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A GENERATION AHEAD, today

Seismic Monitoring Advisory Committee Meeting

17 November 2014
Geothermal Visitors Center
Middletown, California

Reporting Period:
01 April 2014 to 30 September 2014

Craig Hartline
Senior Geophysicist
Calpine Corporation

CLEAN MODERN EFFICIENT FLEXIBLE POWER GENERATION

Seismic Monitoring Advisory Committee Meeting
Calpine Presentation Agenda
Reporting Period 01 April 2014 to 30 September 2014

- Magnitude 6.02 South Napa Earthquake
- Triggered Geysers Seismic Event Analysis
- Field-wide Seismicity Analysis
- Seismicity Hotline
- Yearly Field-Wide Water Injection and Seismicity
- Monthly Field-Wide Water Injection and Seismicity
- Strong Motion Sensor Station Analysis
- 3D Visualization and Structural Model Building
- Calpine Surface Geology Mapping Project
- Additional Seismic Monitoring and Research

- Reference Items

Seismic Monitoring Advisory Committee Meeting
Magnitude 6.02 South Napa Earthquake
Triggered Seismic Event Analysis

24 August 2014	South Napa Earthquake at 03:20 Pacific Time
24 August 2014	Calpine Seismic Event Analysis Begins at 03:25 Pacific Time
26 August 2014	Calpine contacted Dr. David Oppenheimer of the United States Geological Survey (USGS)

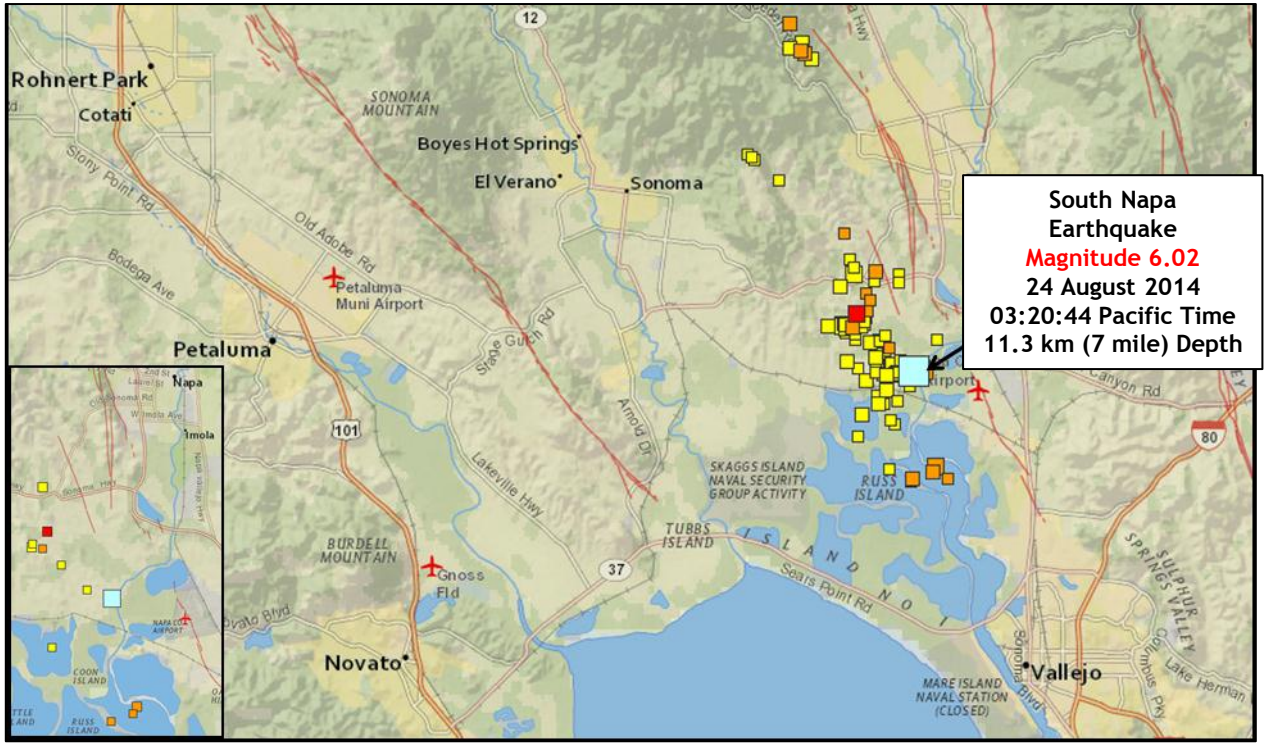
Station COB strong motion values as expected, based on distance and energy of M 6.02 event:

COB: 14.63 cm/sec^2 0.015 g or 1.5 % of g; Modified Mercalli Intensity IV

However, stations ADSP and ADS2 strong motion values approximately 8-10 times expected:

ADSP: 143.99 cm/sec^2 0.147 g or 14.7 % of g; Modified Mercalli Intensity VI

ADS2: 130.75 cm/sec^2 0.133 g or 13.3 % of g; Modified Mercalli Intensity VI



M 6.0 South Napa Earthquake (blue square)
Yellow, orange and red squares are progressively more recent aftershocks.

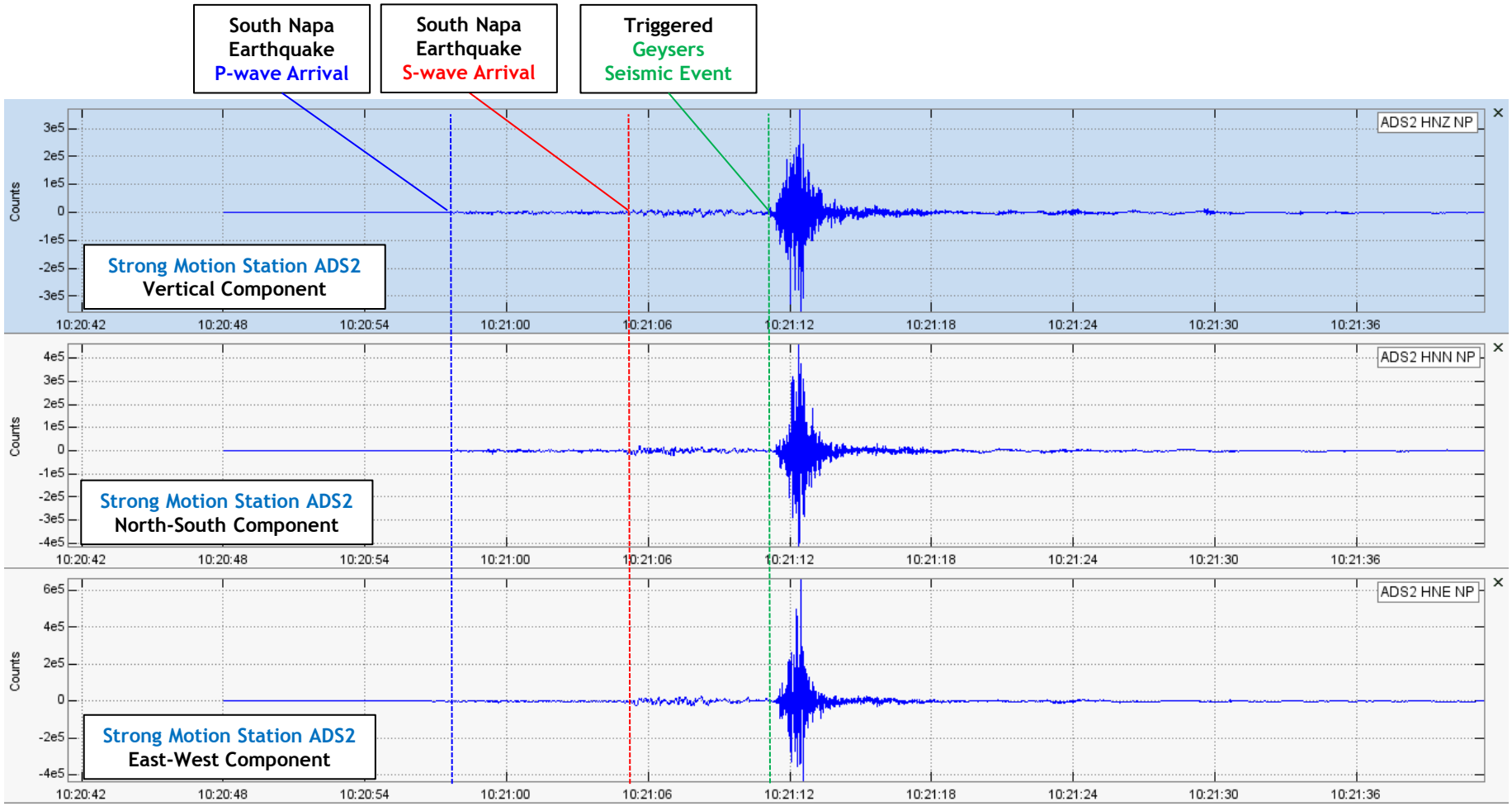
Inset at lower left shows M 6.02 earthquake location and eleven aftershocks of magnitude ≥ 2.5.

These images were created using interactive mapping software available at the USGS Earthquake Hazard Program website: http://earthquake.usgs.gov/earthquakes/map/

Seismic Monitoring Advisory Committee Meeting
Magnitude 6.02 South Napa Earthquake
Triggered Seismic Event Analysis

29 August 2014 The USGS was quite busy with investigation of South Napa Earthquake
However, they rapidly provided an initial determination:
- Anderson Springs ADSP and ADS2 contaminated by a local "interfering" earthquake
- Local earthquake was not isolated by *automated* event processing

Post-event manual processing was requested by Dr. David Oppenheimer



This slide modified from an image provided by Dr. David Oppenheimer of the United States Geological Survey

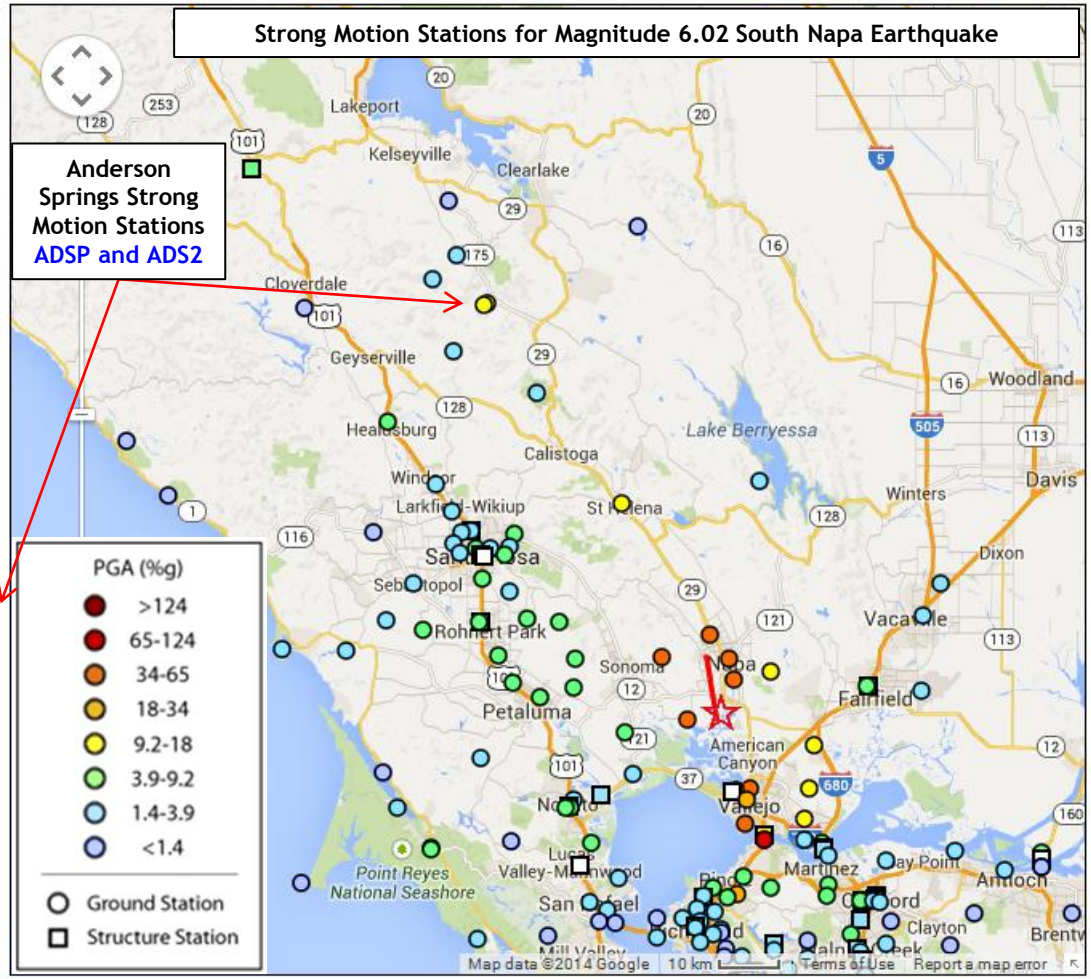
Seismic Monitoring Advisory Committee Meeting
Magnitude 6.02 South Napa Earthquake
Triggered Seismic Event Analysis

16 October 2014

USGS submitted strong motion records to the Center for Engineering Strong Motion Data
ADSP and ADS2 not consistent with regional patterns for peak ground acceleration

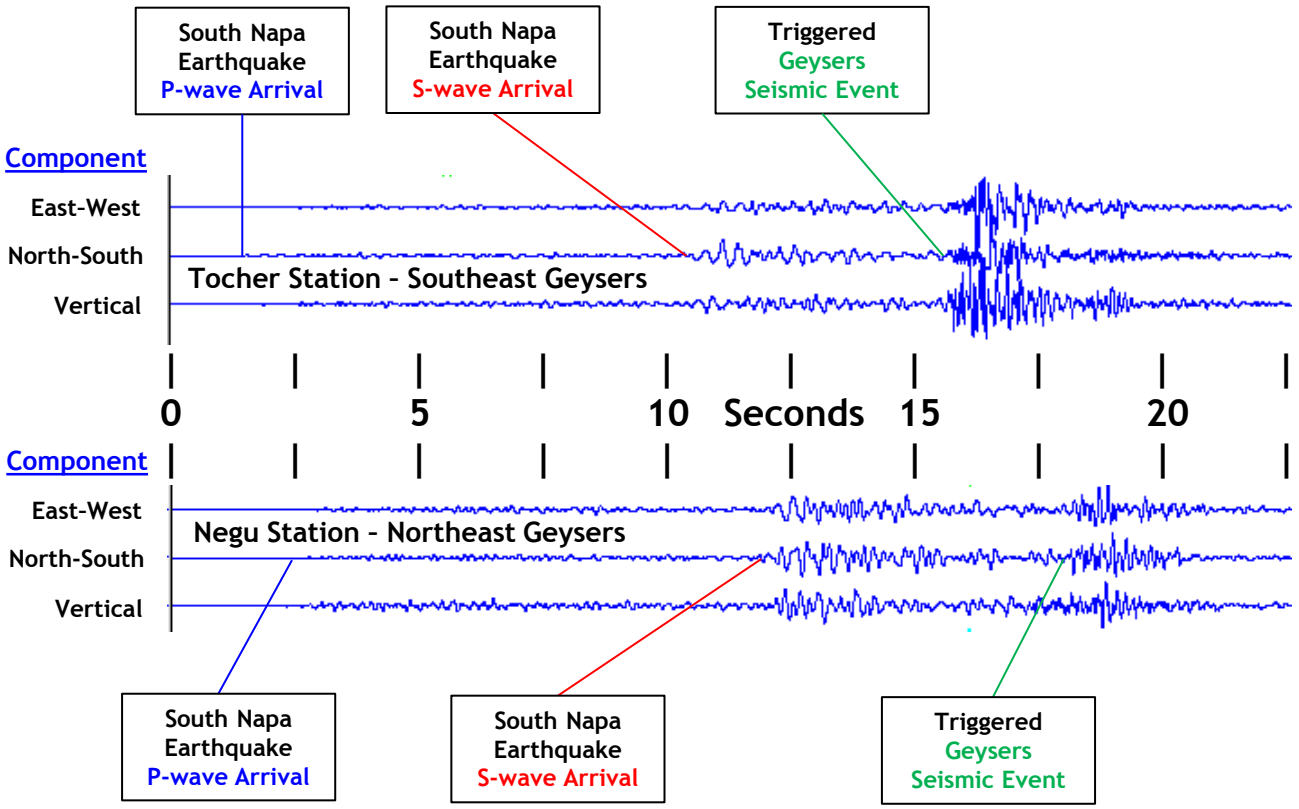
event link: http://strongmotioncenter.org/cgi-bin/CESMD/iqr_dist_DM2.pl?iqrID=SouthNapa_24Aug2014_72282711&SFlag=0&Flag=2

Station	Code /ID	Network	Distance (km)		Peak Ground Acceleration relative to g
			Epic.	Fault	
Crockett - Carquinez Br Geotech Array #1	68206	CGS	19.6	--	**0.995**
Main St, Napa, CA	N016	NCSN	9.1	4.4	**0.611**
Vallejo - Broadway & Sereno	68294	CGS	11.7	12.1	**0.469**
Crockett - Carquinez Br Geotech Array #2	68259	CGS	19.5	--	**0.436**
Napa; Fire Station No. 3	1765	USGS	12.3	3.3	**0.427**
Huichica Creek	NHC	NCSN	3.5	4.4	**0.403**
Napa - Napa College	68150	CGS	7.1	4.5	**0.375**
Mare Island	NMI	NCSN	16.7	16.8	**0.369**
Lovall Valley Loop Rd	N019B	NCSN	12.0	6.4	**0.342**
Vallejo; Fire Station	1759	USGS	13.4	13.6	**0.329**
Pinole - Adobe & Pinole Valley Rd	58368	CGS	26.3	26.9	**0.203**
Vallejo - Hwy 37/Napa River E Geo. Array	68310	CGS	11.0	--	**0.198**
Anderson Springs	ADSP	USGS	70.4	--	**0.174**
CA: Anderson Springs; Town Pool	ADS2	USGS	70.2	--	**0.159**
Vallejo - Carquinez/I80 East Bridge	68184	CGS	18.9	19.4	**0.149**
McCall Drive, Benicia, CA	C032	NCSN	20.3	20.6	**0.140**
Green Valley Road	NGVB	NCSN	11.5	9.7	**0.110**
St. Helena; Fire Station No. 17	1764	USGS	34.7	25.0	**0.104**
Lake Herman	NLH	NCSN	18.0	18.1	**0.094**

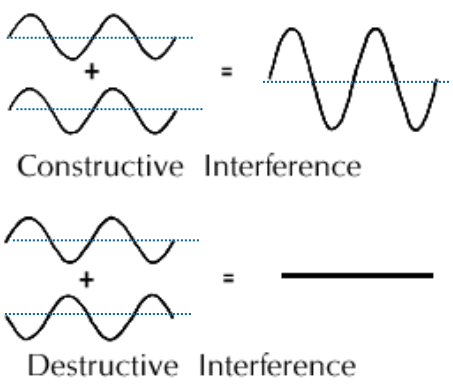


Seismic Monitoring Advisory Committee Meeting
Magnitude 6.02 South Napa Earthquake
Triggered Seismic Event Analysis

10 November 2014 Calpine acquired the most recent version of the Northern California Earthquake Data Catalog
Includes the most recent magnitude and hypocenter determination.
Below are *preliminary conclusions* for 2 of 32 Geysers seismic monitoring stations.



Note: Seismic wave interference complicates magnitude and hypocenter determination and decreases the reliability of the results.



Lawrence Berkeley National Laboratory (LBNL) contractor Ramsey Haught provided the MEQplot software allowing Calpine to analyze the individual recording stations, and assisted with the analysis above.

Dr. Ernie Major and Katie Boyle of LBNL also provided independent analysis for the stations above.

