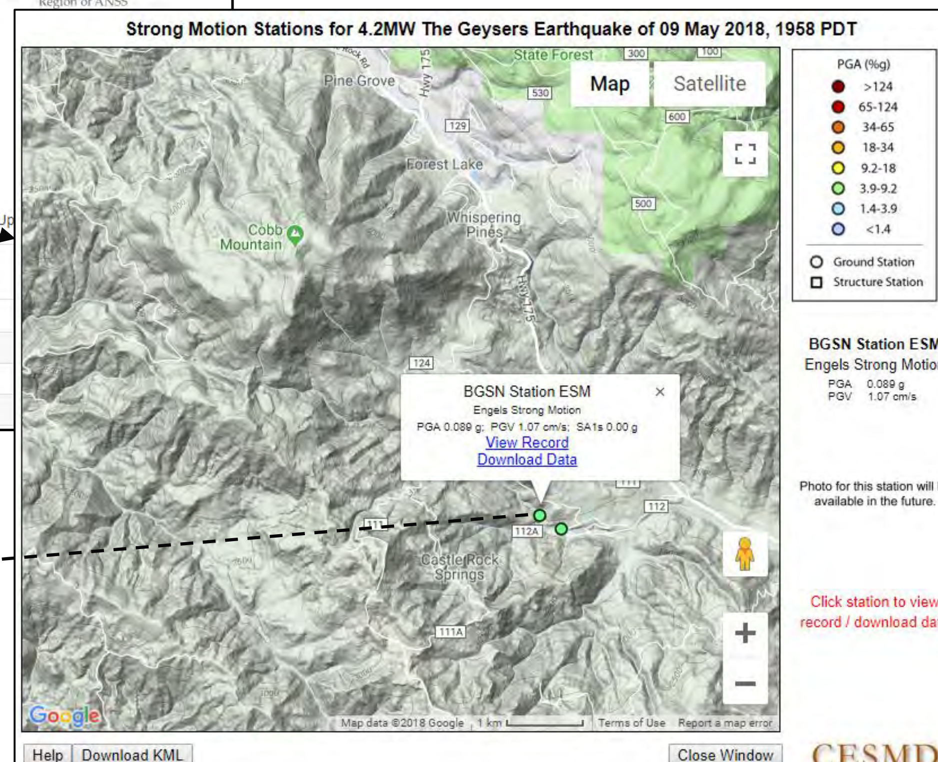
CESMD - A Cooperative Effort

Channel 90 Degree (East-West)

Peak acceleration =	- 86.24	cm/sec/sec
Peak velocity =	1.07	cm/sec
Peak displacement =	0.34	cm

Channel 360 Degree (North-South)

Peak acceleration =	- 67.62	cm/sec/sec
Peak velocity =	- 0.87	cm/sec
Peak displacement =	0.22	cm



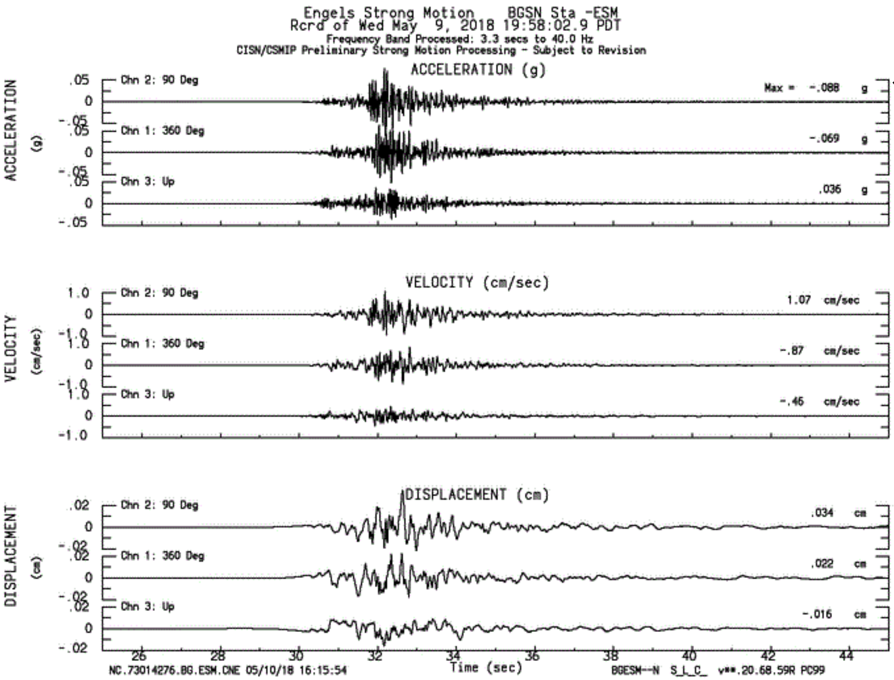
* https://www.strongmotioncenter.org/

Seismic Monitoring Advisory Committee Meeting

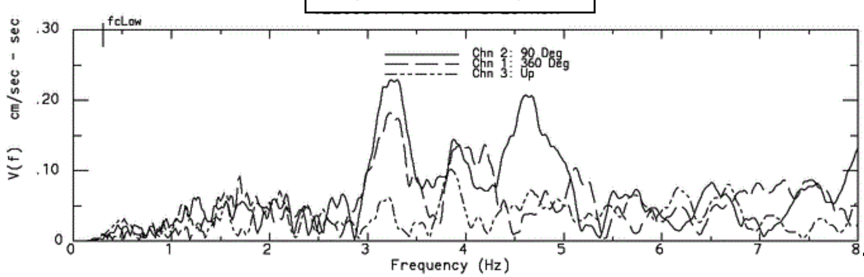
Center for Engineering Strong Motion Data

Engels Strong Motion ESM

Acceleration, Velocity and Surface Displacement

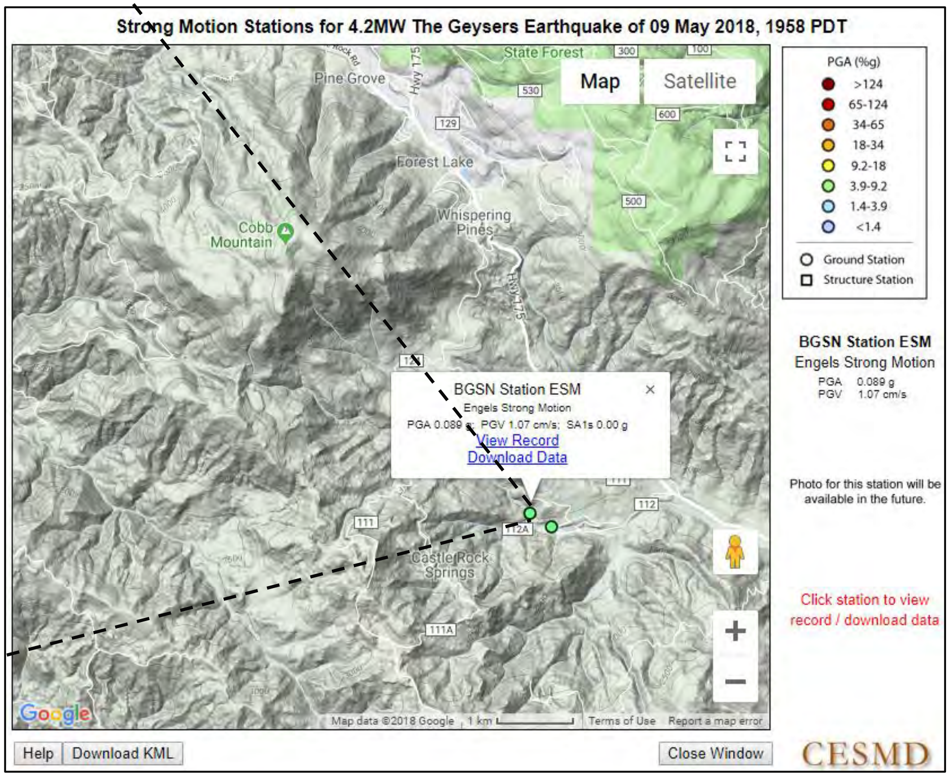


Spectral Analysis



Center for Engineering Strong Motion Data

CESMD - A Cooperative Effort



* https://www.strongmotioncenter.org/

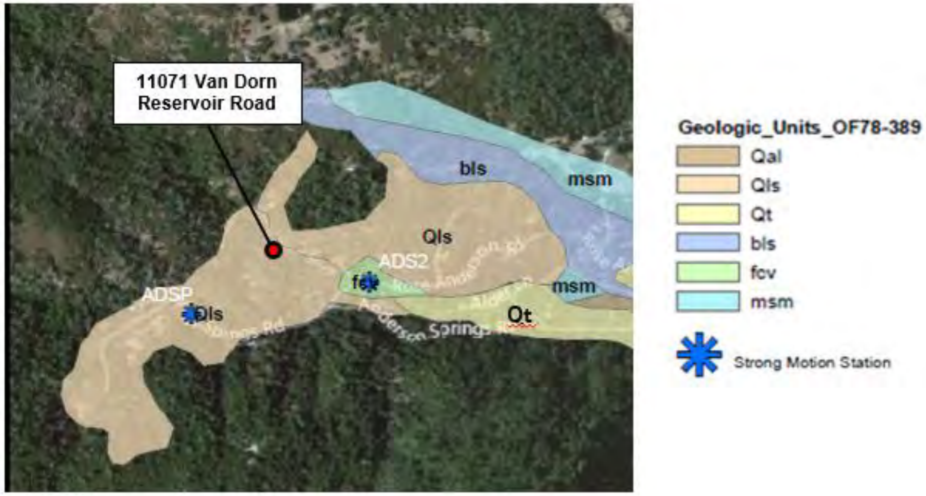
Seismic Monitoring Advisory Committee Meeting

Anderson Springs Strong Motion Station

Engels Strong Motion ESM vs Fire-Damaged ADSP Strong Motion

Site Selection Criteria to Replace ADSP

- Landowner Approval
- Reliable Solar or AC Power Source / Battery Back-up
- Reliable Radio Telemetry Communication
- Good Sensor Coupling
- Representative Peak Ground Acceleration
- ADSP Measurement Continuity ✓
- Area of Minimal Near-term / Long-term Disturbance



ADSP and Engels Strong Motion (ESM) Stations

- Qls landslide deposits
- relatively thin soil overlying rock
- lower shear-wave velocities
- this leads to site amplification at short-to-moderate periods (moderate to high frequencies)
- ESM measurements very consistent with relatively high peak ground acceleration values at ADSP
- consistently higher measurements than ADS2

M 4.2 2018-05-09 19:58:30 Pacific Time					
Engels Strong Motion (ESM)					
HNE cm/sec^2	HNN cm/sec^2	HNZ cm/sec^2	Geometric Mean cm/sec^2	g	% of g
86.24	67.62	35.28	76.36	0.078	7.8
Anderson Springs (ADS2)					
HNE cm/sec^2	HNN cm/sec^2	HNZ cm/sec^2	Geometric Mean cm/sec^2	g	% of g
39.66	44.52	42.97	42.02	0.043	4.3

ADSP 4.3 of g %   ESM 7.8% of g

Perceived Shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	None	None	None	Very Light	Light	Moderate	Mod/Heavy	Heavy	Very Heavy
Peak Acceleration (% of g)	< 0.17	0.17 - 1.4	1.4 - 3.9	3.9 - 9.2	9.2 - 18.0	18.0 - 34.0	34.0 - 65.0	65.0 - 124.0	> 124.0
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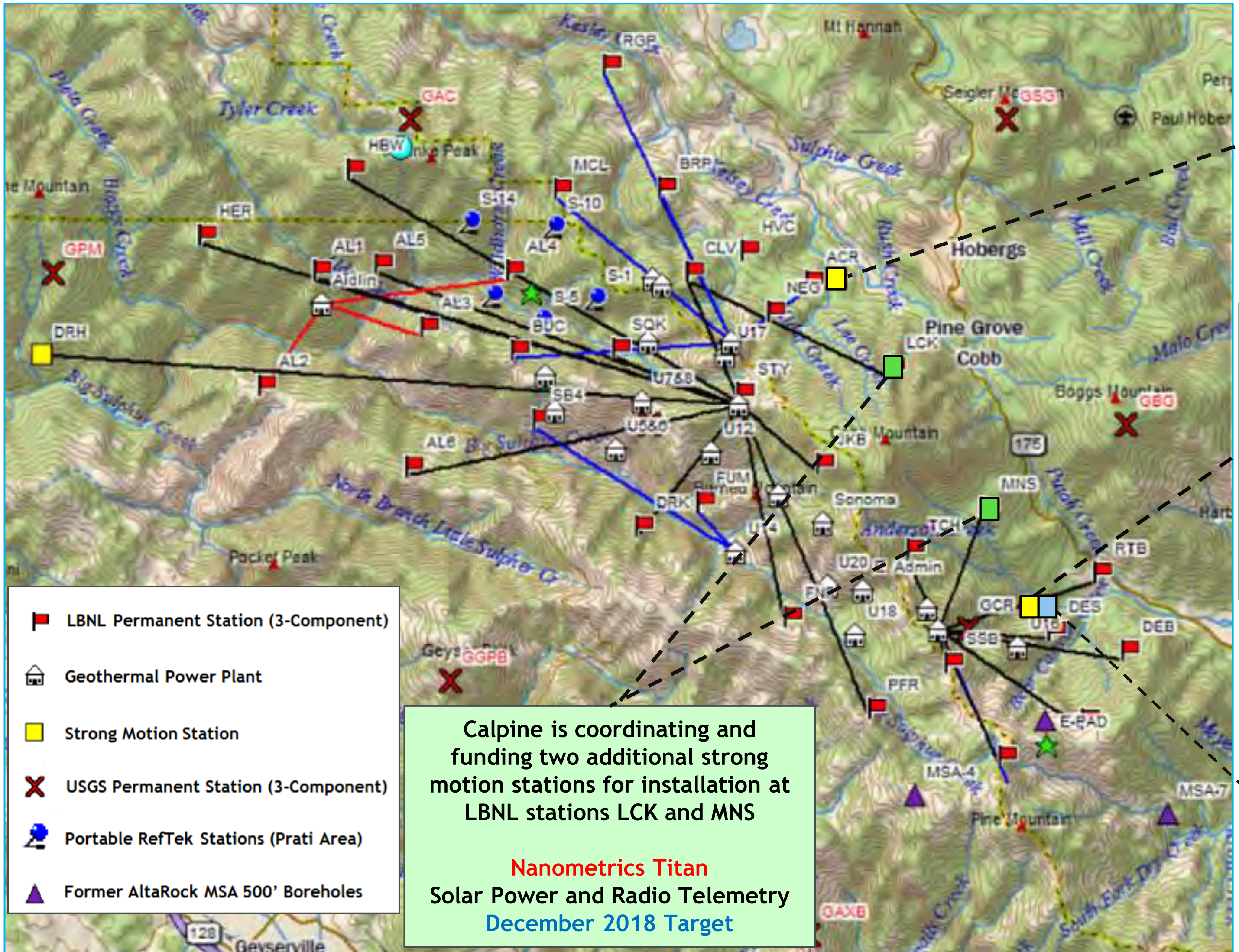
Modified Mercalli Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X

Seismic Monitoring Advisory Committee Meeting

Status of Seismic Monitoring Networks

Integration of Nanometrics Titan Accelerometers into LBNL Network



Calpine is coordinating and funding two additional strong motion stations for installation at LBNL stations LCK and MNS

Nanometrics Titan
Solar Power and Radio Telemetry
December 2018 Target

Cobb
ASM
Strong Motion
At LBNL ACR Site
~2050' WSW of Hess COB Site

LBNL

Nanometrics Titan
Solar Power and Radio Telemetry
May 2018

Anderson Springs
ESM
Strong Motion
Engels Property

LBNL

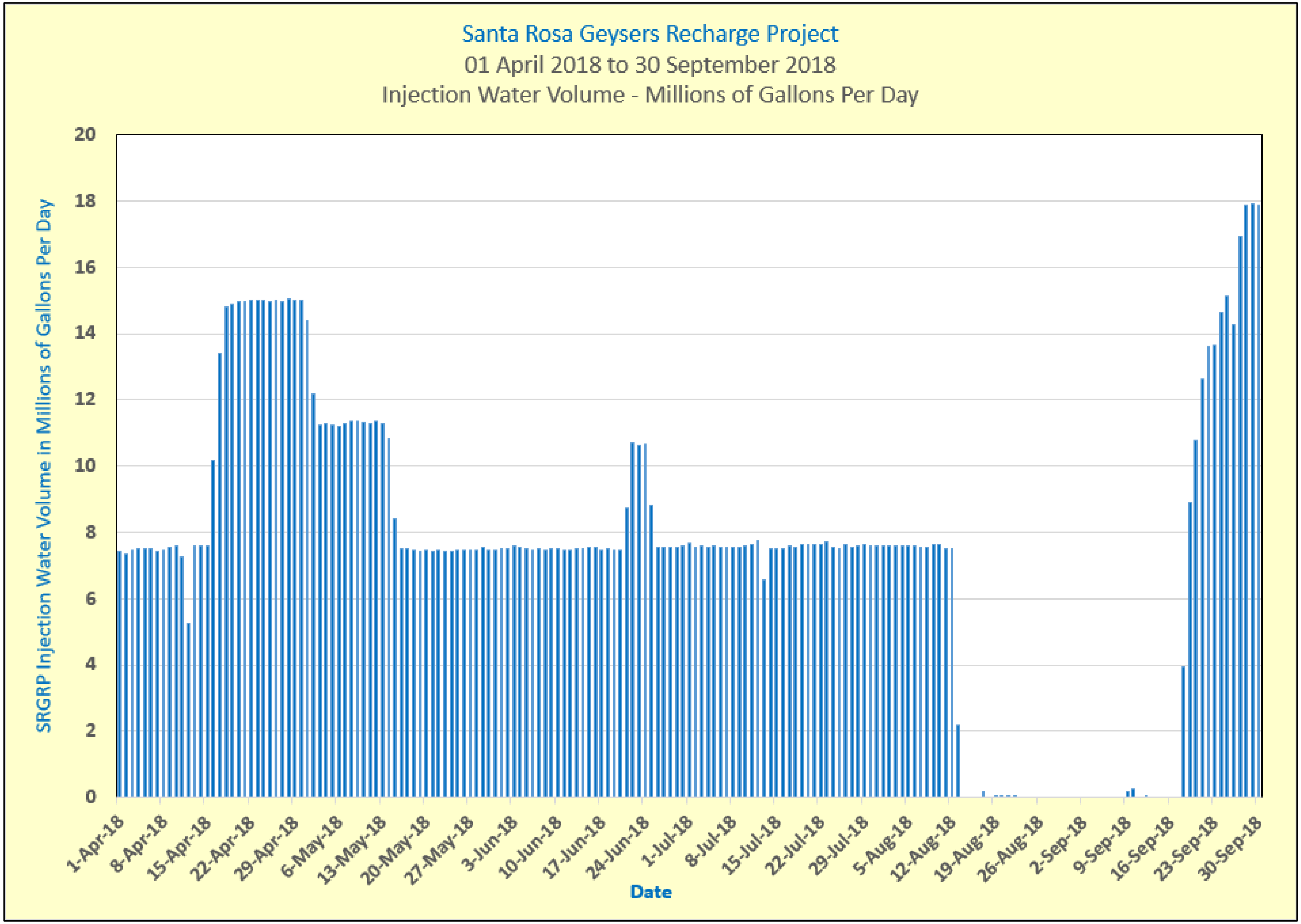
Nanometrics Titan
Solar Power and Radio Telemetry
September 2017

Anderson Springs
ADS2
Strong Motion
Community Center

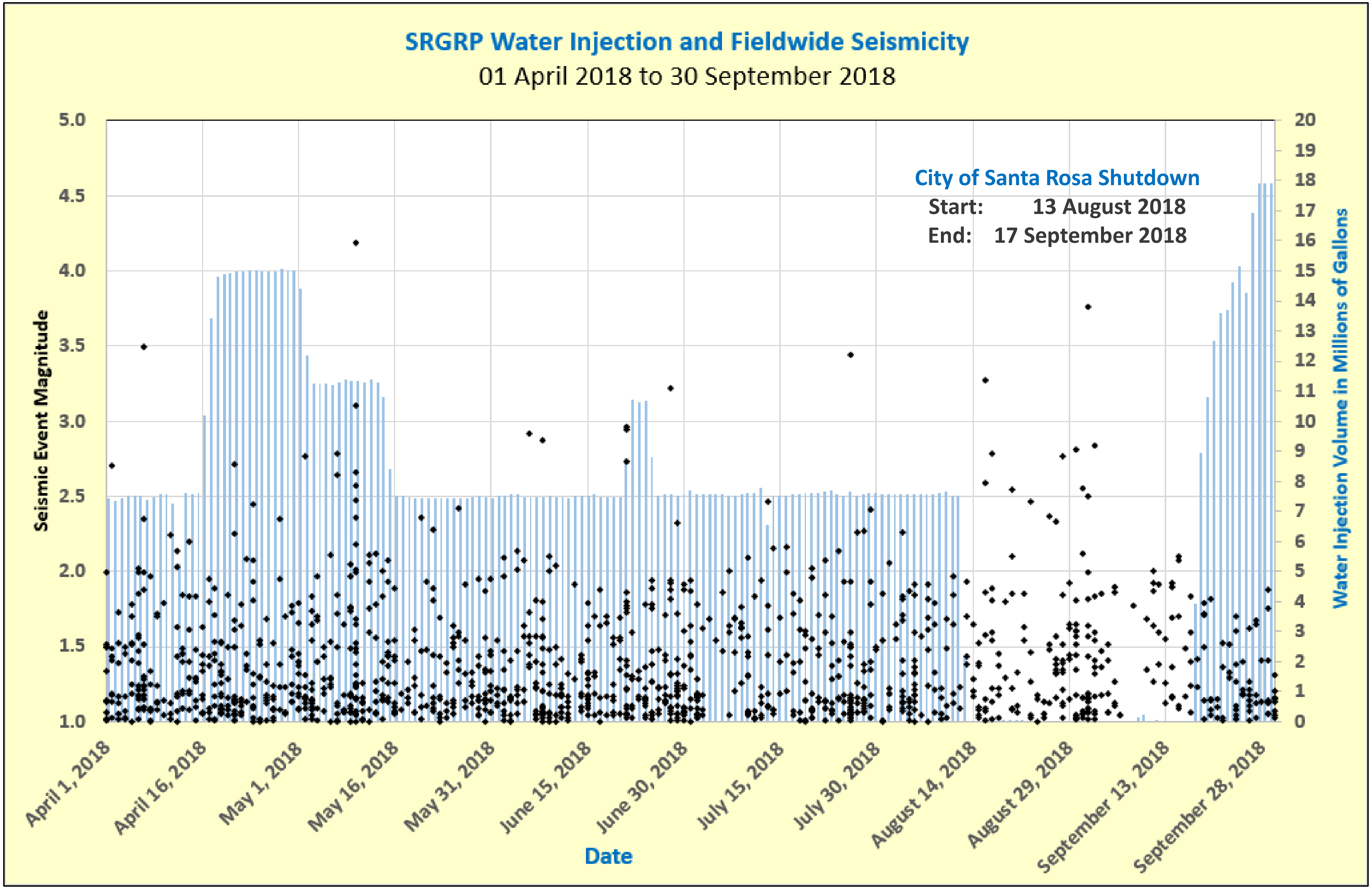
USGS

ETNA
Rural AC Power
Rural Communication
(phone line)
January 2016

Seismic Monitoring Advisory Committee Meeting
Santa Rosa Geysers Recharge Project
Water Injection Volume in Millions of Gallons Per Day



