Seismic Monitoring Advisory Committee Meeting

01 October 2018 to 31 March 2019 Reporting Period

Calpine Geothermal Visitors Center

Middletown, California

13 May 2019

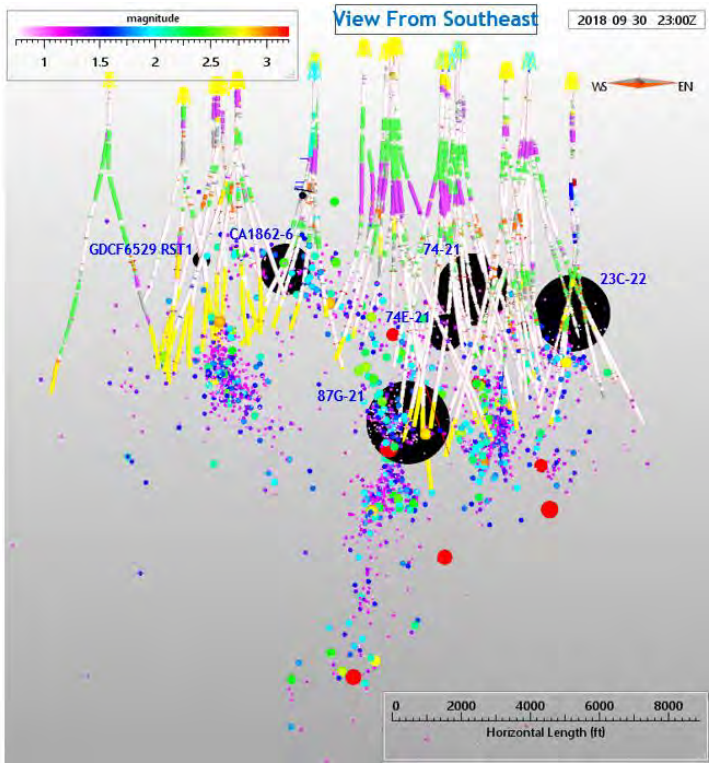
Craig Hartline Senior Geophysicist Calpine Corporation The Geysers

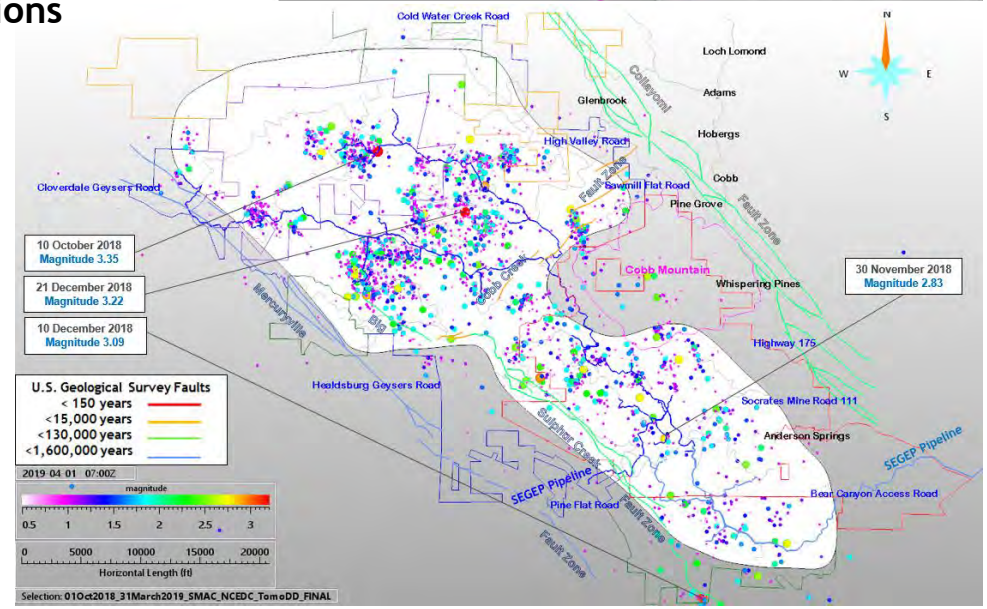
Seismic Monitoring Advisory Committee Meeting

Calpine Presentation Agenda

Reporting Period: 01 October 2018 to 31 March 2019

- California ISO* and Renewable Energy
- Geysers Geothermal Field and Nearby Communities
- Status of Seismic Monitoring Networks
  - LBNL Seismic Monitoring Network
  - USGS / Northern California Seismic Network
  - Strong Motion Network(s)
- Strong Motion Data Access and Analysis (Web-Based Interface)
- 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
  - Well Planning Examples
- Additional Seismic Monitoring and Research





* California Independent System Operators

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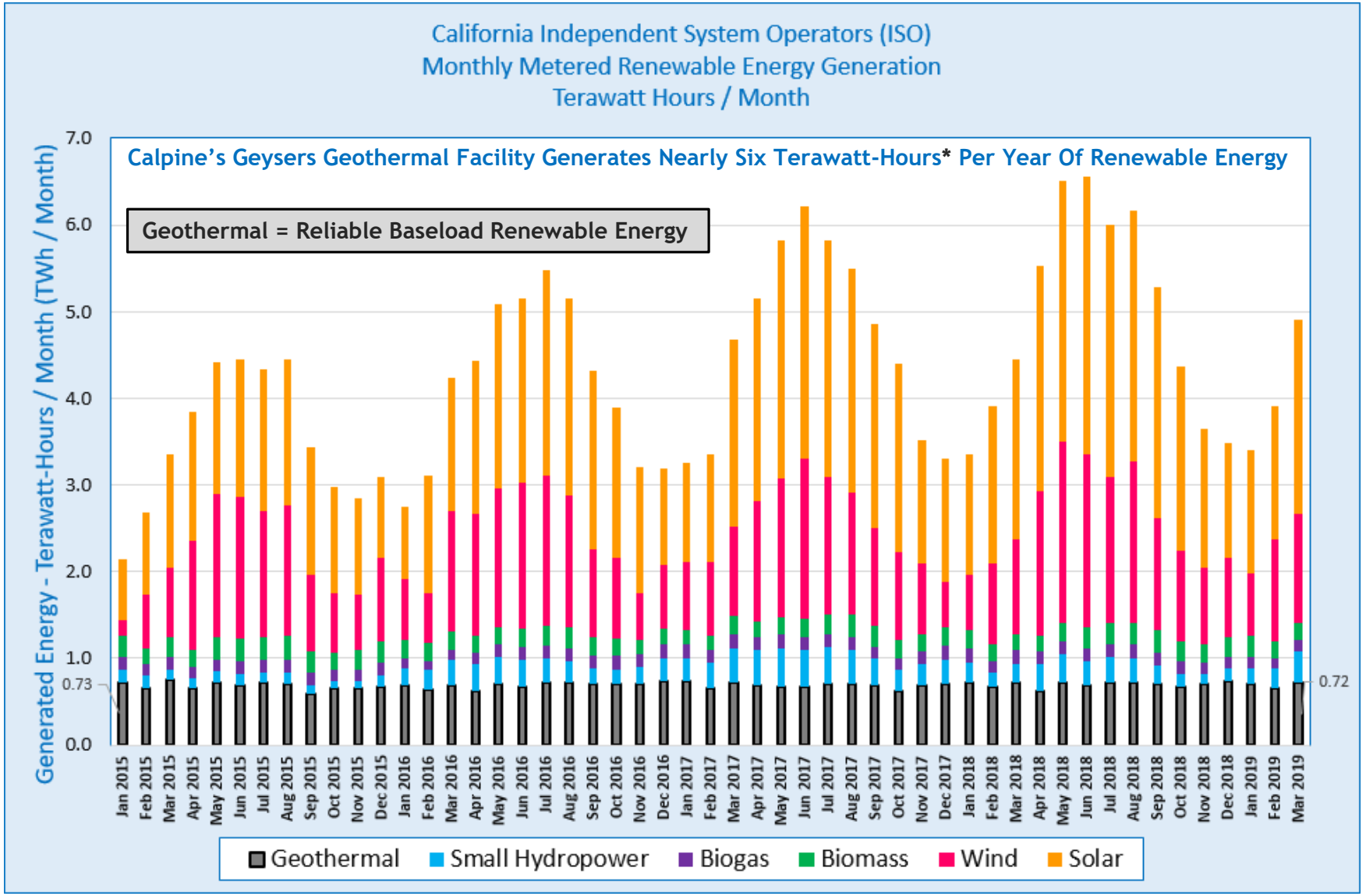
California ISO* Electrical Monthly Renewables Performance



* California Independent System Operator

* Nearly Six Trillion Watt Hours

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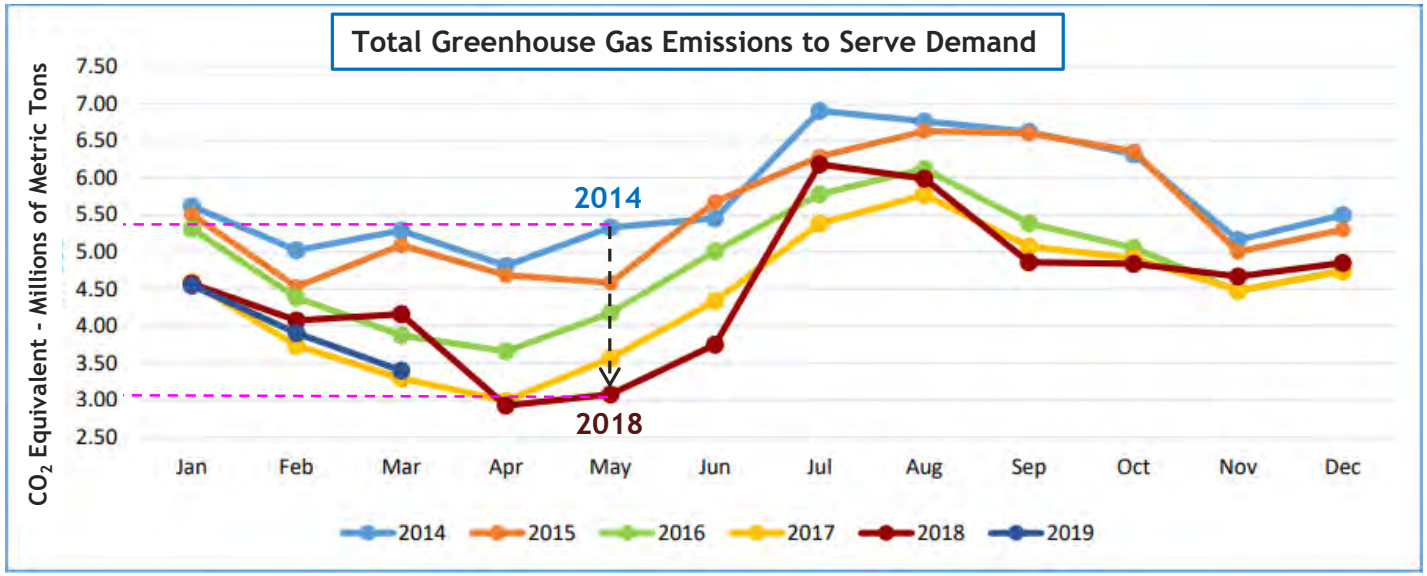
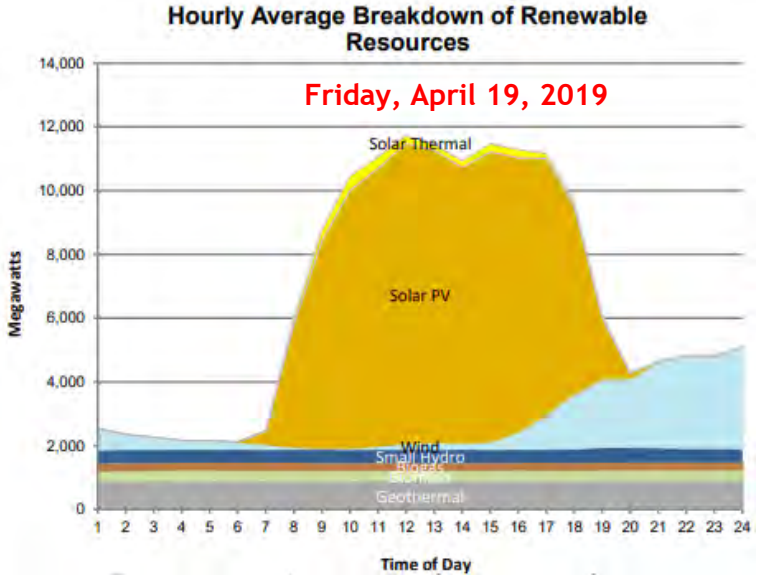
California ISO Electrical Greenhouse Gas Emissions