Seismic Monitoring Advisory Committee Meeting
Field-wide Seismicity Analysis
01 April 2014 to 30 September 2014

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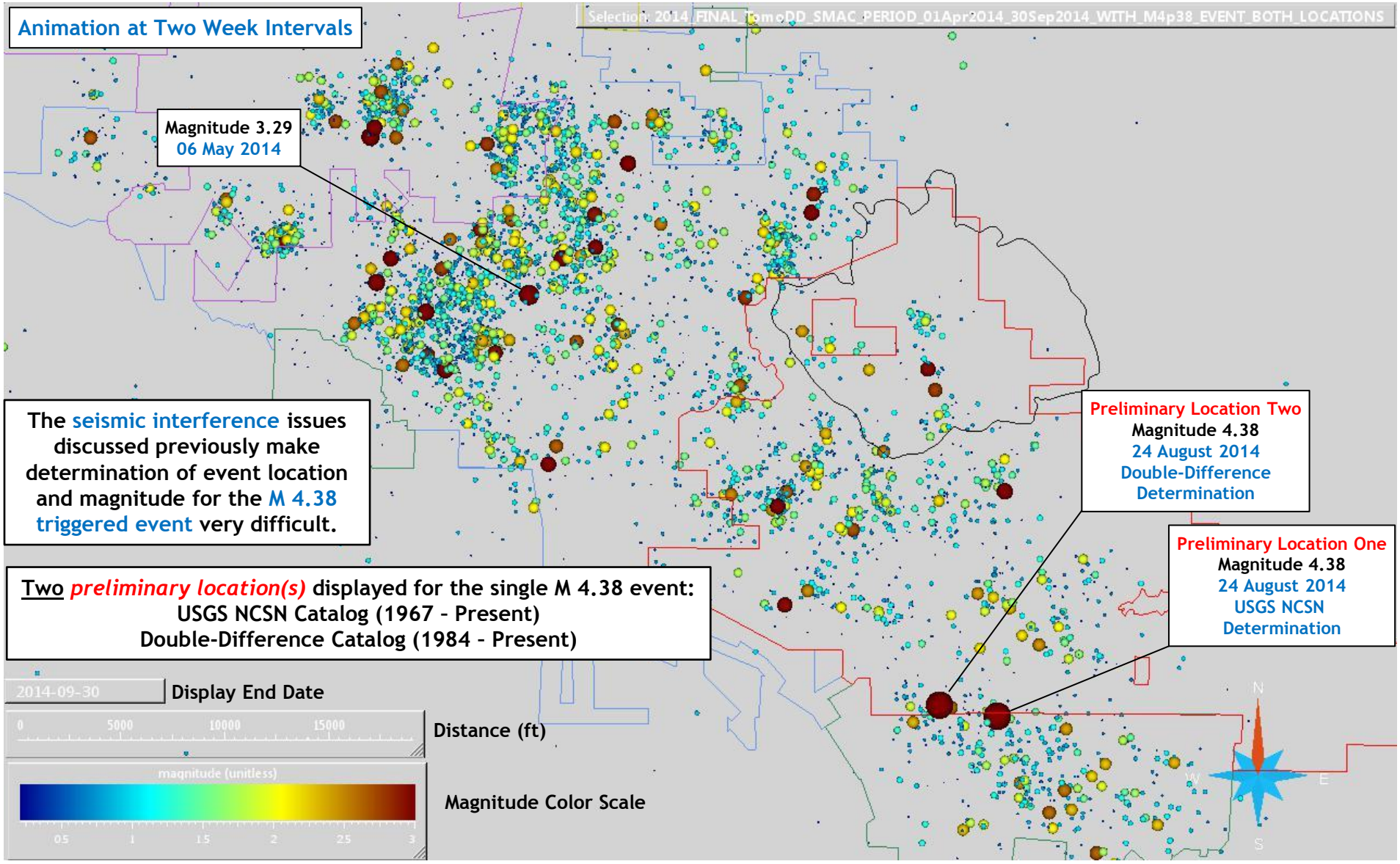

Seismic Monitoring Advisory Committee Meeting

Field-wide Seismicity Analysis
01 April 2014 to 30 September 2014

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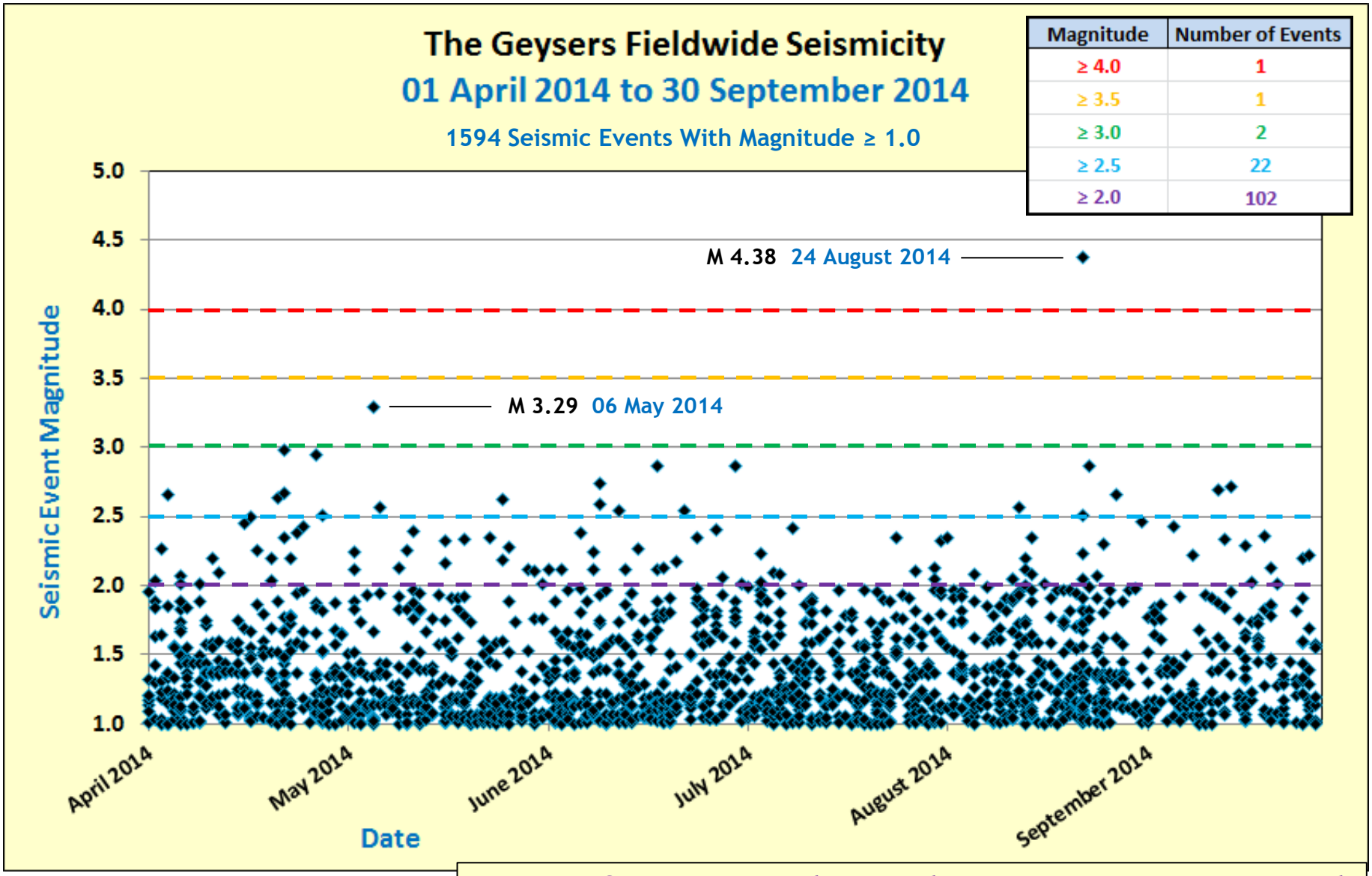

Note: 2280 Seismic Events With Magnitude ≥ 1.0 in Previous Reporting Period

Seismic Monitoring Advisory Committee Meeting
Field-wide Seismicity Analysis
01 April 2014 to 30 September 2014

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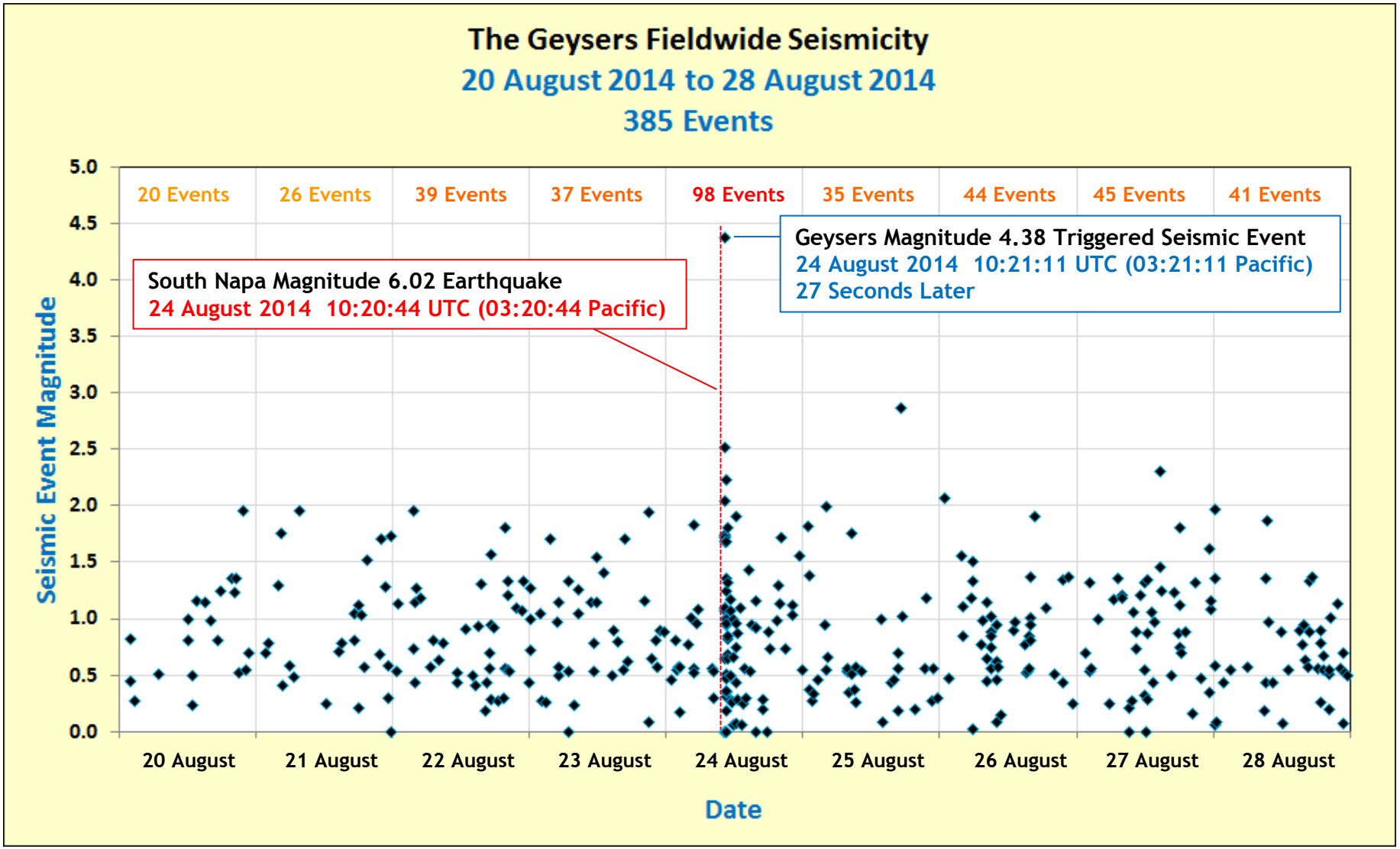
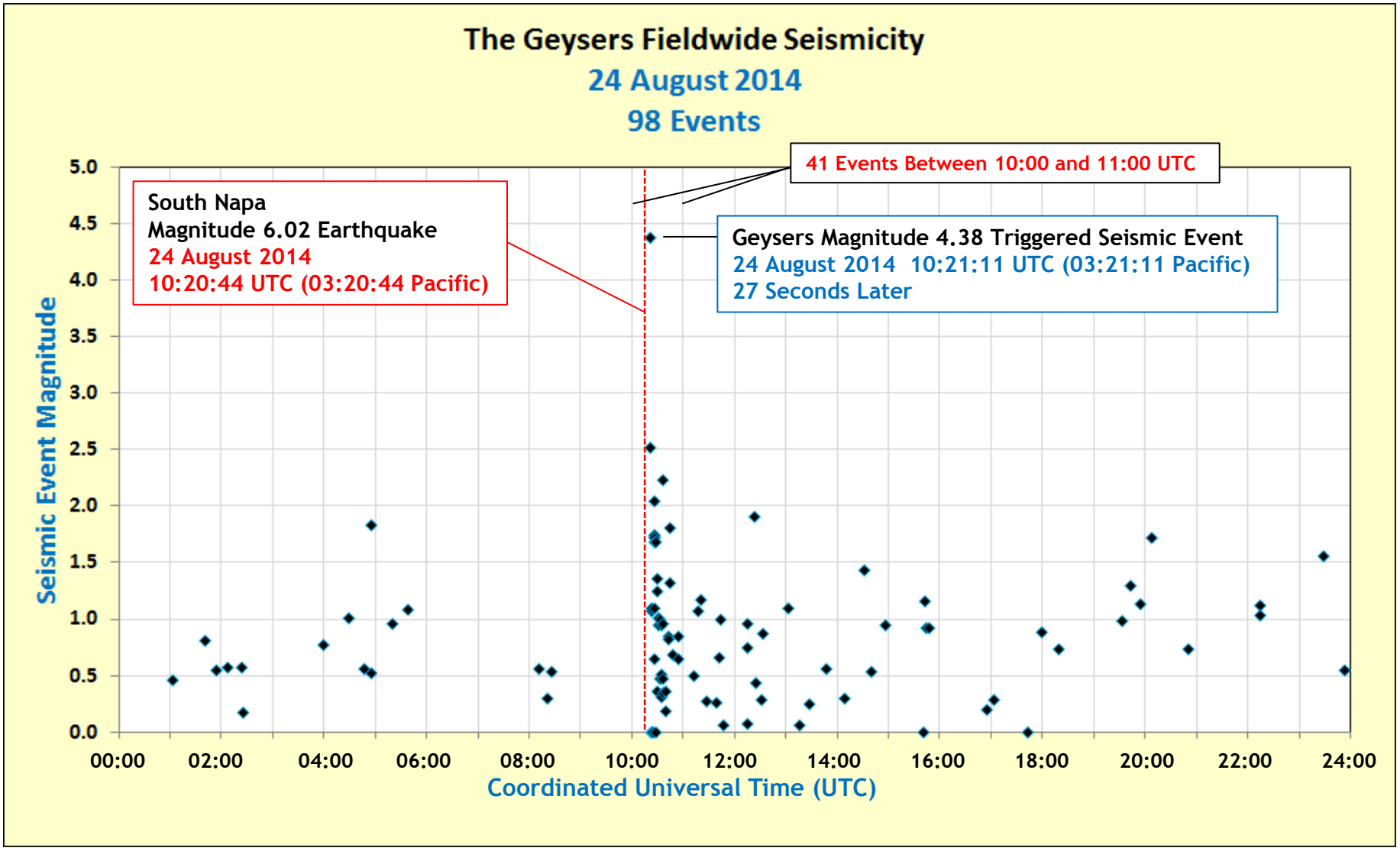


UTC = Coordinated Universal Time (London)
Full Event Parameters: 2014/08/24 10:20:44.06 38.21550 -122.31167 11.250 6.02 Mw 397 28 4 0.18 NCSN 72282711

Field-wide Seismicity Analysis
01 April 2014 to 30 September 2014



Seismic Monitoring Advisory Committee Meeting
01 April 2014 to 30 September 2014
Seismicity Hotline 1-877-4GEYSER (Toll Free)

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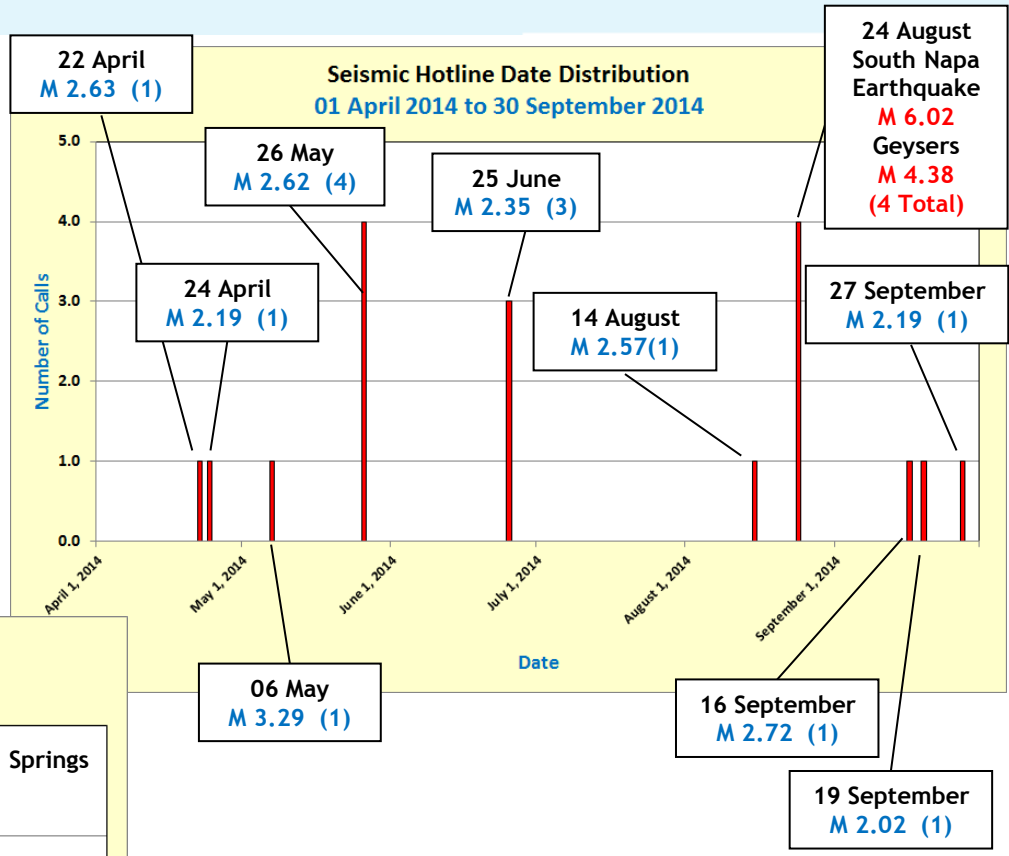
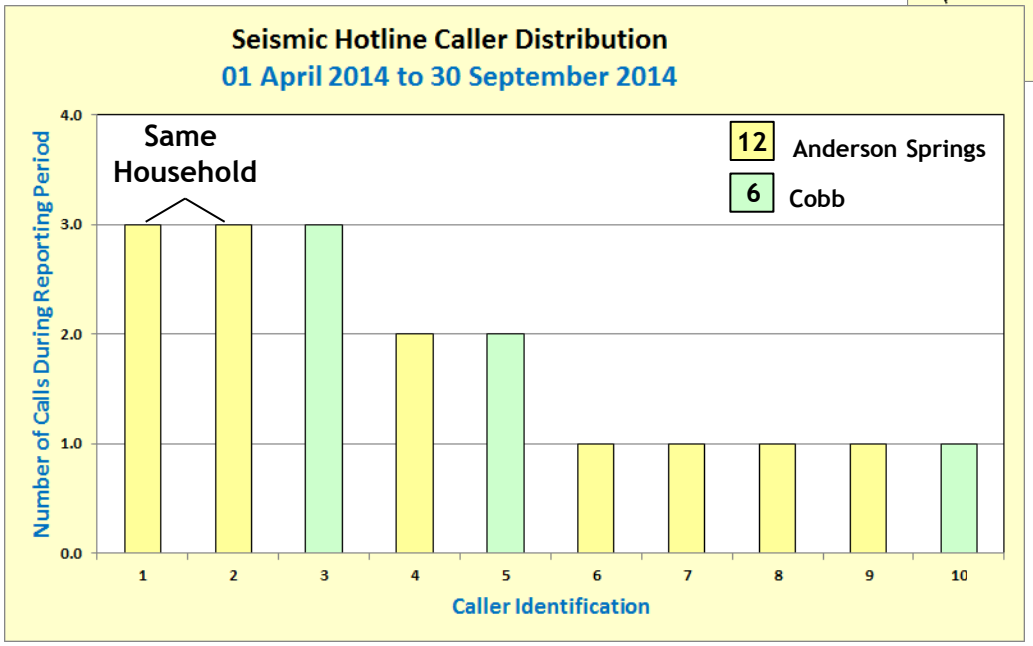
Calls transcribed, distributed and reviewed daily

Current Period
18 calls 01 April 2014 to 30 September 2014
4 calls related to: M 6.00 South Napa Earthquake
M 4.38 Triggered Geysers Event

Previous Period(s)
81 calls 01 April 2013 to 30 September 2013
57 calls 01 October 2013 to 31 March 2014