Seismic Monitoring Advisory Committee Meeting
Santa Rosa Geysers Recharge Project
Water Injection Volume and Fieldwide Seismicity



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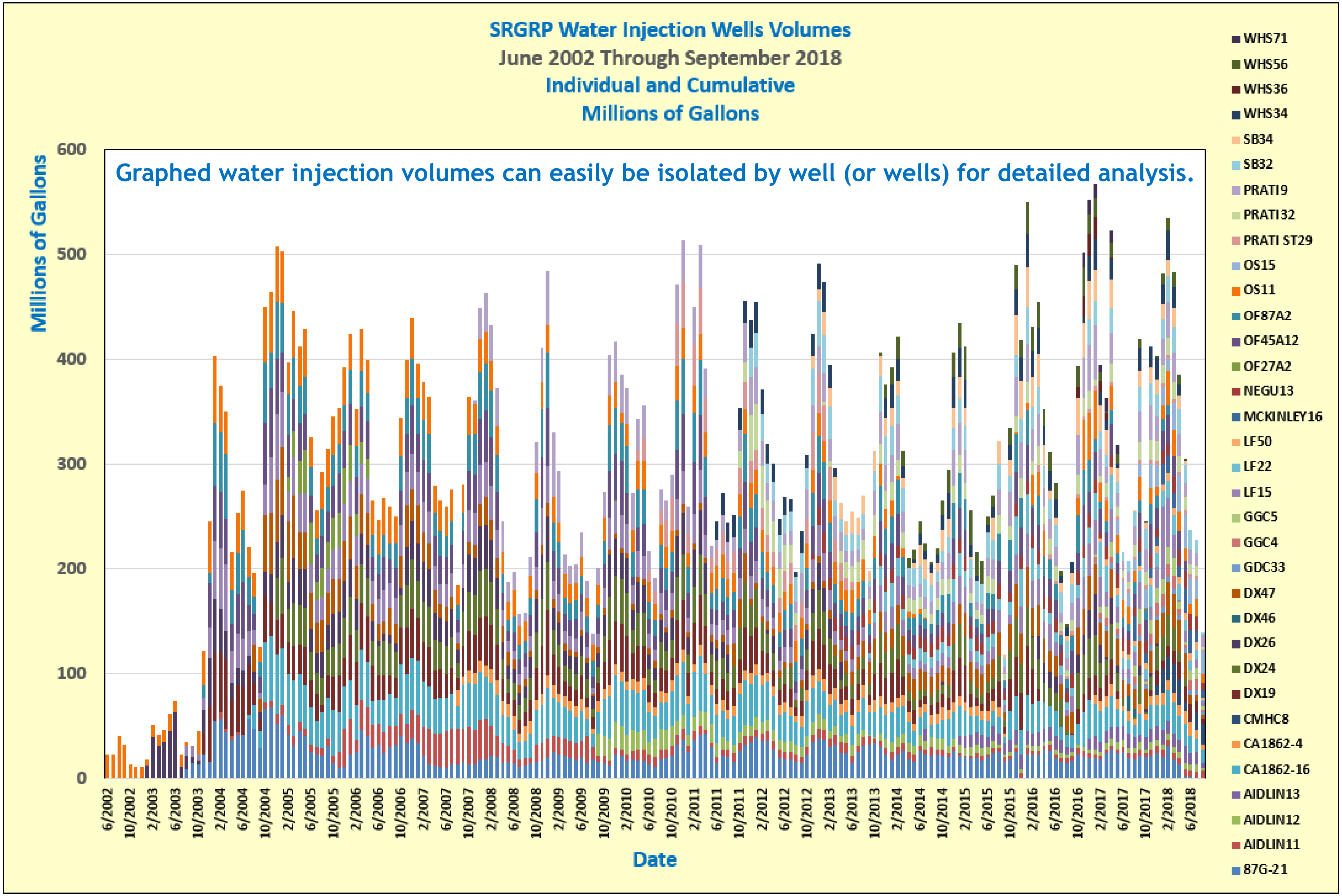
Santa Rosa Geysers Recharge Project Injection By Well
June 2002 Through September 2018



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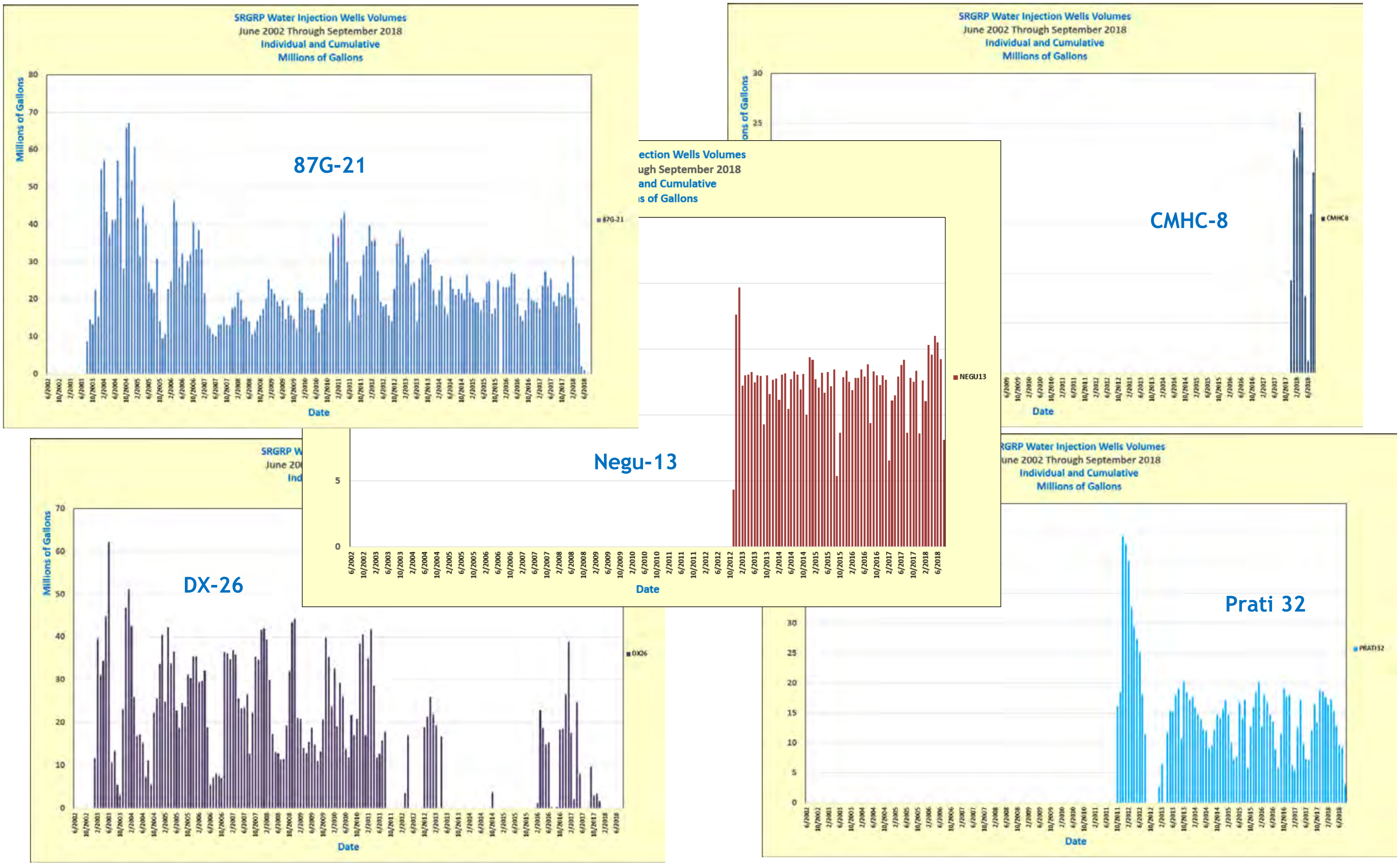
Santa Rosa Geysers Recharge Project Injection By Well Prati 32
June 2002 Through September 2018

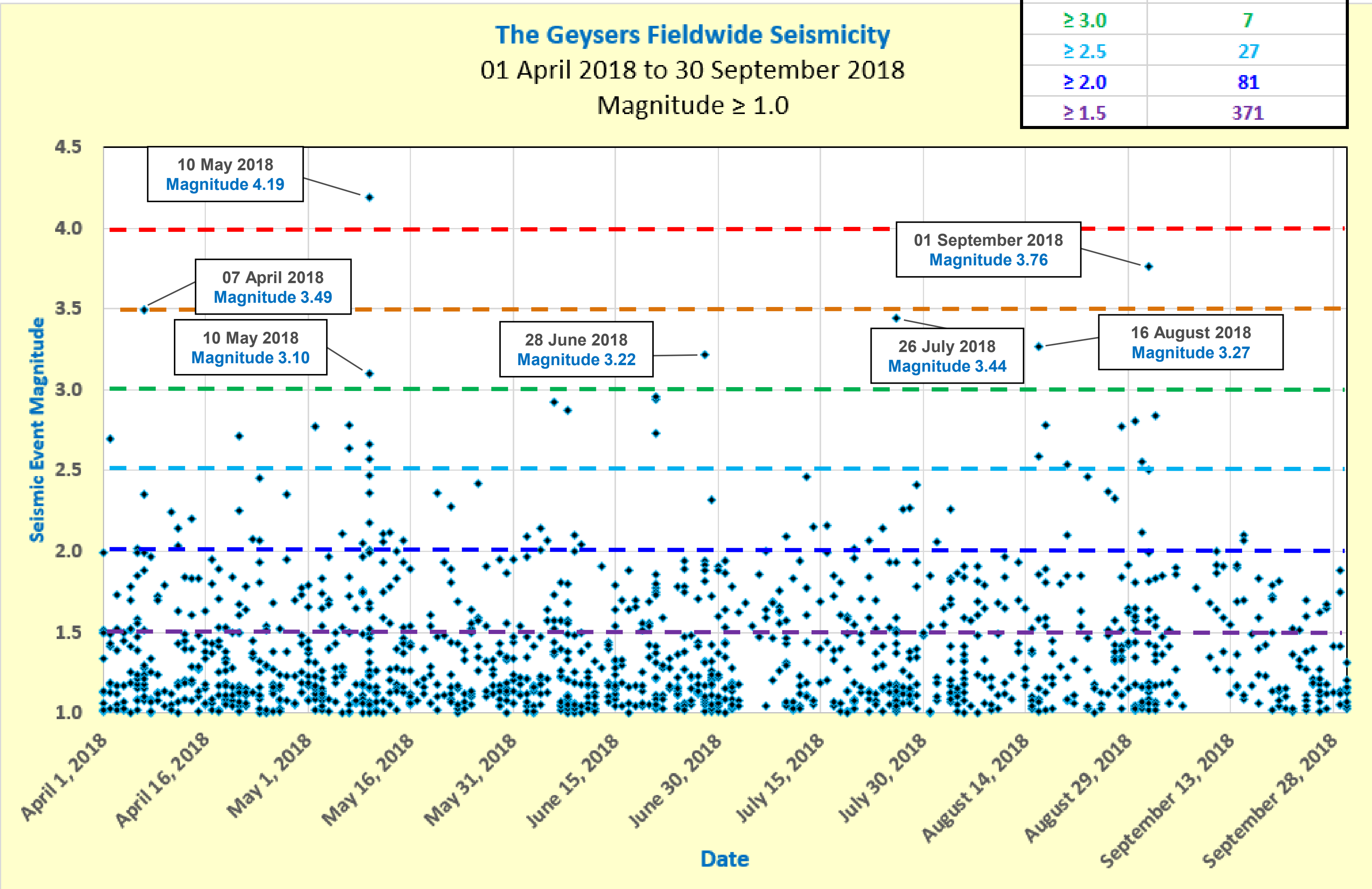


Seismic Monitoring Advisory Committee Meeting

Field-wide Seismicity Analysis

01 April 2018 to 30 September 2018

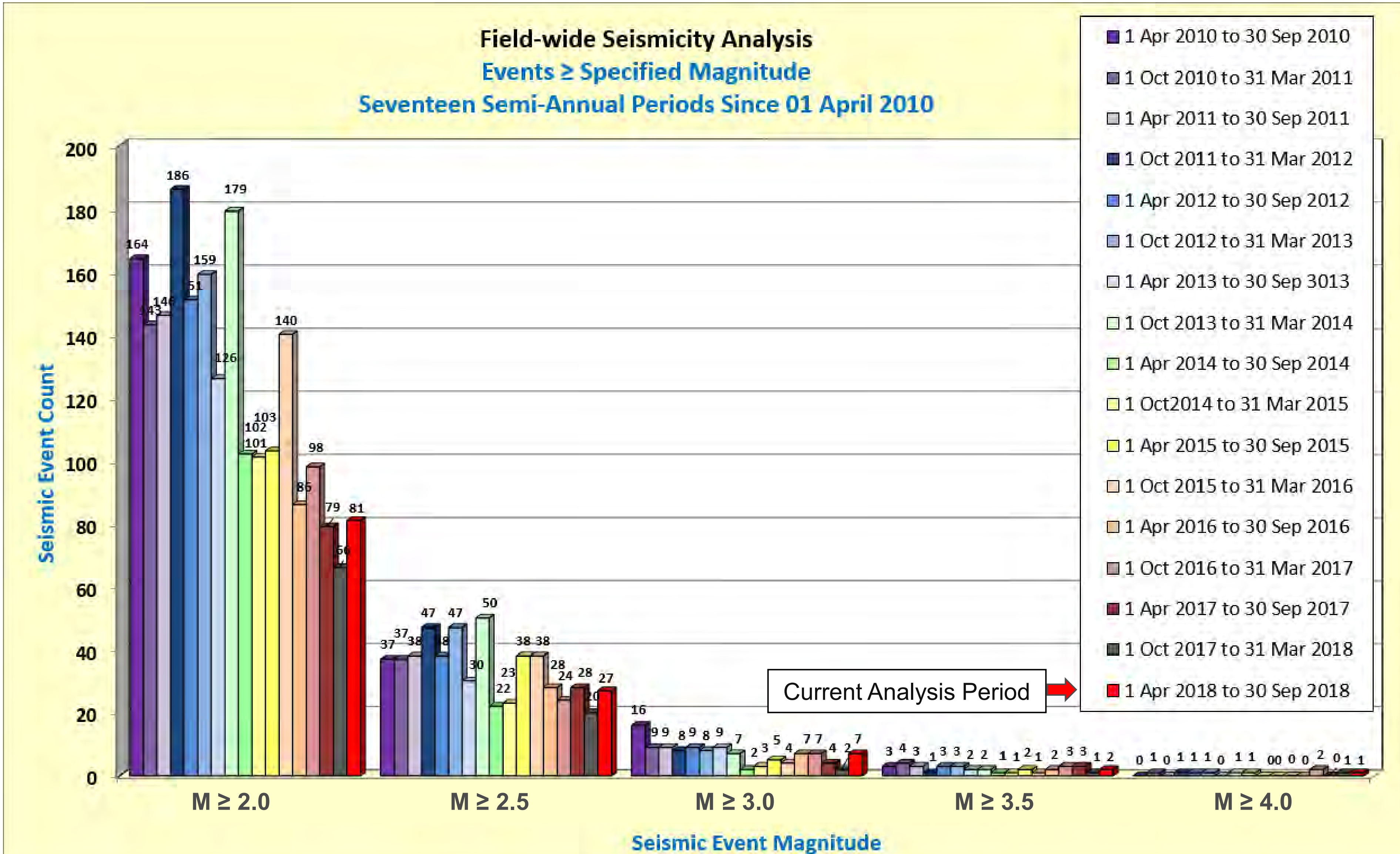
Magnitude	Number of Events
≥ 4.0	1
≥ 3.5	2
≥ 3.0	7
≥ 2.5	27
≥ 2.0	81
≥ 1.5	371



Seismic Monitoring Advisory Committee Meeting

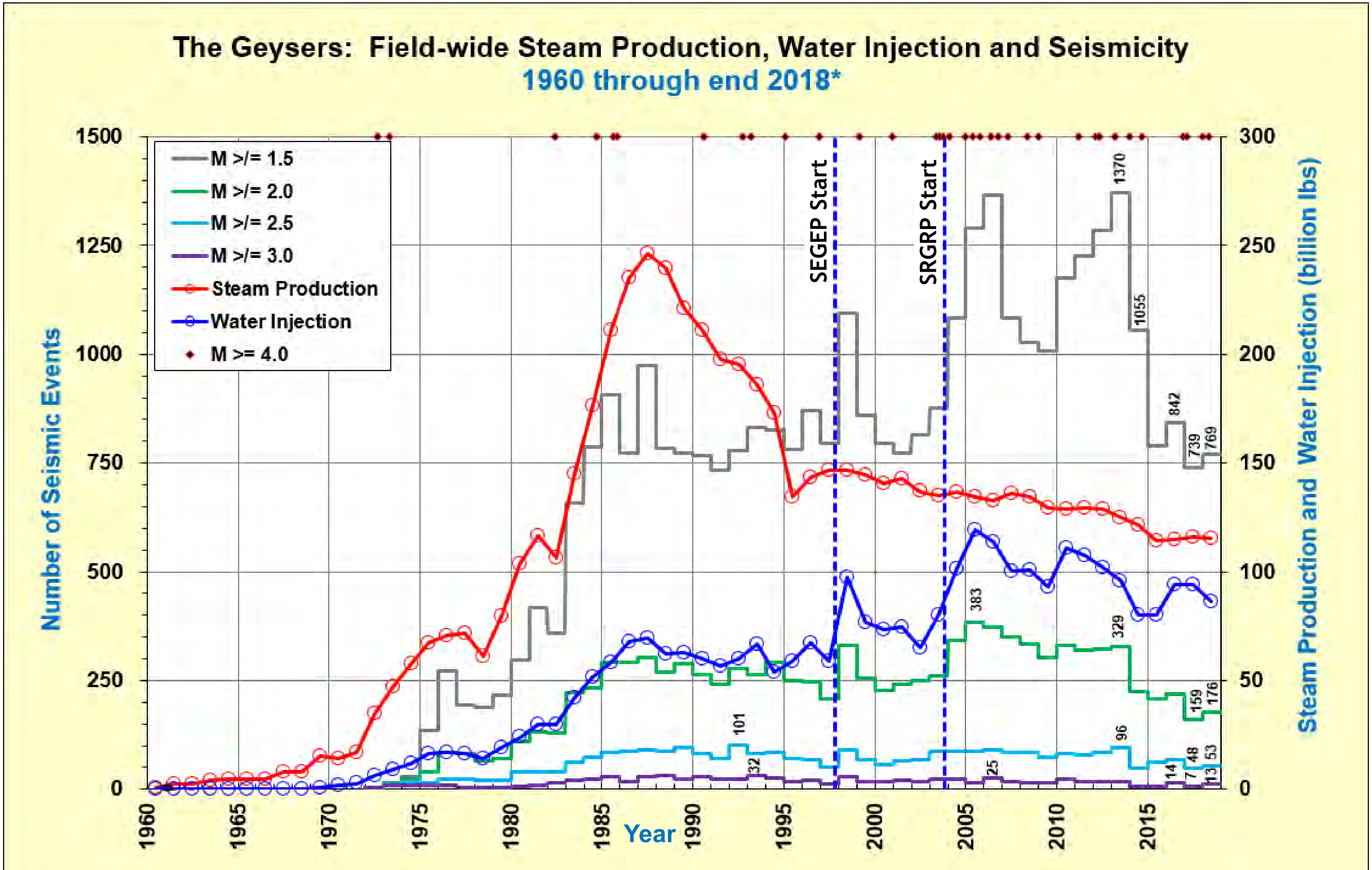
Field-wide Seismicity Analysis

Comparison of Sixteen Semi-annual Reporting Periods



Seismic Monitoring Advisory Committee Meeting

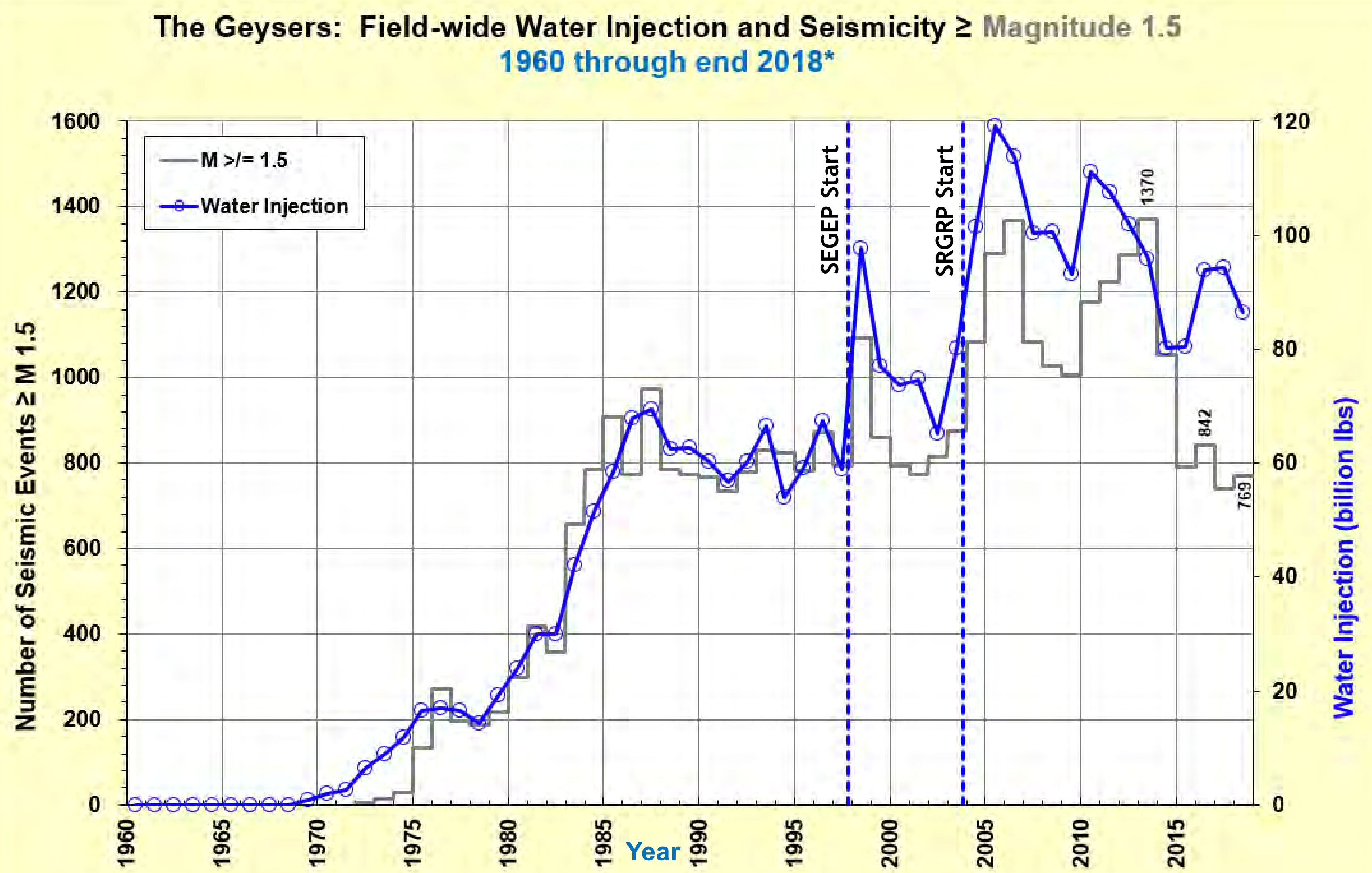
Yearly Field-wide Steam Production, Water Injection and Seismicity