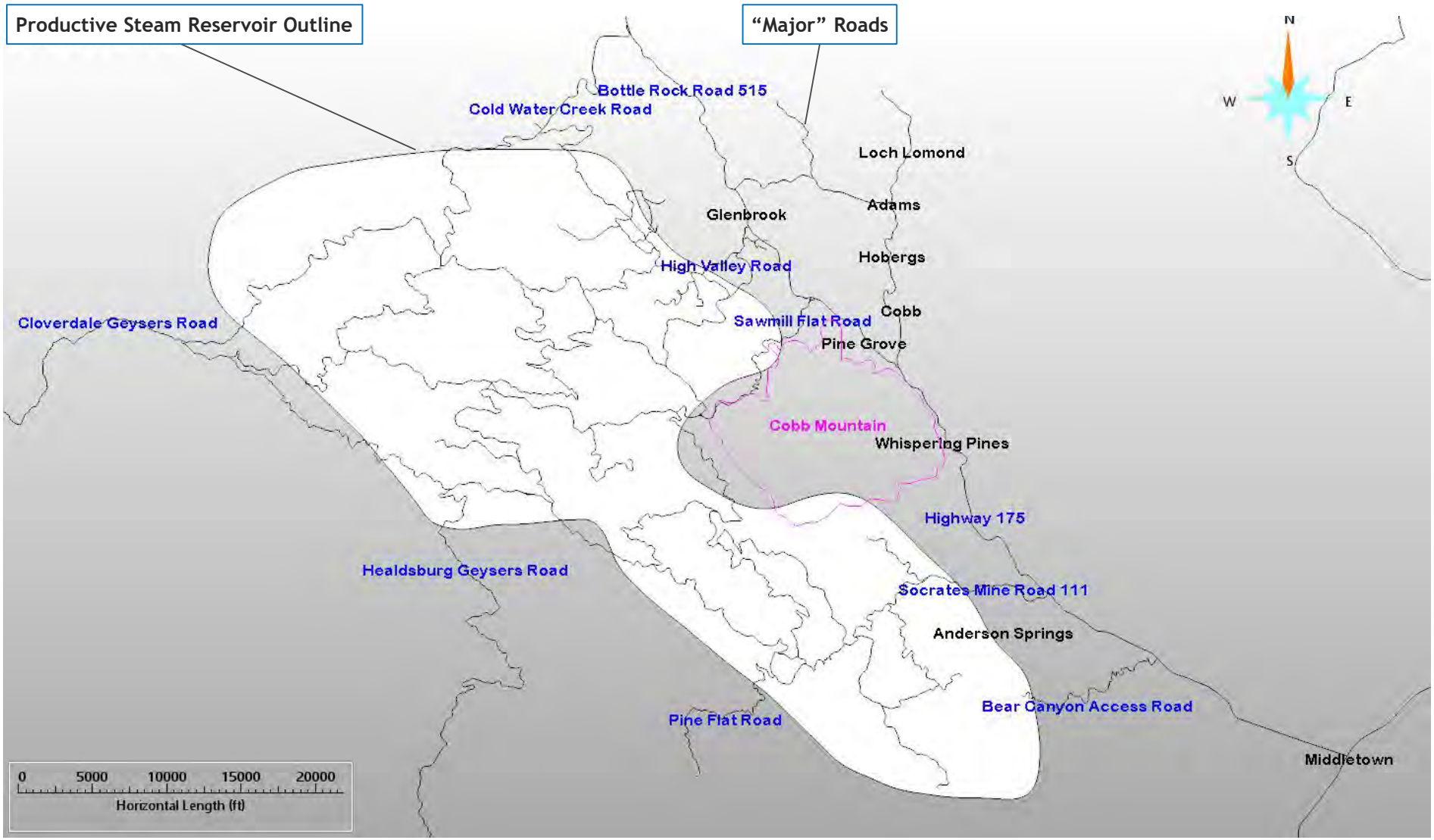


24-Hour Renewables Production

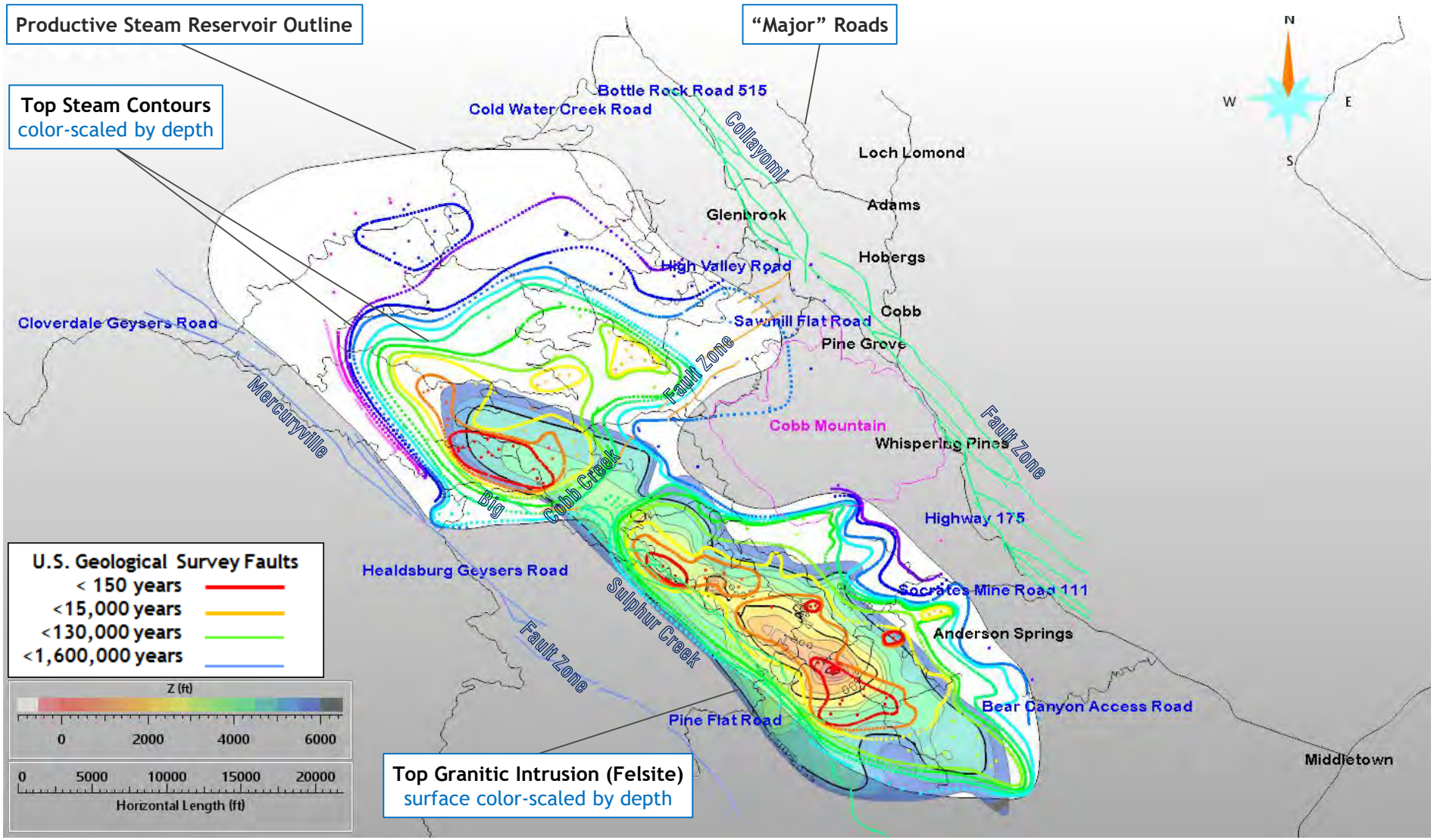
Renewable Resources	Peak Production Time	Peak Production (MW)	Daily Production (MWh)
Solar Thermal	9:47	489	2,839
Solar	11:42	9,875	88,461
Wind	23:59	3,338	22,852
Small Hydro	18:10	493	10,635
Biogas	19:20	226	5,306
Biomass	4:25	350	8,057
Geothermal	23:30	918	21,578
Total Renewables	Friday, April 19, 2019		**159,728**
Total 24-Hour System Demand (MWh):			*572,066*



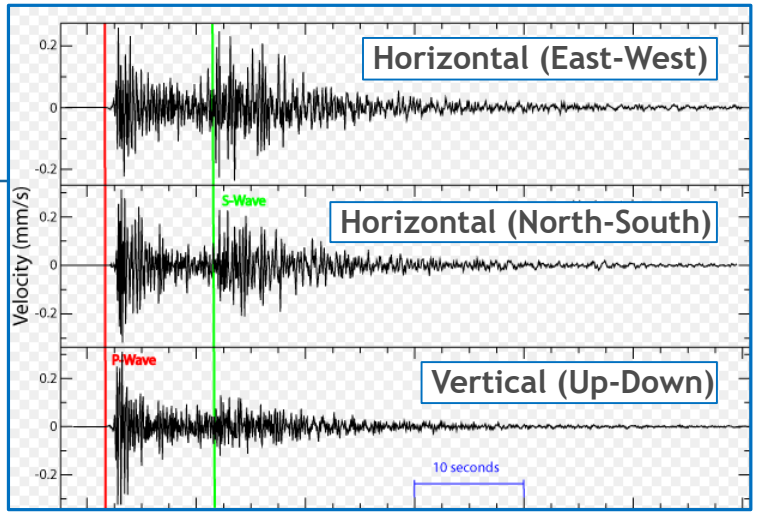
Seismic Monitoring Advisory Committee Meeting
Geysers Geothermal Field and Nearby Communities



Seismic Monitoring Advisory Committee Meeting
Geysers Geothermal Field and Nearby Communities



Seismic Monitoring Advisory Committee Meeting
Status of Seismic Monitoring Networks



LBNL Seismic Monitoring Network

Fully Functional
Three Developing Concerns and Solutions

1) Individual Sensor Components Sticking

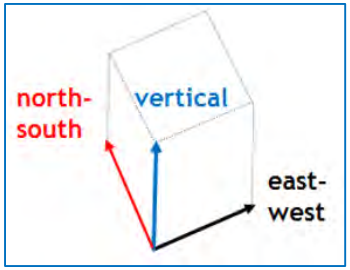
Late 2018: Calpine Purchased 16 Three-Component Geospace 2 Hz Sensors

May 2019: 6 Sensor Replacements Completed

Summer 2019: 16 Sensor Replacements Planned

July 2019: Calpine Purchasing 8 (24 Total) Three-Component Geospace 2 Hz Sensors

End 2019: 24 Sensor Replacements Planned



2) Department of Energy Funding Ends in 2019

Since 2015, Dr. Ernie Majer and Dr. Kurt Nihei have provided warning that this could occur.

2019 Calpine contribution of $75,000 for network maintenance.

2020 Calpine contribution of $110,000 for yearly maintenance and upgrades.

3) LBNL Contractor Ramsey Haught Retirement

Ramsey Haught primarily responsible for network installation, maintenance and upgrades.

Difficult to replace his very specialized skills and experience at The Geysers.

2019 Calpine contribution covers direct transitional period labor by Ramsey Haught.

2020 Calpine contribution covers future **Jarpe Data Solutions*** maintenance and upgrades.

* Jarpe Data Solutions has existing relationship with LBNL concerning seismic acquisition testing and seismic databases

Seismic Monitoring Advisory Committee Meeting
Status of Seismic Monitoring Networks

LBNL Seismic Monitoring Network

24 Geospace HS-1 3C arrays and cables purchased by mid 2019; all 24 installations planned by end 2019.

Calpine funded system upgrades totaling $69,600 by end 2019:

Equipment: $2,400 per sensor station
Installation: $ 500 per sensor station
Total: $2,900 per sensor station

DIMENSIONS	metric	US
Height, with Handle	13.61 cm	5.36 in.
Height, no Handle	9.22 cm	3.63 in.
Diameter	14.94 cm	5.88 in.
Weight	3.595 kg	7.925 lbs.