Field-wide Seismicity Analysis
Comparison of Nine Semi-annual Reporting Periods

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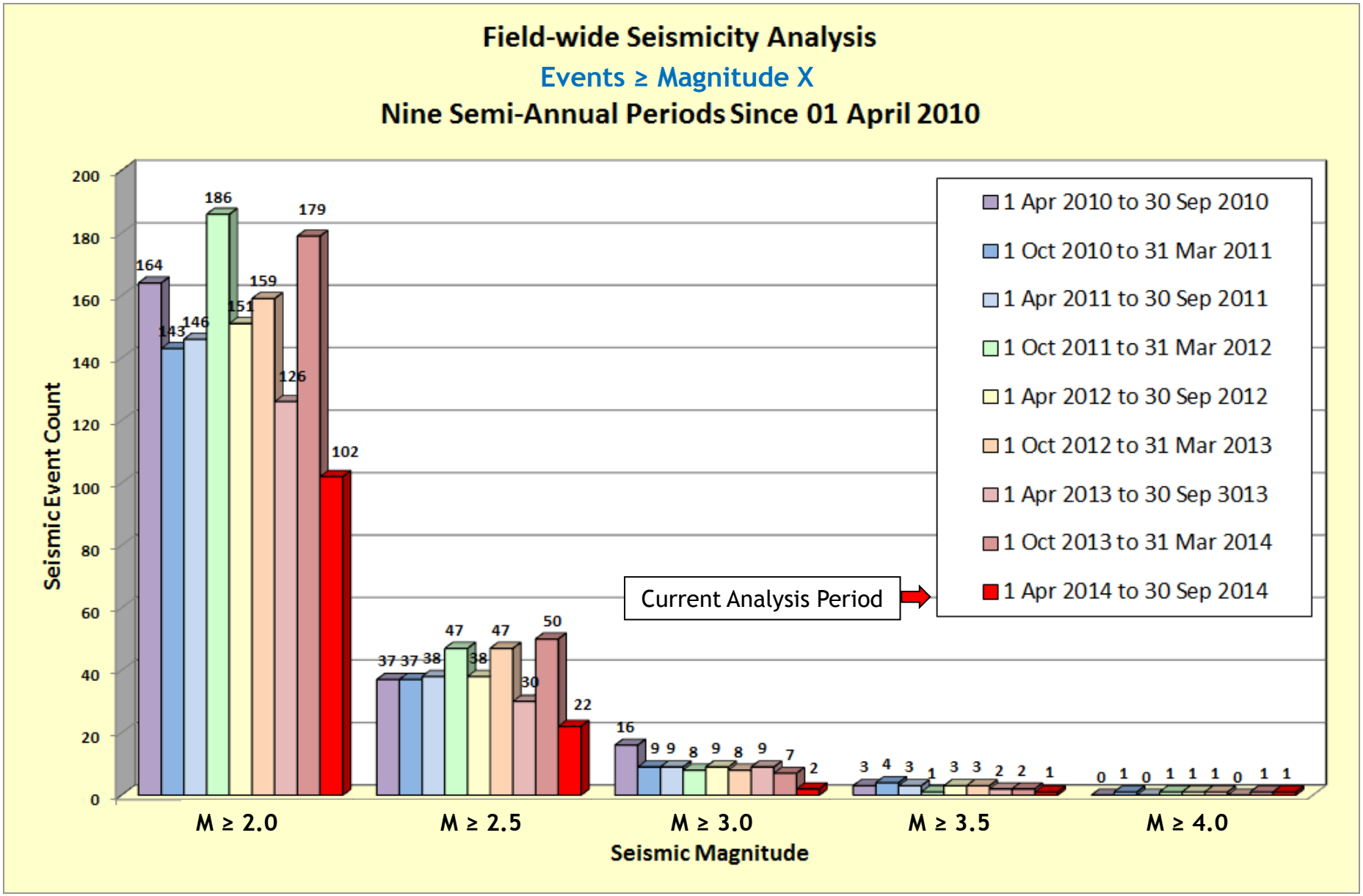
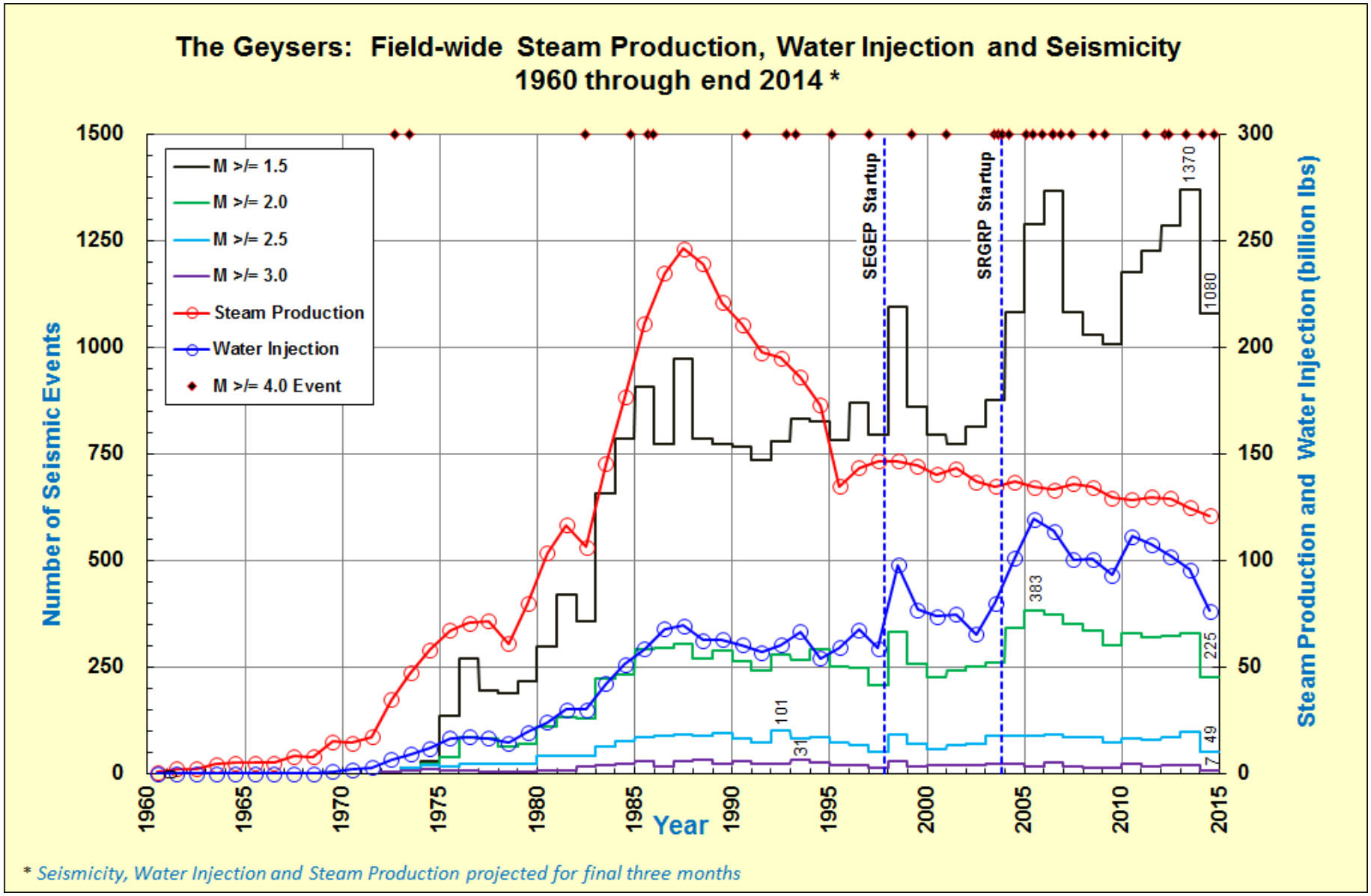


Yearly Field-wide Steam Production, Water Injection and Seismicity Starting 1960; Projected Through End 2014 *



* *Seismicity, Water Injection and Steam Production projected for final three months*

Yearly Field-wide Water Injection and M ≥ 1.5 Seismicity 1960 through end 2014 *

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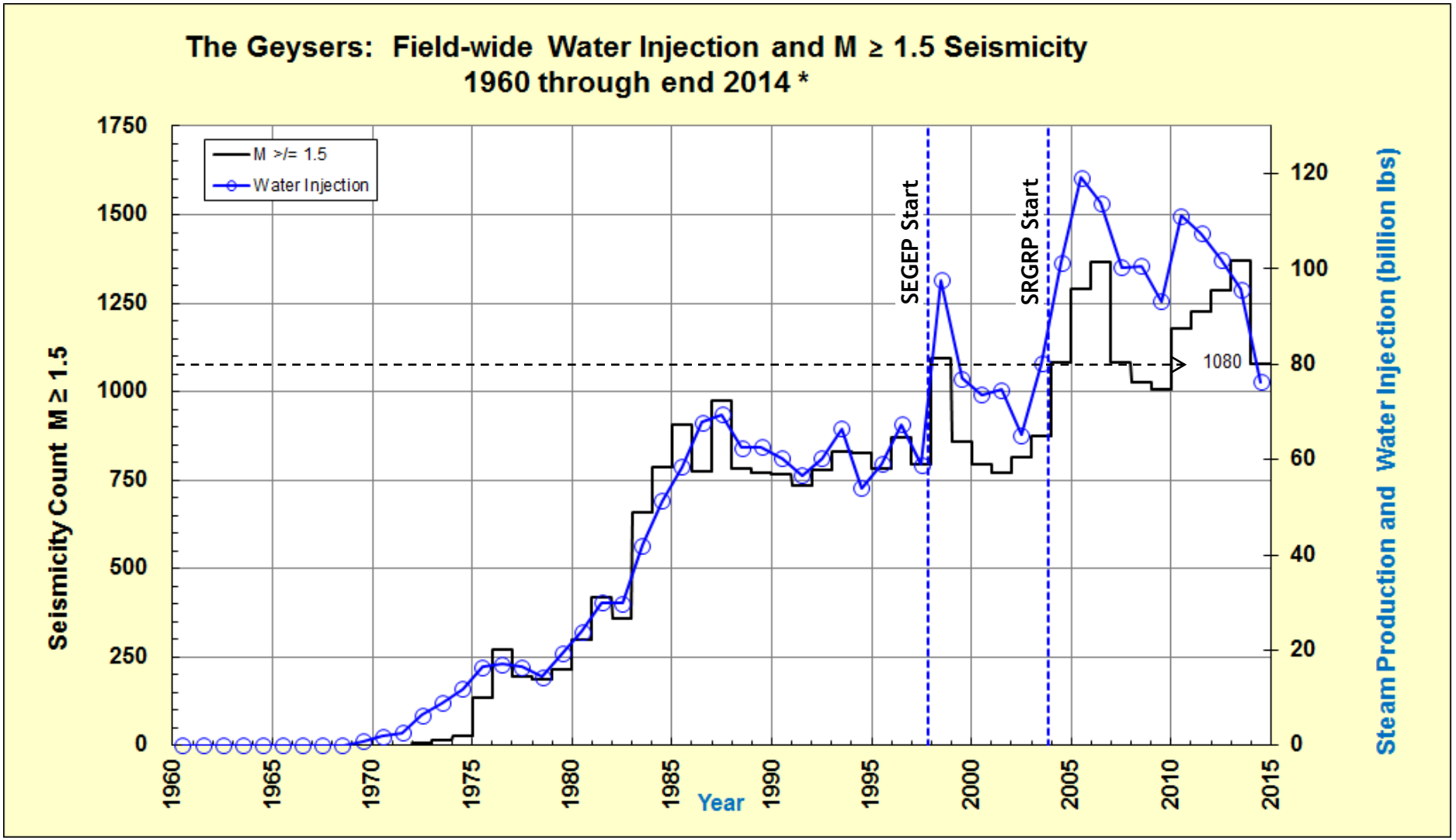
* *Seismicity, Water Injection and Steam Production projected for final three months*



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Yearly Field-wide Water Injection and M ≥ 2.0 Seismicity
1960 through end 2014 *

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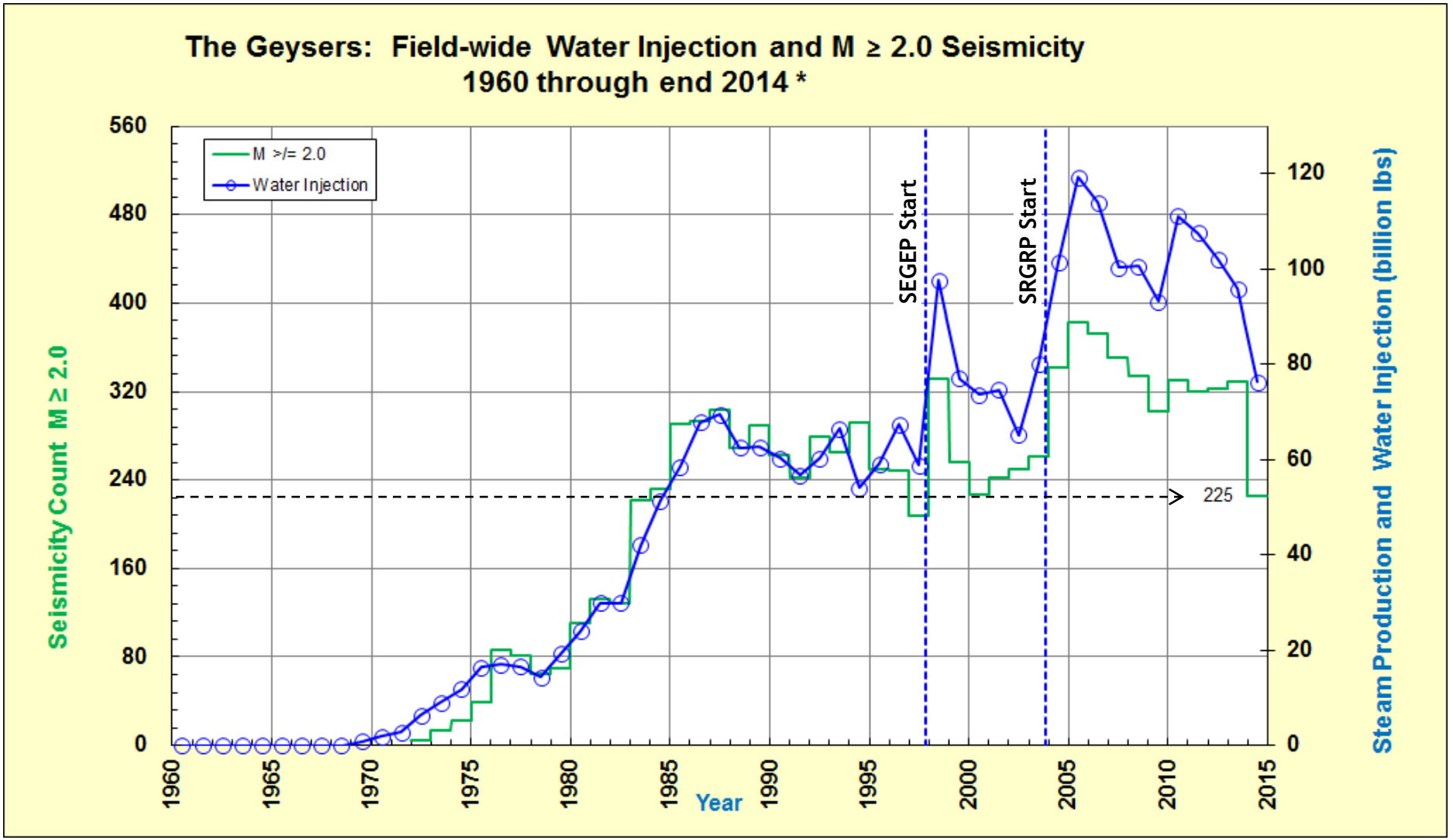
** Seismicity, Water Injection and Steam Production projected for final three months*



Seismic Monitoring Advisory Committee Meeting
Yearly Field-wide Water Injection and M ≥ 2.5 Seismicity 1960 through end 2014 *

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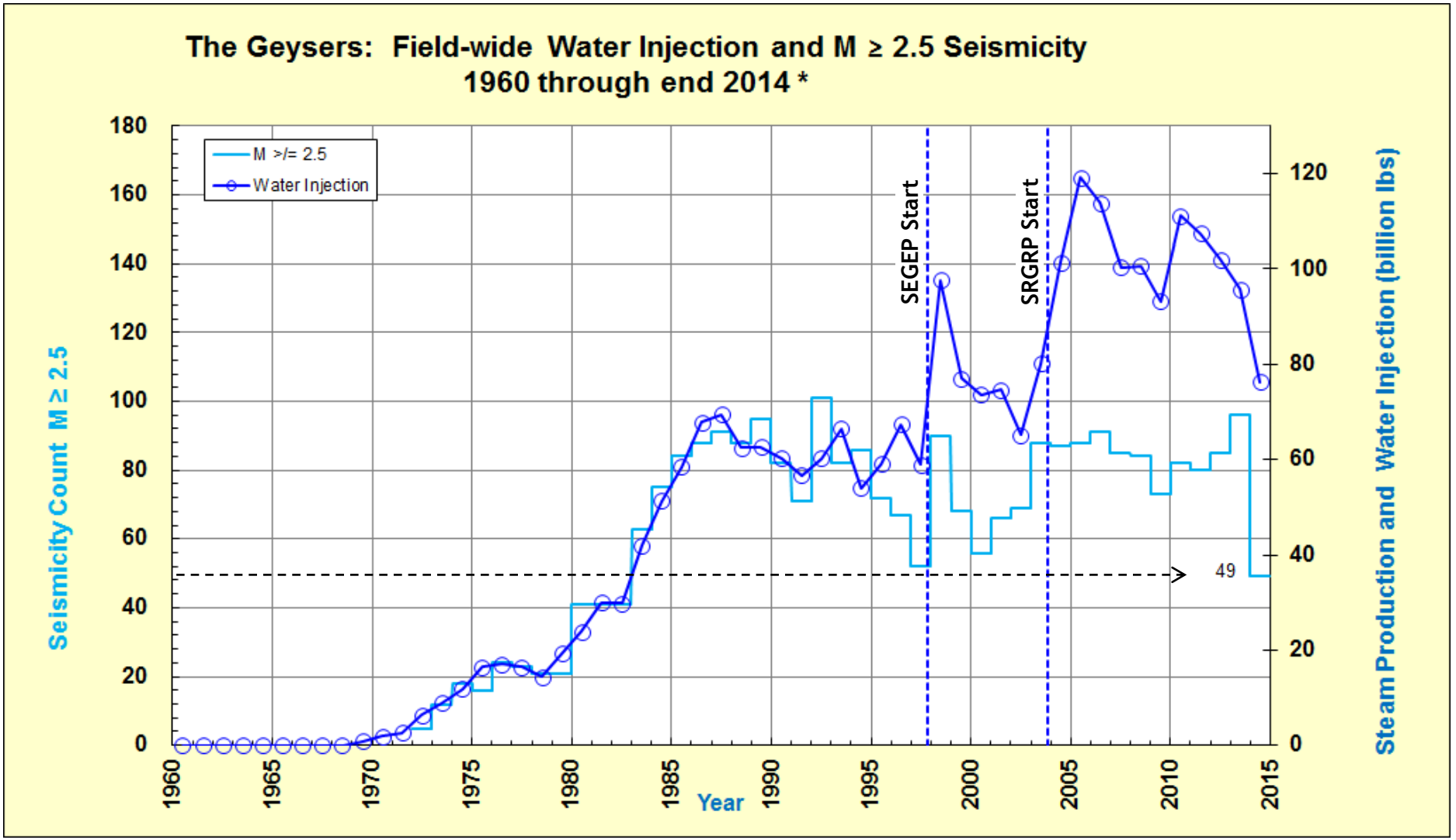
** Seismicity, Water Injection and Steam Production projected for final three months*



Seismic Monitoring Advisory Committee Meeting
Yearly Field-wide Water Injection and M ≥ 2.5 Seismicity
1960 through end 2014 *

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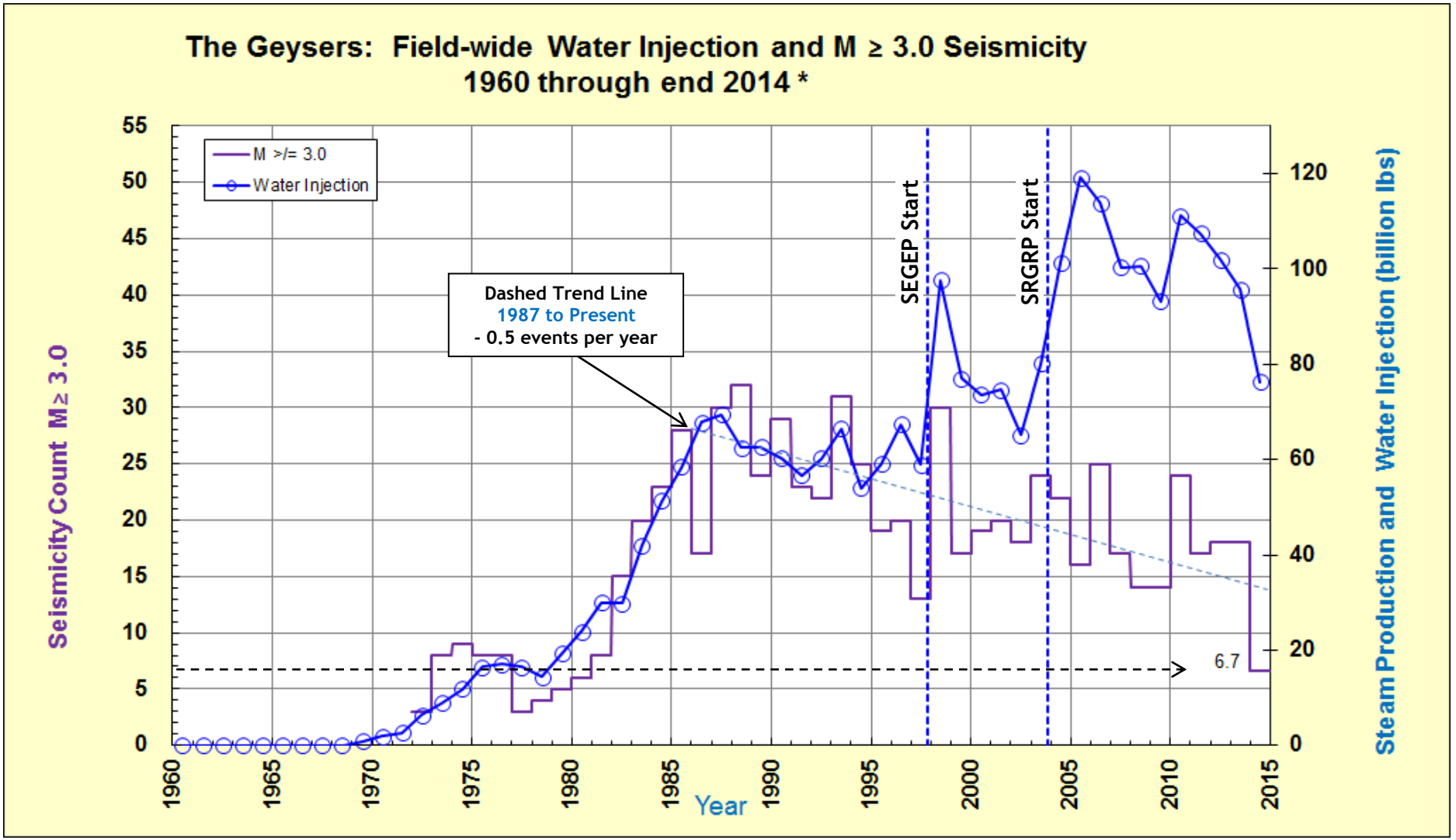
** Seismicity, Water Injection and Steam Production projected for final three months*