* Yearly steam production and water injection volumes *projected* from 01 October 2018; seismic event counts *projected* from 15 October 2018

Seismic Monitoring Advisory Committee Meeting

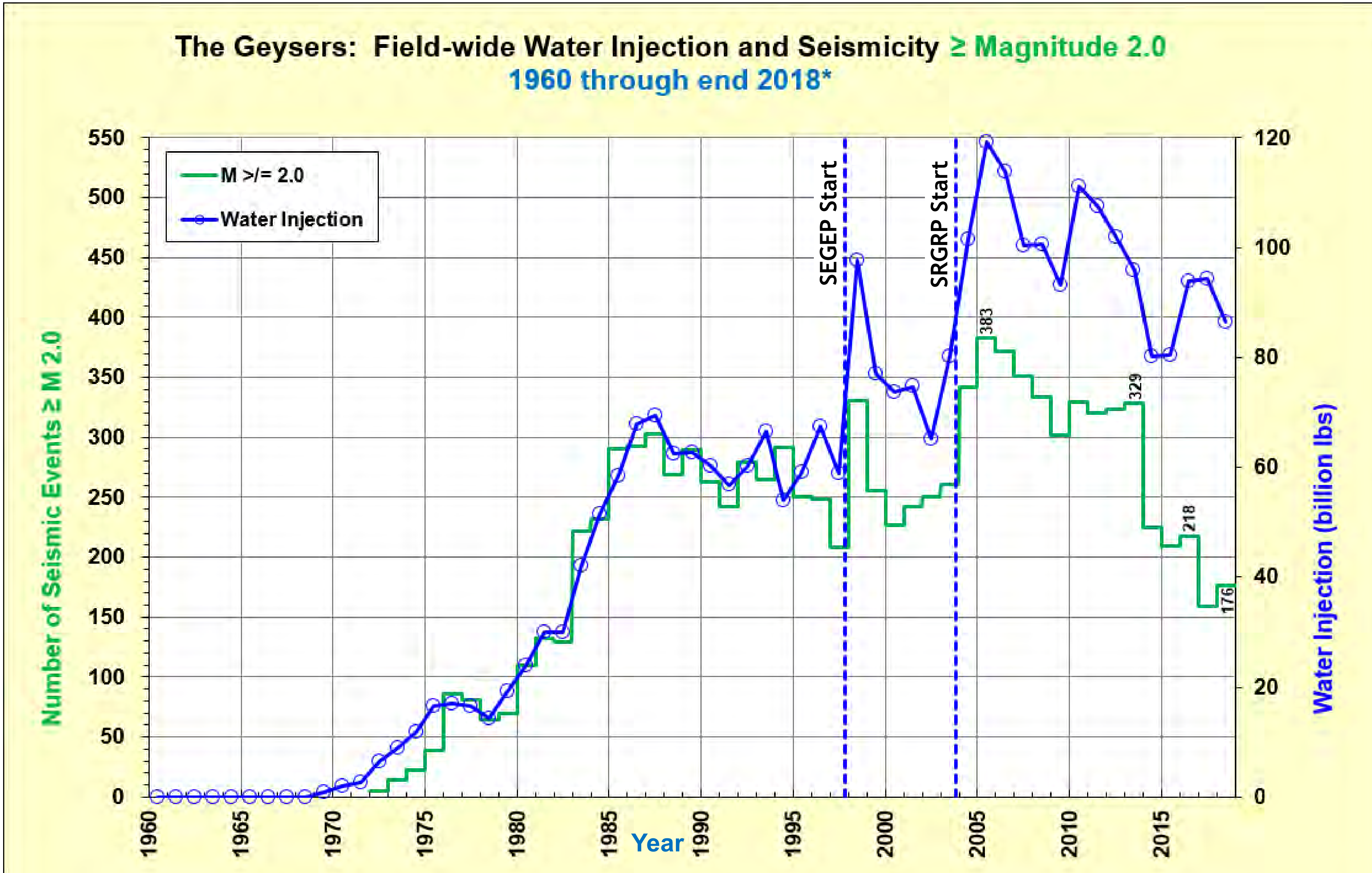
Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 1.5



* Yearly steam production and water injection volumes *projected* from 01 October 2018; seismic event counts *projected* from 15 October 2018

Seismic Monitoring Advisory Committee Meeting

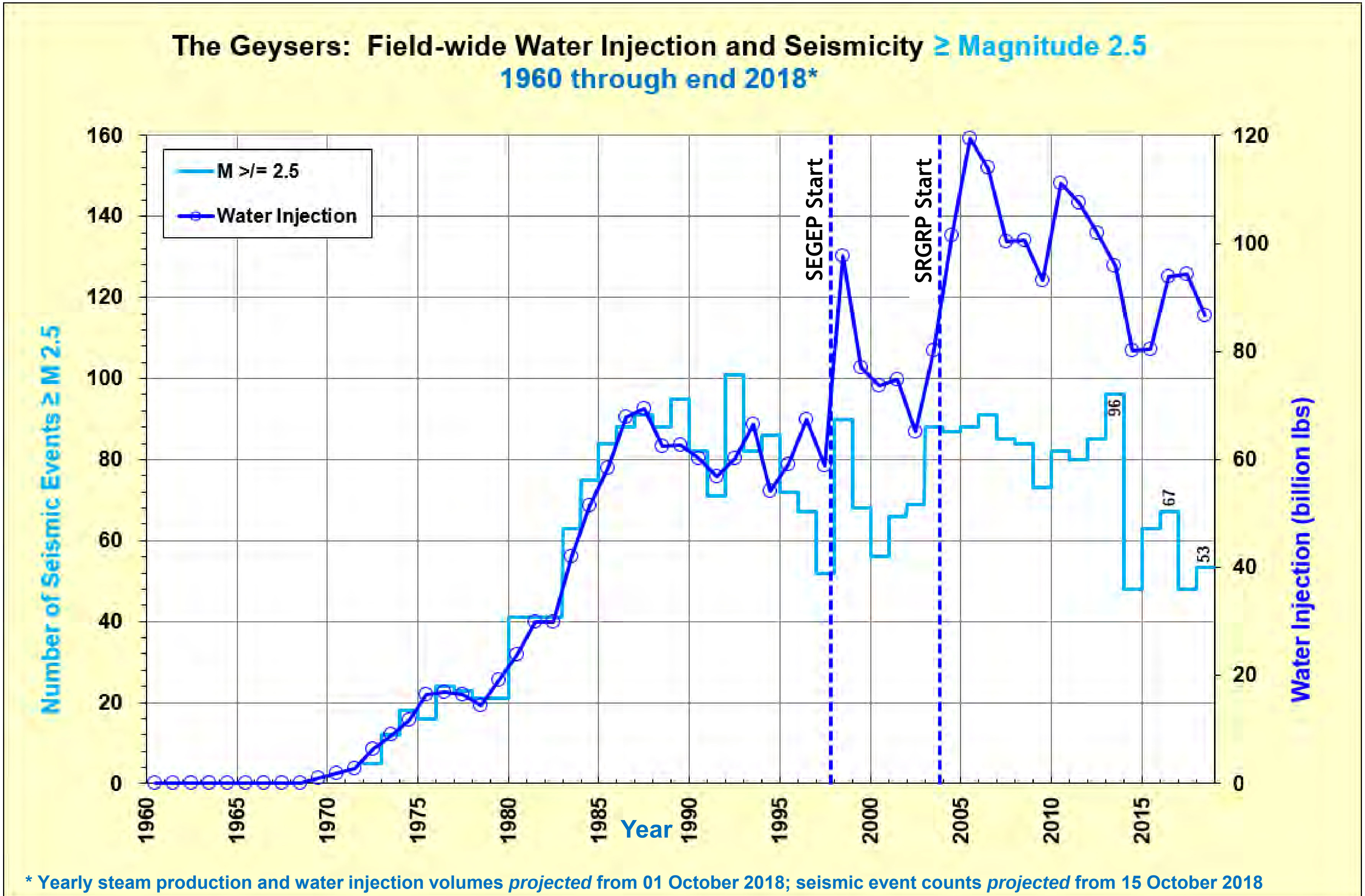
Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 2.0



* Yearly steam production and water injection volumes *projected* from 01 October 2018; seismic event counts *projected* from 15 October 2018

Seismic Monitoring Advisory Committee Meeting

Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 2.5



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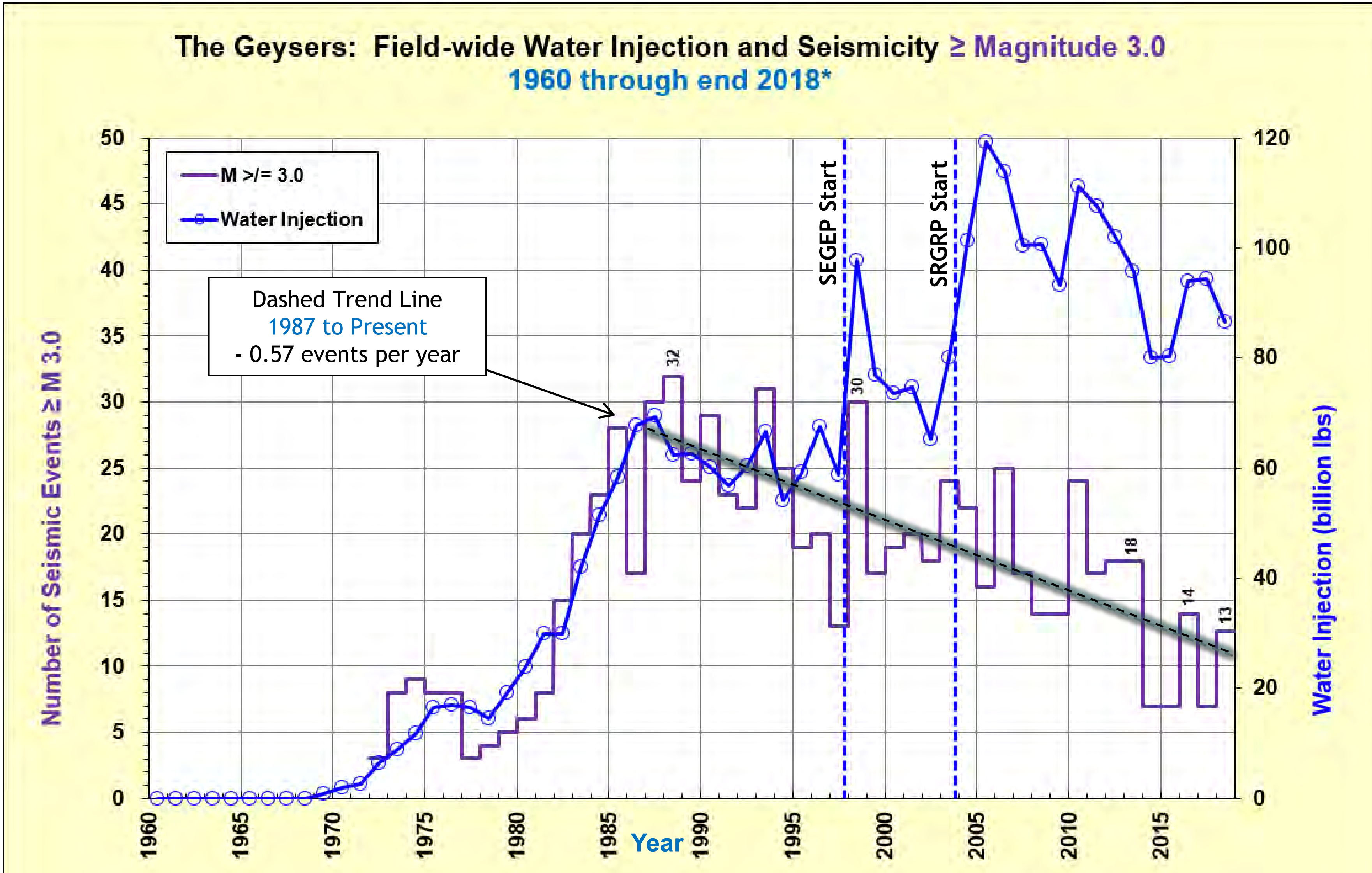
Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 3.0



* Yearly steam production and water injection volumes *projected* from 01 October 2018; seismic event counts *projected* from 15 October 2018

Seismic Monitoring Advisory Committee Meeting

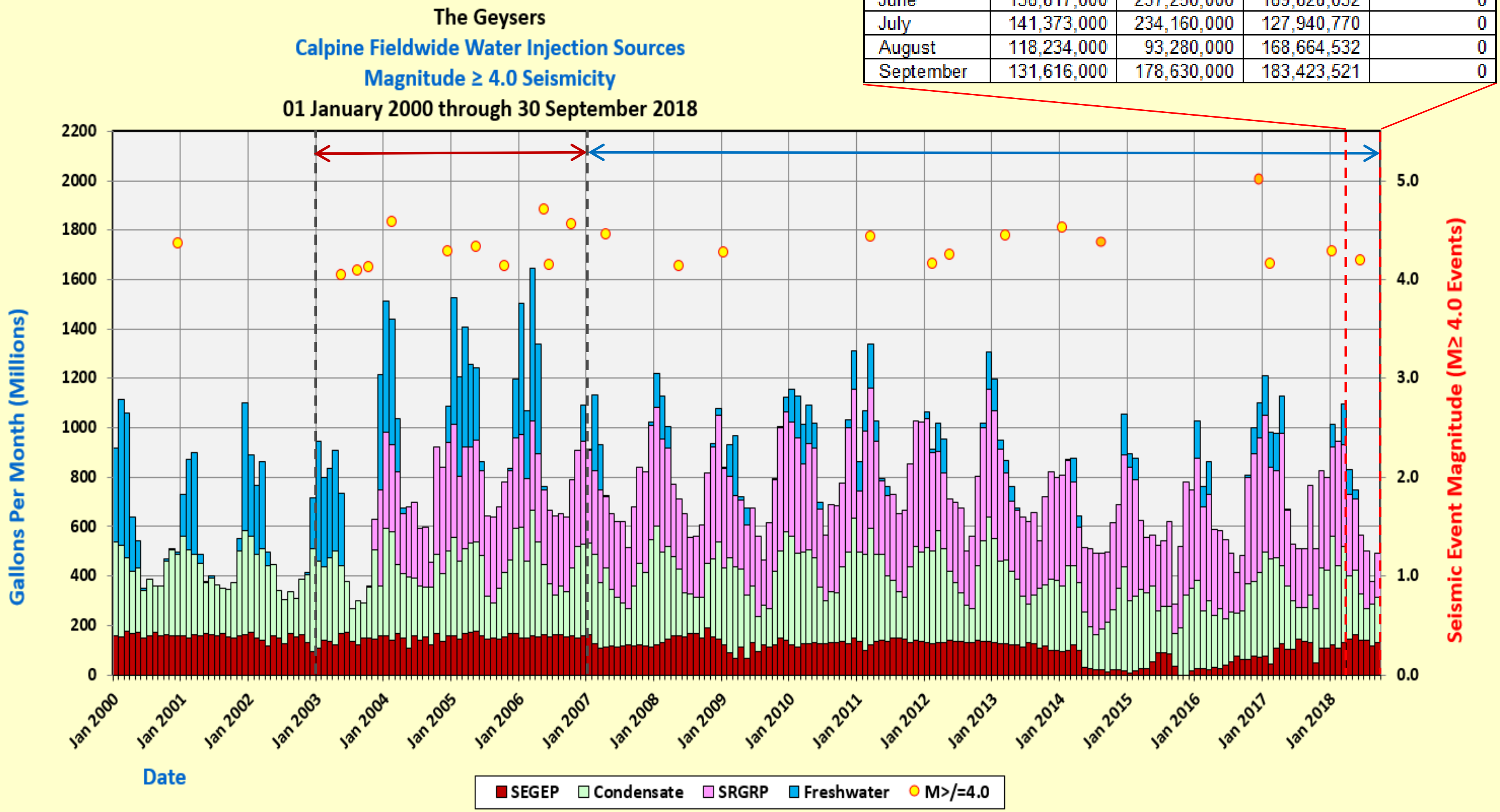
Monthly Field-wide Water Injection By Source vs. Magnitude ≥ 4.0 Seismicity

Average Number of Magnitude ≥ 4.0 Events Per Year Significantly Less Than 2003-2006 Peak

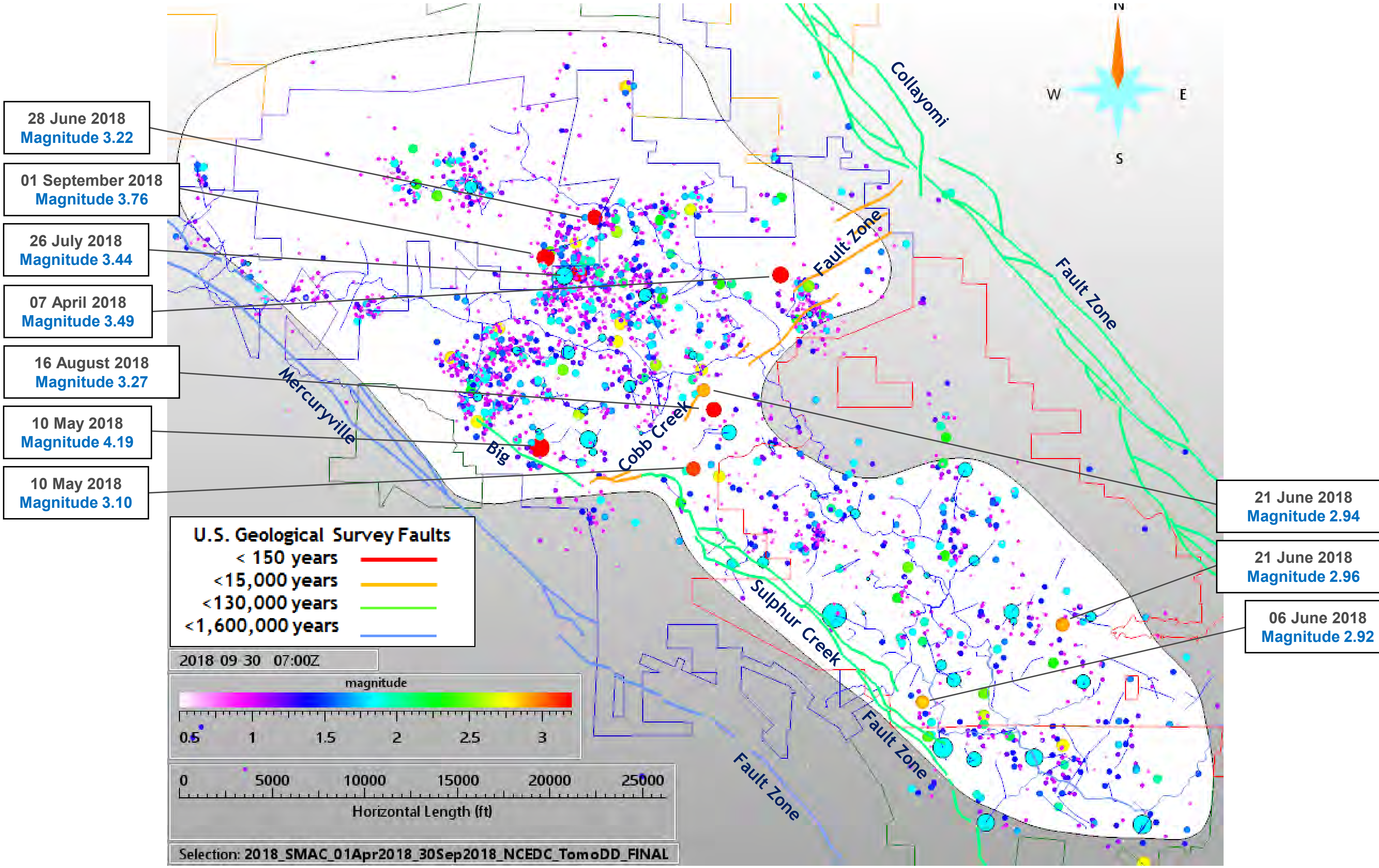
Time Period	Magnitude ≥ 4.0 Seismic Events
January 2003 through December 2006	2.5 per year
January 2007 through September 2018	1.1 per year