PHYSICAL SPECIFICATIONS	
Operating & Storage Temperature	–40 to +100° C (–40 to +212° F)
Operational Range	Vertical to 7.5° Horizontal to 0.5°
Portable Case	Aluminum
	Double O-ring sealed top and bottom
	Carrying handle
	Leveling bubble built into top

ELECTRICAL SPECIFICATIONS		
Sensor Type	HS-1 Seismometer	
Triaxial Orientation	Orthogonal	
Natural Frequency	2.0 Hz	
DC Resistance Options	1250 Ω	3810 Ω
Sensitivity Options	1.04 V/in/s	2.0 V/in/s
Extended Bandwidth	up to 500 Hz	

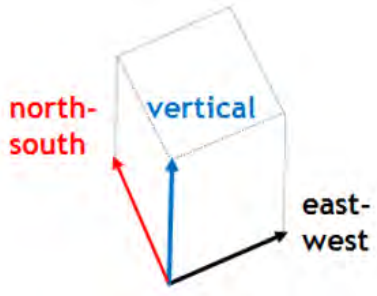
"ideally suited for seismological, engineering, and scientific applications where passive, low noise, short period, tri-axial sensors are required"

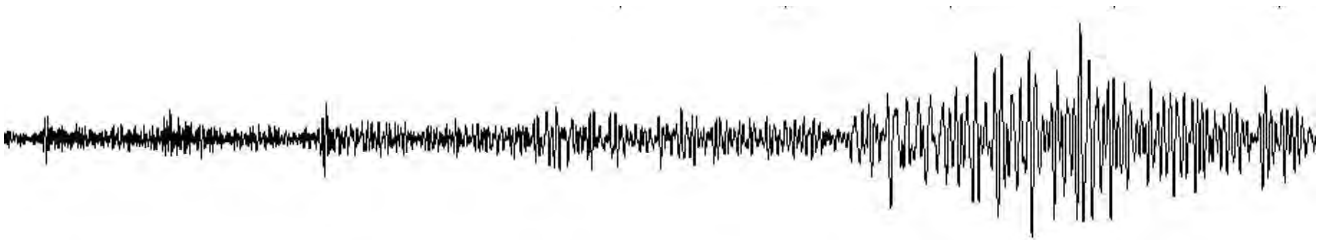
Status of Seismic Monitoring Networks

USGS*/ Northern California Seismic Network

The USGS and collaborating agencies provide services of significant value to The Geysers.
The USGS Regional Seismic Network is responsible for these fully functional items:

Seismic Data	
Acquisition	Six three-component USGS seismic stations contribute to seismicity determinations within The Geysers.
Processing	Seismic waveforms are intially compiled and p-wave arrival times calculated at the USGS "Waveserver"located within the Geysers Administration Center (and adjacent to the LBNL seismic data server).
Transfer	Merged LBNL/USGS station waveforms and arrival times are forwarded by a Northern California Seismic Network radio link to their Geysers Peak microwave hub, then transmitted to the USGS facility at Menlo Park.
Integration	LBNL/USGS P-wave arrival times are integrated with P-wave arrival times from other monitoring networks operated by the USGS, UC Berkeley, the California Geological Survey, and the California Department of Water Resources.
Analysis	Automatic determination of seismic event magnitude, hypocenter, first-motion mechanisms, and moment tensor solutions/shake maps (for seismic events with magnitude > 3.5). Seismologists complete reviews of more significant events.
Distribution	The USGS Eartquake Hazards Program website (https://earthquake.usgs.gov/) is the starting point for access to almost unlimited seismicty information, including nearly "real-time" availability of earthquake information (https://earthquake.usgs.gov/earthquakes/map/).
Archival	Waveforms and event determinations retrieved hourly for archival at the UC Berkeley Northern California Earthquake Data Catalog. Data derived from this catalog, including tomographic double-difference refined seismicty hypocenter determinations, contributes to Calpine/NCPA seismicity analysis, along with worldwide seismic research collaborations.





* United States Geological Survey

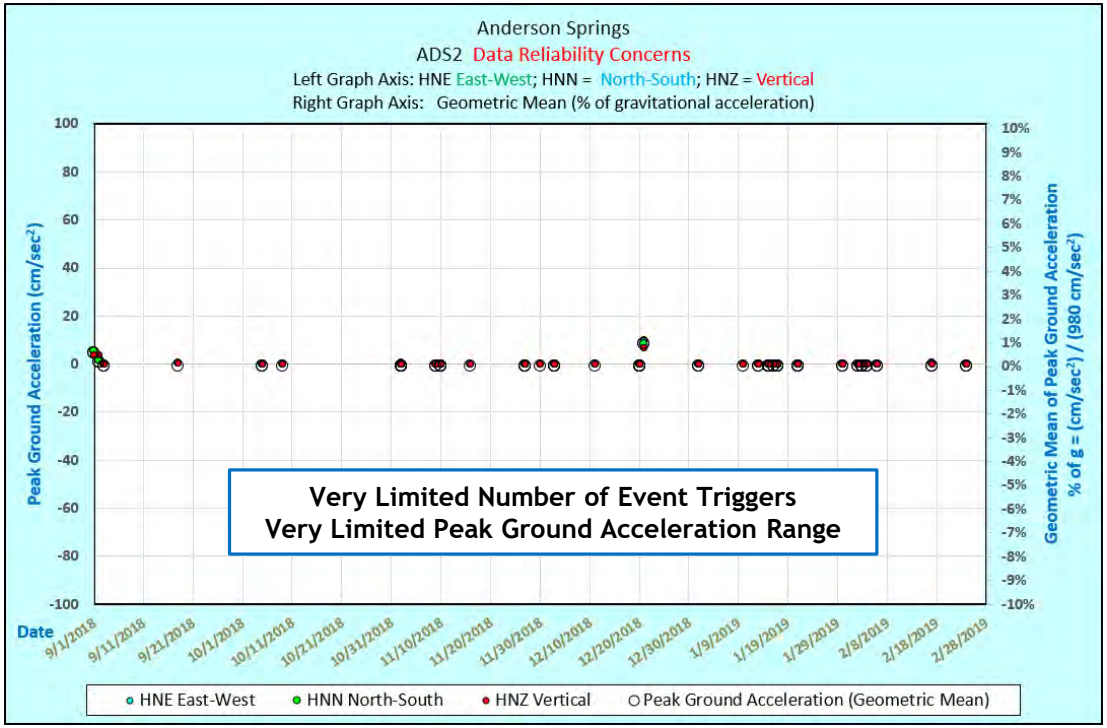
USGS* Strong Motion Station ADS2

United States Geological Survey budget restrictions and project reprioritization, including earthquake early warning system research, have limited the resources available for strong motion 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 program, including database maintenance and updates.

- **Anderson Springs**
  ADS2
  Community Center Strong Motion
  2003 ETNA 3C Accelerometer
  Rural Power and Communication
  * Equipment and/or Database Currently Not Considered Reliable

Proposed Solution:
Nanometrics Titan 3C Accelerometer
Solar Power
Radio Telemetry
(integrated into LBNL Seismic Network)



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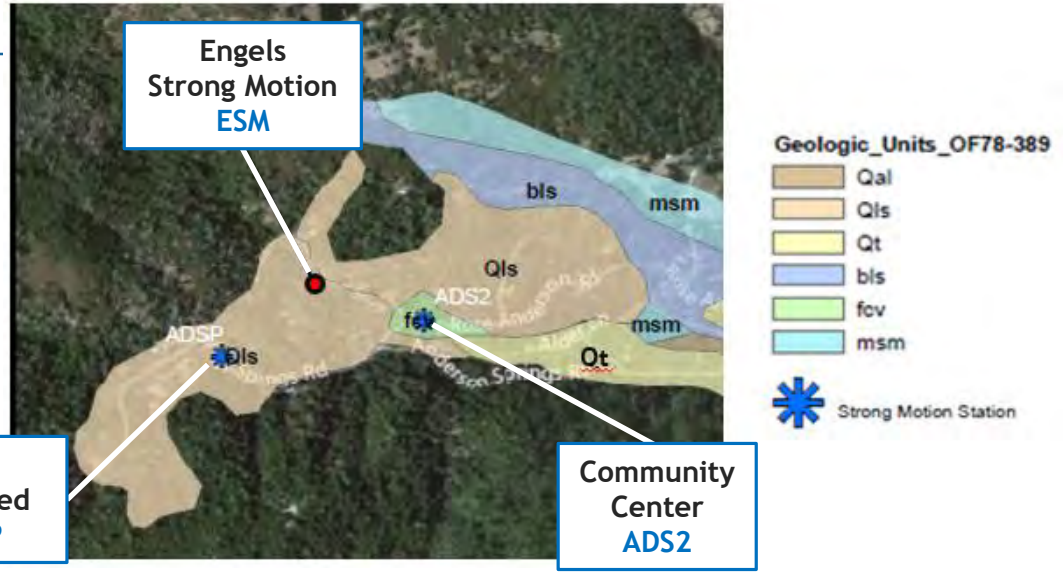
Relationships Between Anderson Springs Strong Motion Stations For Reference



Anderson Springs Community Center ADS2

- Sited on bedrock (fcv)
- Higher shear-wave velocities
- Consistently lower peak ground acceleration than:
  - Current Engels Strong Motion ESM
  - Previous Fire-Damaged ADSP

Anderson Springs Engels Strong Motion ESM

- Sited on previous landslide deposits (Qls)
- Relatively thin soil overlying bedrock
- 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 Fire Damaged ADSP station
- Consistently higher peak ground acceleration than Community Center ADS2 (can be around 1.8x)

M 4.2 2018-05-09 19:58:30 Pacific Time					
Engels Strong Motion (ESM)					
HNE cm/sec²	**HNN cm/sec²**	**HNZ cm/sec²**	**Geometric Mean cm/sec²**	**g**	**% of g**
86.24	67.62	35.28	76.36	0.078	7.8
Anderson Springs (ADS2)					
HNE cm/sec²	**HNN cm/sec²**	**HNZ cm/sec²**	**Geometric Mean cm/sec²**	**g**	**% of g**
39.66	44.52	42.97	42.02	0.043	4.3

ADS2 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
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

LBNL / Calpine Strong Motion Data Network

Calpine Corporation has purchased four Nanometrics Titan 3C accelerometers and cables:

Equipment: $4,800 per sensor station

$4,060 Titan Accelerometer, Triaxial, +/-4g to +/-0.25g, DC-430Hz
$ 740 10m Cable, Seismometer 14-Pin Straight to Nanometrics Digitizer

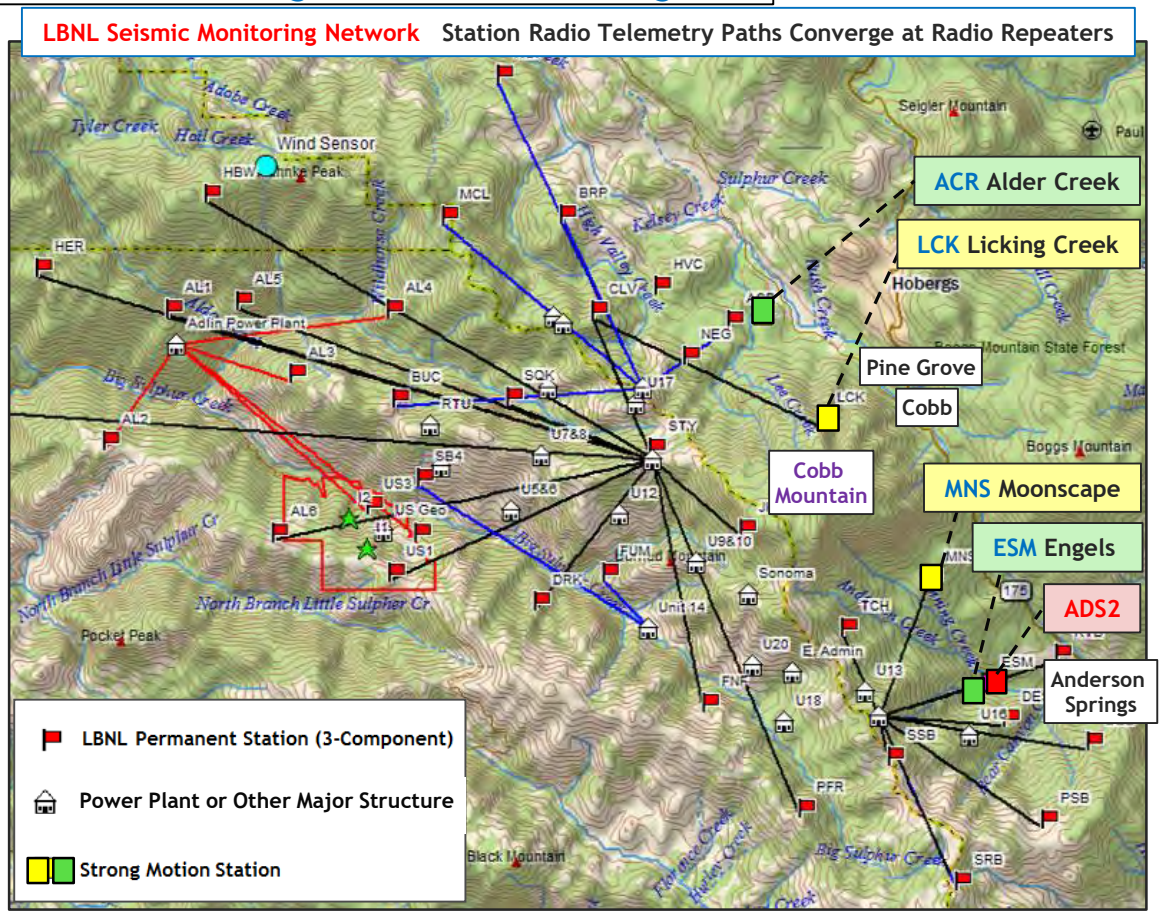
Installation: $2,500 per sensor station

Total: $7,300 per sensor station

Now integrated with existing LBNL seismic monitoring network:
- ESM Engels Strong Motion - Anderson Springs
- ACR Alder Creek – Cobb Area