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Field-wide Water Injection Sources vs. M ≥ 4.0 Seismicity
Monthly Values from 01 January 2000 to 30 September 2014

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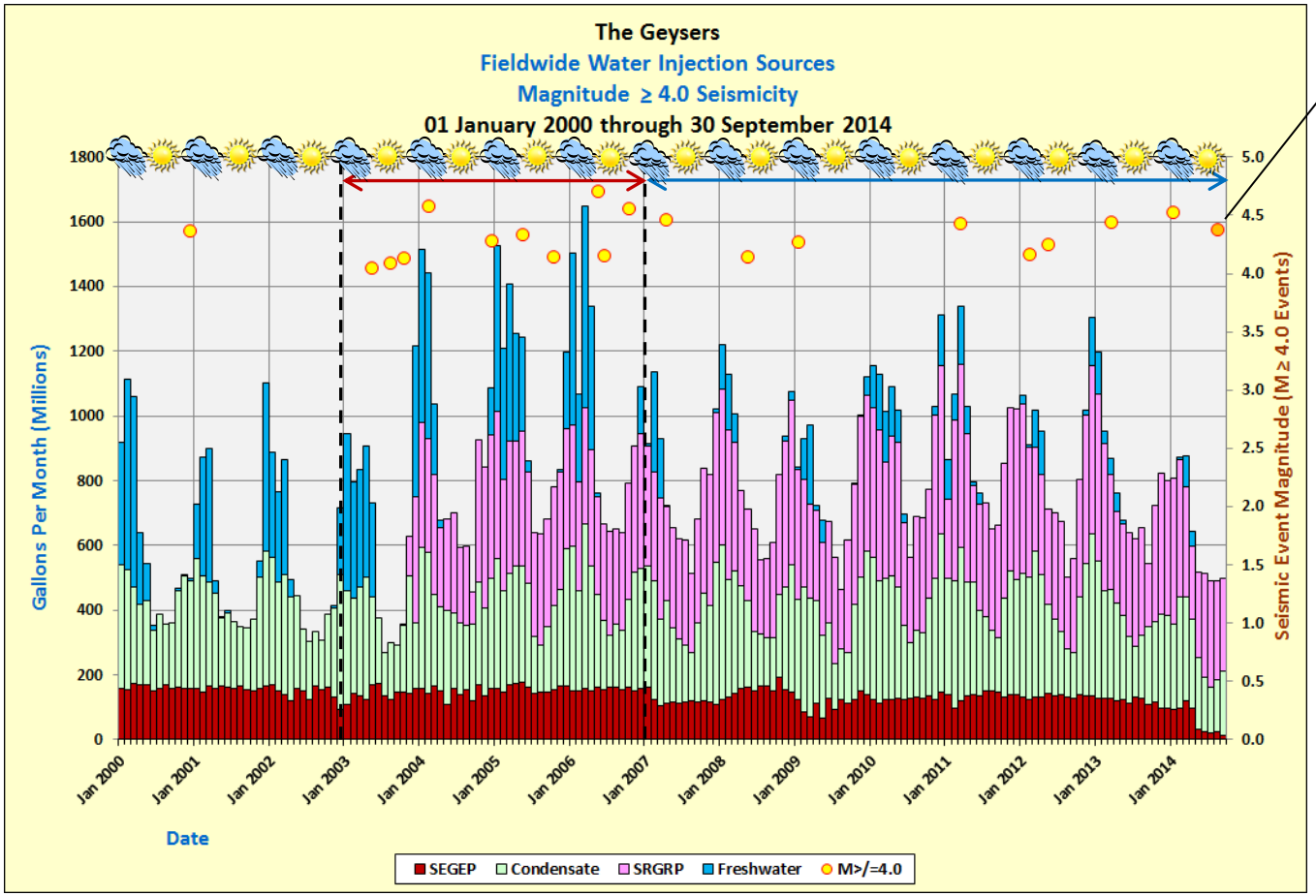
Number of Magnitude ≥ 4.0 Events Per Year Significantly Less Than 2003-2006 Peak

Time Period	M ≥ 4.0 Seismic Events	
January 2003 through December 2006	2.50 events per year	10.0 / 4.0
January 2007 through September 2014	1.16 events per year	9.0 / 7.75



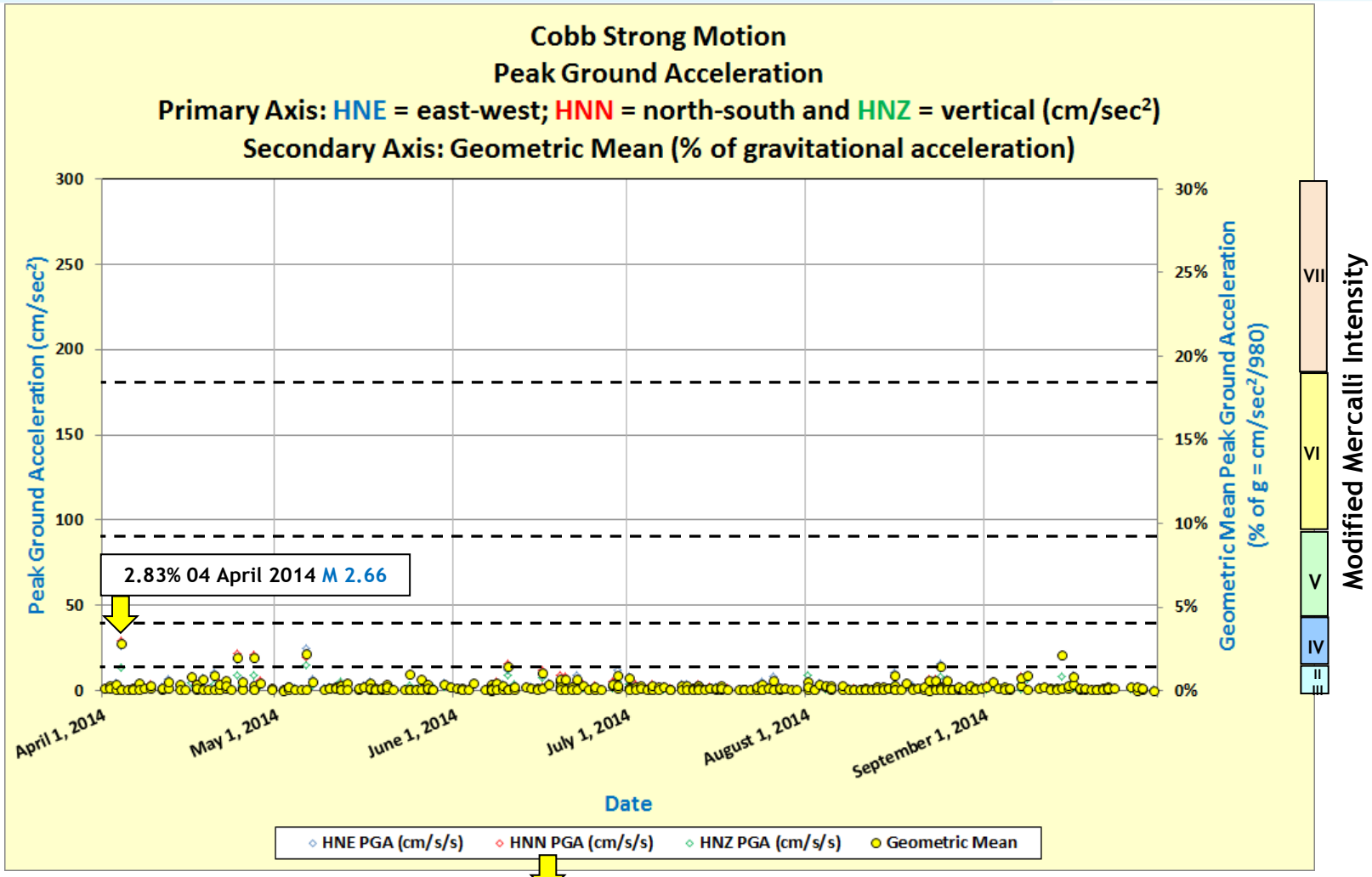
Geysers Magnitude 4.38 Seismic Event

Triggered by South Napa Earthquake

Seismic Monitoring Advisory Committee Meeting

Cobb Peak Ground Acceleration

01 April 2014 to 30 September 2014



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 Peak Ground Acceleration
01 April 2014 to 30 September 2014

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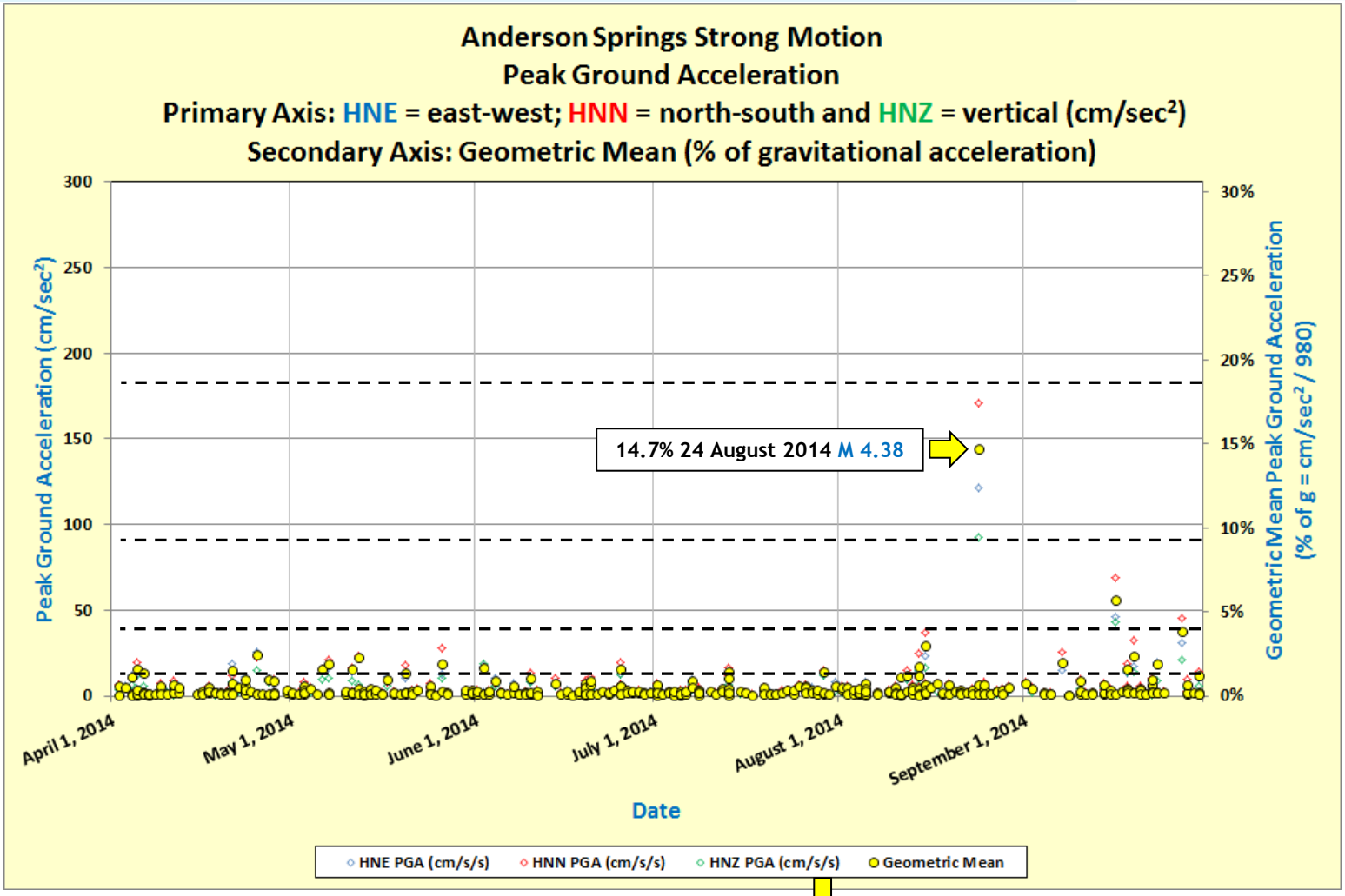

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Potential Damage	None	None	None	Very Light	Light	Moderate	Mod/Heavy	Heavy	Very Heavy
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Peak Velocity (cm/sec)	< 0.10	0.1 - 1.1	1.1 - 3.4	3.4 - 8.1	8.1 - 16.0	16.0 - 31.0	31.0 - 60.0	60.0 - 116.0	> 116.0
Modified Mercalli Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X

Seismicity
Calpine 3D Visualization and 3D Structural Model Building

Seismic event magnitude is dependent on:

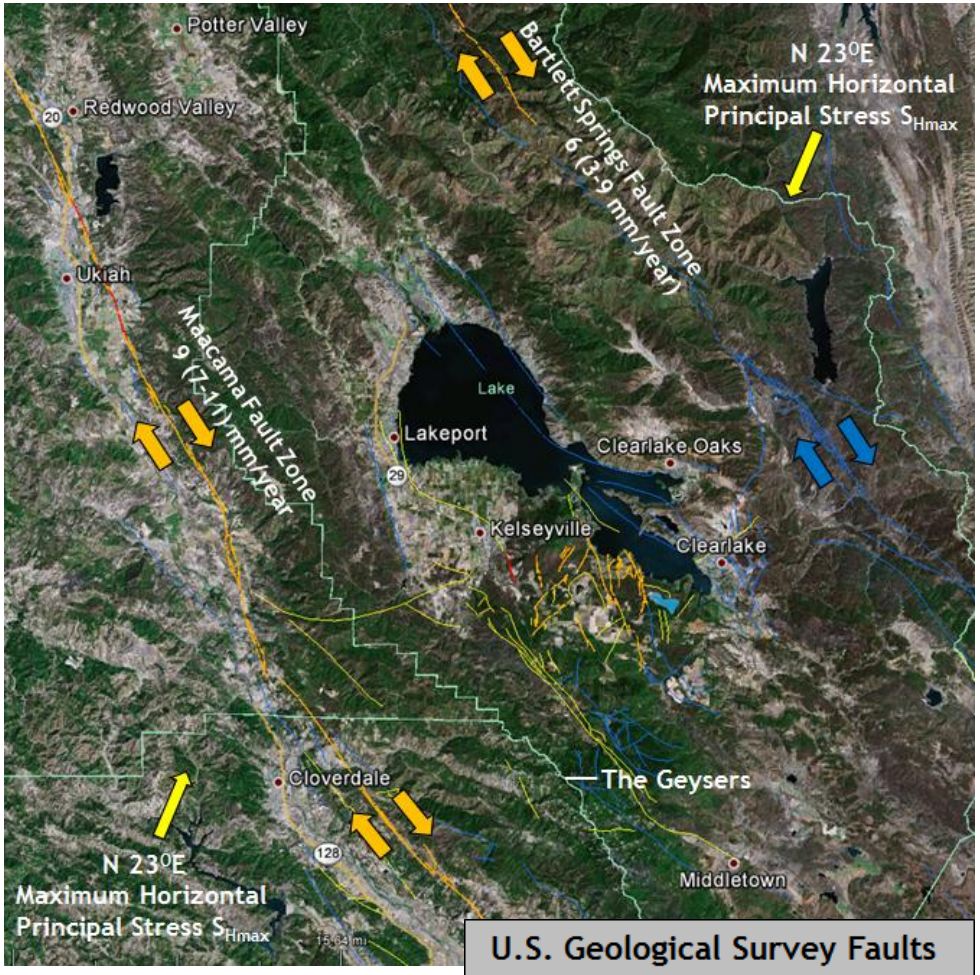
- Fault Area
- Average Slip
- Rock Rigidity

The Earth's crust is crossed by a network of pre-existing faults and fractures of various sizes.

Within The Geysers, CGS/USGS* mapped faults are inactive and restricted in area. This does limit the maximum possible seismic event magnitude.

A three-dimensional geological/geophysical model is currently under development for The Geysers geothermal field.

This 3D structural model (including pre-existing fault zones and fractures) will assist in understanding induced seismicity at The Geysers.



2012 Google Earth

* California Geological Survey, United States Geological Survey

Seismic Monitoring Advisory Committee Meeting
3D Structural Model Building (South Geysers)
Utilizing 2000-2014 Tomographic Double-Difference Data @ 500 Foot Intervals

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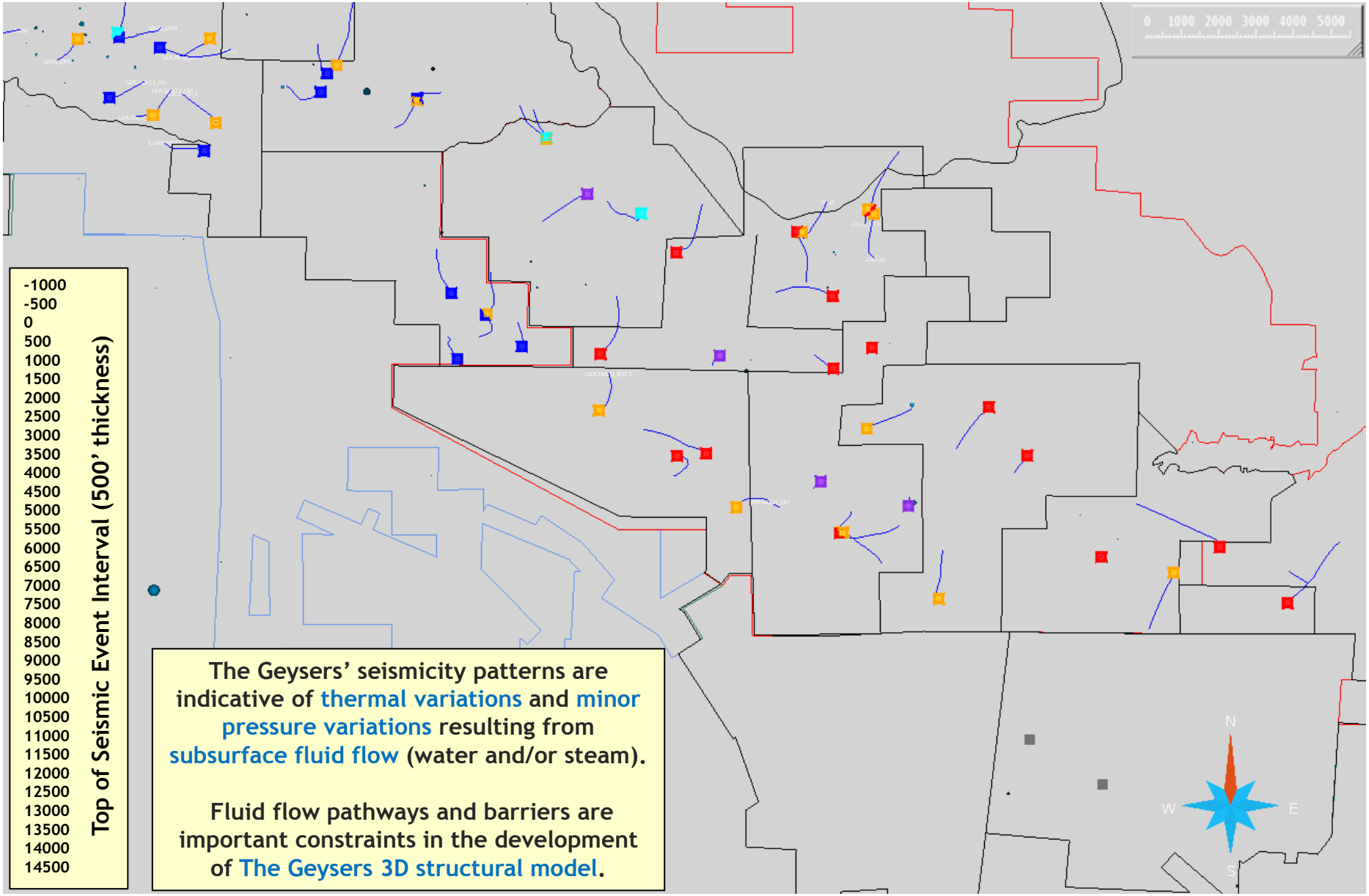

The Geysers' seismicity patterns are indicative of thermal variations and minor pressure variations resulting from subsurface fluid flow (water and/or steam).