Water Supply for Reporting Period (Six Months)

Water Injection Sources (Gallons)				
Month	SEGEP	SRGRP	Condensate	Fresh Water
April	142,669,000	328,360,000	258,555,899	100,878,250
May	164,386,000	289,440,000	259,886,566	36,698,091
June	138,817,000	237,250,000	189,828,032	0
July	141,373,000	234,160,000	127,940,770	0
August	118,234,000	93,280,000	168,664,532	0
September	131,616,000	178,630,000	183,423,521	0



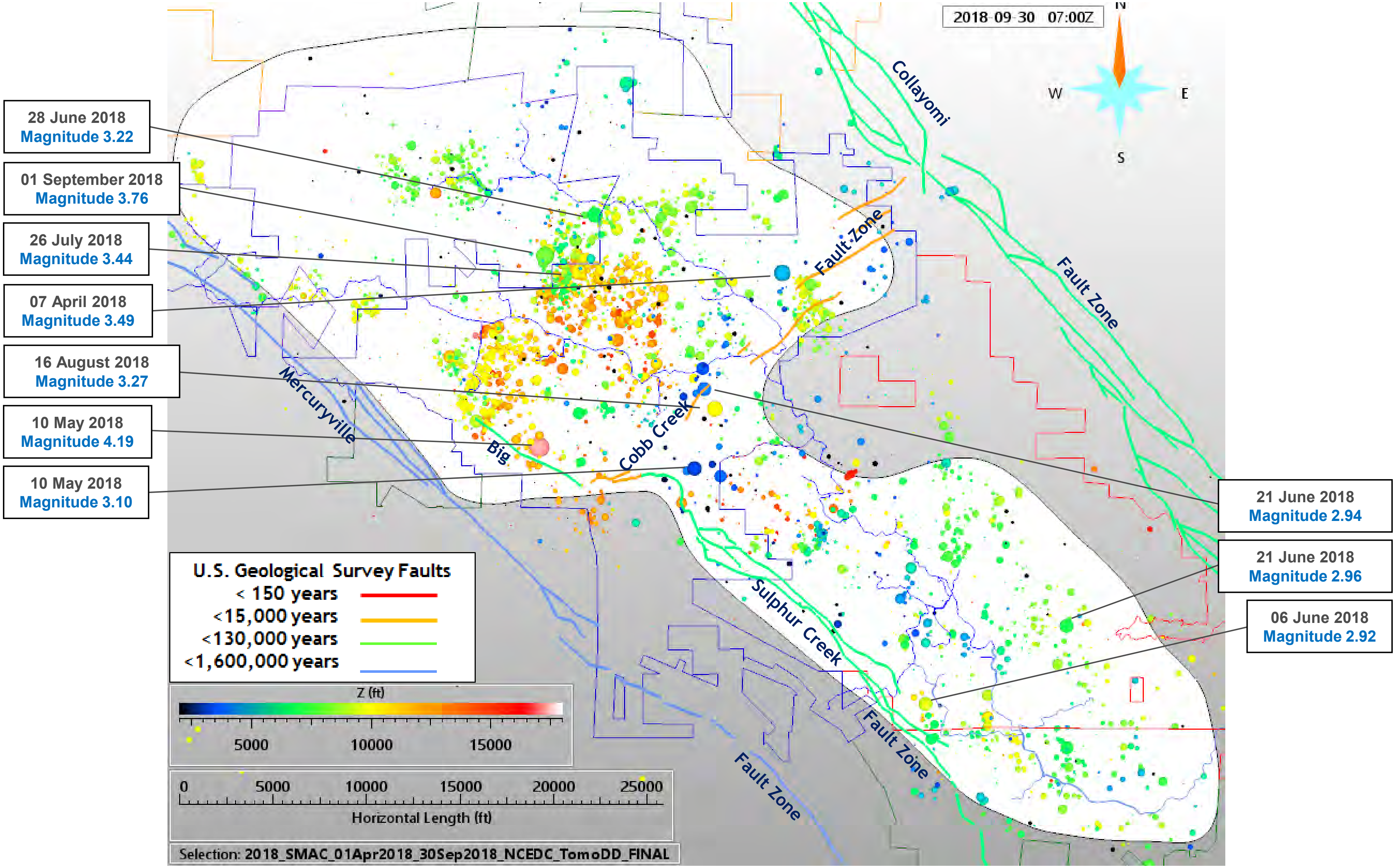
Seismic Monitoring Advisory Committee Meeting
Fieldwide Water Injection and Induced Seismicity Animation
01 October 2017 to 31 March 2018 at Two Week Interval



Seismic Monitoring Advisory Committee Meeting

Fieldwide Water Injection and Induced Seismicity Animation

01 October 2017 to 31 March 2018 at Two Week Interval



Seismic Monitoring Advisory Committee Meeting

Calpine Community Hotline

The communities continue to focus on efforts to recover from the Valley Fire, resulting in only three calls to the Calpine Community Hotline during the current reporting period of 01 April 2018 to 30 September2018. The seismic event responsible for both calls:

Magnitude 2.92 Seismic Event

Date and Time: 21 June 2018 at 07:03:12 Pacific Time
21 June 2018 at 14:03:12 UTC
Latitude: North 38.77517
Longitude: West 122.71367
Depth: 4100 Feet (1.25 km) Below Sea Level

Anderson Springs Calls(2)

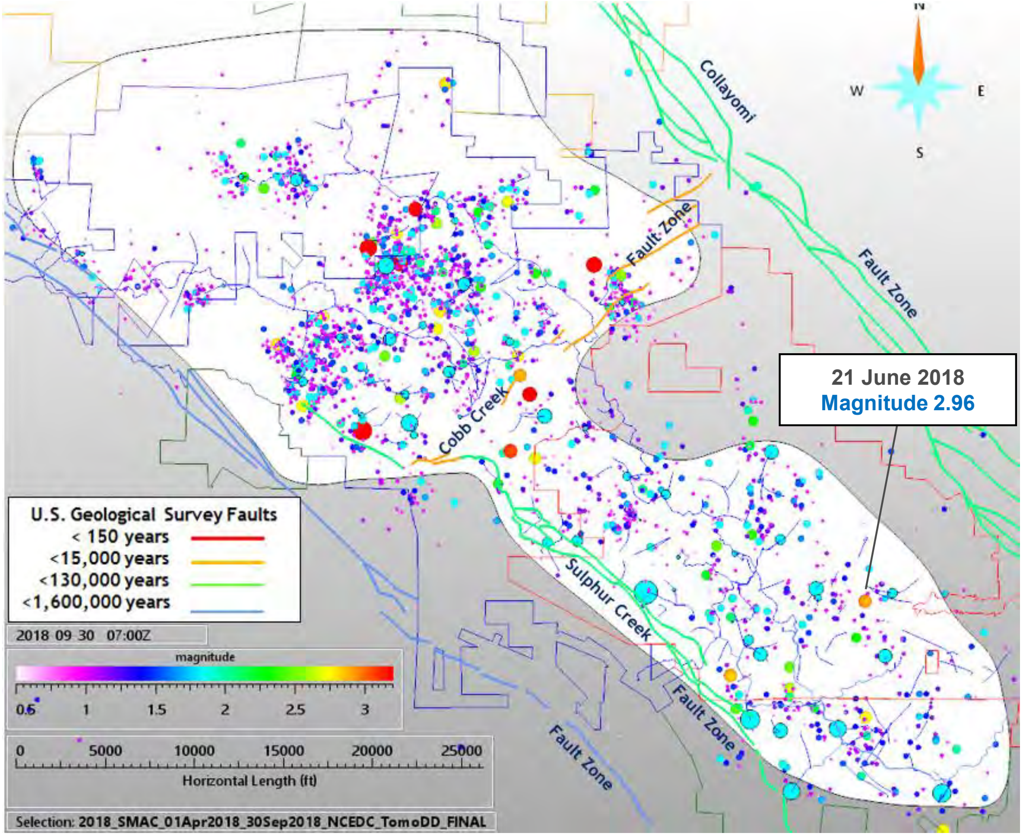
21 June 2018 at 09:06 am and 11:21 am

Limited duration but the strongest event ever felt.
Very loud, and knocked things off the shelves.
Please investigate this very strong event.
Several small aftershocks.

Middletown Call (1)

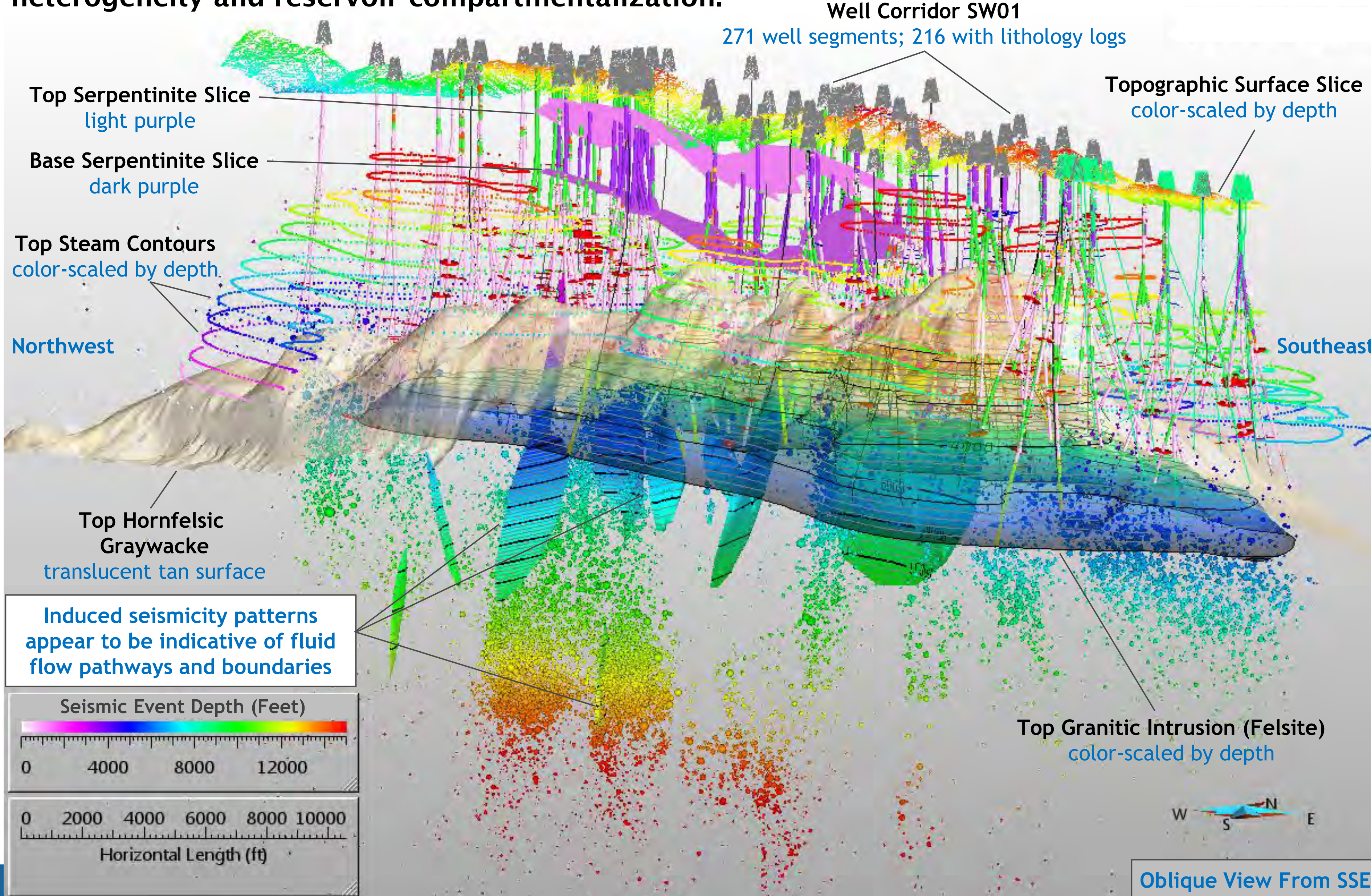
21 June 2018 at 11:13 am

Heard rumbling before seismic event.
Lasted about 1-2 seconds.
Not a jolt - a rolling motion.



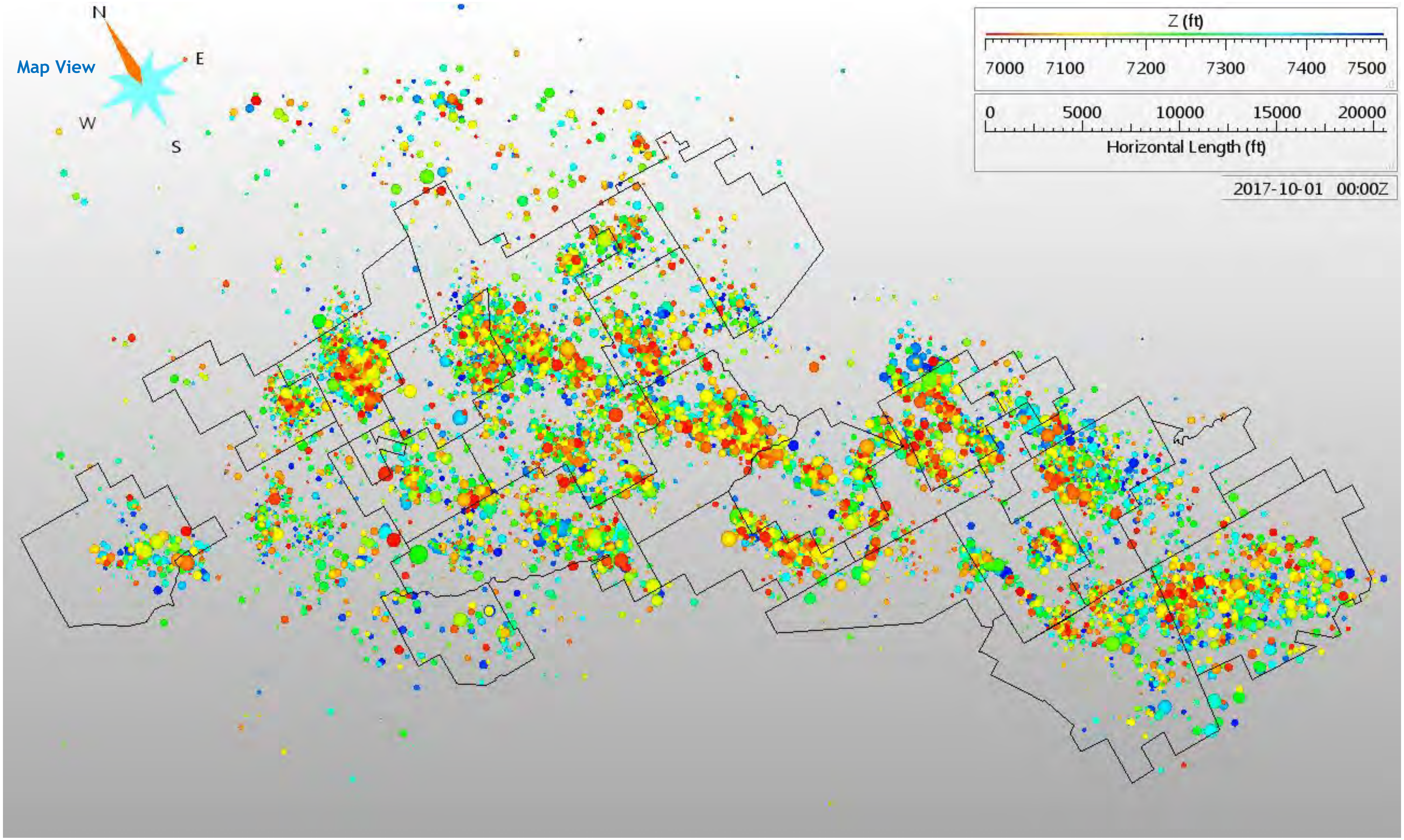
Seismic Monitoring Advisory Committee Meeting

3D Structural Model Building Goal: Improved reservoir management and induced seismicity mitigation through a refined understanding of fluid flow paths, fluid boundaries, reservoir heterogeneity and reservoir compartmentalization.



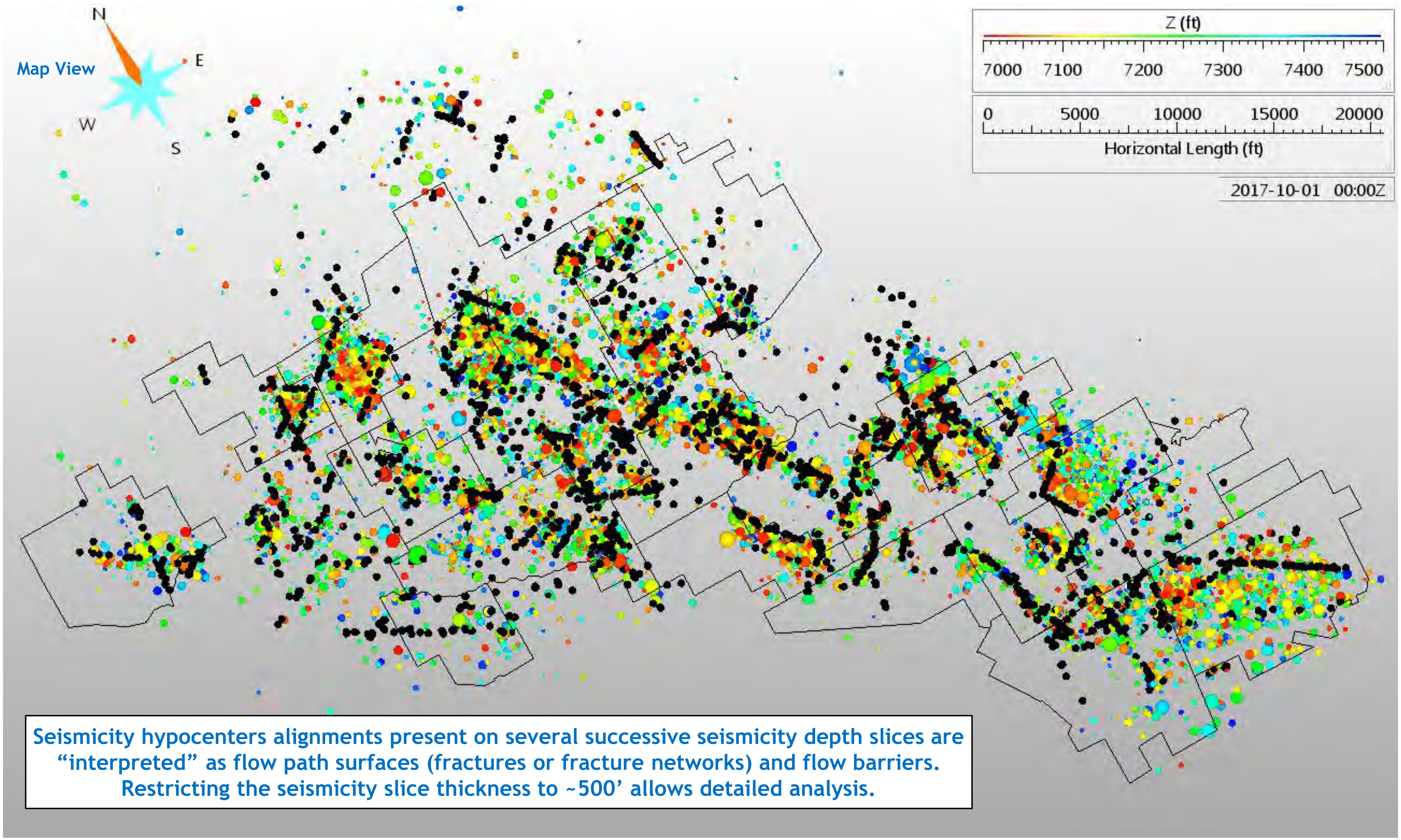
Seismic Monitoring Advisory Committee Meeting

Fault/Fracture Analysis and Interpretation
Depth Slice 7000 to 7500 Feet Subsea



Seismic Monitoring Advisory Committee Meeting

Fault/Fracture Analysis and Interpretation
Depth Slice 7000 to 7500 Feet Subsea

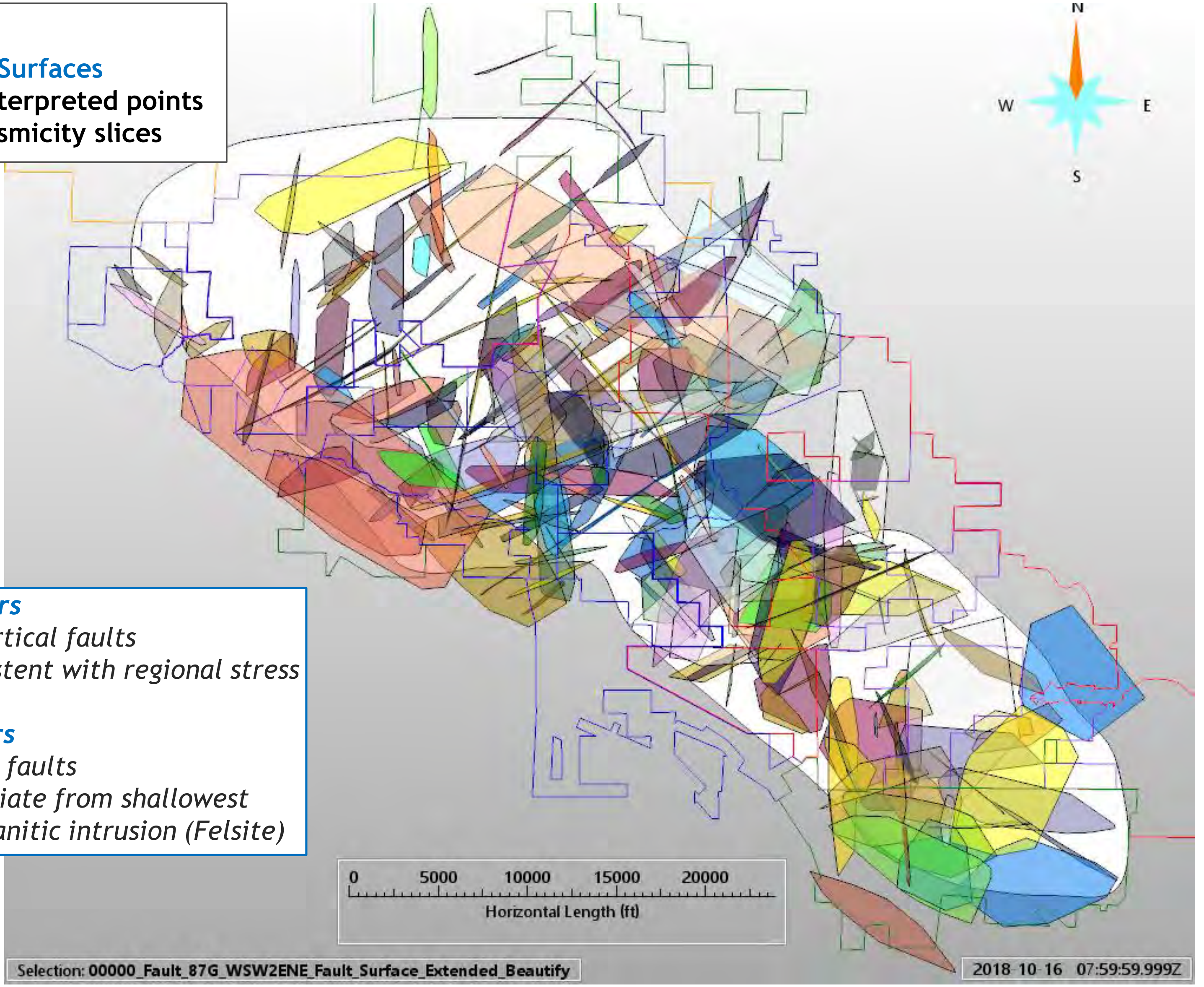


Seismicity hypocenters alignments present on several successive seismicity depth slices are "interpreted" as flow path surfaces (fractures or fracture networks) and flow barriers. Restricting the seismicity slice thickness to ~500' allows detailed analysis.