Soon integrated with existing LBNL seismic monitoring network:
- LCK Licking Creek
- MNS Moonscape

These stations provide the following significant upgrades for improved strong motion data accuracy and reliability:
- Nanometrics Titan 3C Accelerometers
- Solar Power
- Radio Telemetry



Strong Motion Data Access (Web-Based Interface)

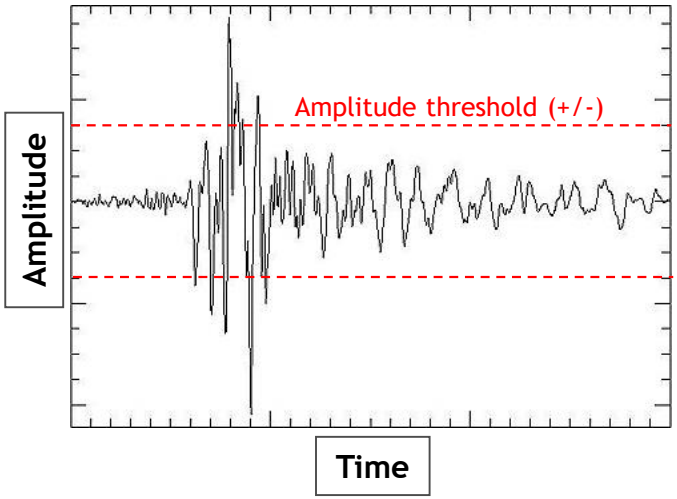
Calpine Corporation funded and provided technical oversight for the 2018-2019 development of a web based interface* allowing critical data from The Geysers Nanometrics Titan 3C accelerometers to be (1) extracted from wave files; (2) stored in a permanent database; and (3) recovered for analysis based on user-provided criteria (time range, peak ground acceleration threshold, station).

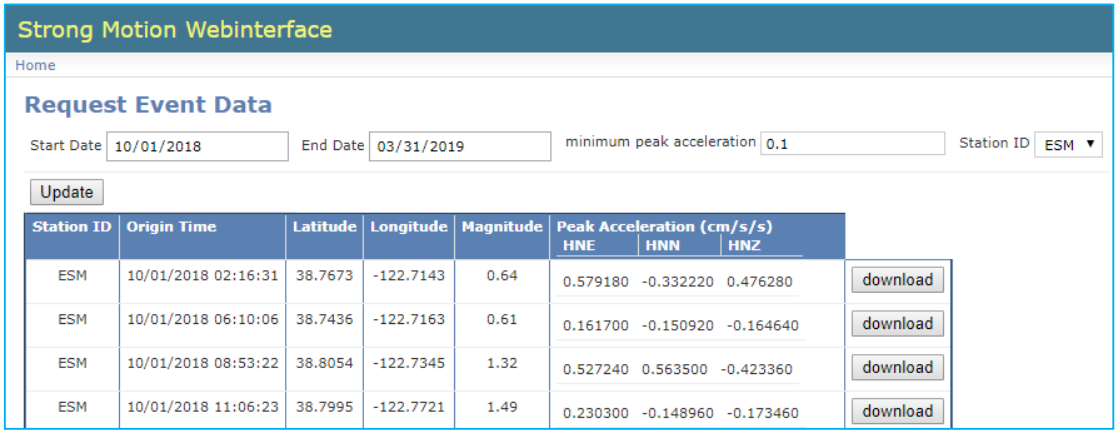
This interface is now fully functional for "real-time" access to peak ground acceleration, peak ground velocity, and peak ground displacement values from LBNL network integrated strong motion stations:

- ESM Engels Strong Motion - Anderson Springs
- ACR Alder Creek - Cobb Area
- DRH Hale Ranch - Midway between Aidlin power plant and Cloverdale

Data from the following stations will also be accessible at the web-based interface once installed:

- LCK Licking Creek
- MNS Moonscape





Station ID	Origin Time	Latitude	Longitude	Magnitude	Peak Acceleration (cm/s/s) HNE	HNN	HNZ	
ESM	10/01/2018 02:16:31	38.7673	-122.7143	0.64	0.579180	-0.332220	0.476280	download
ESM	10/01/2018 06:10:06	38.7436	-122.7163	0.61	0.161700	-0.150920	-0.164640	download
ESM	10/01/2018 08:53:22	38.8054	-122.7345	1.32	0.527240	0.563500	-0.423360	download
ESM	10/01/2018 11:06:23	38.7995	-122.7721	1.49	0.230300	-0.148960	-0.173460	download

* http://fracture.lbl.gov:8000/ Developed with Ramsey Haught (LBNL contractor) and Jarpe Data Solutions (subcontractor)

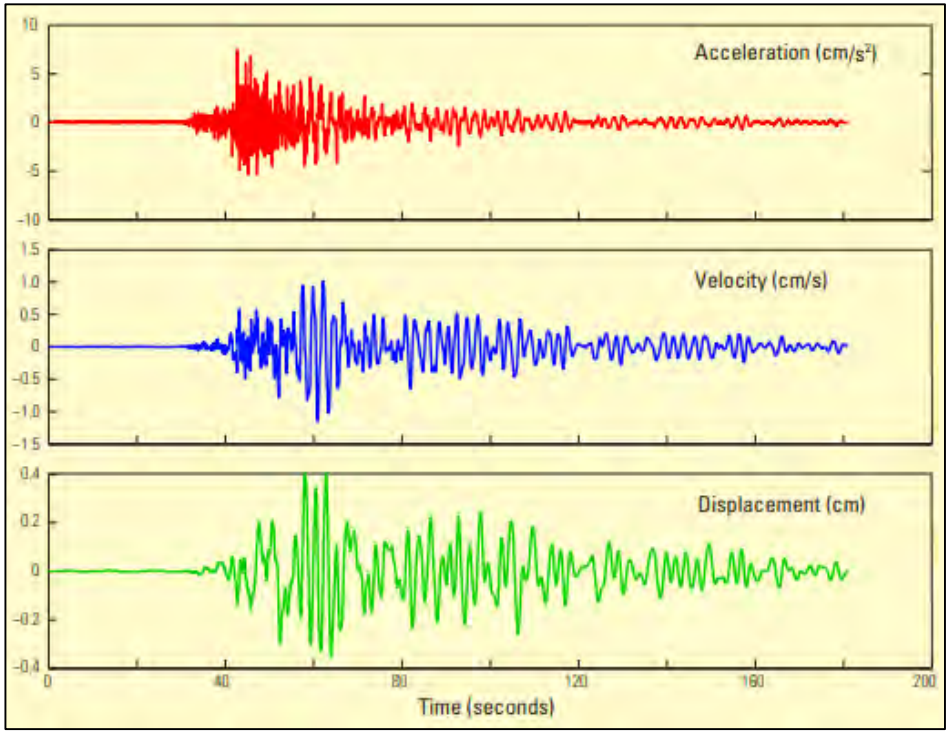
Strong Motion Data Visualization

PRISM (Processing and Review Interface for Strong-Motion data) software developed by the United States Geological Survey will be used for detailed strong motion data analysis.

The PRISM software package consists of two applications:

1) The PRISM record processing engine for automatically processing a large number of records and
2) A review tool that is an interactive graphical user interface (GUI) for visually inspecting, editing, and processing individual records.

USGS science for a changing world



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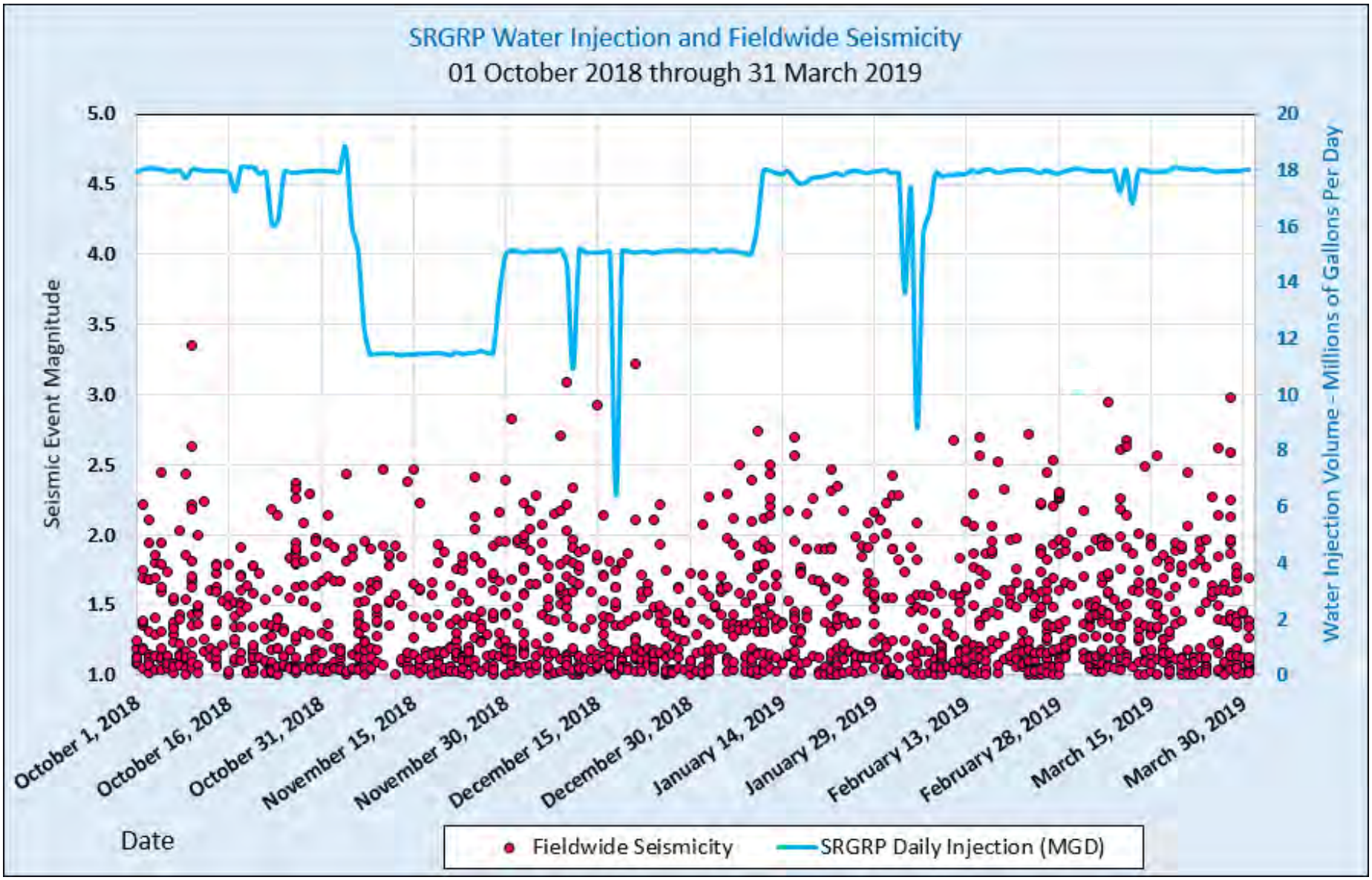
Santa Rosa Geysers Recharge Project