Fluid flow pathways and barriers are important constraints in the development of The Geysers 3D structural model.

Seismic Monitoring Advisory Committee Meeting
3D Structural Model Building (South Geysers)
Utilizing 2000-2014 Tomographic Double-Difference Data @ 500 Foot Intervals

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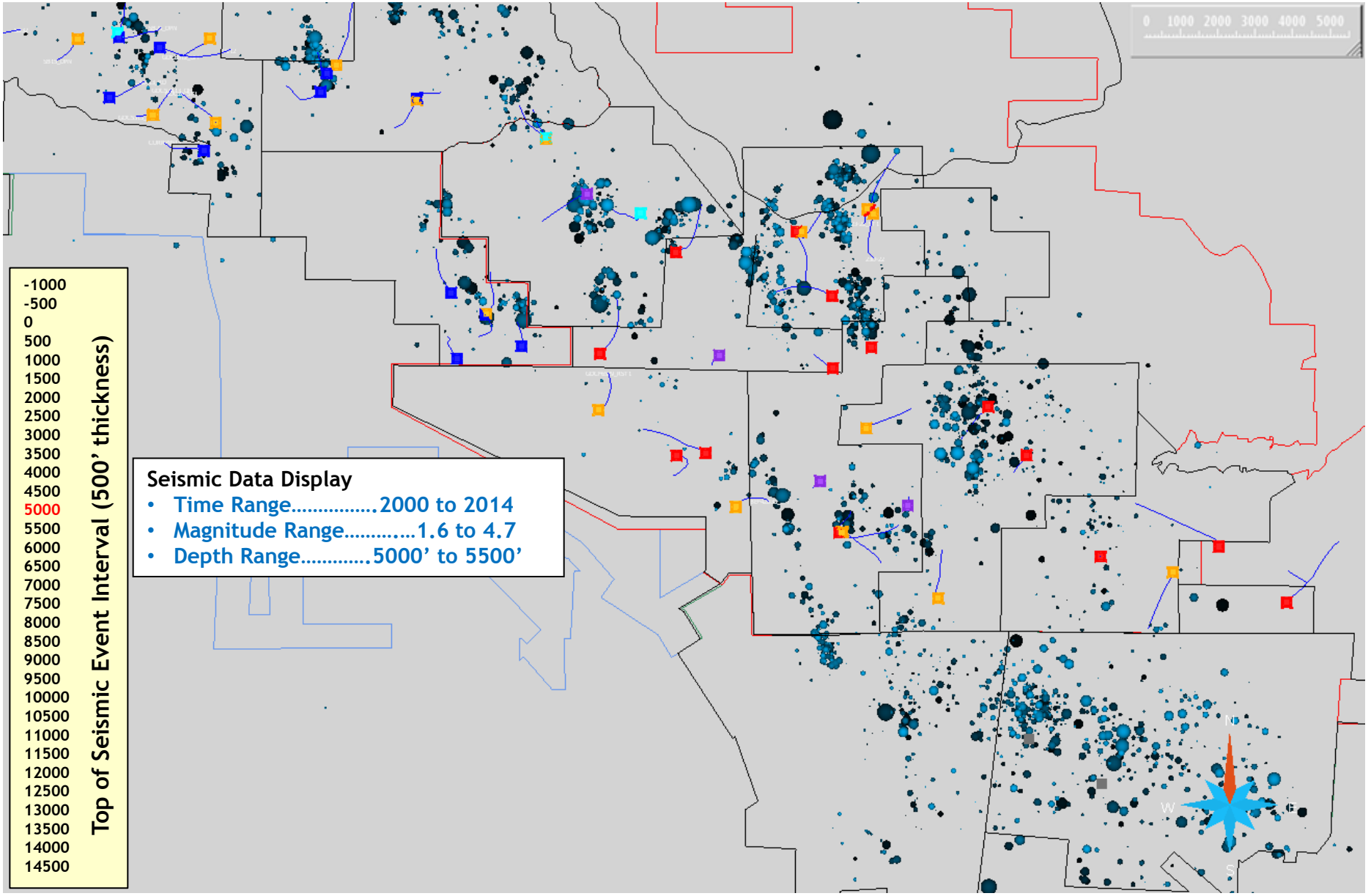

Seismic Monitoring Advisory Committee Meeting

3D Structural Model Building (North Geysers)

2000-2014 Tomographic Double-Difference Data @ 500 Foot Intervals

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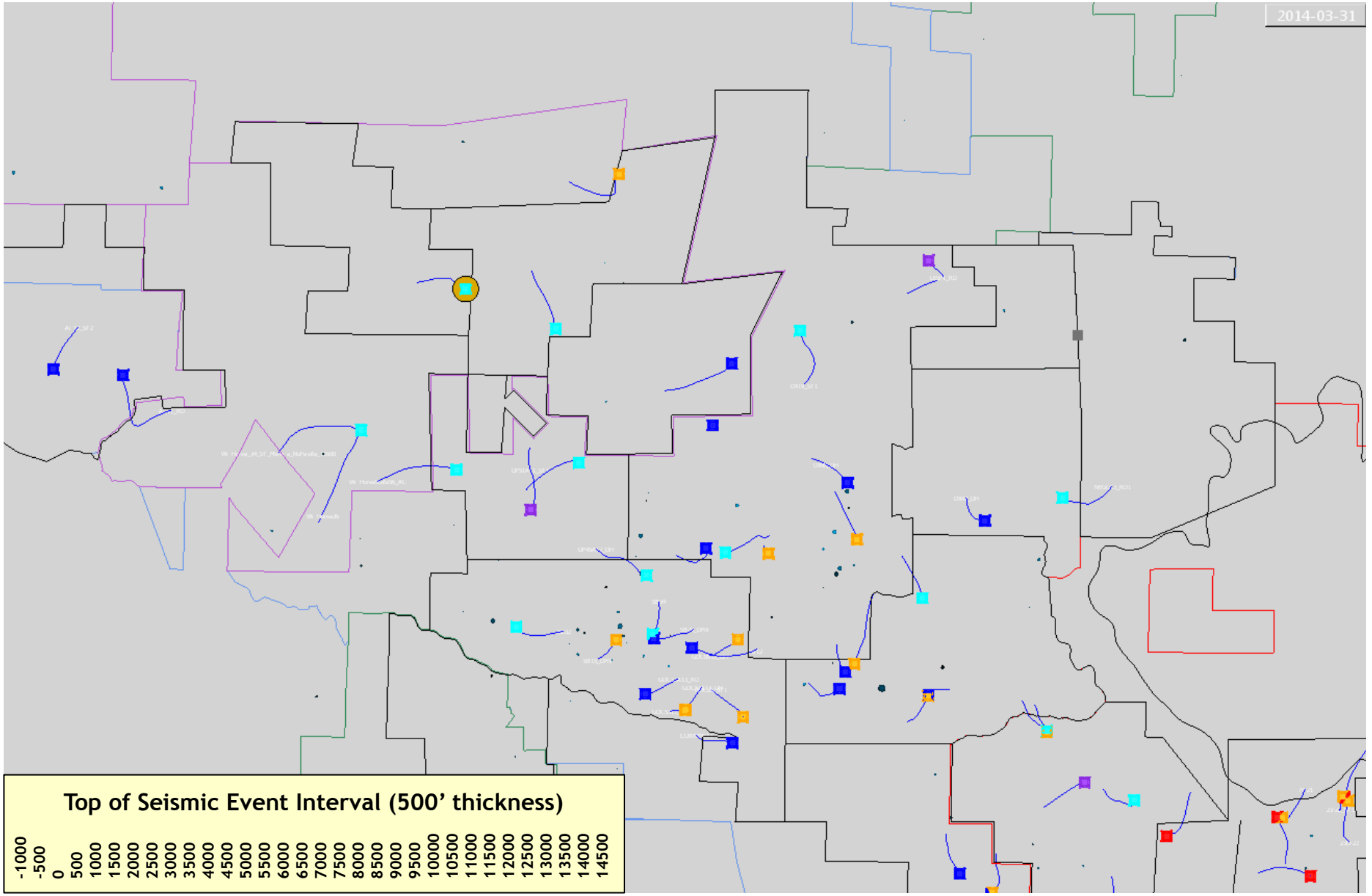

Seismic Monitoring Advisory Committee Meeting
3D Structural Model Building (North Geysers)
2000-2014 Tomographic Double-Difference Data @ 500 Foot Intervals

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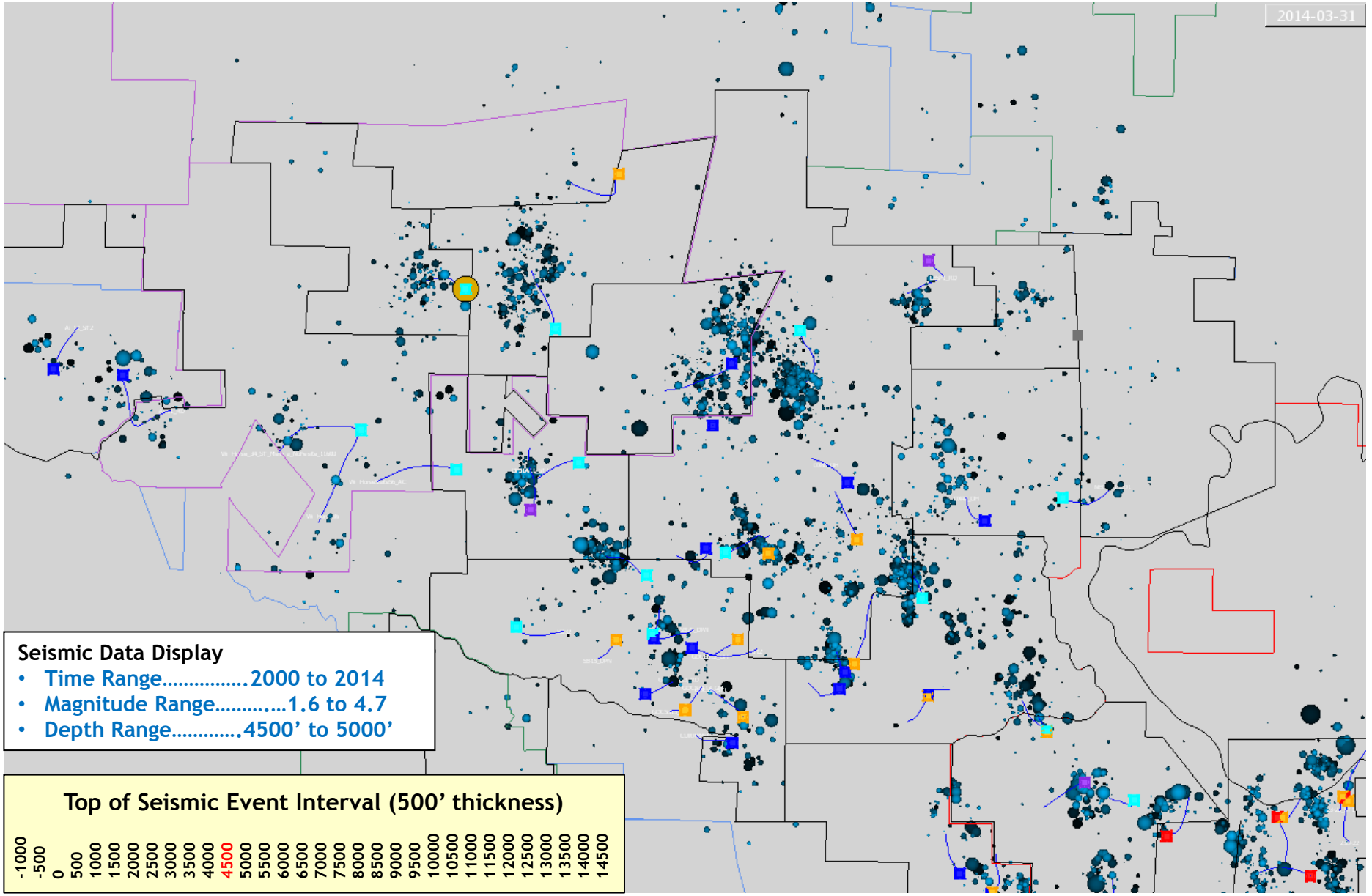

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3D Structural Model - Paradigm Geophysical SKUA / GOCAD Software

SKUA Subsurface Knowledge Unified Analysis
GOCAD Geologic Object Computer Assisted Design

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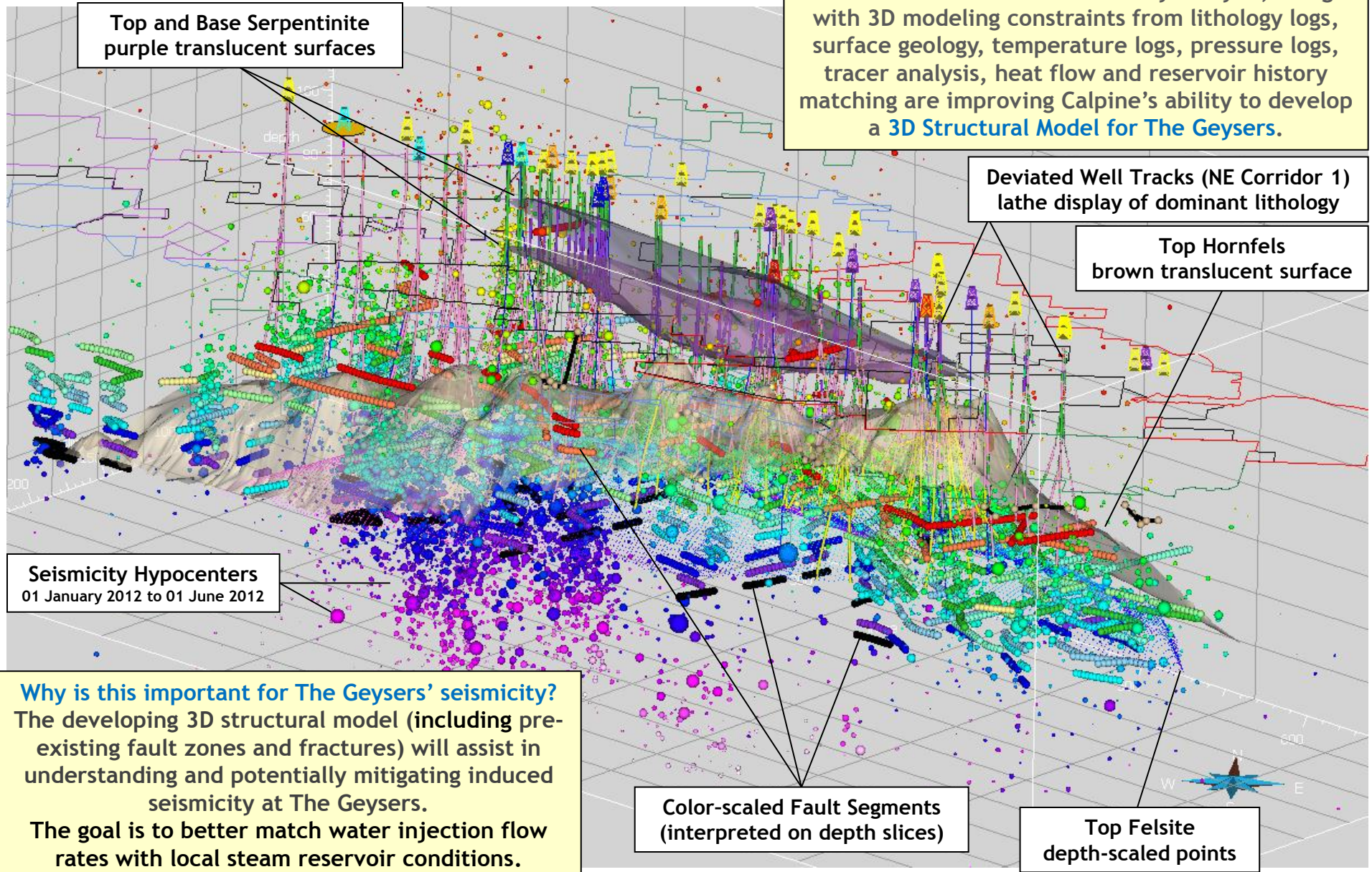
Software advances for seismicity analysis, along with 3D modeling constraints from lithology logs, surface geology, temperature logs, pressure logs, tracer analysis, heat flow and reservoir history matching are improving Calpine's ability to develop a 3D Structural Model for The Geysers.



Why is this important for The Geysers' seismicity?

The developing 3D structural model (**including** pre-existing fault zones and fractures) will assist in understanding and potentially mitigating induced seismicity at The Geysers.

The goal is to better match water injection flow rates with local steam reservoir conditions.

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Paradigm Geophysical SKUA / GOCAD Software

SKUA Subsurface Knowledge Unified Analysis
GOCAD Geologic Object Computer Assisted Design

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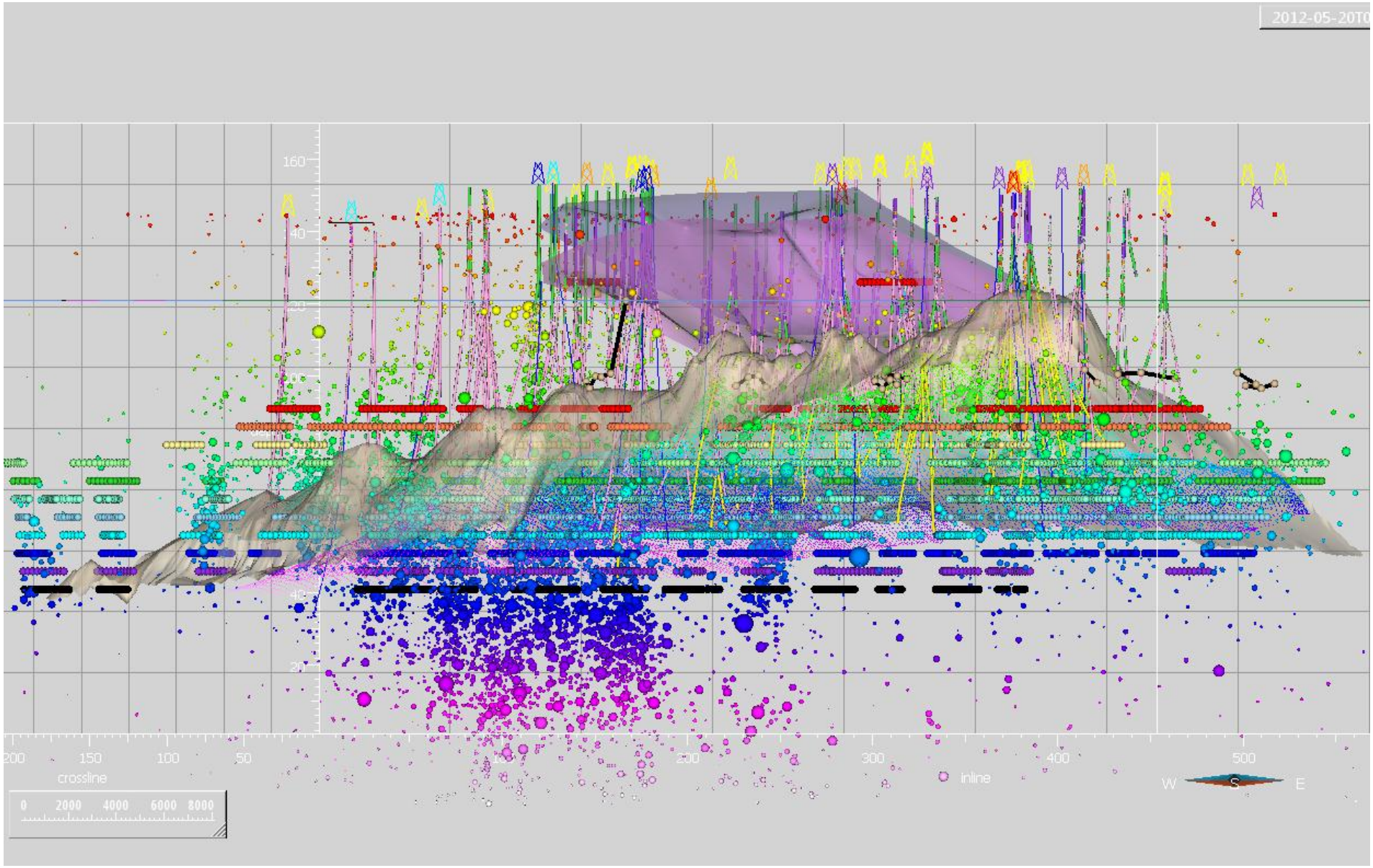