Seismic Monitoring Advisory Committee Meeting

3D Structural Model
Fault/Fracture Interpretation With Seismicity Slices

As of November 2018:
- 246 Refined Fault/Fracture Surfaces
- From 28,420 individually interpreted points
- Using variously-oriented seismicity slices



Northwest Geysers
Primarily near vertical faults
Orientation consistent with regional stress

Southeast Geysers
More non-vertical faults
Several faults radiate from shallowest penetration of granitic intrusion (Felsite)

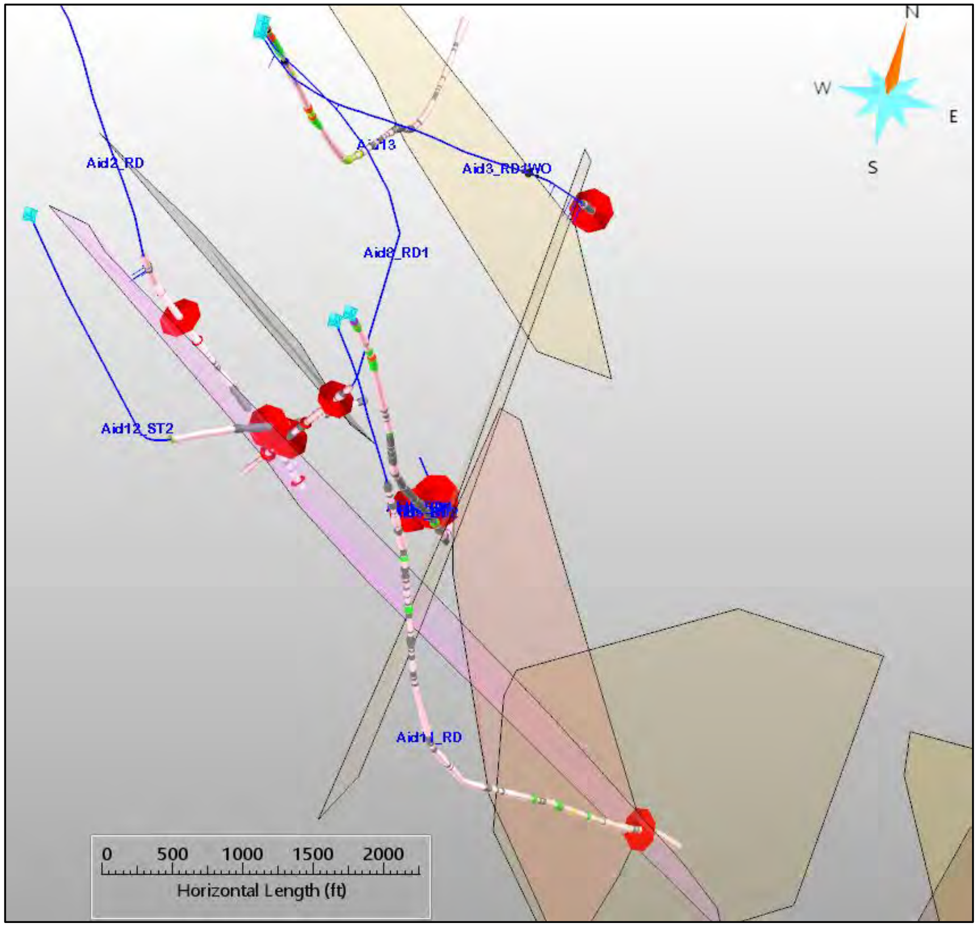
Seismic Monitoring Advisory Committee Meeting

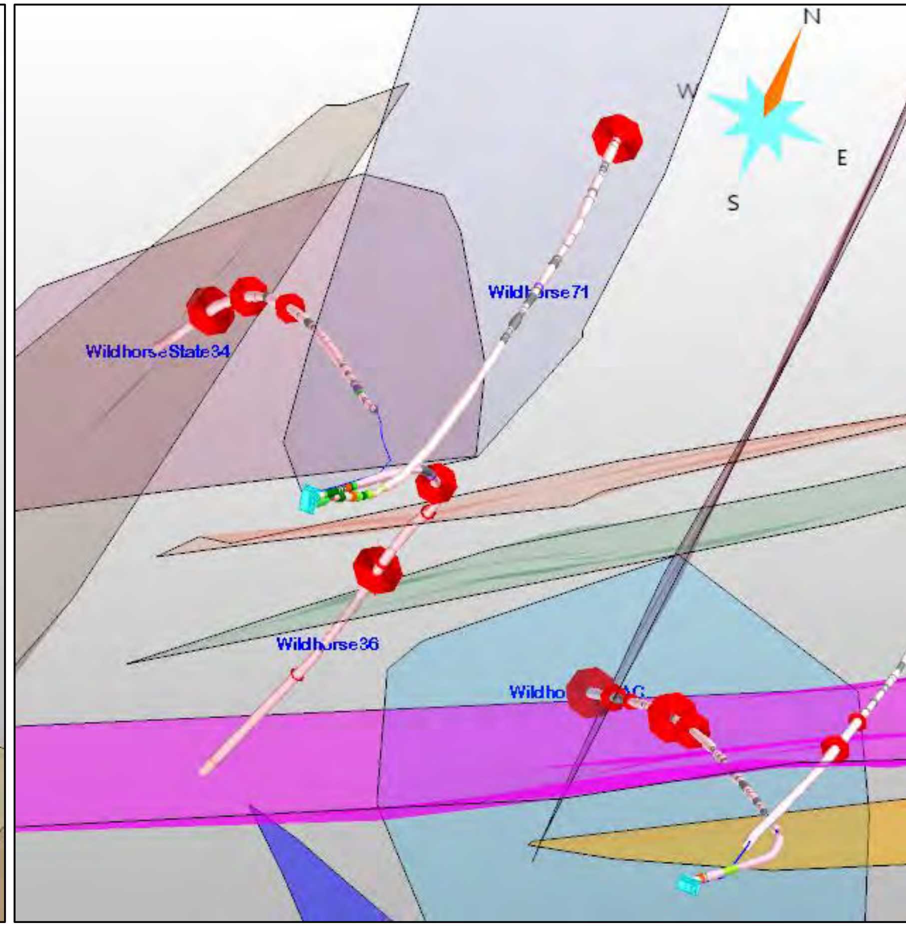
Aidlin and Wildhorse Area 3D Fault Interpretation
Water injection Well Steam Entries vs. Interpreted Fracture Surfaces (Unbiased)

Aidlin Area (left) and Wildhorse Area (right)

The majority of significant steam entries for the injection wells shown occur at *approximately* the intersection with the interpreted fracture surfaces.
Fluid flow from water injection wells appear to be illuminating fault/fracture systems.

Many fault/fracture surface associated with steam production wells are not illuminated by seismicity.





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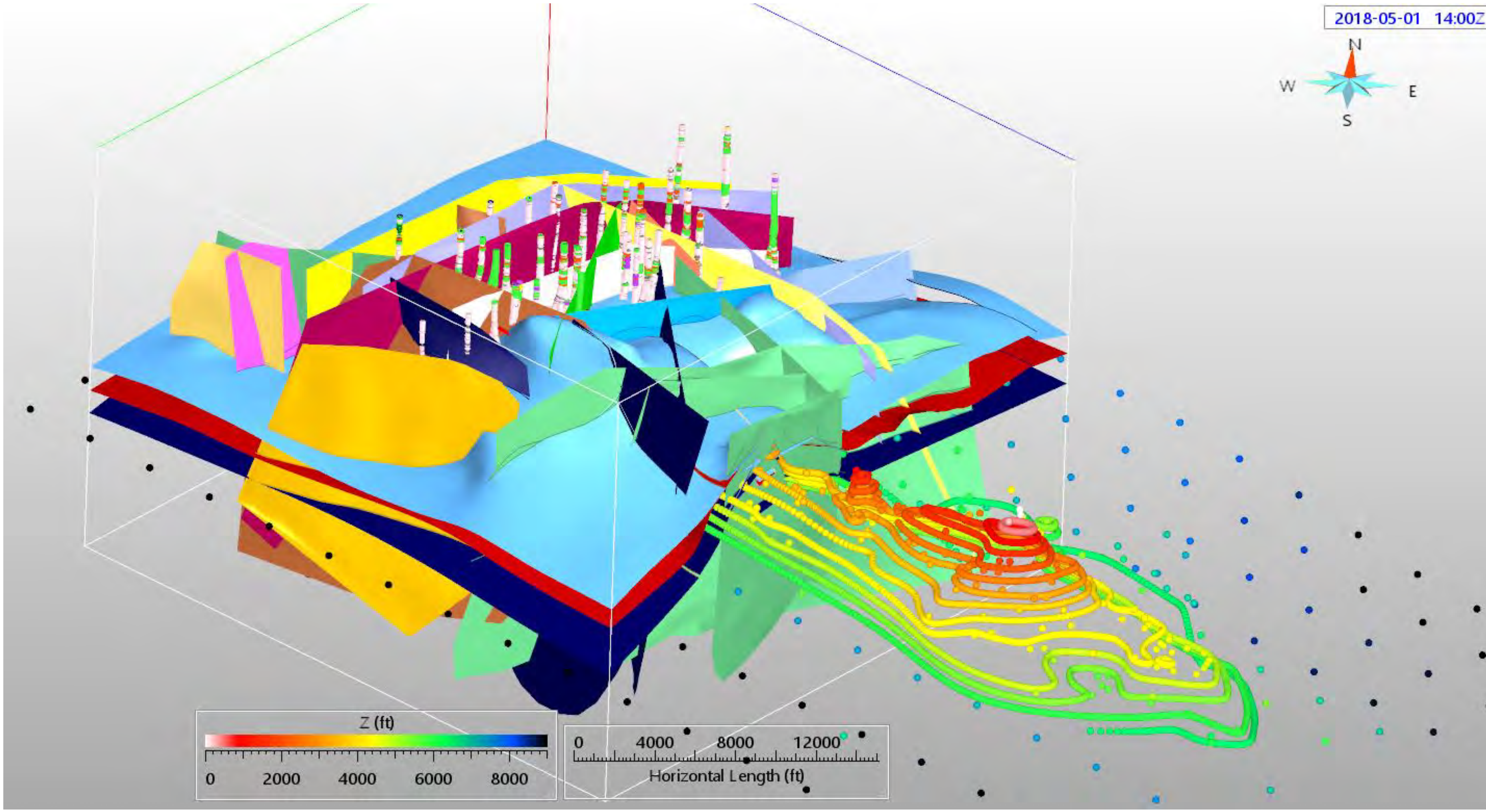
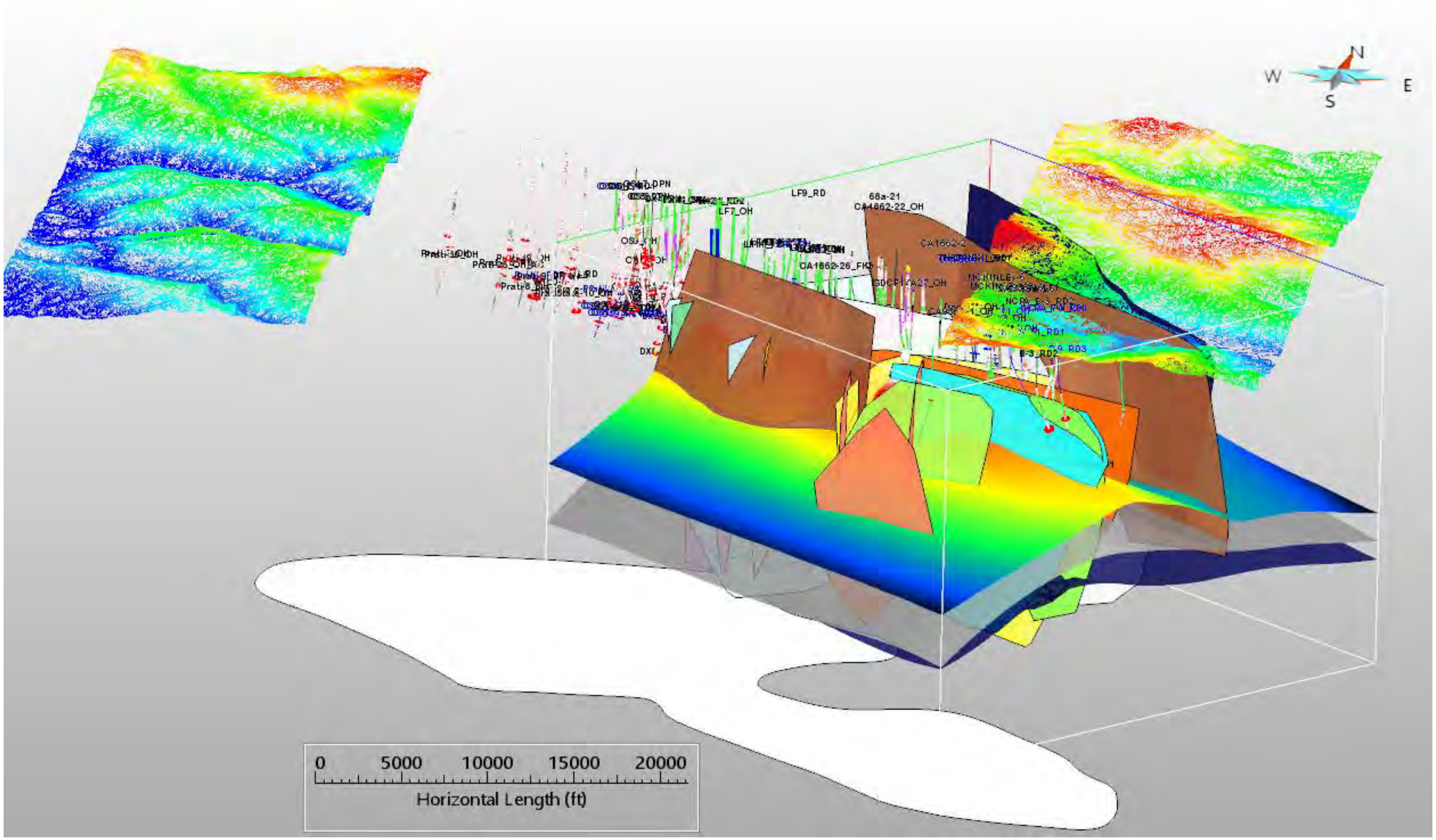
Structural Model Development – Northwest Geysers With Refined Fault/Fracture Interpretation



3D Structural Model Building: Oblique 3D view from south-southwest of the color depth-scaled Top Felsite contours and markers throughout the field, along with the faults and faulted horizons within the north Geysers test volume. Top Felsite points have been extended to the model boundaries base on the available lithological and seismicity constraints.

Calistoga Injection Well Options

Structural Model Development – Southeast Geysers With Refined Fault/Fracture Interpretation



3D Structural Model Building: Oblique 3D view from south-southeast showing the developing 3D structural model within the south half of The Geysers. Shown are color-scaled topographic surfaces "above" the model, the test volume or voxet boundary box, the intersecting faults and 3D structural horizons developed within the 3D structural and stratigraphic workflow, a NW-SE oriented corridor of wells with lithology (rock type) logs assigned, and a deeper surface representing the productive steam reservoir outline.

Calpine Geysers Water Injection Goals

Improve Injection Distribution

Expansion to northwest and away from communities

Additional injection wells

Shallow low-rate injectors (~150 gallons/minute)

Minimize Injection Rate Variations

Individual wells and field-wide

Emphasis on limited variation for wells nearest communities

Designed any tests concerning injection rate variability far from communities

More gradual transition of SRGRP water for injection

Suitable injection rates per well continually evaluated (dependent on local geology)

The ideal reservoir recharge program would be a light, continuous “rainfall” throughout The Geysers.

3D Structural Model Utilized For Recent Water Injection Well Planning and Real-Time Drilling Analysis:

CMHC-8 (2017)

GDC-34 (2018)

Calistoga Water Injection Well Planning (2018)

- The Calistoga area has had several relatively large seismic events since 2010.
- Recent detailed 3D seismicity analysis utilizing the 3D structural model strongly suggests that water injection well 87G-21, in service since 2003, is primarily responsible for a southeastern migration of induced seismic events exceeding magnitude 3.0.
- Subsequent slides provide a summary of recent 87G-21 induced seismicity analysis.
- Well planning in progress proposes two “conversion to injection” well programs.
- Designed to better distribute the fluid flow with a goal of induced seismicity mitigation.