Water Injection Volume and Fieldwide Seismicity



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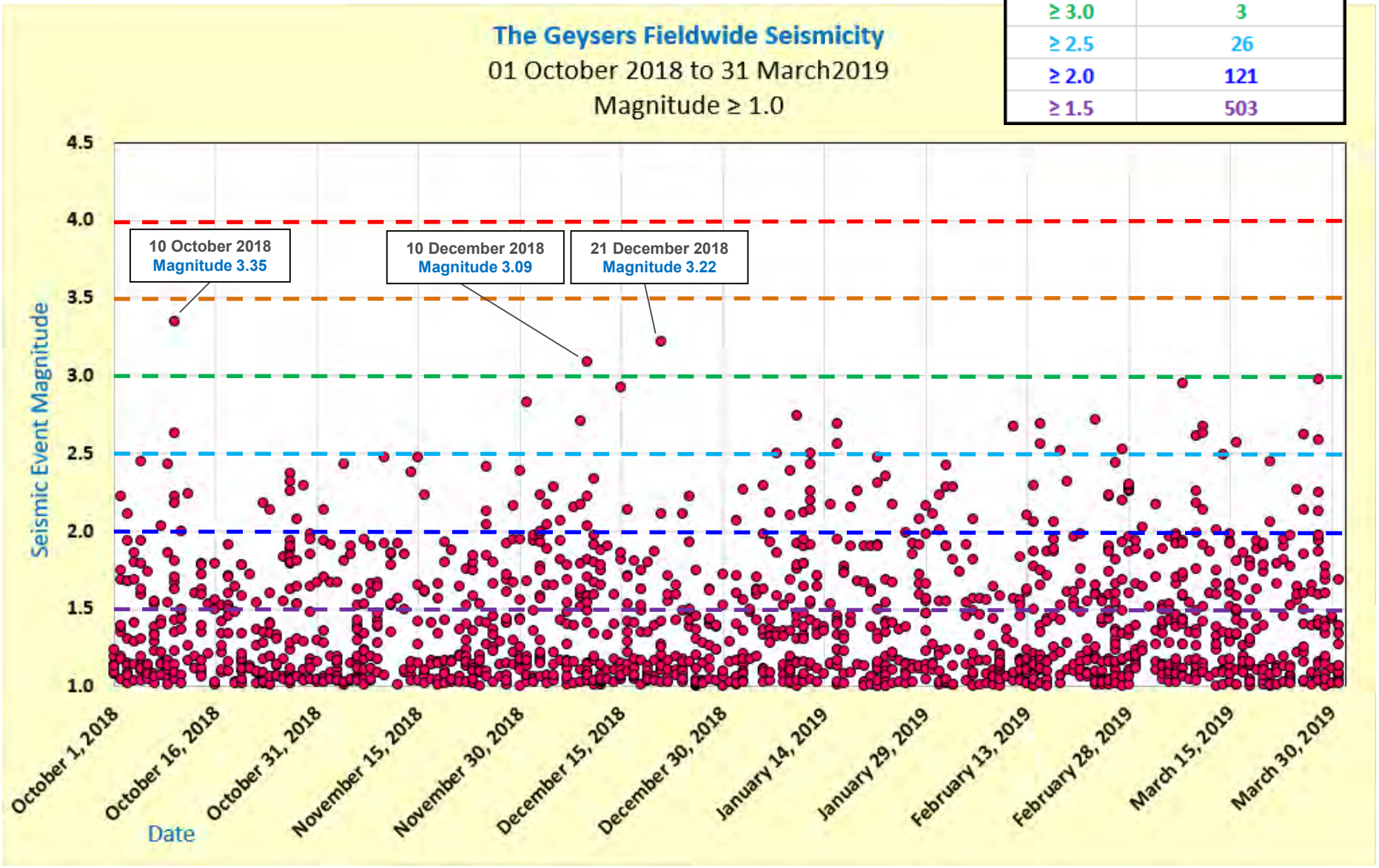
Field-wide Seismicity Analysis
01 October 2018 to 31 March 2019

Magnitude	Number of Events
≥ 4.0	0
≥ 3.5	0
≥ 3.0	3
≥ 2.5	26
≥ 2.0	121
≥ 1.5	503



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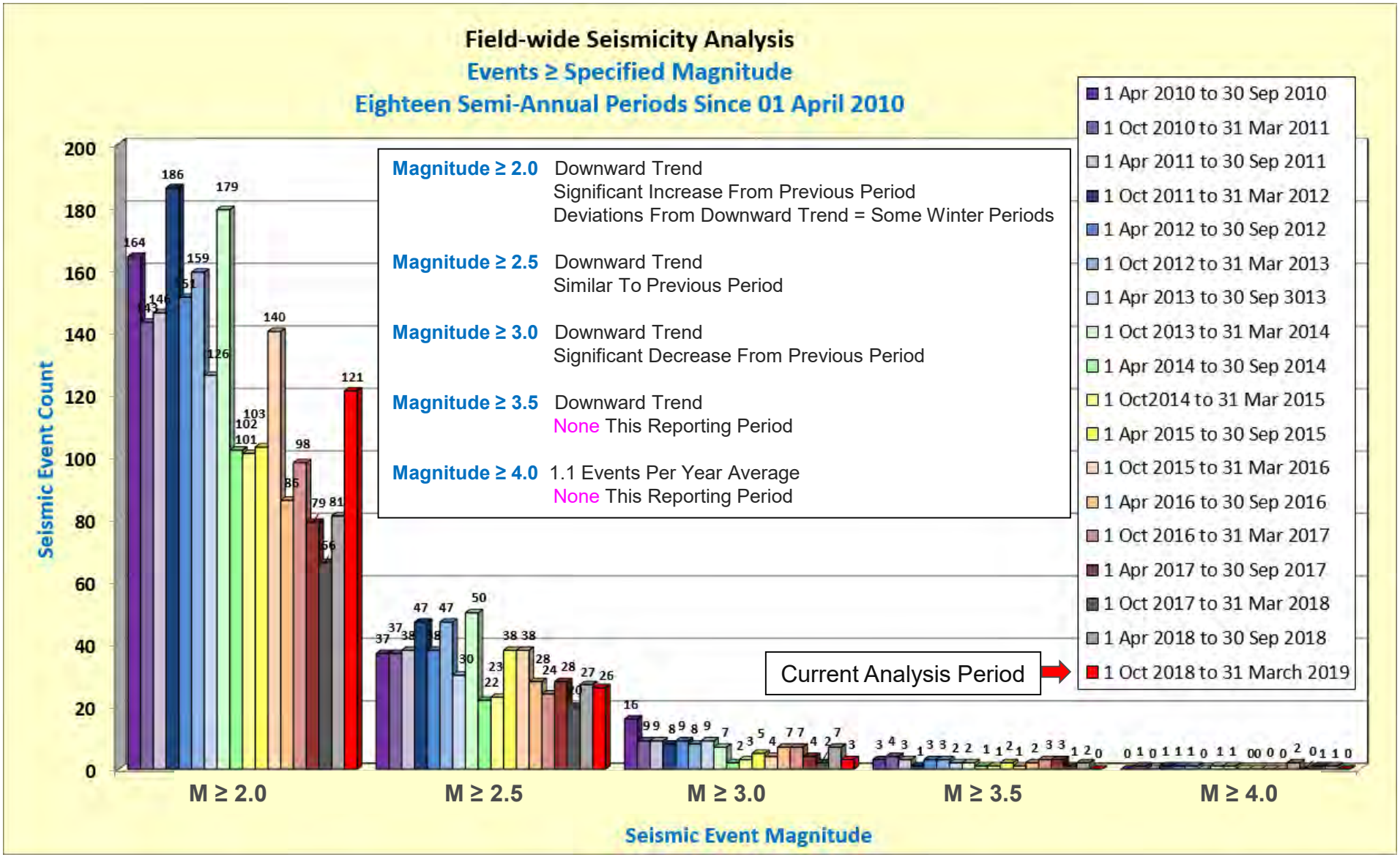
Field-wide Seismicity Analysis

Comparison of Eighteen Semi-annual Reporting Periods



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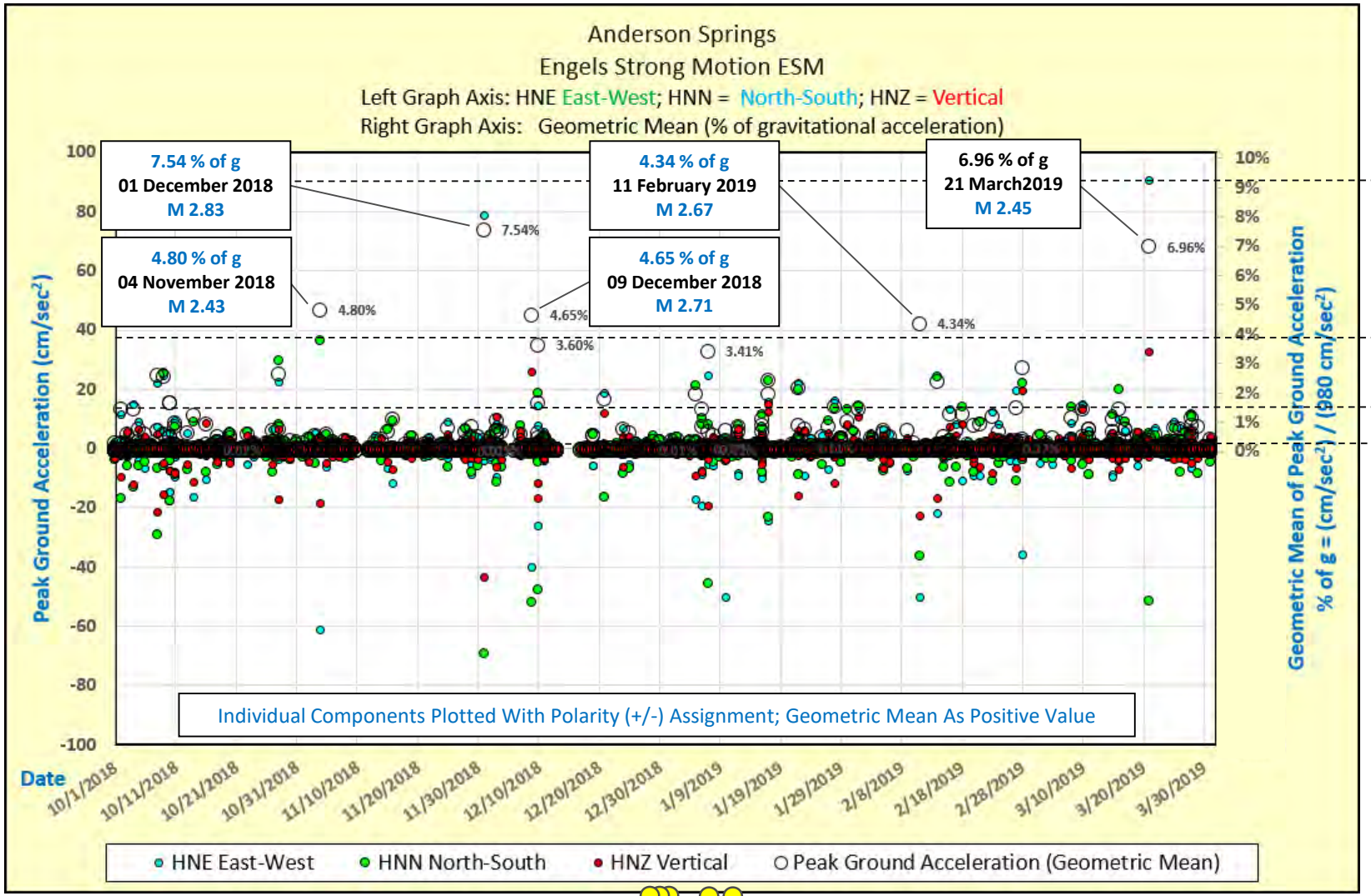
Anderson Springs Engels Strong Motion ESM



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

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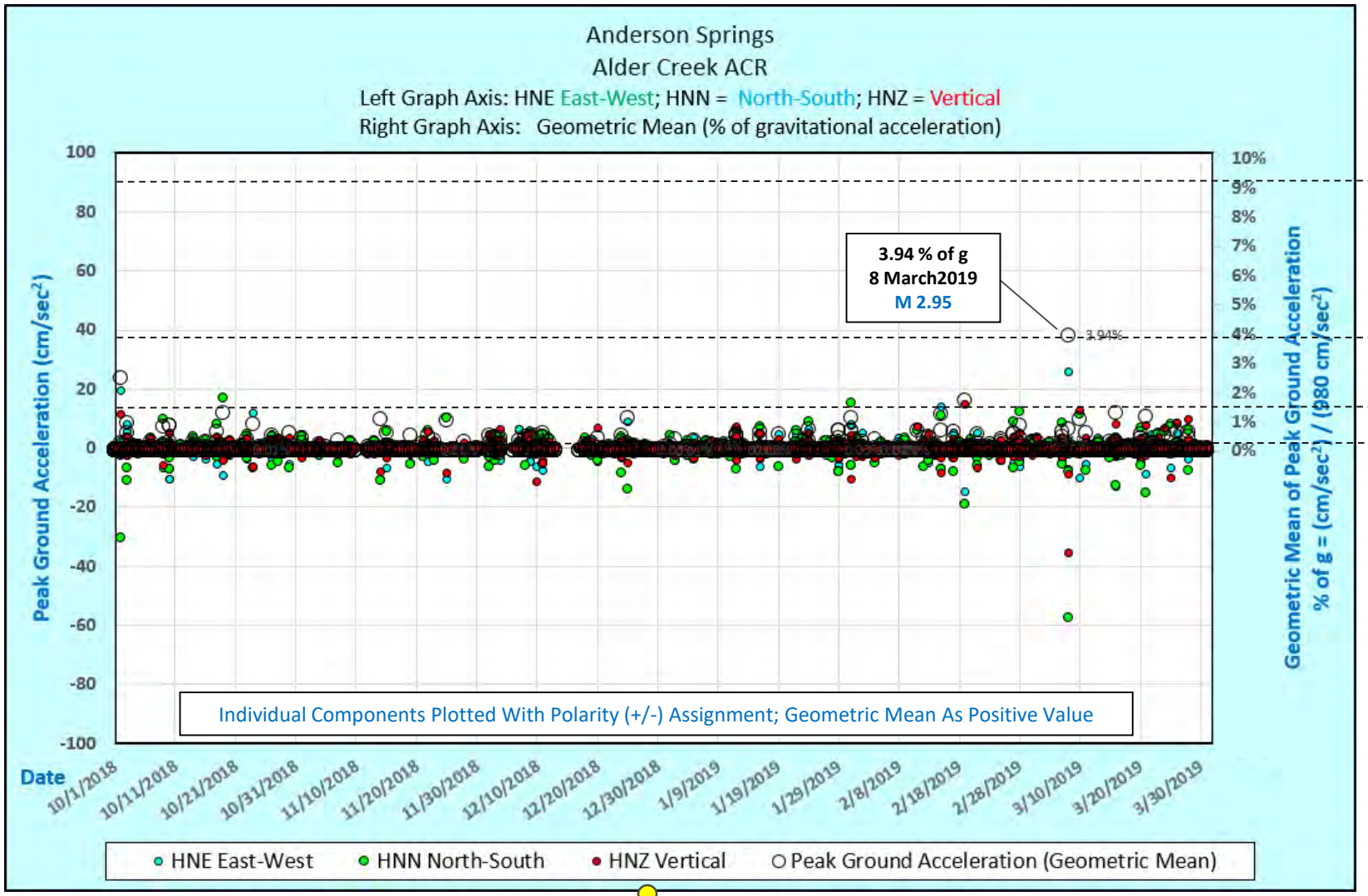
Anderson Springs Engels Strong Motion ESM