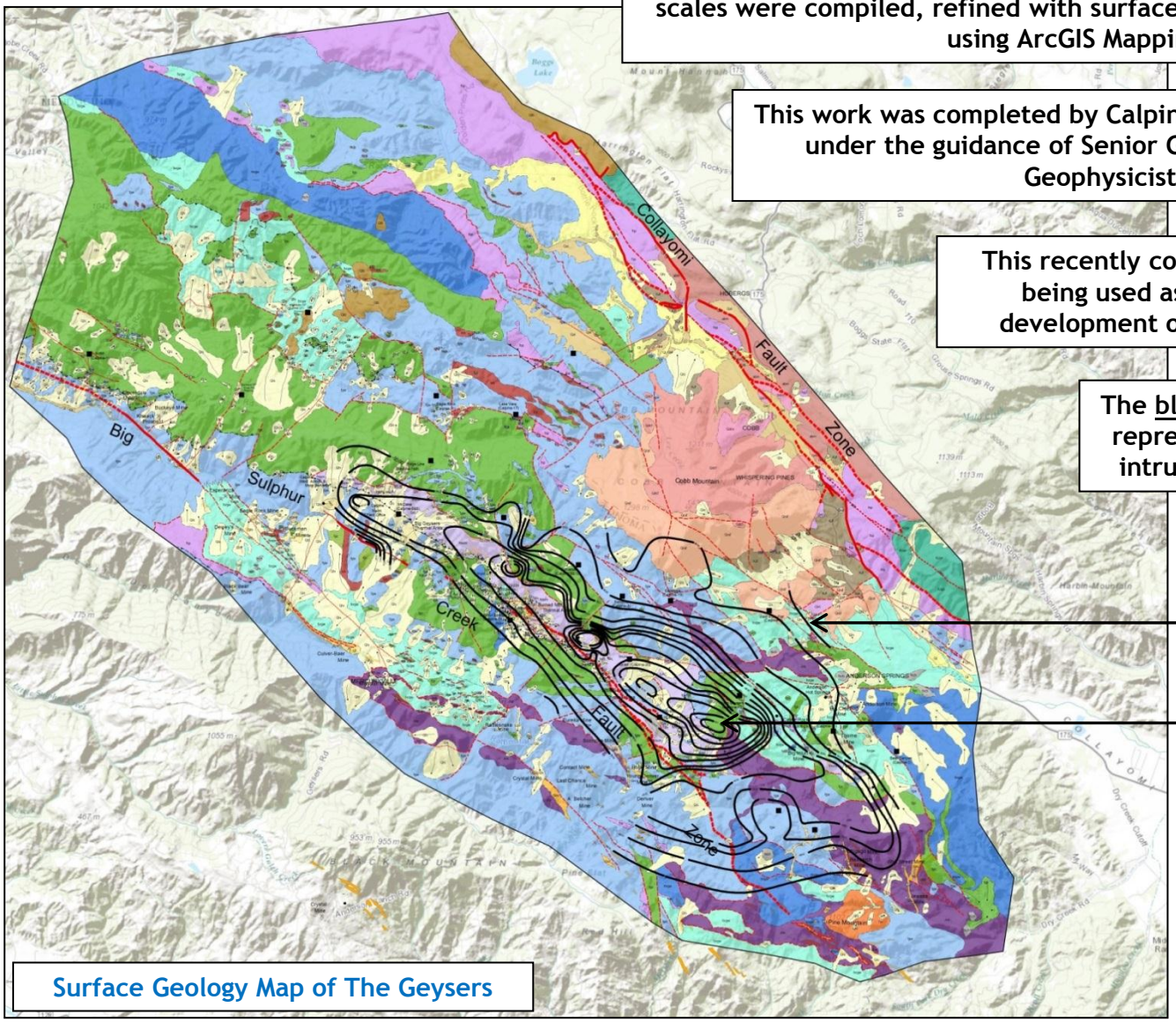
Seismic Monitoring Advisory Committee Meeting
Calpine Surface Geology Mapping Project

Hard copy (paper) surface geology maps with varying creation dates, formats and scales were compiled, refined with surface investigations, and merged digitally using ArcGIS Mapping Software.

This work was completed by Calpine 2014 Summer Intern Corina Forson under the guidance of Senior Geologist Mark Walters and Senior Geophysicist Craig Hartline.

This recently completed surface mapping project is being used as an additional constraint on the development of the Geysers 3D Structural Model

The black lines are overlain contours which represent the "Top Felsite". This granitic intrusion occurred ~ 1 million years ago.



7000 feet below sea level

500 feet above sea level

Surface Geology Map of The Geysers

Seismic Monitoring Advisory Committee Meeting

Additional Seismic Monitoring and Research

Seven AltaRock Microseismic Array (MSA) Boreholes Transferred to Calpine Corporation

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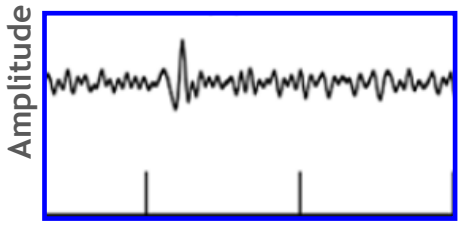
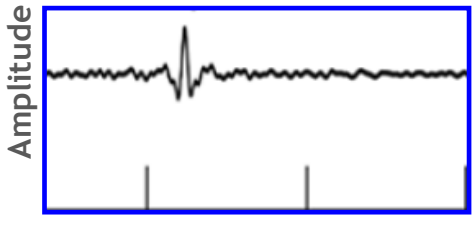
Collaboration with Lawrence Berkeley National Laboratory.

Three-component borehole seismic monitoring stations installed at:
MSA-3 …… 457’ depth
MSA-8 …… 490’ depth
Three additional MSA borehole stations installed soon – program suspended during high fire hazard.

Surface Sensor – More noise



Borehole Sensor – Less noise



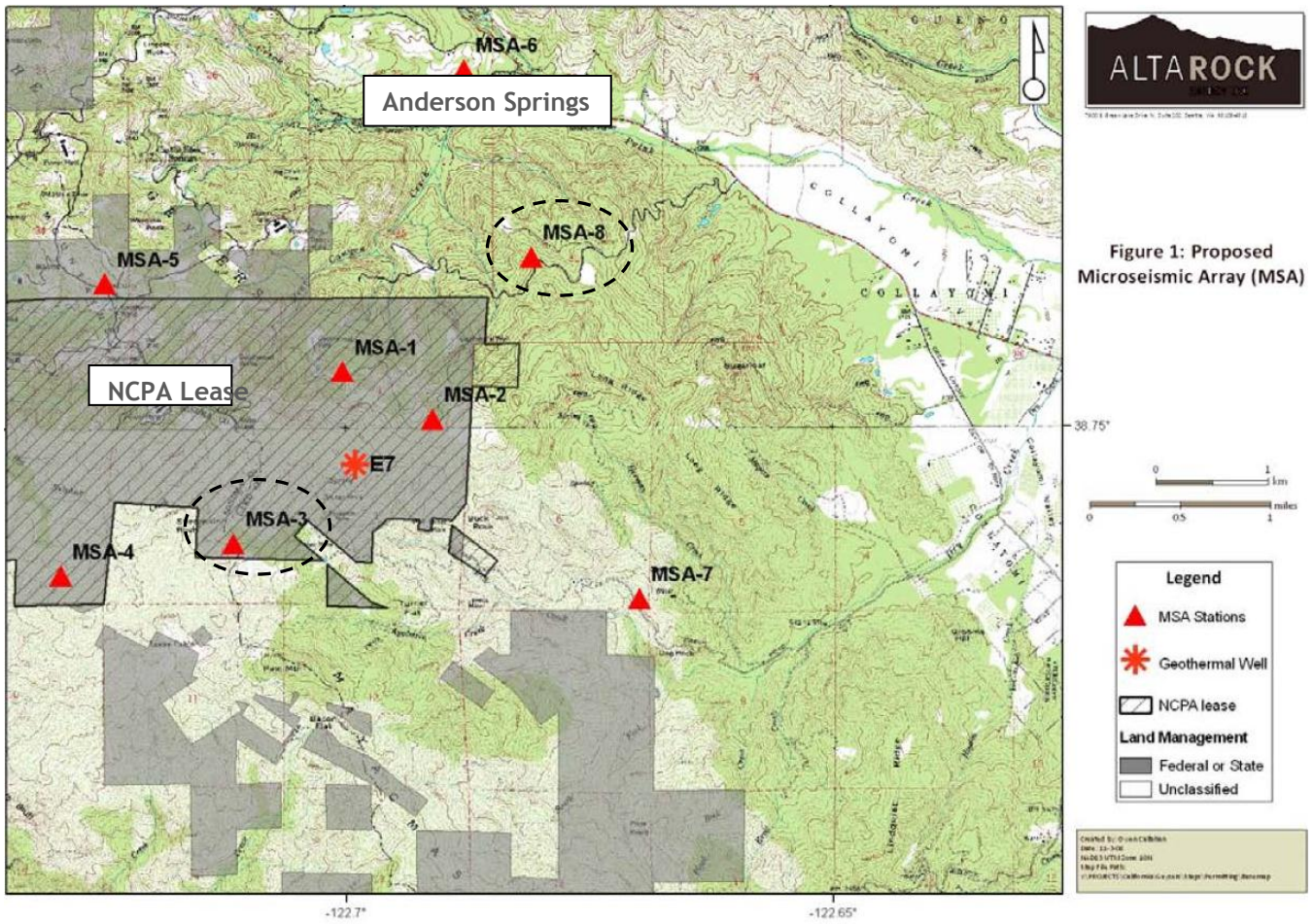


Figure 1: Proposed Microseismic Array (MSA)

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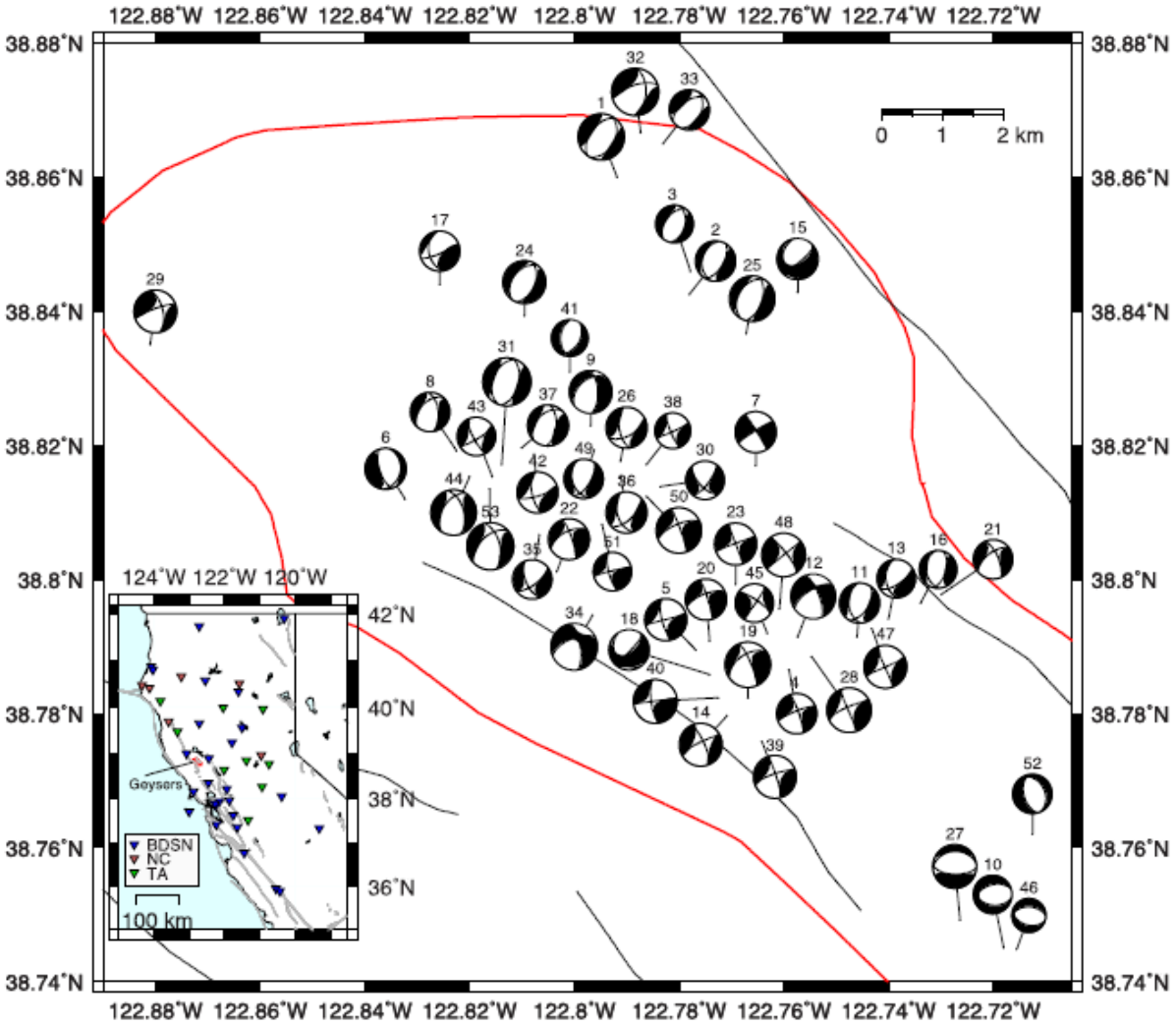
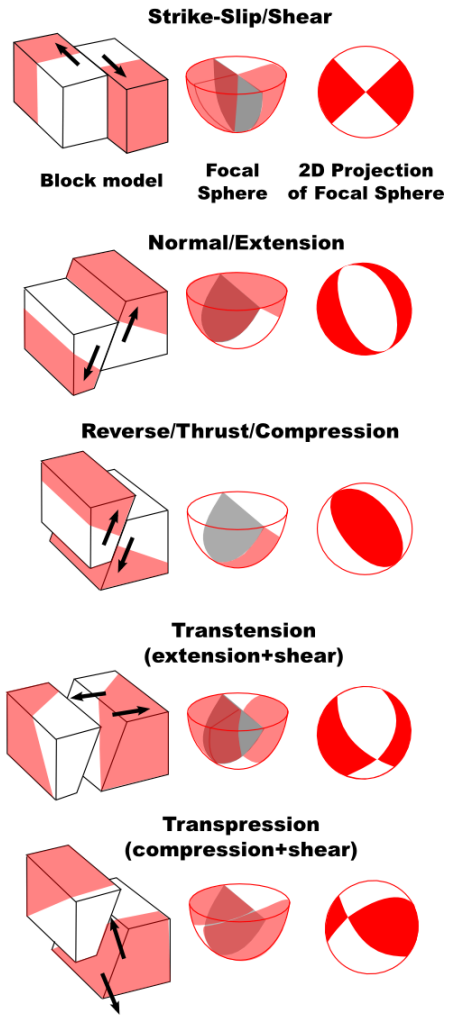
Additional Seismic Monitoring and Research

"Towards the Understanding of Induced Seismicity in Enhanced Geothermal Systems"
R. Gritto, D. Dreger, O. Heidbach and L. Hutchings (2014)

Deviatoric (Double Couple Assumption) Moment Tensor Solutions
53 magnitude ≥ 3.0 Events Analyzed





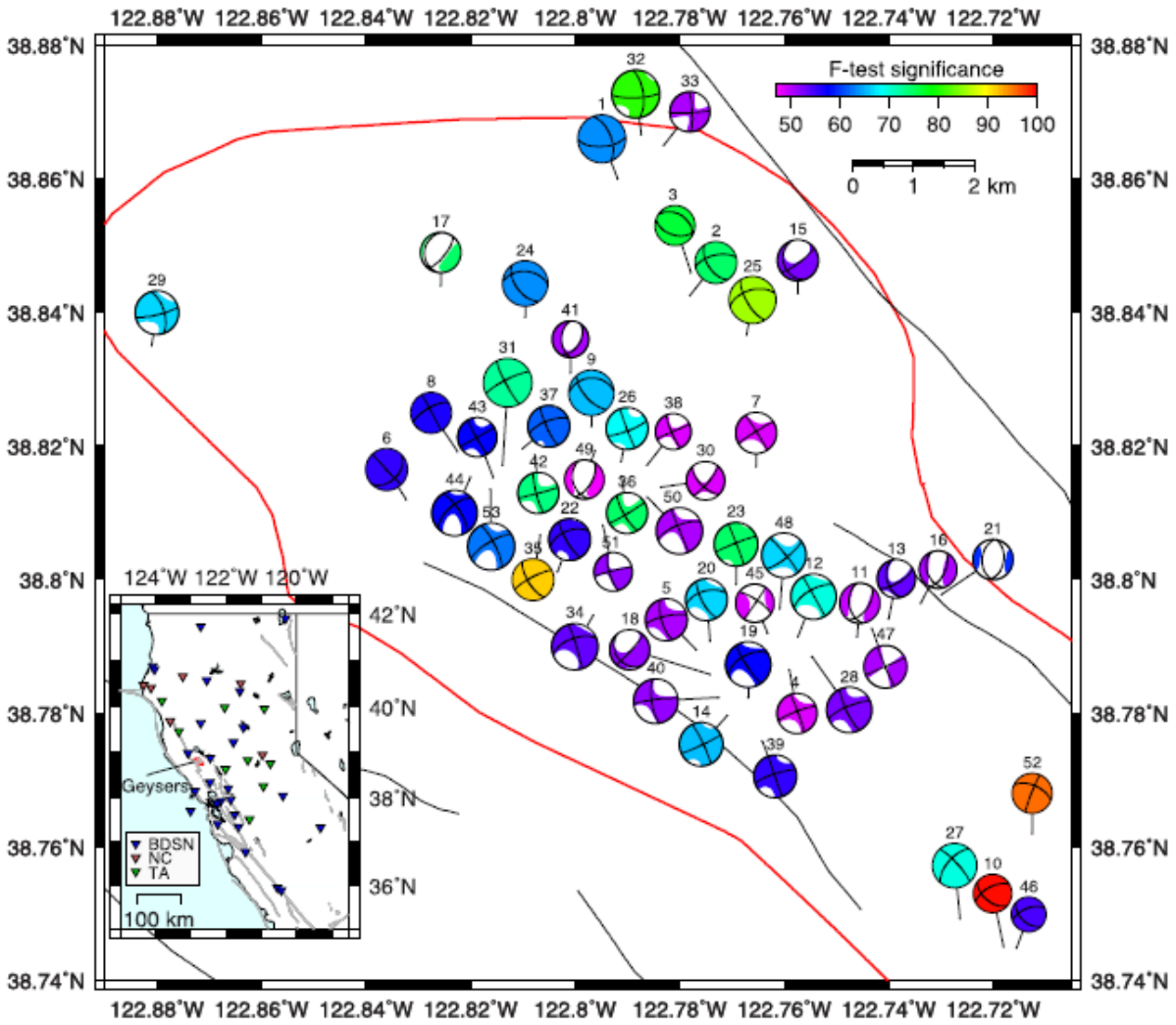
Seismic Monitoring Advisory Committee Meeting

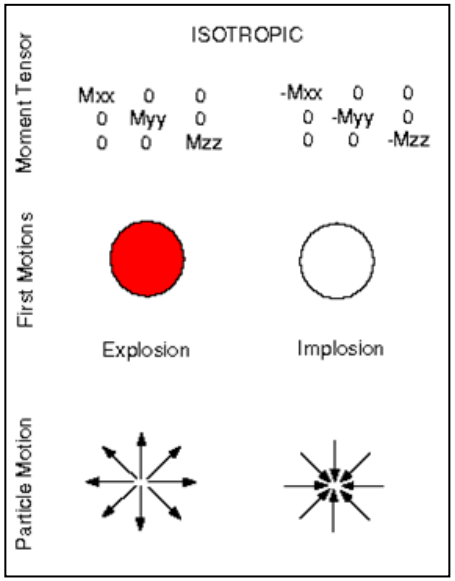
Additional Seismic Monitoring and Research

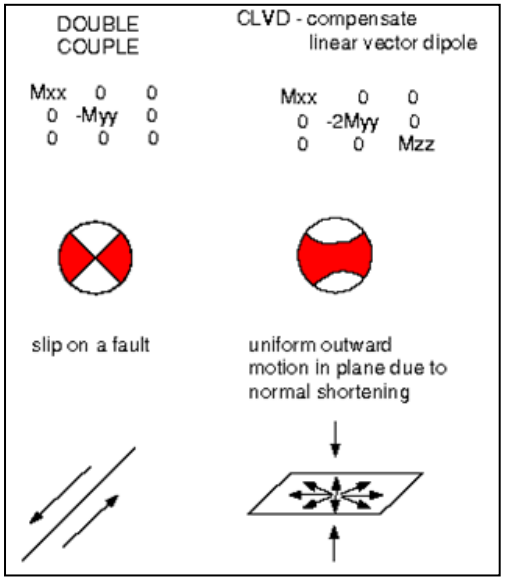
"Towards the Understanding of Induced Seismicity in Enhanced Geothermal Systems"
R. Gritto, D. Dreger, O. Heidbach and L. Hutchings (2014)

CALPINE
NYSE CPN

Full (Six Element) Moment Tensor Solutions
53 magnitude ≥ 3.0 Events Analyzed







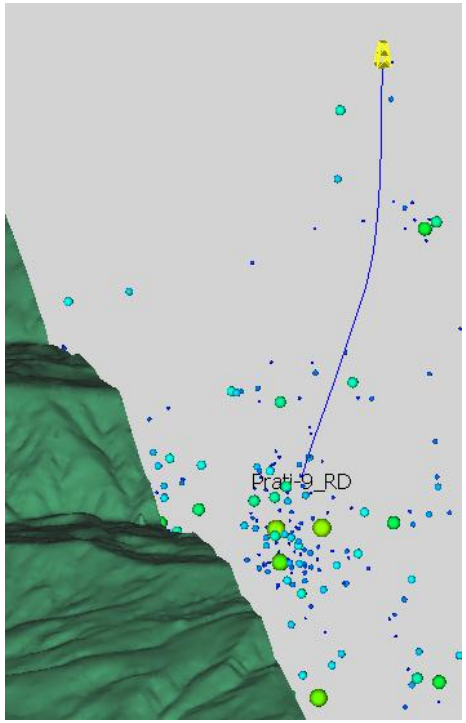
Helmholtz-Centre Potsdam GFZ German Research Centre for Geosciences, Potsdam, Germany (1)
Free University Berlin, Institute of Geological Sciences, Berlin, Germany (2)
Calpine Corporation, The Geysers, Middletown, California, USA (3)

Spatiotemporal changes, faulting regimes and source-parameters of induced seismicity:
A case study from The Geysers geothermal field

Patricia Martínez-Garzón[1], Grzegorz Kwiatek[1], Marco Bohnhoff [1,2], Hiroki Sone[1], Georg Dresen[1], Craig Hartline[3]

This recently initiated collaboration has been excellent. The review process is complete for publication of a detailed analysis of Prati 9 water injection and associated induced seismicity in the Journal of Geophysical Research.