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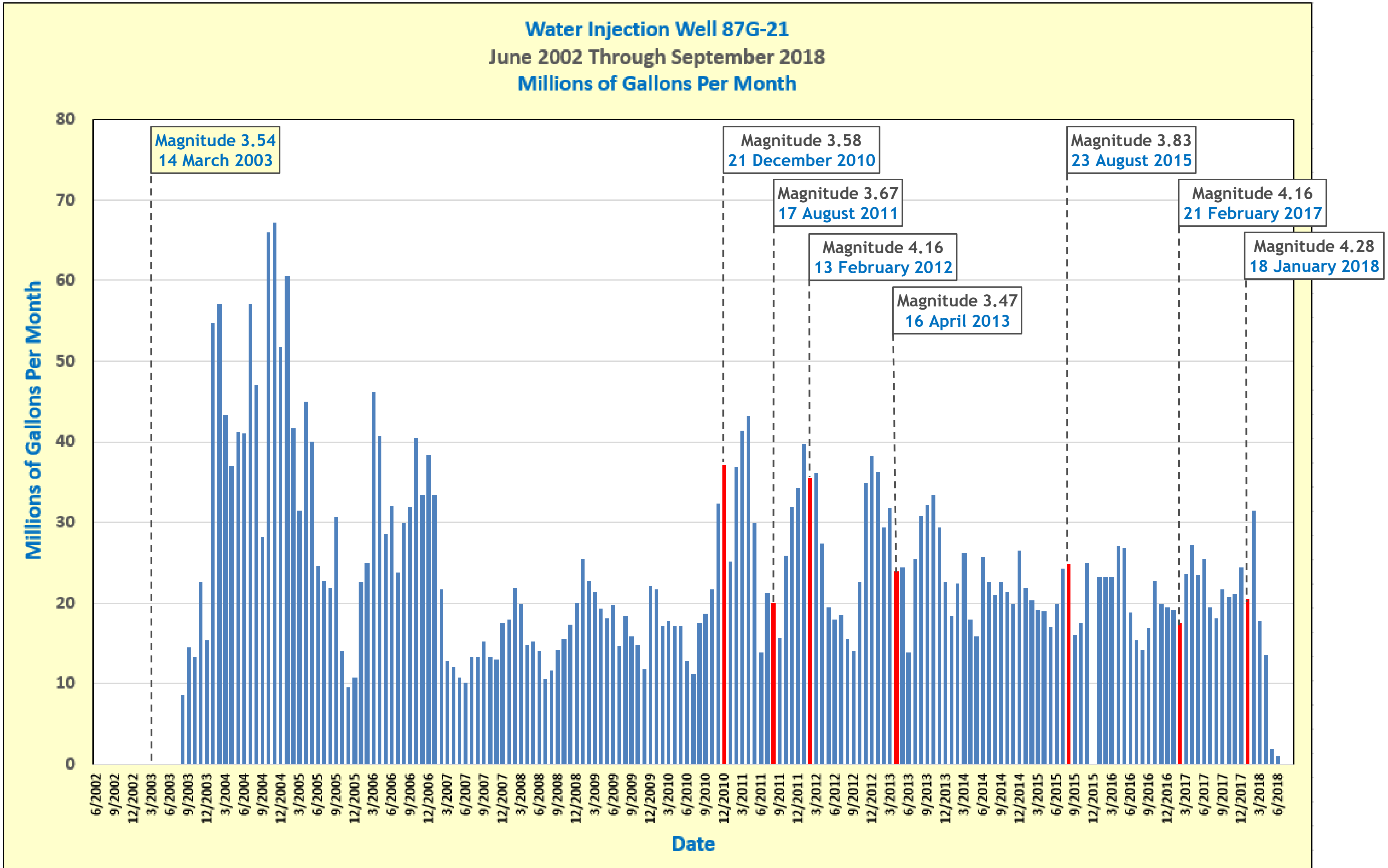
87G-21 Water Injection and Seismicity in Vicinity



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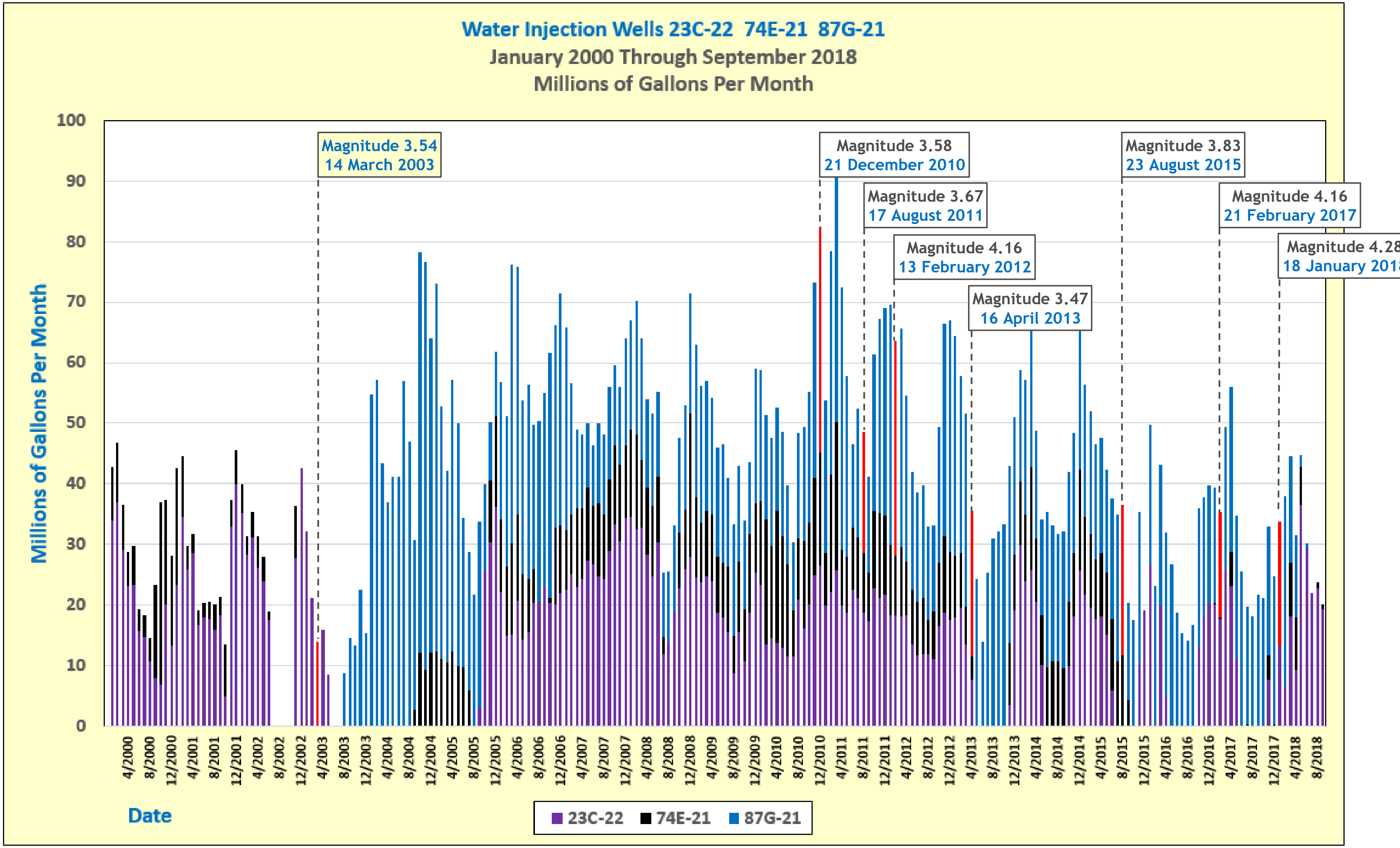
Calistoga Water Injection Wells 23C-22, 74E-21, 87G-21 and Seismicity in Vicinity



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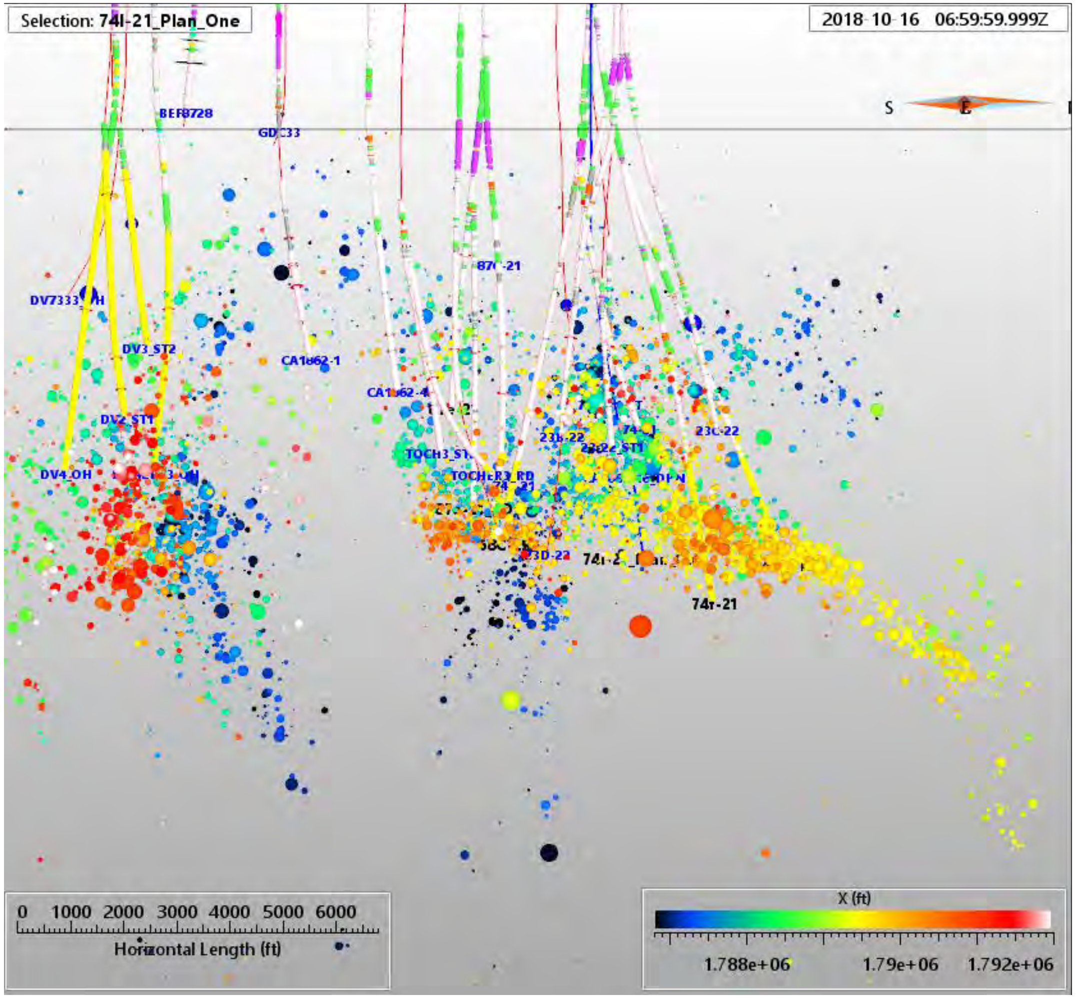
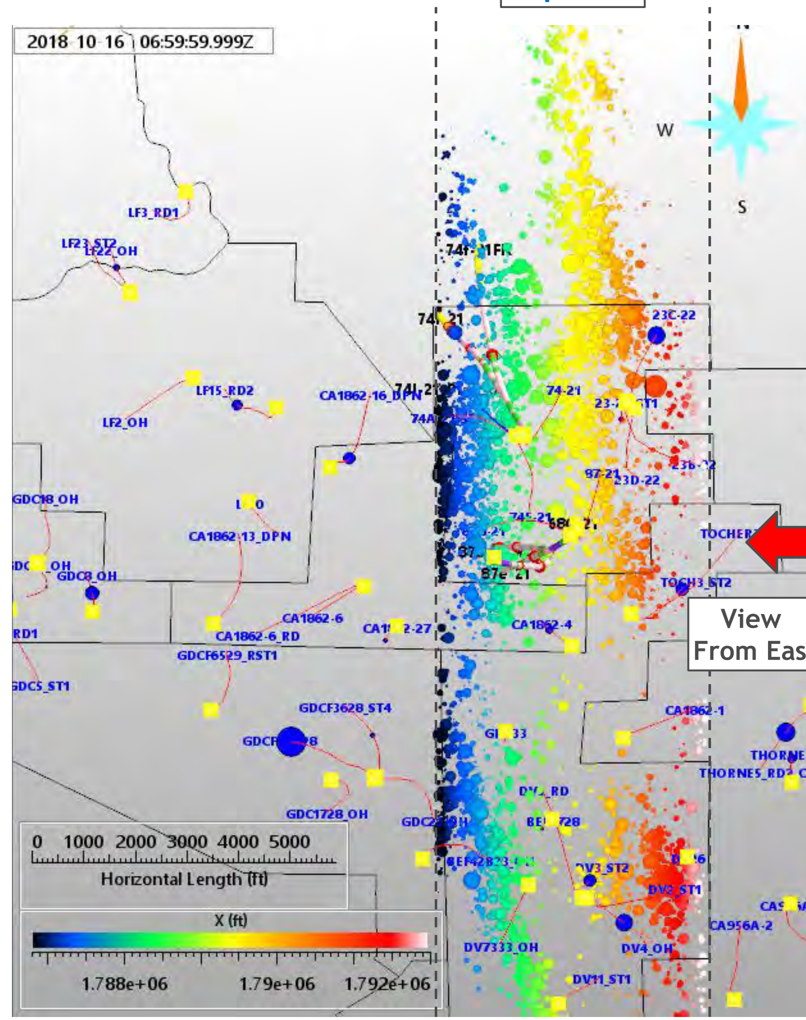
Calistoga Area Water Injection and North to South Oriented Seismicity Animation

View From East



Map View



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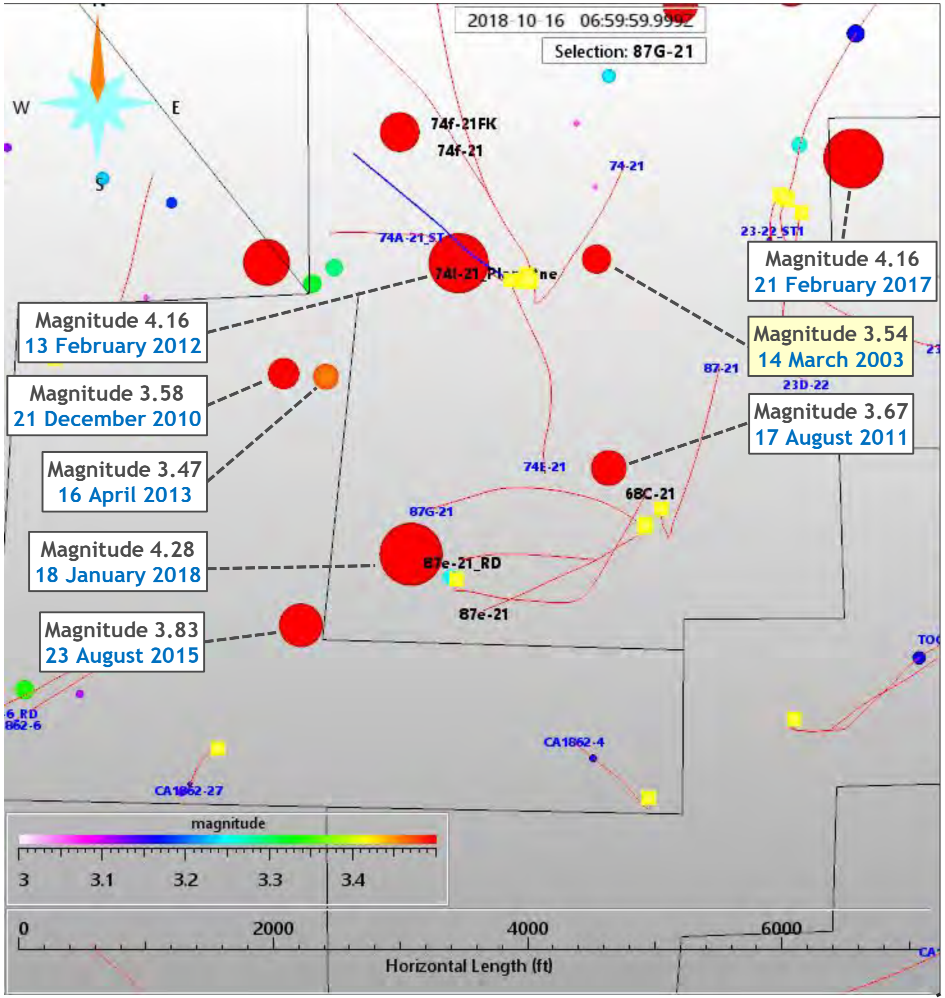
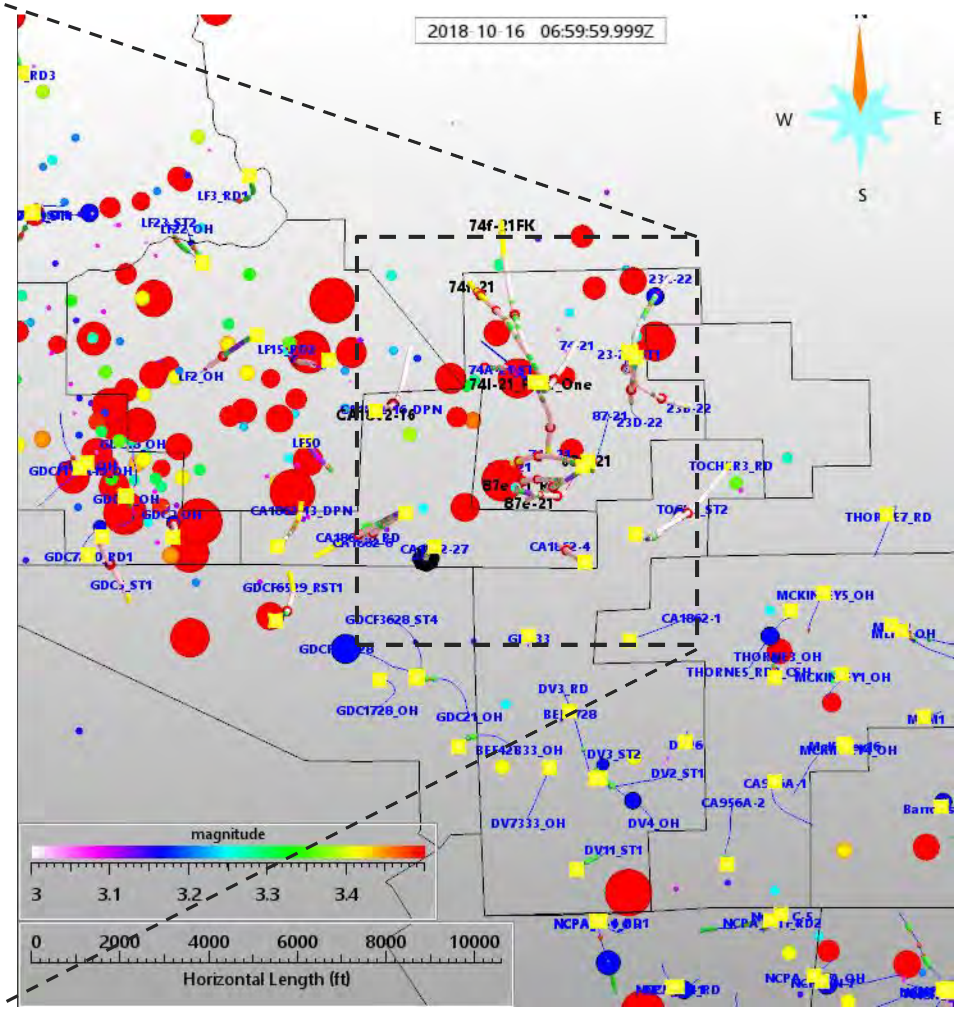
Calistoga Area Water Injection and Seismicity Animation

Map View (87G-21 At Center)



Map View



Emphasis of Seismic Events Exceeding Magnitude 3.0

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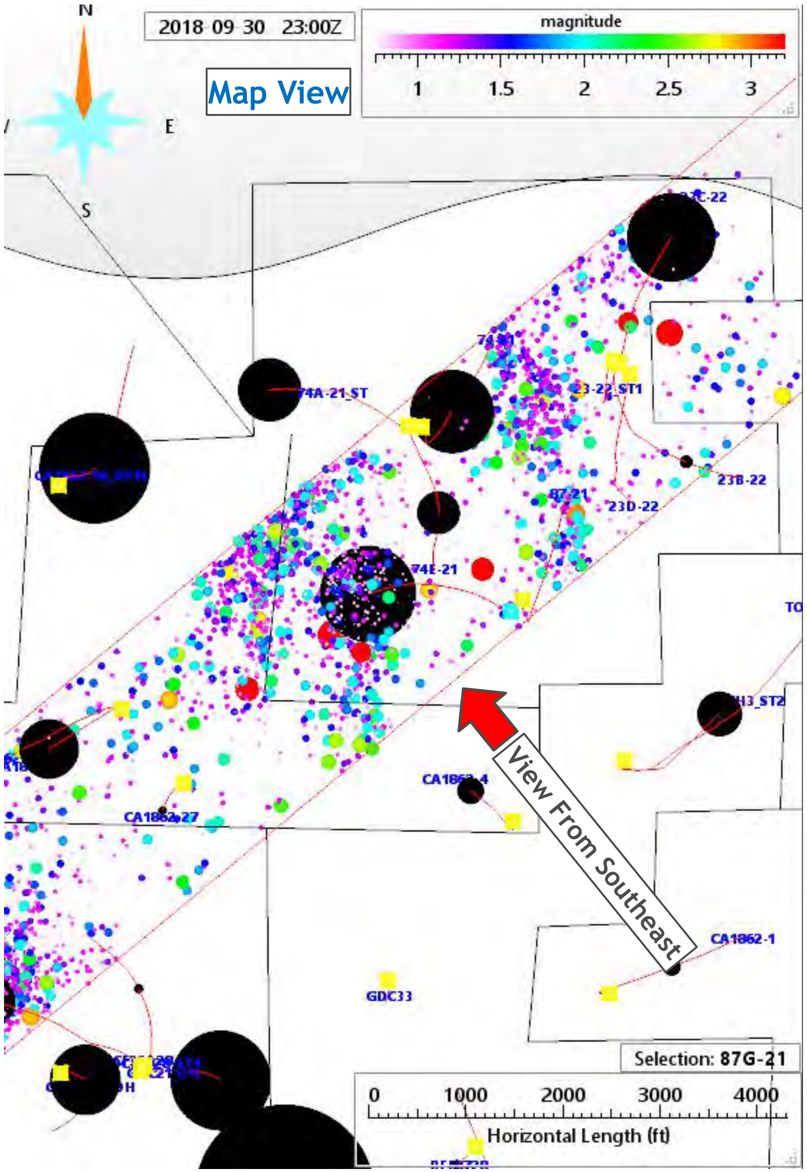
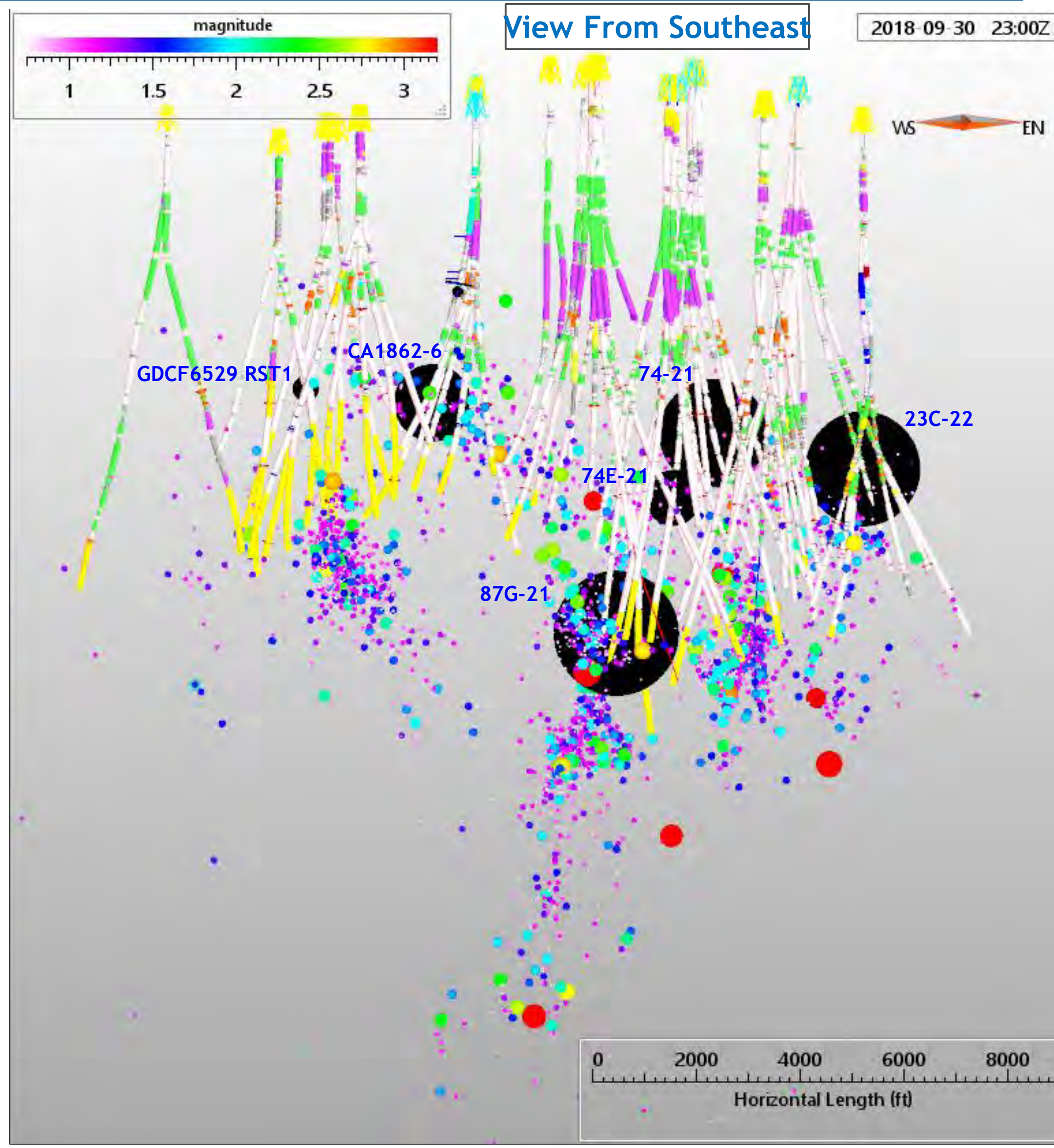
Calistoga Area Cumulative Water Injection and Induced Seismicity Animation