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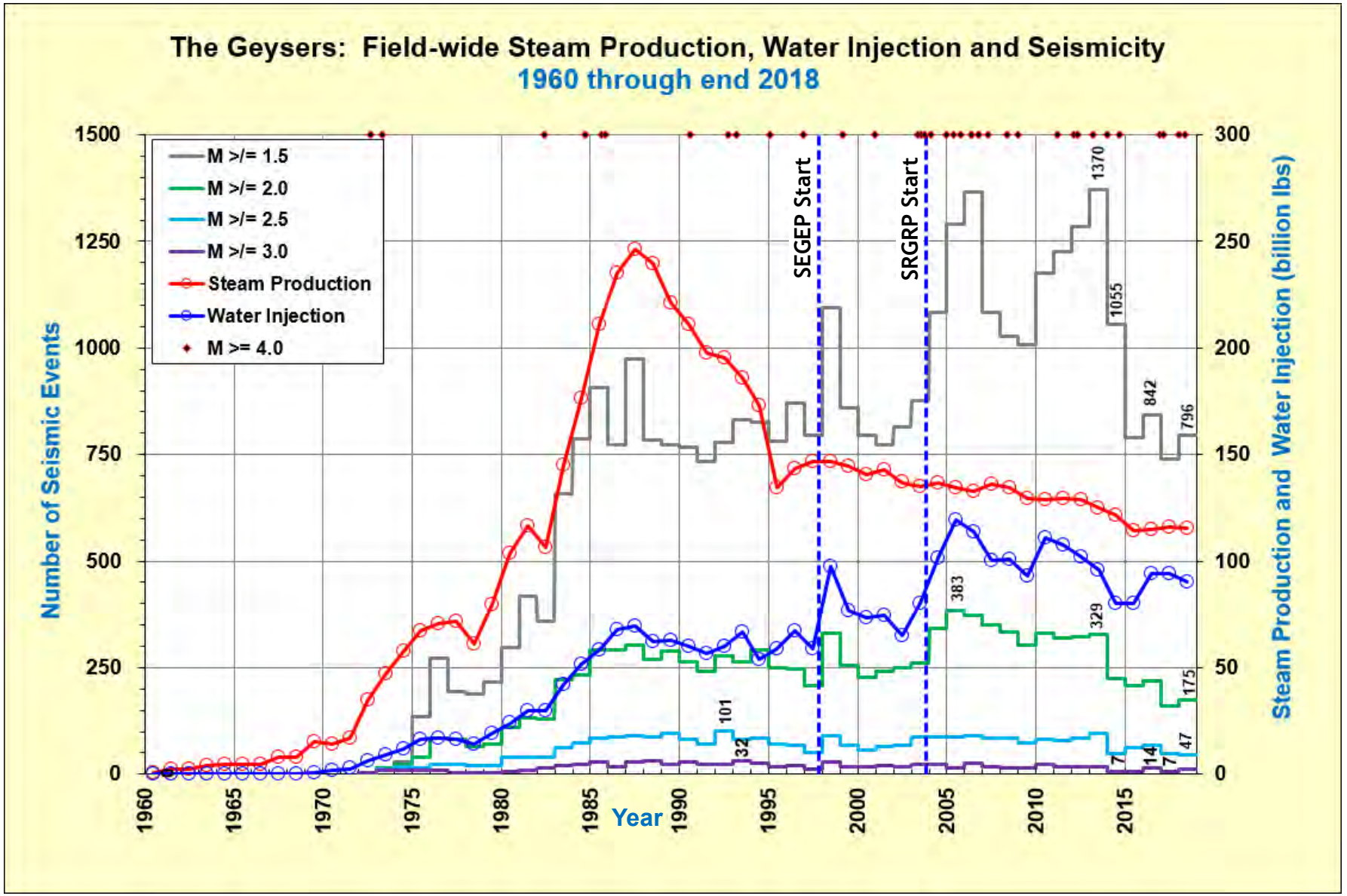
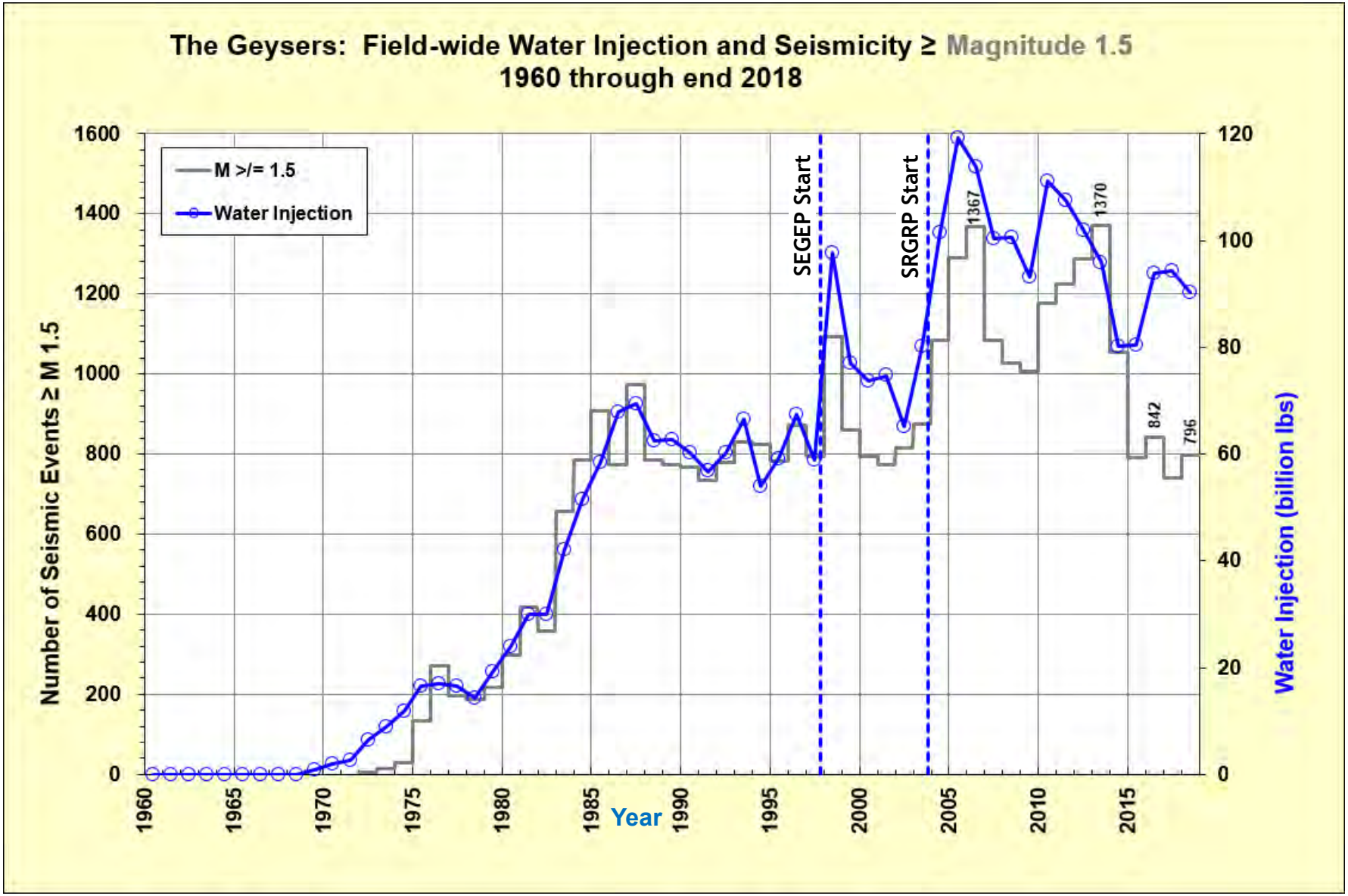
Modified Mercalli Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X

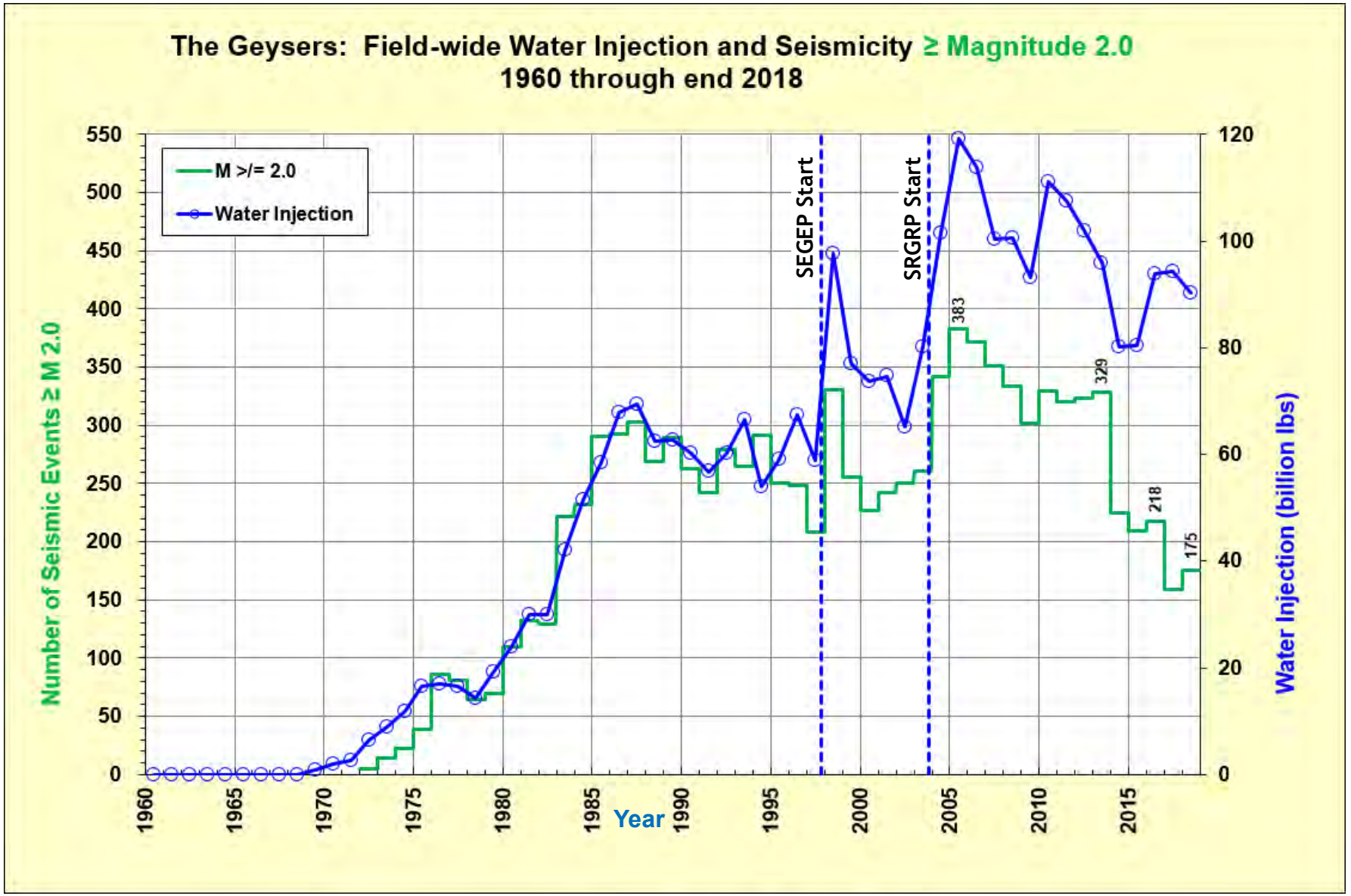
Yearly Field-wide Steam Production, Water Injection and Seismicity