Currently planning additional studies related to The Geysers induced seismicity.



	During peak injection	Potential implications
Number of strike-slip and thrust faulting events	⇧	Temporal change in faulting
Hypo-/epicentral distance	⇧	Temporal change in spatial scale
Relative stress magnitude	⇧	Pore pressure increase
(b-value)	⇩	Correlation with mean stress level
(stress drop thrust faulting)	⇧	Observation
Alignment with S_{HMax}	⇧	Change in reservoir stresses

Seismic Monitoring Advisory Committee Meeting
Additional Seismic Monitoring and Research
California Energy Commission Program Opportunity Notice 15-307

The team of:

- Björn Paulsson Paulsson Incorporated
- Ernie Majer Lawrence Berkeley National Laboratory
- Craig Hartline Calpine Corporation

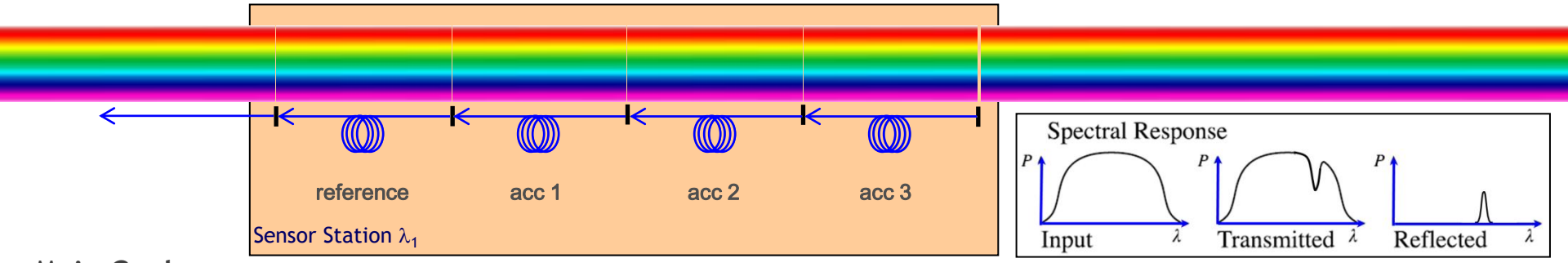
submitted a proposal to the California Energy Commission and was awarded nearly $900,000 for the following research project:

Borehole seismic monitoring
Two high temperature North Geysers wells

- passive – induced seismicity
- active – 3D vertical seismic profiling – Vibroseis source

Utilizing recently developed high-temperature vector fiber optic sensors (with Fiber Bragg Gratings)

A Fiber Bragg grating partially reflects light of a specific wavelength (other wavelengths transmitted)



Main Goals

Test recently developed high-temperature vector fiber optic sensors
Broad bandwidth passive seismic analysis and direct imaging of faults and fractures

Calpine is also determining a suitable borehole* for a limited test program with high temperature three-component fiber optic sensors developed by United States Seismic Sensor Systems Incorporated.

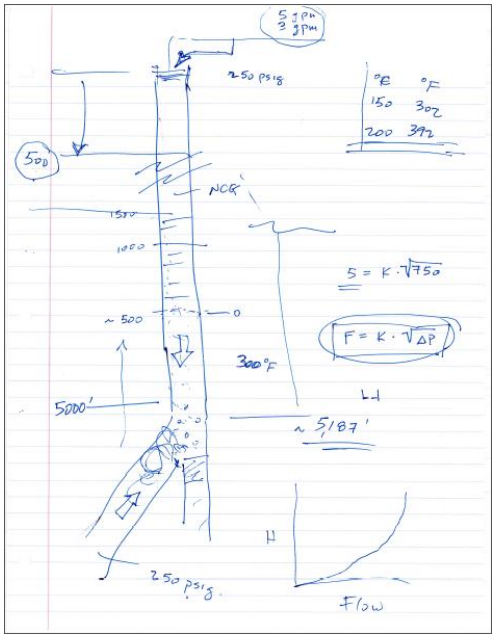
Monitoring Program

Borehole seismic monitoring within a single North Geysers wells

- passive monitoring – induced seismicity
- active monitoring – Vibroseis source likely

Main Goals

Test recently developed high-temperature vector fiber optic sensors
Test borehole clamping mechanism (for improved coupling)
Broad bandwidth passive seismic analysis



USSSI OptiPhone HD
Three-component Fiber Opric Sensor Sondes
Operating Temperature ..Up to 200°C (392°F)
Operating Pressure .....Up to 10000 psi

Downhole Clamp

Calpine Corporation is promoting the development of next-generation seismic sensor technologies suitable for extreme borehole conditions and providing improved seismic data resolution.

* The most likely candidate well is Prati-State 29

Additional Seismic Monitoring and Research

System Installed 15 September 2014 – Fully Functional

CALPINE NYSE CPN

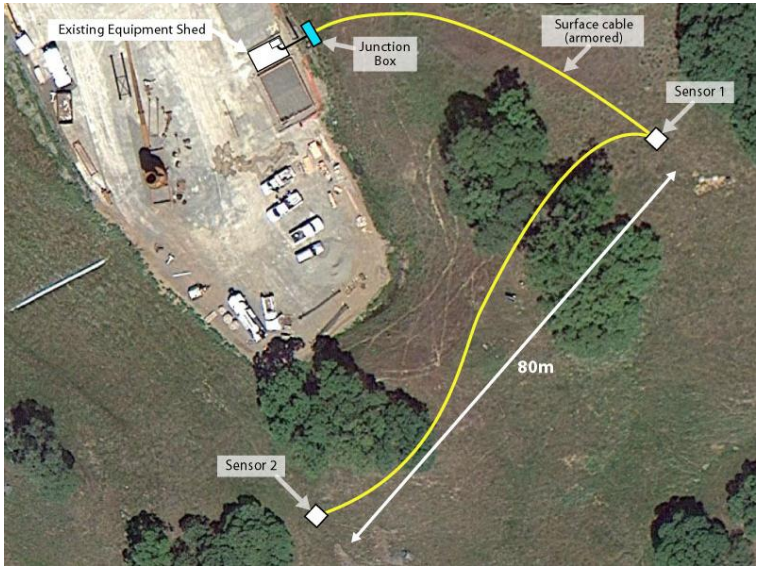
Research Collaboration with Seismic Warning Systems
Early Detection and Warning System for Natural Earthquakes

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.
Tied in to Calpine power and communications.



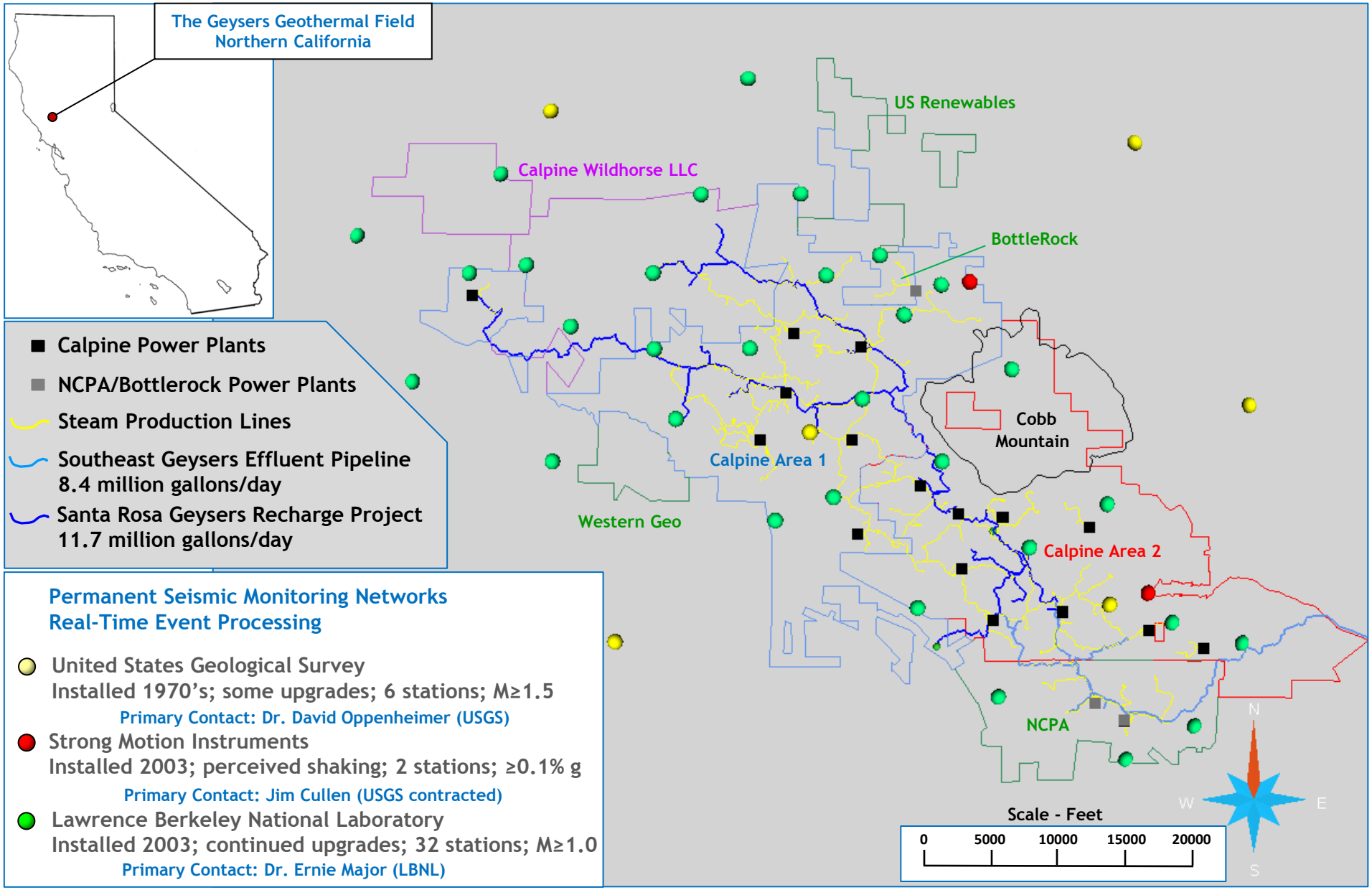
Geysers Project Goal

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

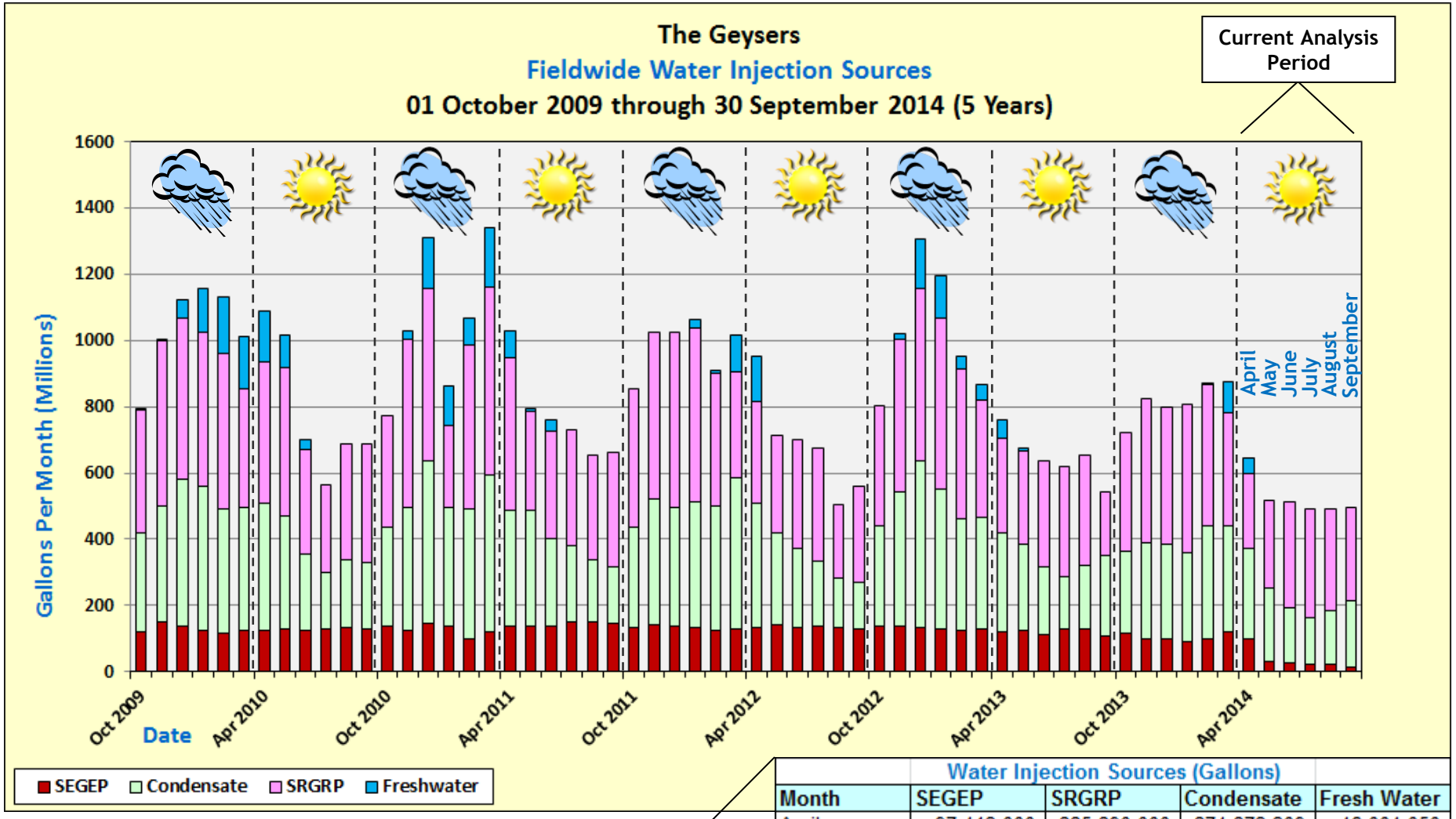

CALPINE®
NYSE CPN

Reference
Permanent Seismic Monitoring Networks



Reference

Field-wide Water Injection Sources
Monthly Values from 01 April 2010 to 31 March 2014

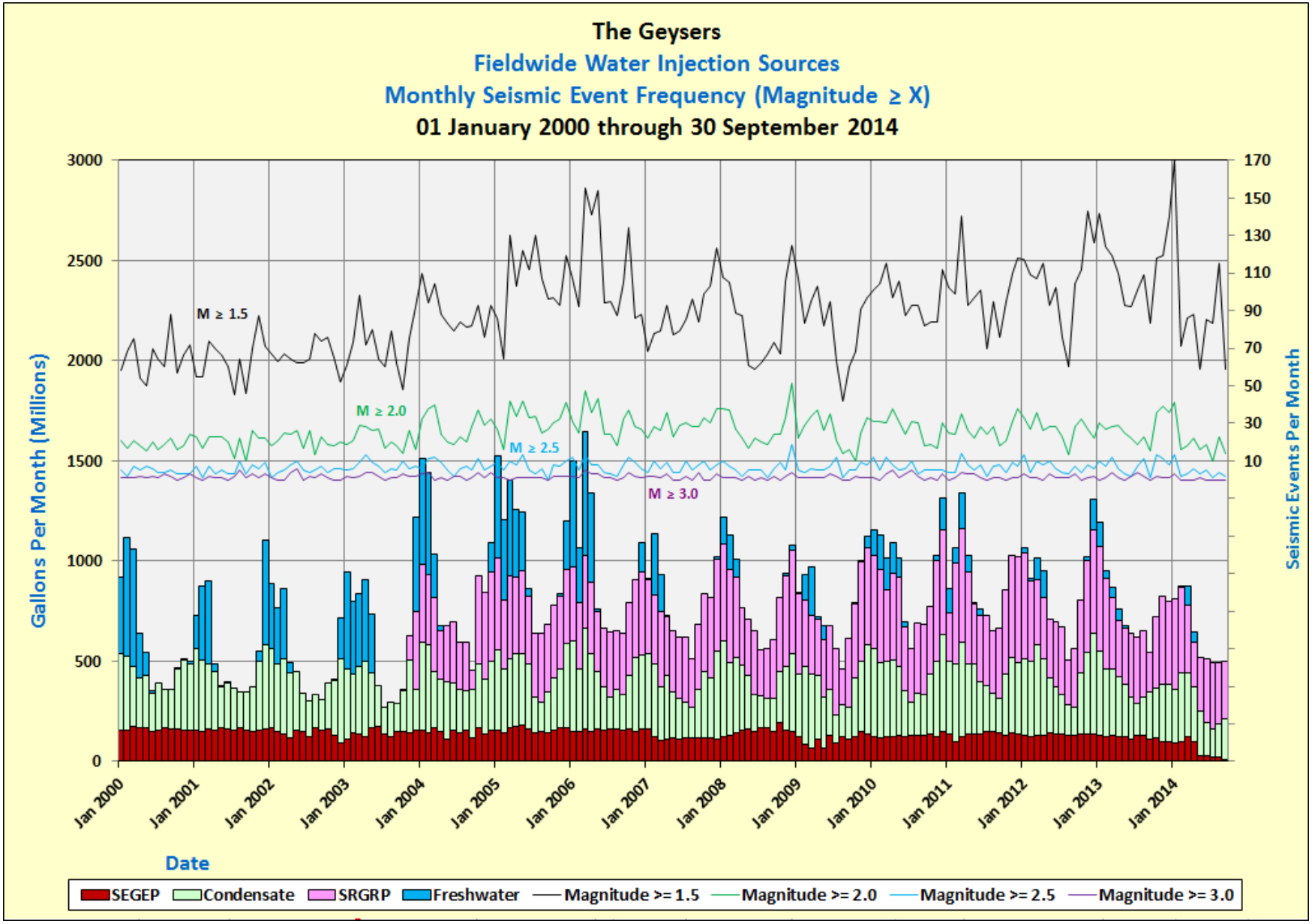


Current Analysis Period

	Water Injection Sources (Gallons)			
Month	SEGEP	SRGRP	Condensate	Fresh Water
April	97,413,000	225,290,000	274,873,309	46,004,050
May	31,045,000	264,250,000	221,191,730	-
June	25,928,000	318,510,000	167,282,447	-
July	22,675,000	326,830,000	141,001,274	-
August	23,195,000	304,570,000	162,317,473	-
September	11,997,000	284,390,000	200,355,933	-