Relationship Between 87G-21 Cumulative Water Injection and Recent Induced Seismic Events Exceeding Magnitude 3.5

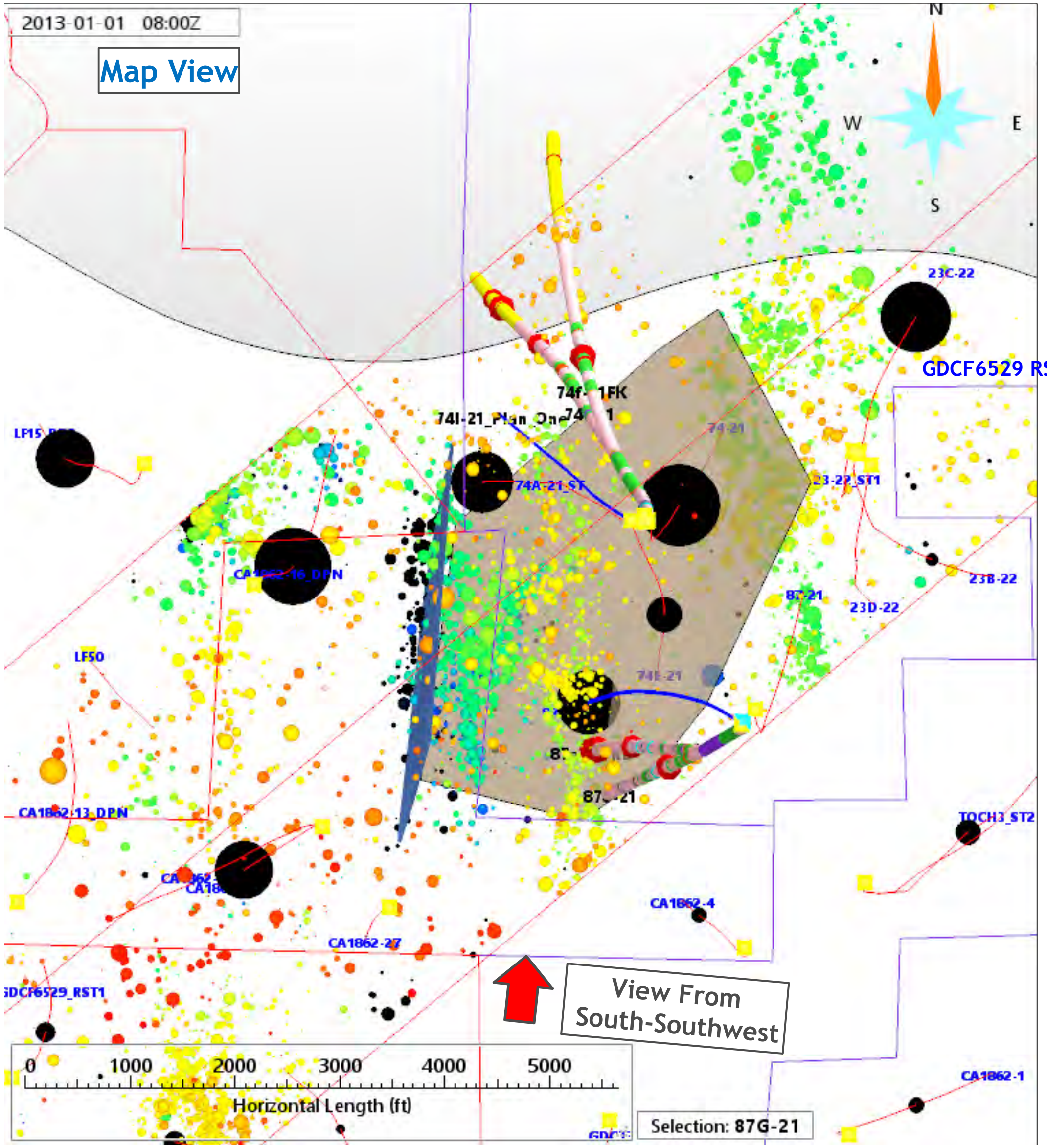


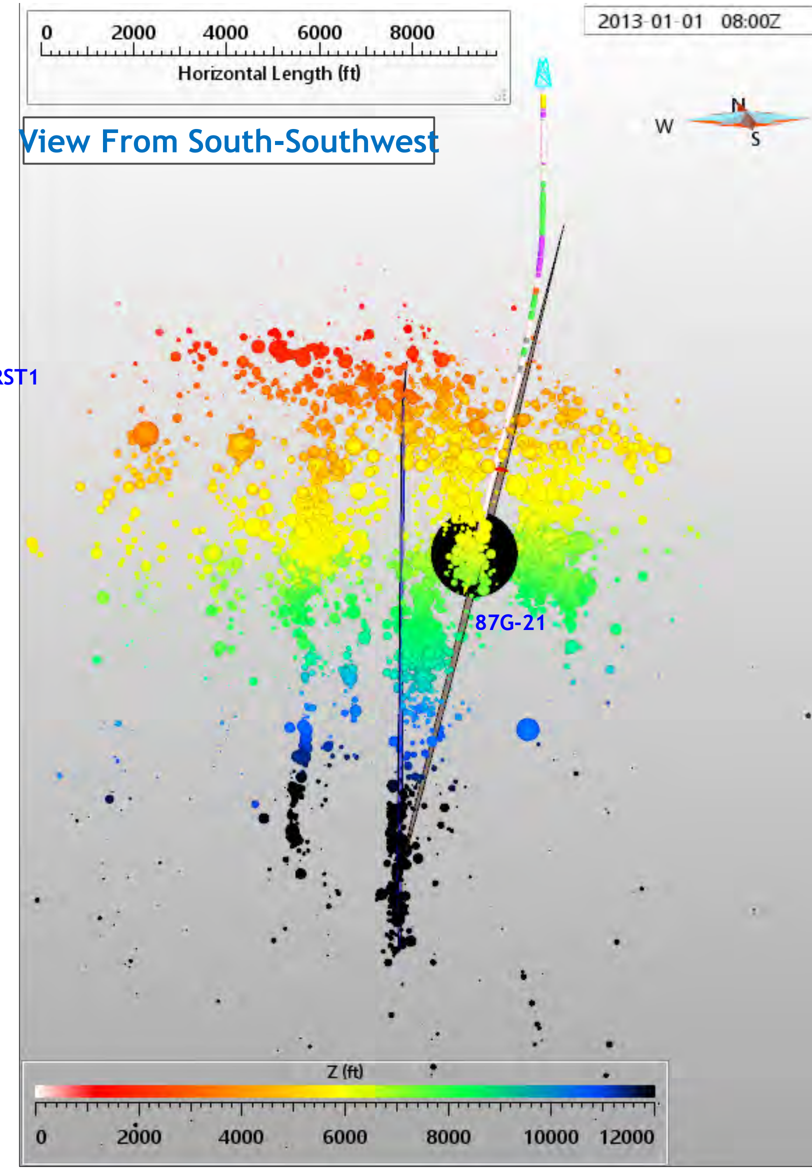


Seismic Monitoring Advisory Committee Meeting

Calistoga Area Fault/Fracture Interpretation With Seismicity Slice Animation

Induced seismicity patterns indicative of fluid flow pathways, fluid flow boundaries, reservoir heterogeneity and reservoir compartmentalization at The Geysers should contribute to improved reservoir management and induced seismicity mitigation.





Seismic Monitoring Advisory Committee Meeting

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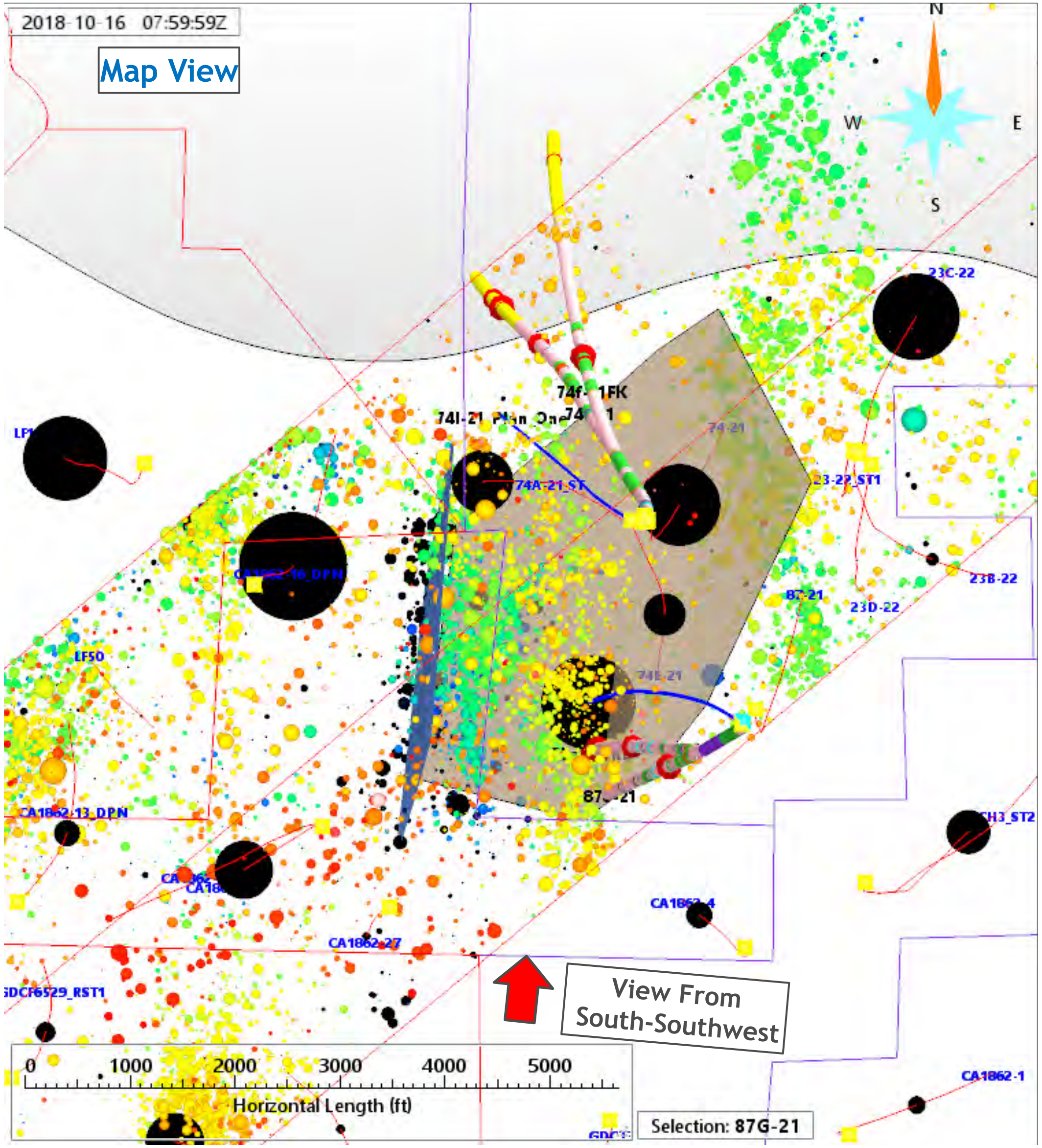

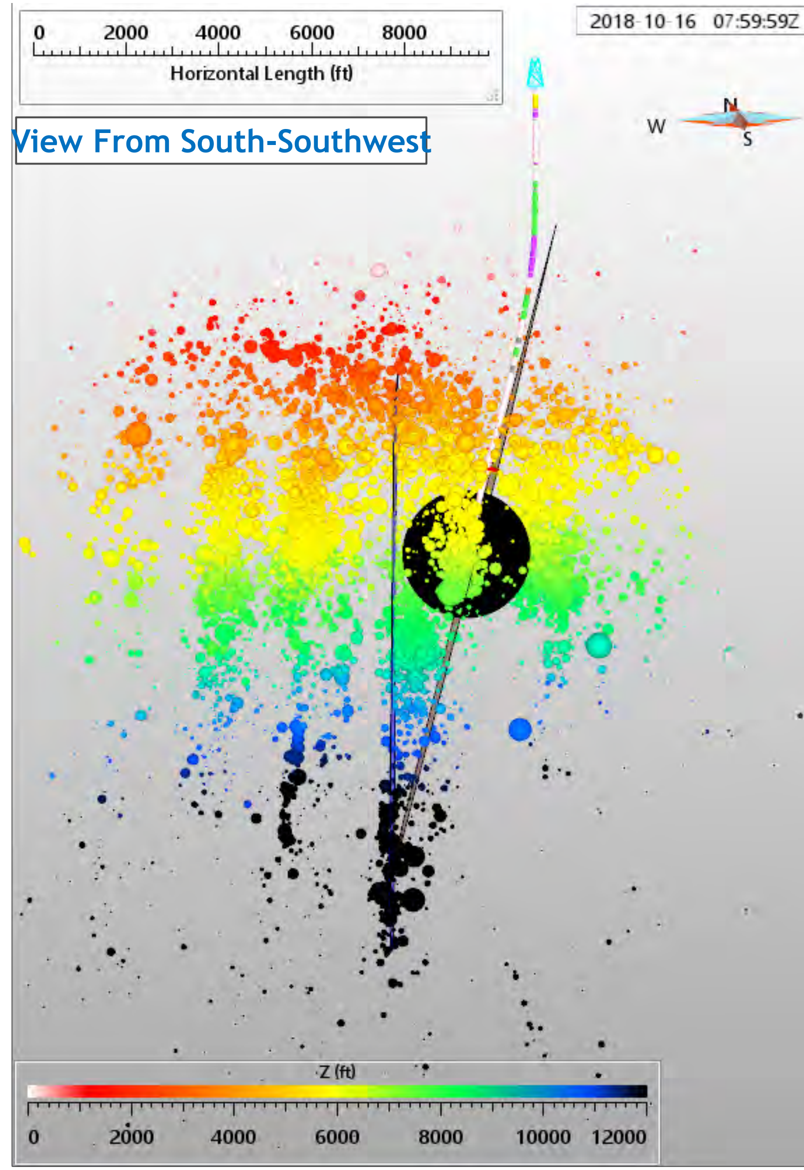

Seismic Monitoring Advisory Committee Meeting

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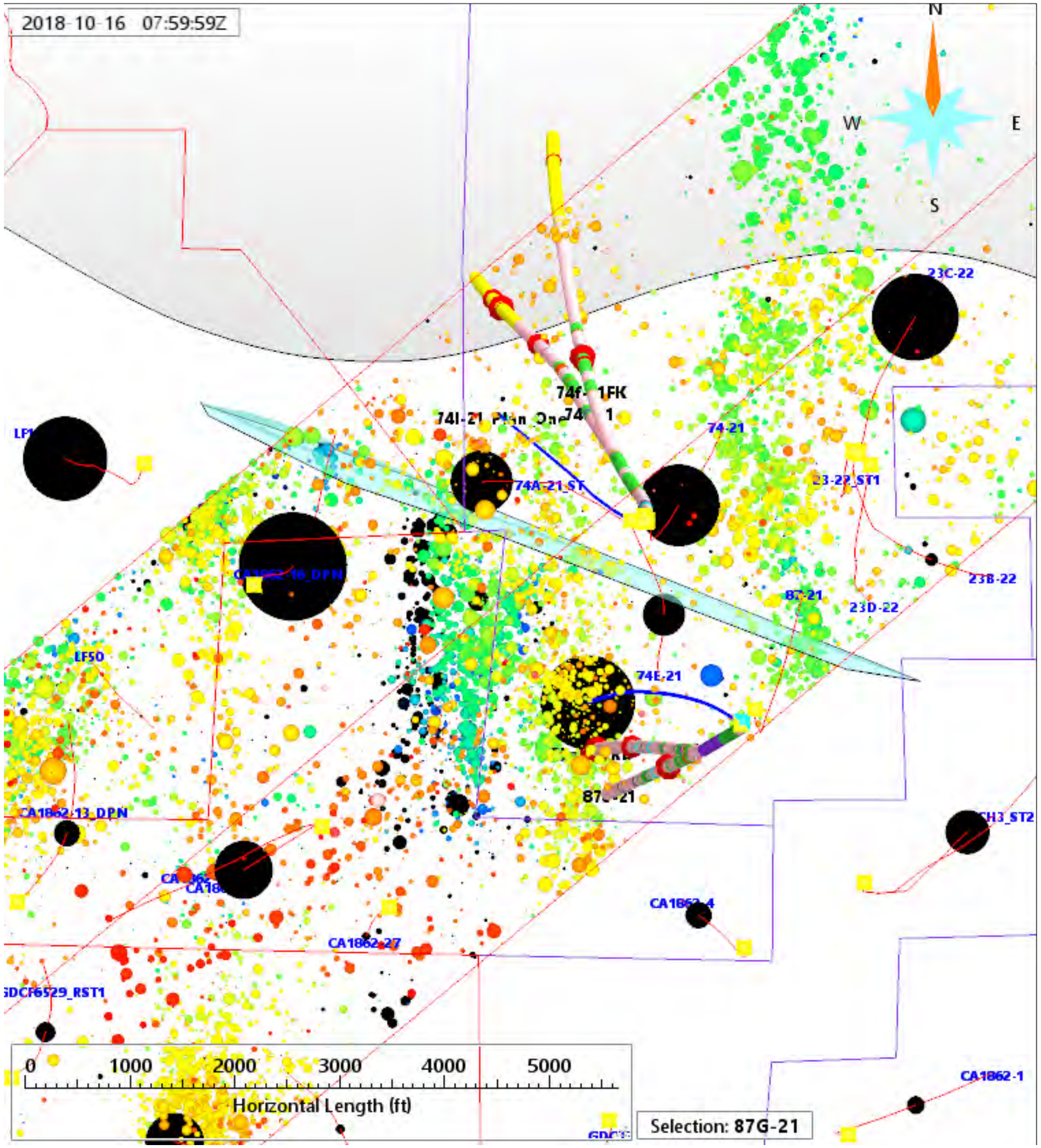
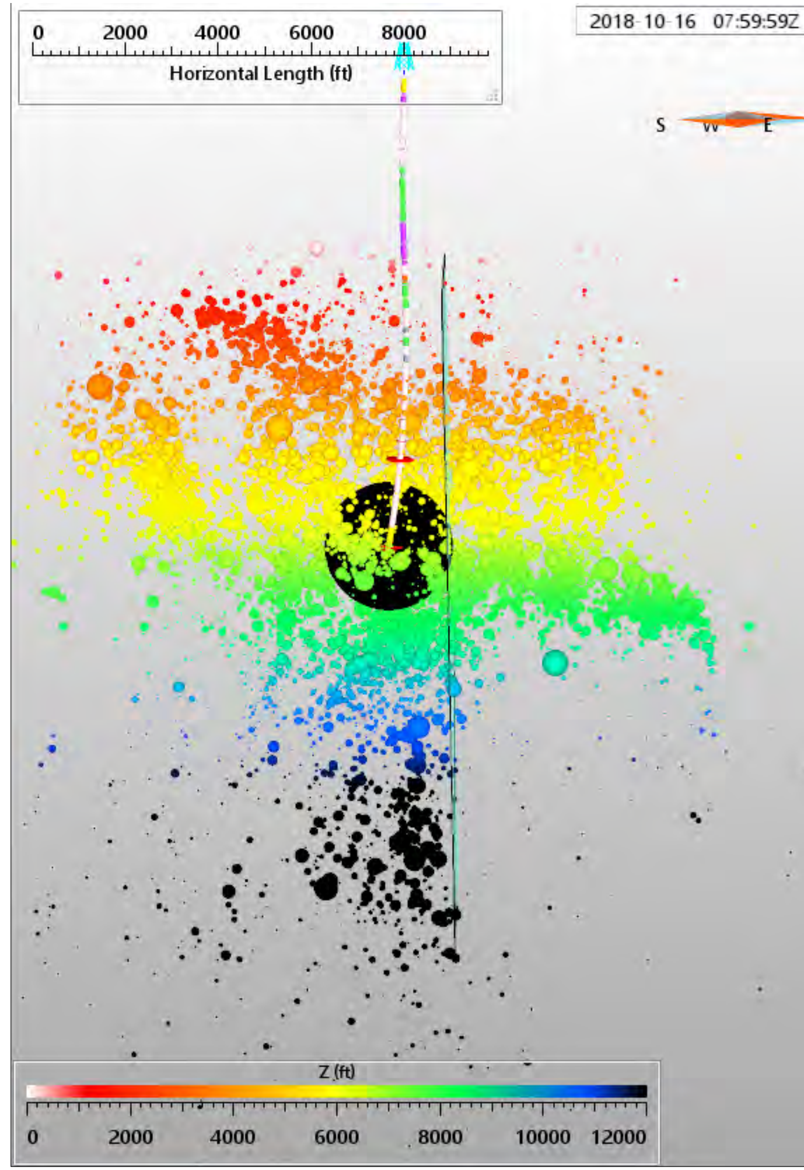
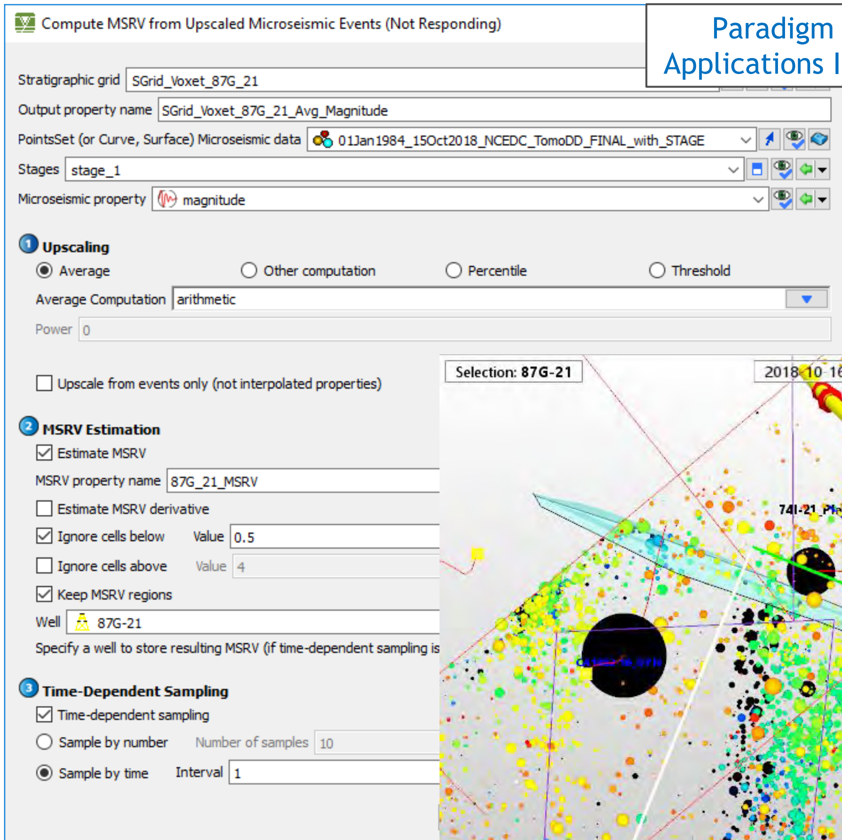