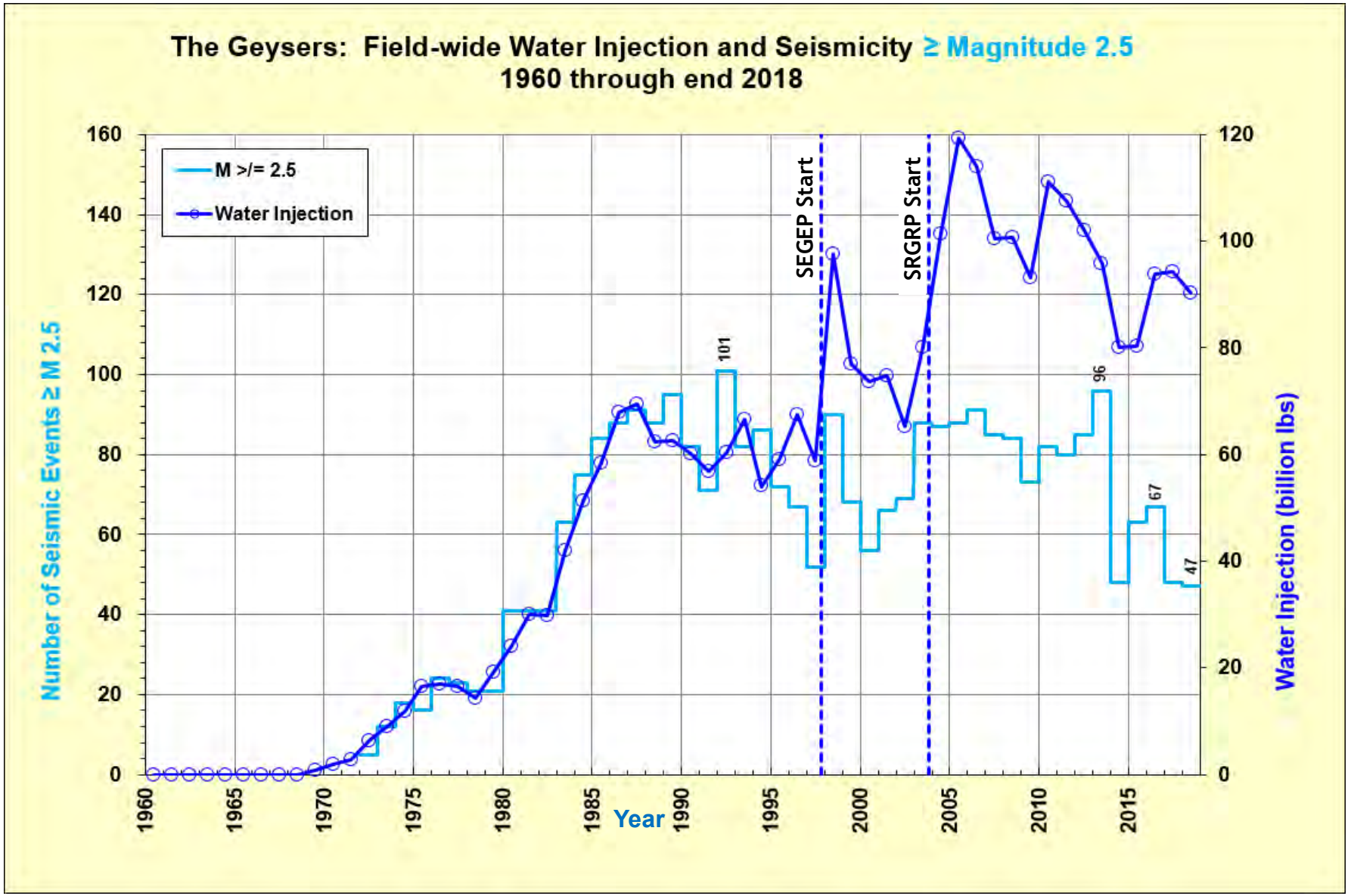
Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 1.5



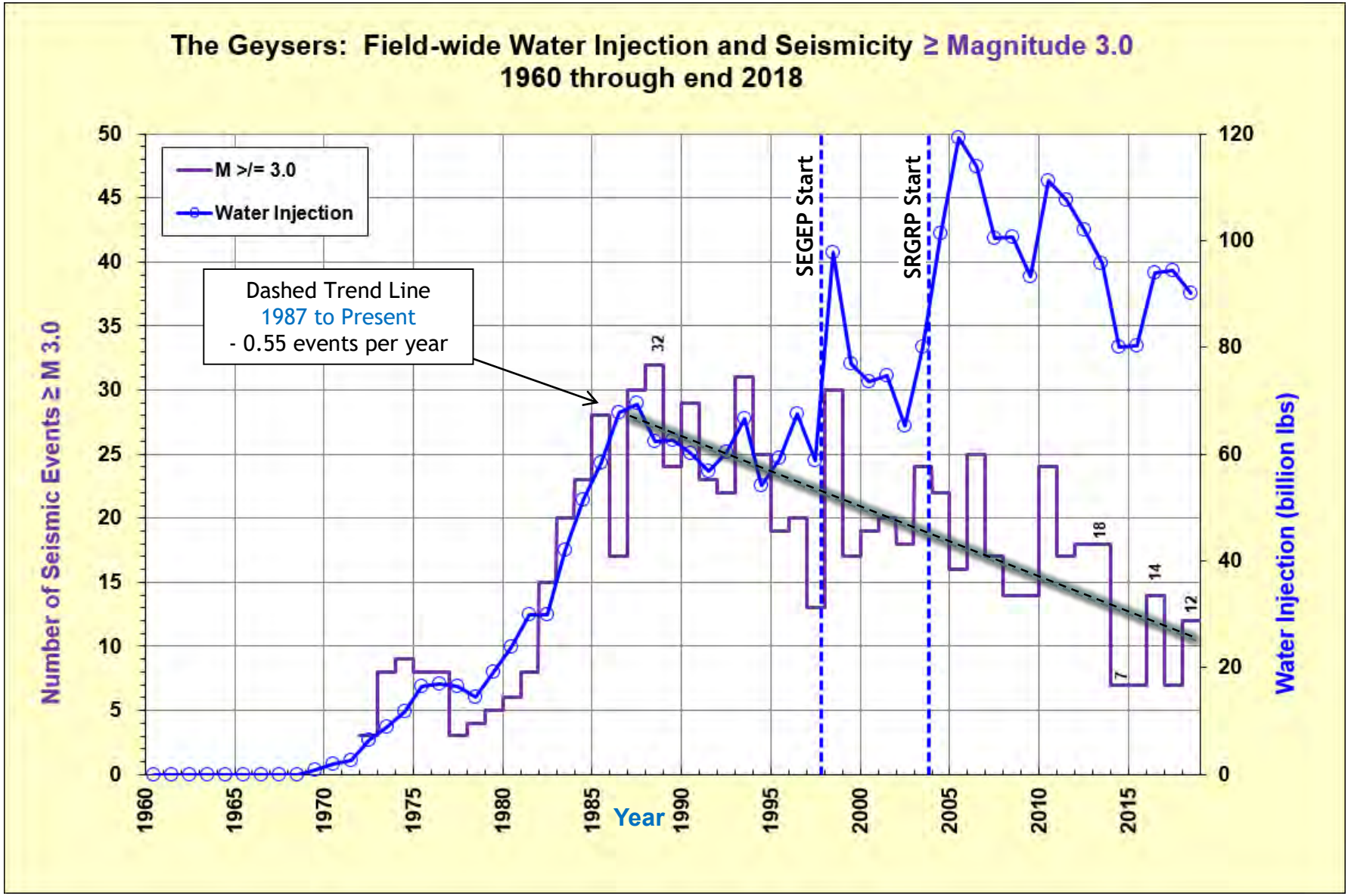
Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 2.0



Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 2.5



Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 3.0



Seismic Monitoring Advisory Committee Meeting

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

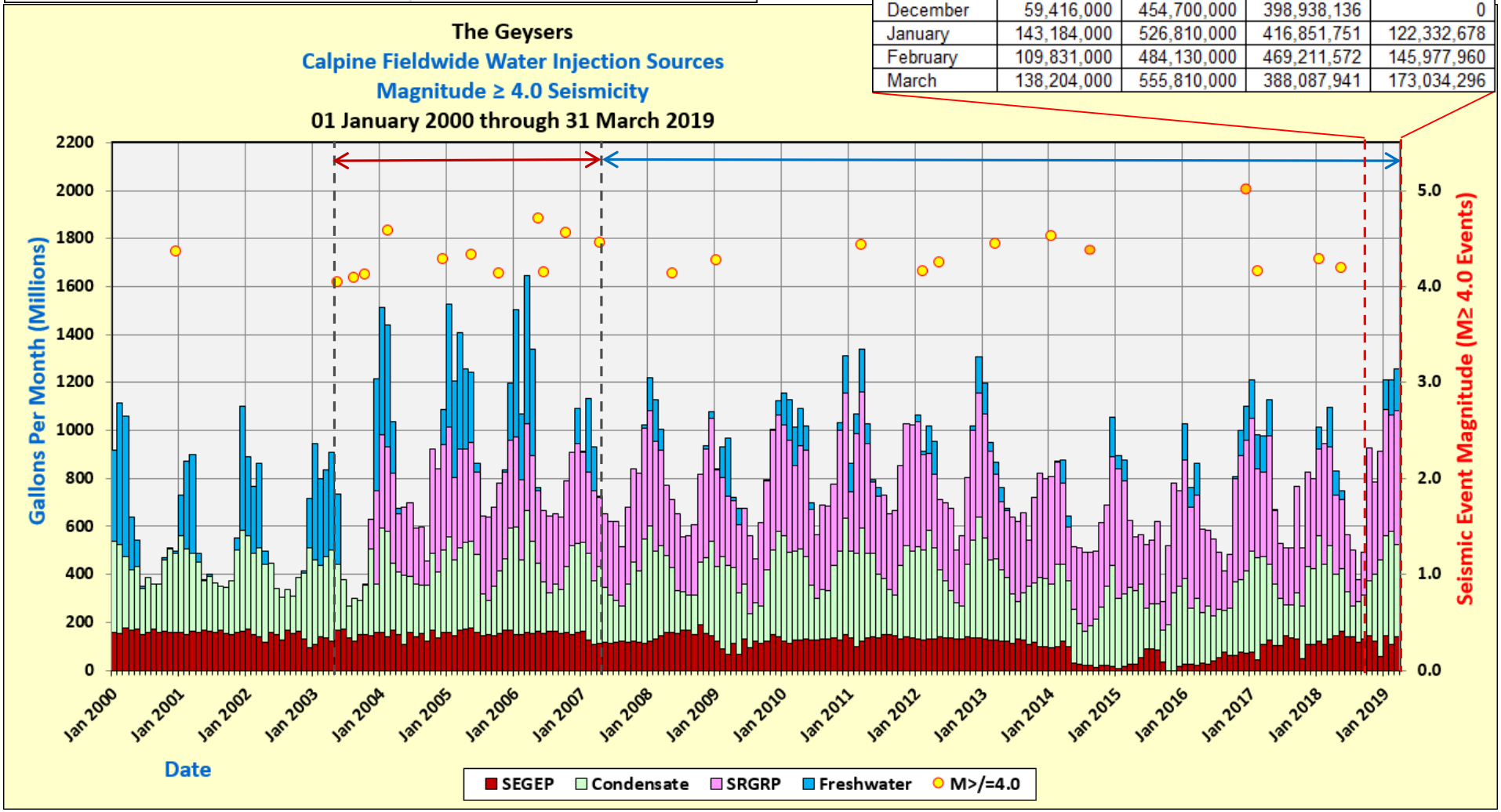
Average Number of Magnitude ≥ 4.0 Events Per Year Significantly Less Than 2003-2006 Peak

Time Period	Magnitude ≥ 4.0 Seismic Events
January 2003 through December 2006	2.5 per year
January 2007 through March 2019	1.1 per year

Water Supply for Reporting Period (Six Months)

Water Injection Sources (Gallons)

Month	SEGEP	SRGRP	Condensate	Fresh Water
October	142,354,000	552,770,000	231,426,846	0
November	121,137,000	385,290,000	278,993,444	0
December	59,416,000	454,700,000	398,938,136	0
January	143,184,000	526,810,000	416,851,751	122,332,678
February	109,831,000	484,130,000	469,211,572	145,977,960
March	138,204,000	555,810,000	388,087,941	173,034,296



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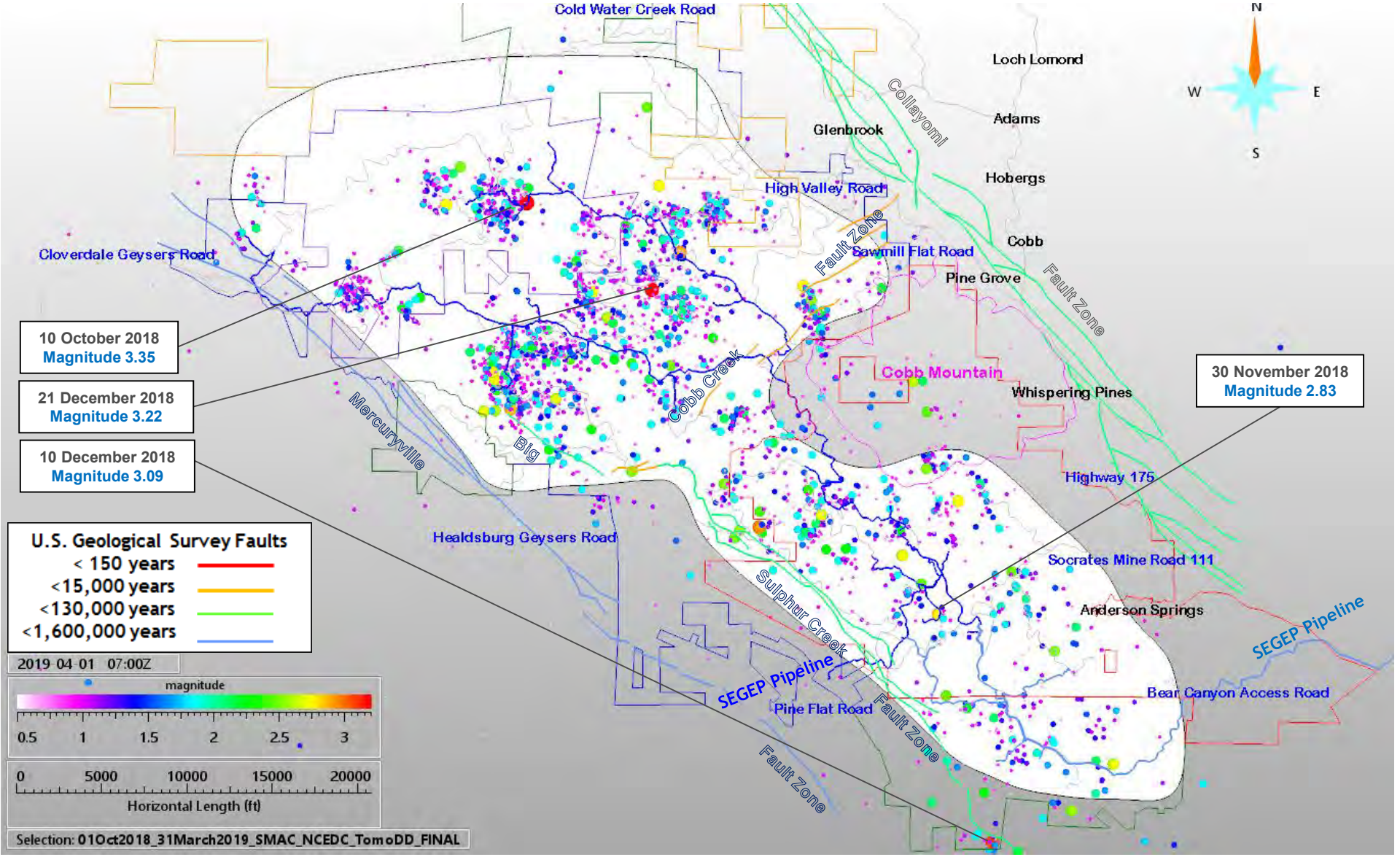
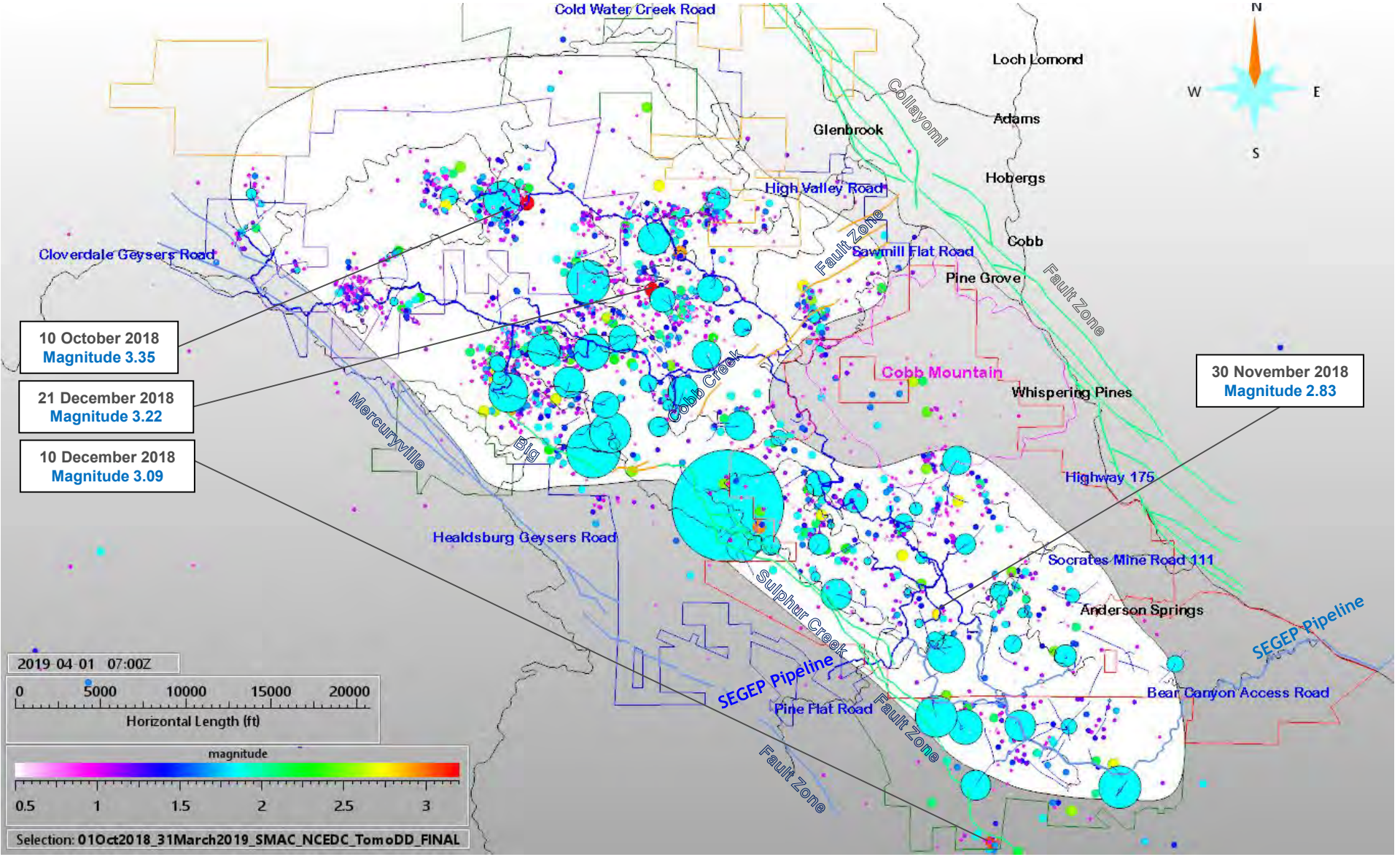
Field-wide Seismicity Animation

Seismic Events Color Scaled By Magnitude



Seismic Monitoring Advisory Committee Meeting

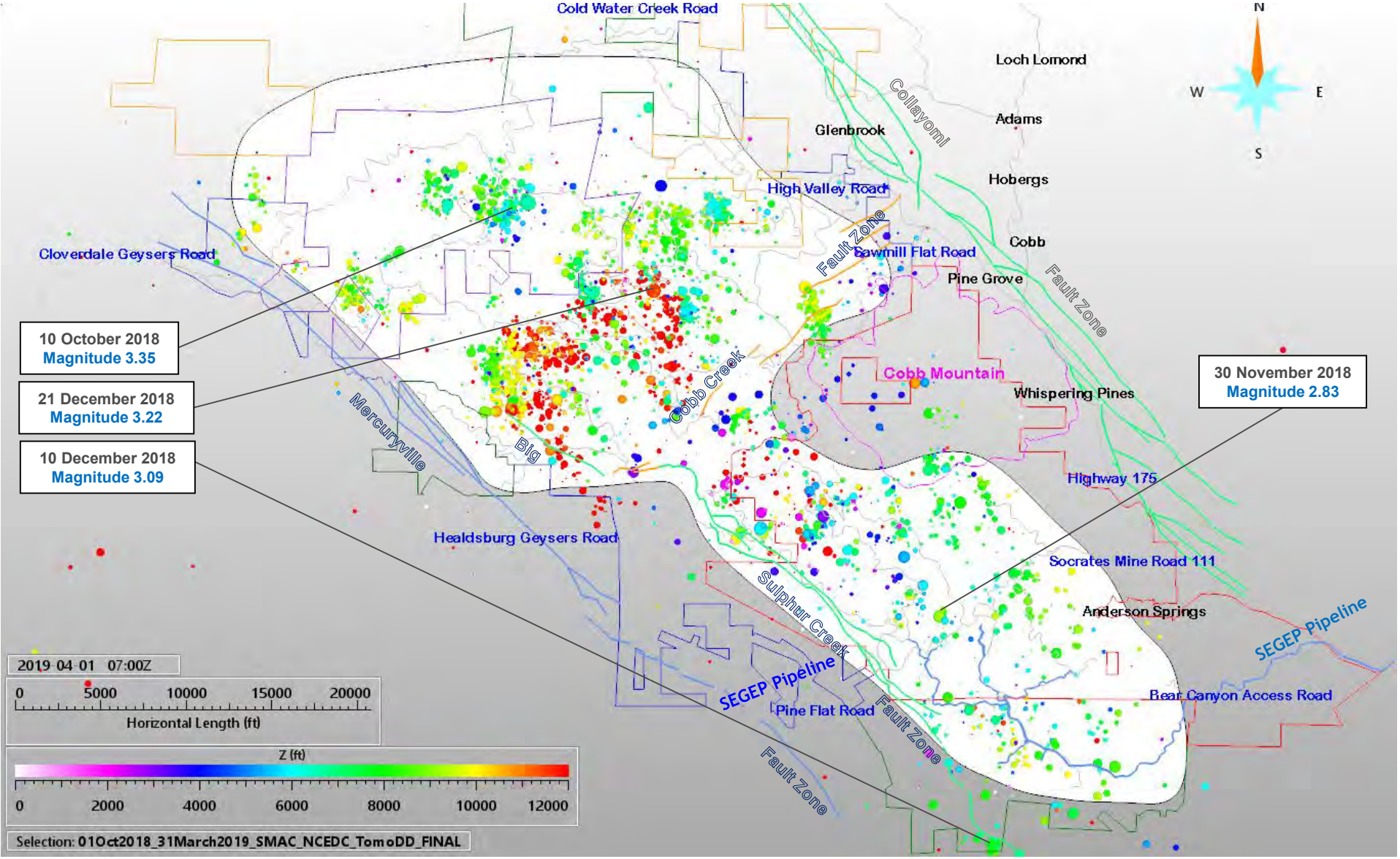
Field-wide Water Injection and Seismicity Animation



Seismic Monitoring Advisory Committee Meeting

Field-wide Seismicity Animation

Seismic Events Color Scaled By Depth



Seismic Monitoring Advisory Committee Meeting
Calpine Community Hotline

The communities continue to focus on efforts to recover from the Valley Fire, resulting in only two calls to the Calpine Community Hotline during the current reporting period of 01 October 2018 to 31 March 2019:

Magnitude 2.83 Seismic Event

Date and Time: 30 November 2018 at 20:37:58 Pacific Time
01 December 2018 at 04:37:58 UTC
Latitude: North 38.77183
Longitude: West 122.73183
Depth: 6529 Feet (1.99 km) Below Sea Level

Magnitude 2.45 Seismic Event

Date and Time: 21 March 2019 at 06:51:36 Pacific Time
21 March 2019 at 13:51:36 UTC
Latitude: North 38.77733
Longitude: West -122.71967
Depth: 4888 Feet (1.49 km) Below Sea Level

Anderson Springs Calls

30 November 2018 at 11:18 am

Large short duration jolt that shook the house and caused me to me yell - quite strong.

21 March 2019 at 10:12 am

Just a shake but a fairly strong shake. Guessing it was close but it didn't last very long.