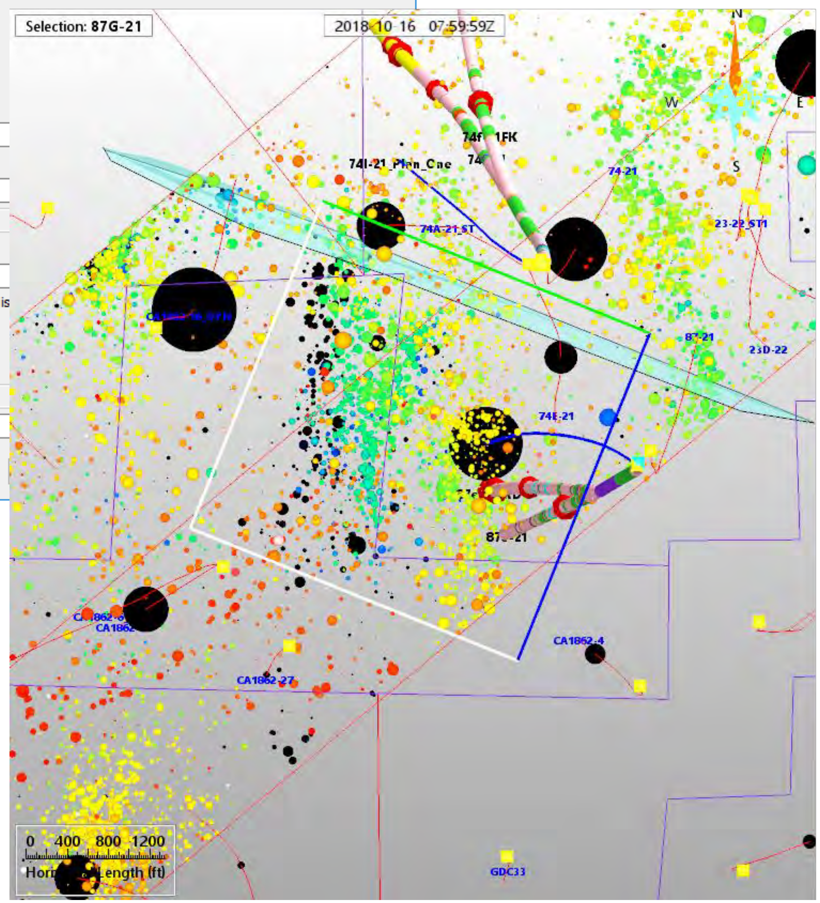


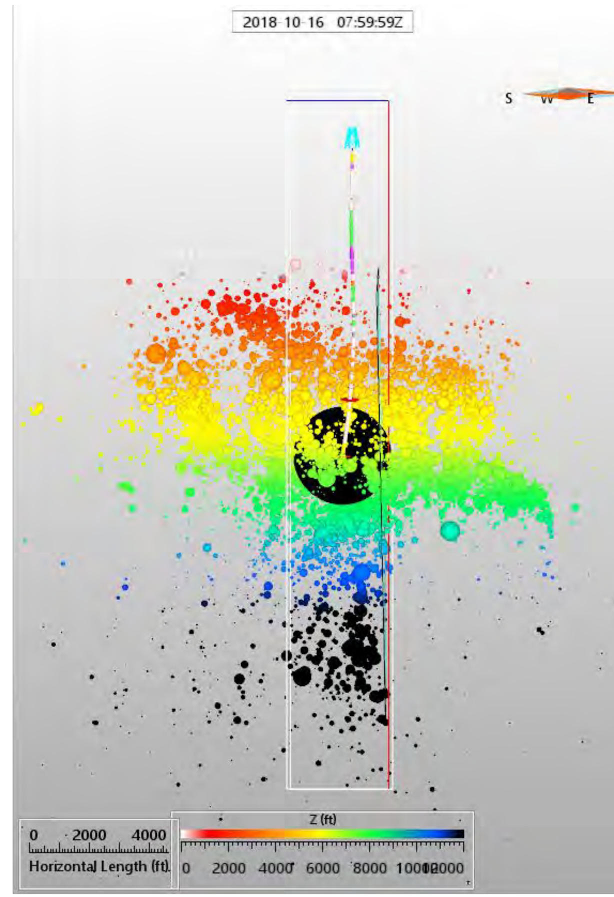
Seismic Monitoring Advisory Committee Meeting

Microseismic Stimulated Reservoir Volume Analysis

Paradigm Geophysical SKUA GOCAD Software, Originally Developed for Oil and Gas Applications Includes Many Tools For Improved Understanding of Reservoir Fluid Behavior.







Seismic Monitoring Advisory Committee Meeting

Additional Seismic Monitoring and Research

California Energy Commission Electric Program Investment Charge (EPIC) Program EPC-16-021

Accepted Proposal

High-Resolution Micro-Earthquake Imaging of Flow Paths Using a Dense Seismic Network and Fast-Turnaround, Automated Processing *

Program Goal

Development of advanced, low-cost, microseismic imaging for high-resolution spatial and temporal images of subsurface fluid flow, flow barriers and heterogeneity in producing geothermal fields. The project will focus on microseismicity imaging challenges that are unique to geothermal reservoirs.

Improved 3D and time-lapse subsurface resolution is anticipated to assist with seismicity mitigation efforts at The Geysers.

Applicant

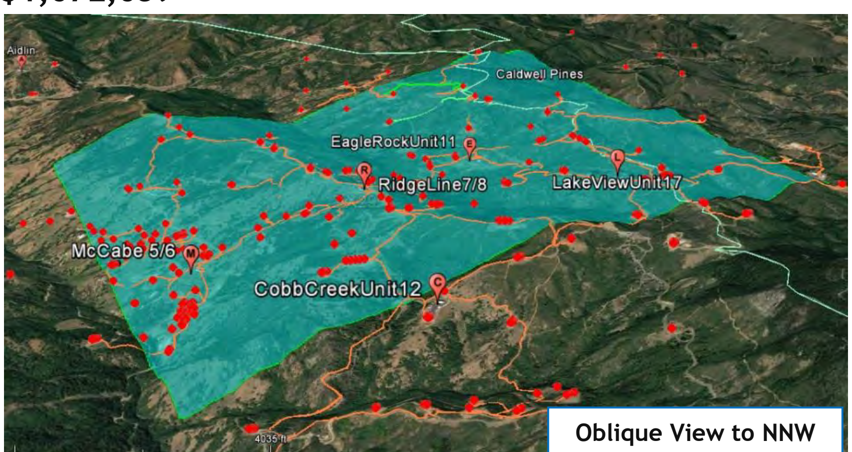
Lawrence Berkeley National Laboratory

Project Partners

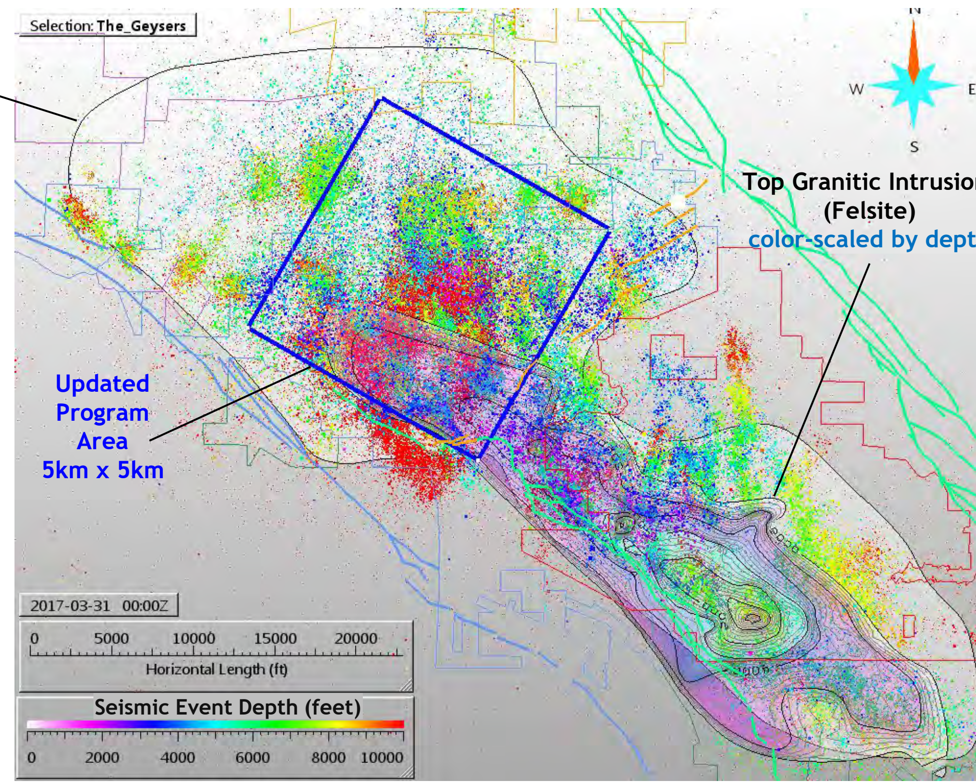
Calpine Corporation
Array Information Technology

California Energy Commission Funds Recommended

$1,672,639



Productive Steam Reservoir Outline

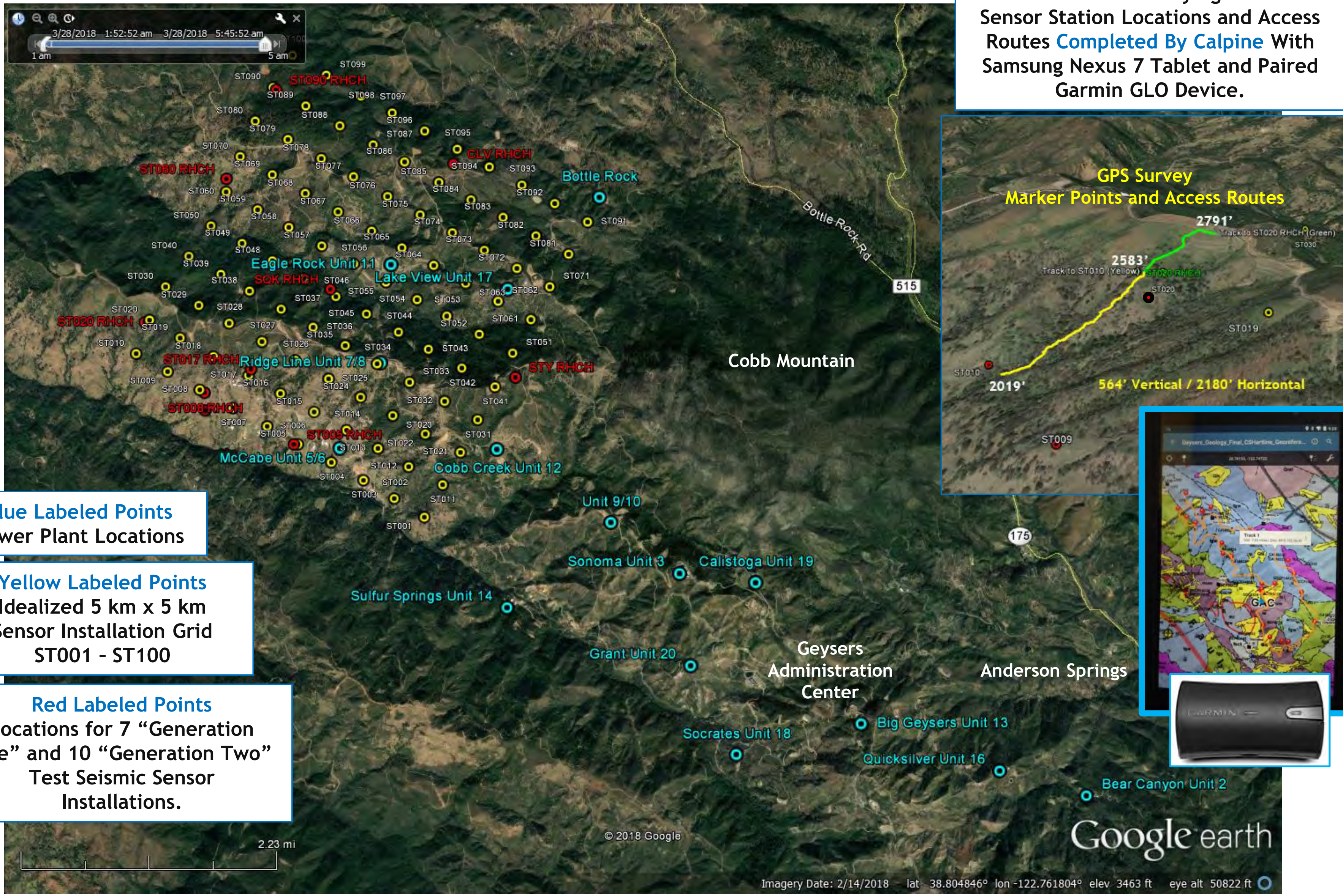


Seismic Monitoring Advisory Committee Meeting

Additional Seismic Monitoring and Research

California Energy Commission Electric Program Investment Charge (EPIC) Program EPC-16-021

Pre-Installation Surveying of 23 Test Sensor Station Locations and Access Routes Completed By Calpine With Samsung Nexus 7 Tablet and Paired Garmin GLO Device.



Blue Labeled Points
Power Plant Locations

Yellow Labeled Points
Idealized 5 km x 5 km Sensor Installation Grid ST001 – ST100

Red Labeled Points
Locations for 7 "Generation One" and 10 "Generation Two" Test Seismic Sensor Installations.

Seismic Monitoring Advisory Committee Meeting

Additional Seismic Monitoring and Research

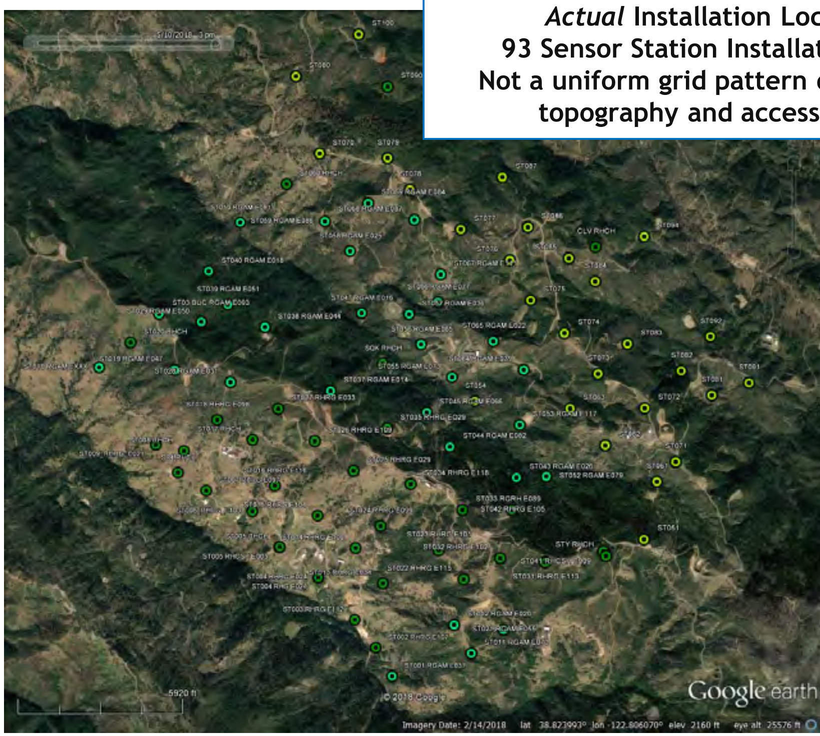
California Energy Commission Electric Program Investment Charge (EPIC) Program EPC-16-021

An extensive seismic sensor test program was planned and conducted with the project scientists.

Calpine Corporation provided:

- The field location for this program.
- Technical support with survey design planning.
- On-site assessments including GPS surveying with updated equipment and techniques.
- Assistance to LBNL Contractor Ramsey Haught during 17 seismic sensor test installations.
- Coordination and updating of GPS surveys/maps data recovery at 2-3 month intervals.

Green Labeled Points
Actual Installation Locations for
93 Sensor Station Installation Program.
Not a uniform grid pattern due to extreme
topography and access concerns.



Generation Three Sensor Station

Sensor Installation on Rock Outcrop

Seismic Monitoring Advisory Committee Meeting

Seismic Research Collaboration with Seismic Warning Systems

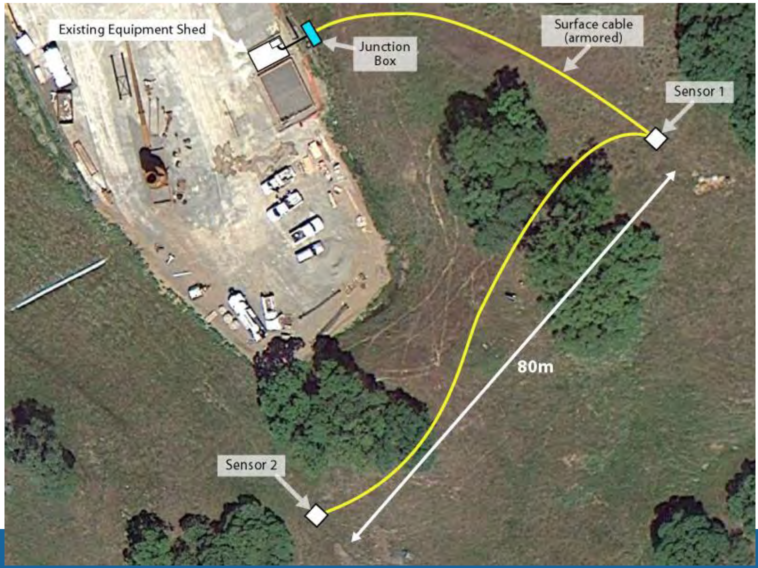
Early Detection and Warning System for Natural Earthquakes

SEISMIC WARNING SYSTEMS

Primary Goal

Automated control (and shutdown) of natural gas, electricity and water supply for refineries, chemical plants, public schools, medical facilities, …

Two test sensors at The Geysers Prati 32 well pad.
Installation date 15 September 2014.
Tied in to Calpine power and communications.



Geysers Project Goals

Refinement of event detection software to:

- Avoid false positives (caused by human activity)
- Distinguish between:
  - smaller seismic events typical of The Geysers these should be ignored
  - large seismic events (earthquakes) triggering automated warnings and shutdowns

Seismic Monitoring Advisory Committee Meeting
Research Collaborations

Calpine has greatly appreciated the experience and friendly guidance of Joe Austin; Division of Oil, Gas and Geothermal Resources concerning geological issues and seismicity analysis at The Geysers.

Lawrence Berkeley National Laboratory

36 station three-component permanent seismic monitoring network

Collaboration on successful DOE co-funded EGS Demonstration Project, including two temporary seismic monitoring networks

Collaboration on high-temperature tolerant borehole fiber optical seismic sensor testing

Borehole seismic sensor installation and testing in the southeast Geysers

Initiating collaboration for high-resolution imaging of fluid flow paths using a dense seismic network and automated processing

United States Geological Survey

Geysers' seismicity processing and real-time availability, detailed analysis of magnitude ≥ 3.5 events

Collaboration on full-waveform six-component (3 translational/3 rotational) seismic sensor testing

Collaboration on Silicon Audio high-sensitivity optical accelerometer testing

Massachusetts Institute of Technology

Collaboration on installation and operation of three continuous monitoring GPS instruments

Array Information Technology

Research Collaborations with European GEISER Project

Installation and recovery of 32 continuous broadband seismic recording instruments from GFZ Potsdam / GEISER Instrument Pool

GFZ Potsdam

Collaboration on studies of spatiotemporal induced seismicity changes associated with variable water injection in the northwest Geysers

United States Seismic Systems

High-temperature tolerant borehole fiber optical seismic sensor array test program

Seismic Warning Systems

Northwest Geysers test site for calibration of earthquake early warning systems

Zizmos

Geothermal Visitor Center test site for cloud-connected seismic network earthquake early warning systems