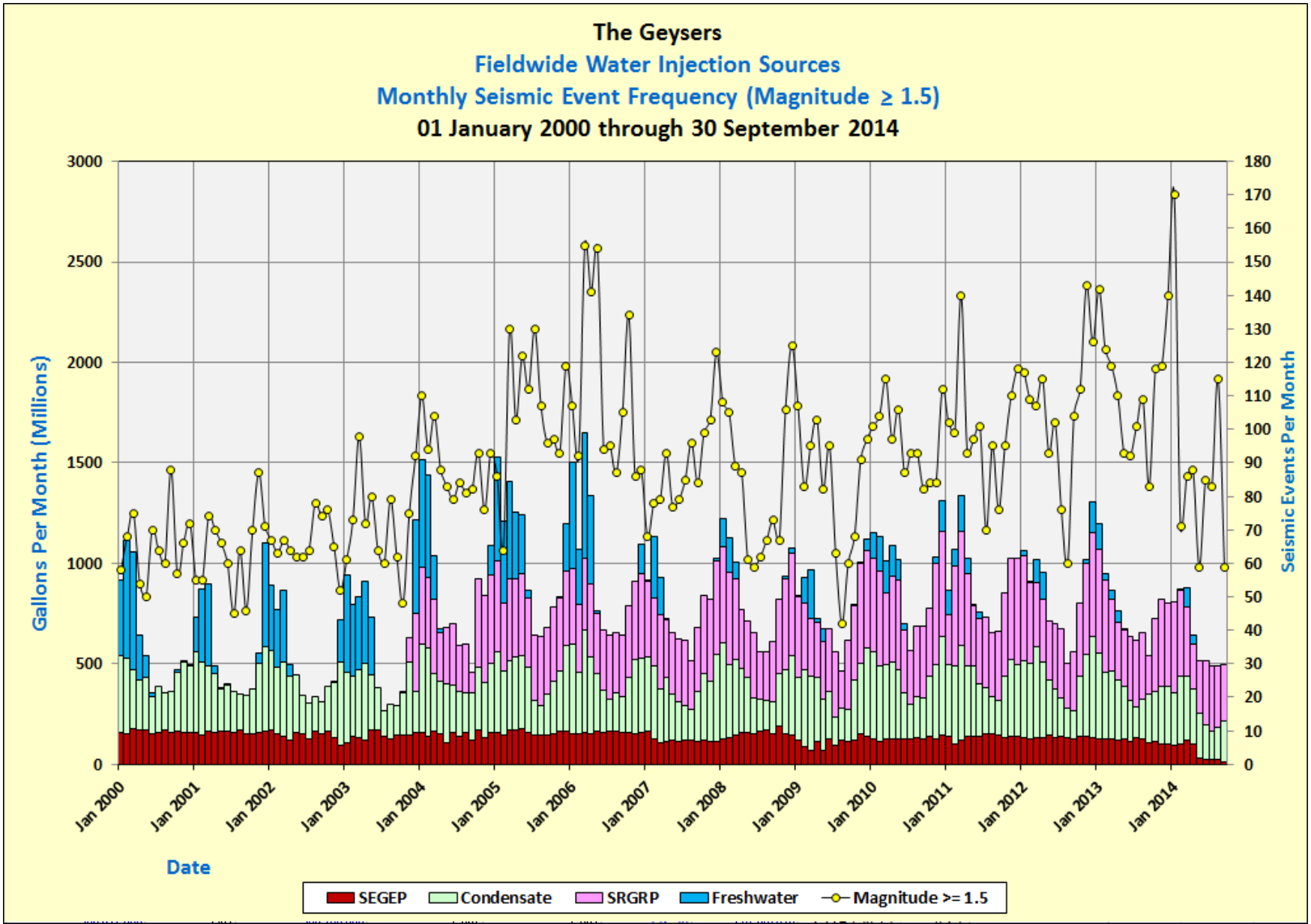
Reference

Field-wide Injection Sources vs. Seismicity
Monthly Values from 01 January 2000 to 30 September 2014



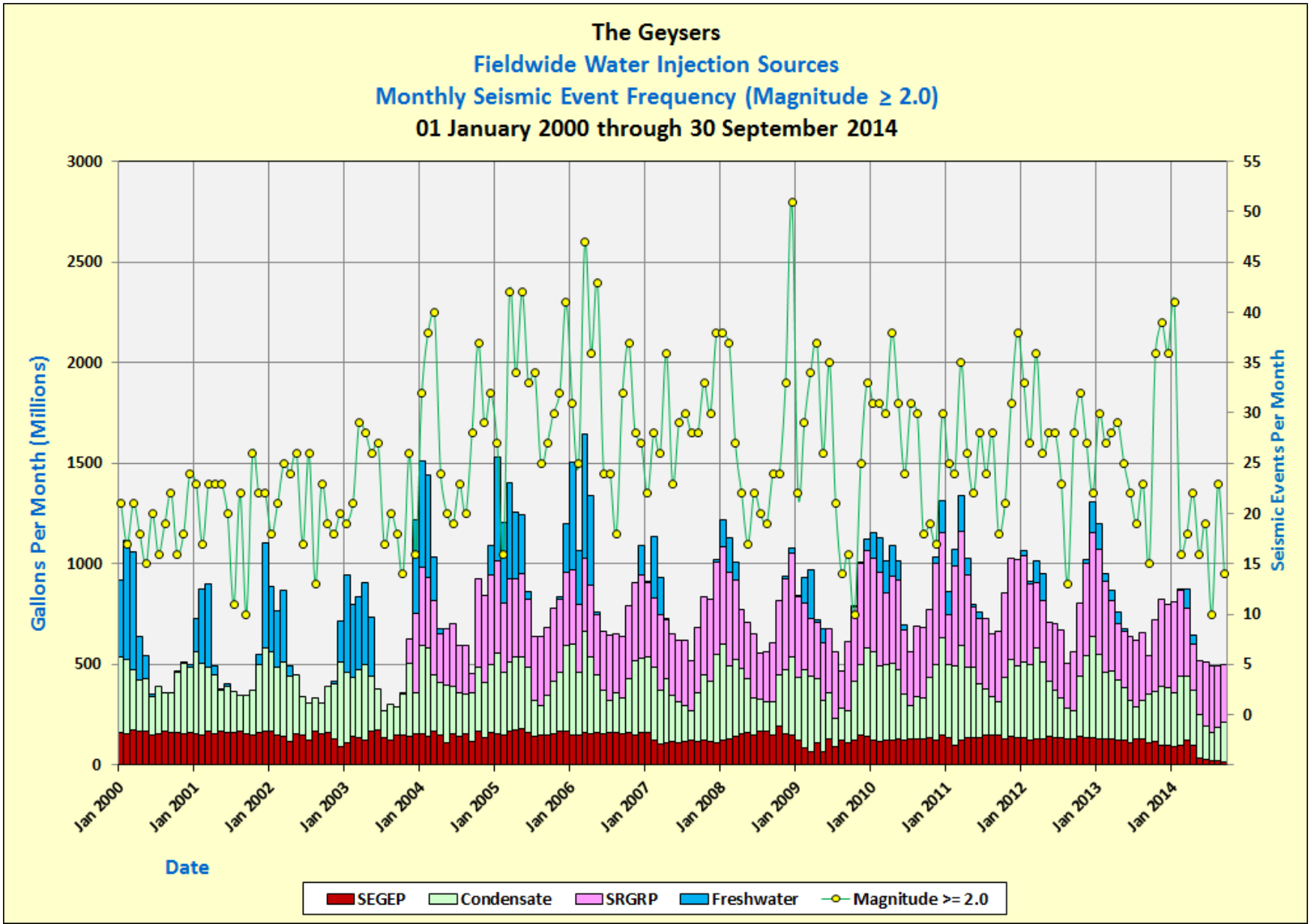
Reference

Field-wide Injection Sources vs. Magnitude ≥ 1.5 Seismicity
Monthly Values from 01 January 2000 to 30 September 2014



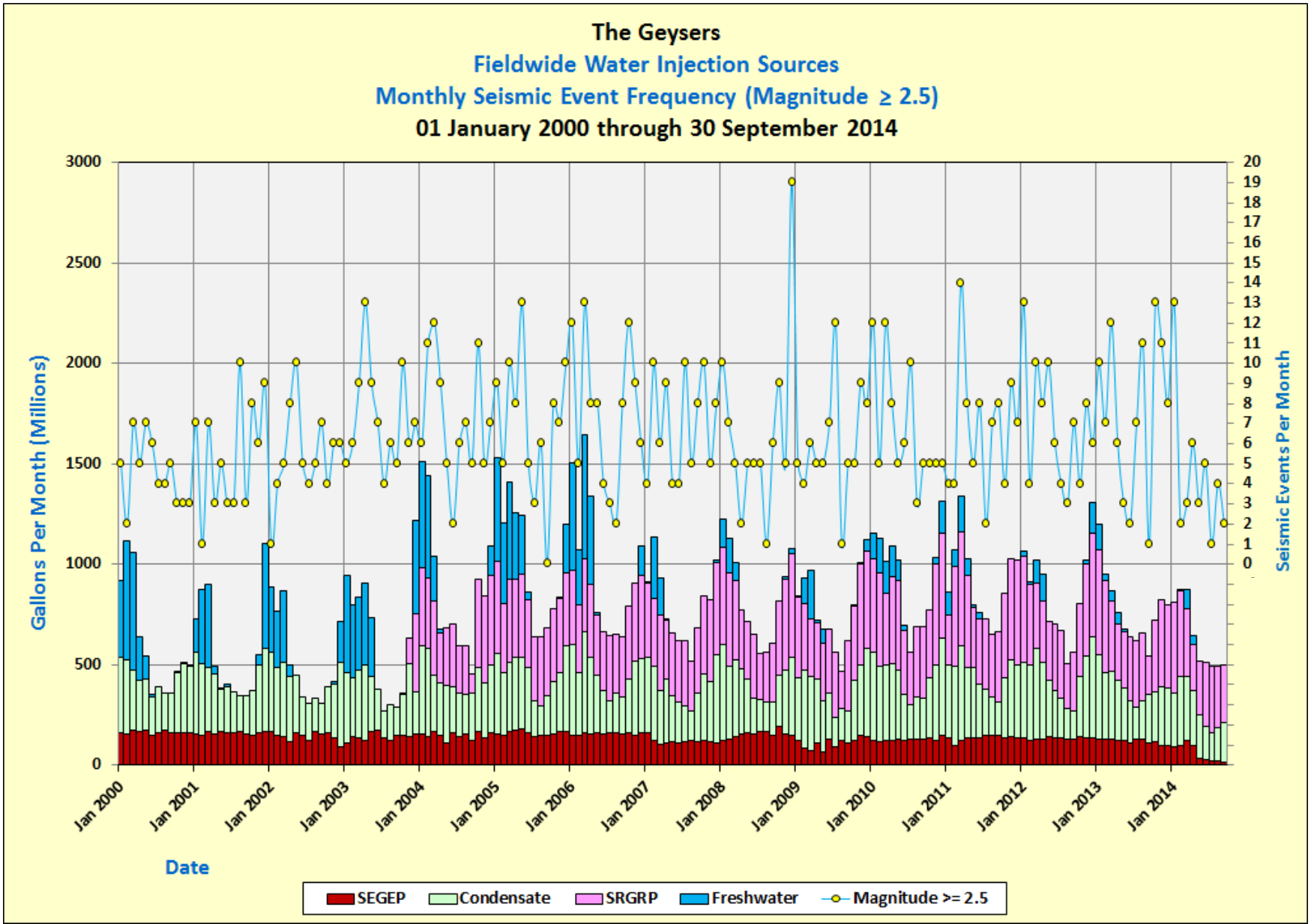
Reference

Field-wide Injection Sources vs. Magnitude ≥ 2.0 Seismicity
Monthly Values from 01 January 2000 to 30 September 2014



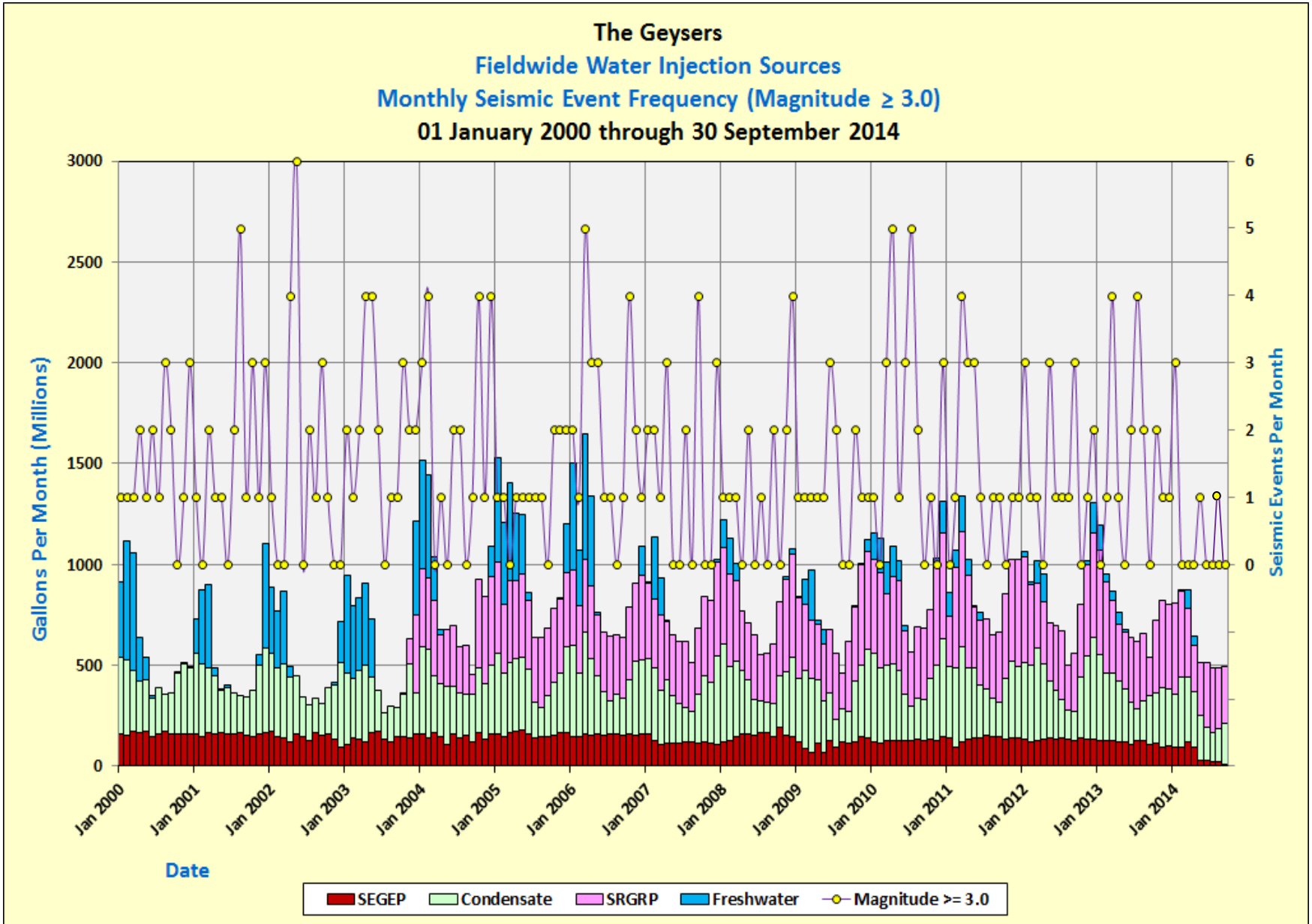
Reference

Field-wide Injection Sources vs. Magnitude ≥ 2.5 Seismicity
Monthly Values from 01 January 2000 to 30 September 2014



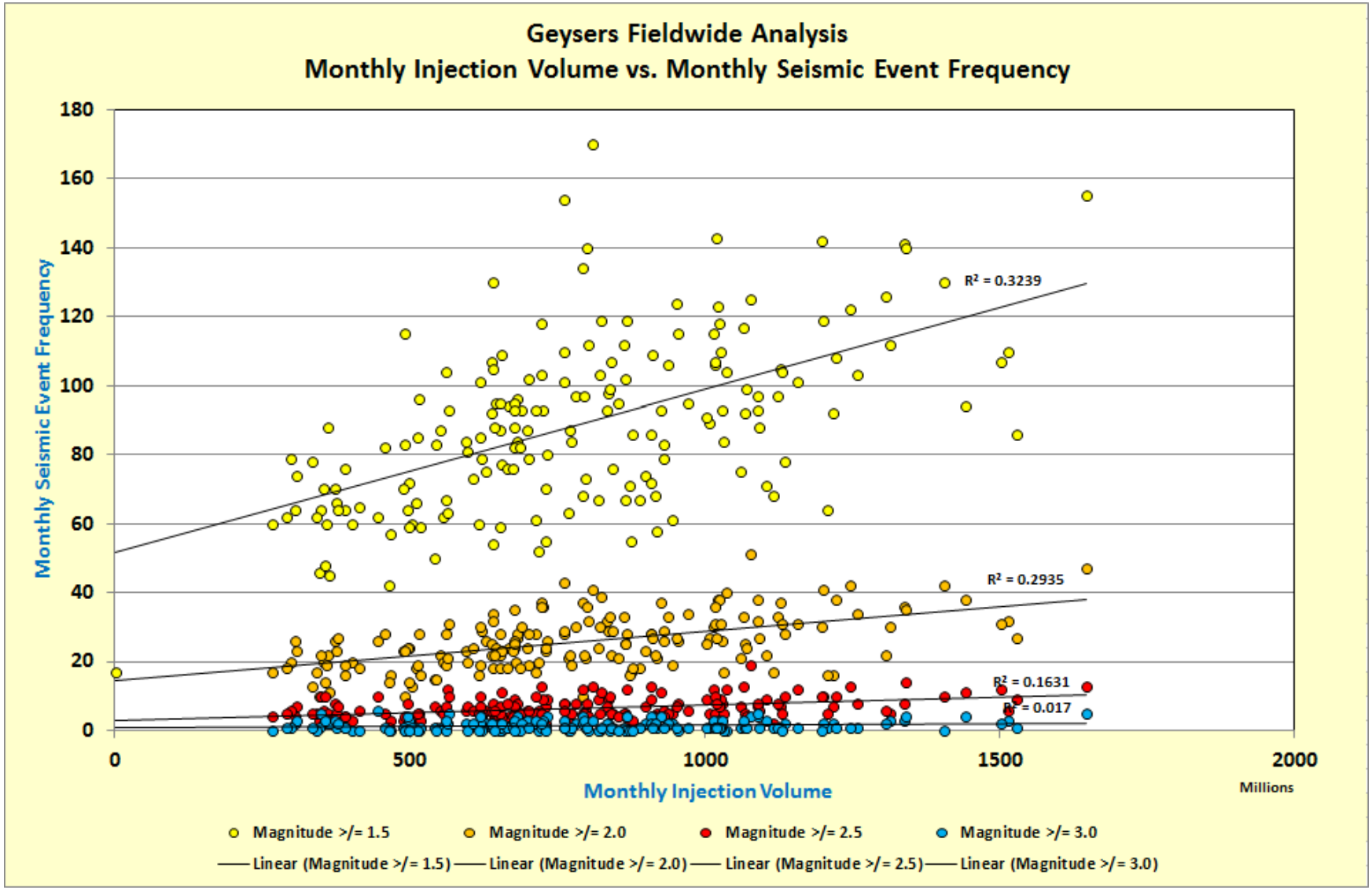
Reference

Field-wide Injection Sources vs. Magnitude ≥ 3.0 Seismicity
Monthly Values from 01 January 2000 to 30 September 2014



Reference

Monthly Water Injection Volume vs. Seismic Event Frequency Field-wide 2000 through end 2014 *



Geysers Community Relations Overview

- Seismic Monitoring and Advisory Committee (SMAC) Biannual Meetings
  - Field Activity and Seismicity Update to Community, Industry and Academic Representatives
  - Presentations Available Upon Request and Posted at www.geysers.com
- Seismic Hotline: 877-4-GEYSER, 707-431-6161 *(alternate number if main line is not working: 916-491-3365)*
  - Community Calls Transcribed Six (6) Days a Week by Calpine
  - Community Call-Back Requests are Handled Promptly
  - Input Compared with Strong-motion Measurements for Cobb and Anderson Springs Stations
- Calpine Provides Detailed Reporting of Events of M>/= 4.0 (or M >/=3.5; MMI >/= 5; PGA >/= 3.9%)
  - For Employees, Community Leaders, Industry and Academic Representatives
- Santa Rosa Geysers Recharge Project (SRGRP) Biannual Reporting to the City of Santa Rosa
  - SRGRP Injection and Seismicity Relationships
  - URS Corporation Geophysicists Perform Independent Data Analysis and Report Generation
- NCPA & Calpine Meet Monthly with Anderson Springs Community; and Cobb Community (Calpine only)
  - Each Community has Geothermal Mitigation and Community Investment Committee:
    - Review Seismicity Related Claims and Funding for Community Benefit Projects
    - Geothermal Operators Provide Geysers Operational Updates and Announcements
- Calpine Geothermal Visitors Center: Open to the Public Wednesday - Saturday, 11 a.m. to 5 p.m.
- Geysers Tours: Free Community Tours Offered Spring through Fall

Reference
2014 Calpine Geysers Field Facts

- 75 miles north of San Francisco, California
- 10 power plants in Sonoma County: Aidlin, Sonoma, McCabe, Ridgeline, Eagle Rock, Cobb Creek, Sulphur Springs, Lake View, Socrates and Grant.
- 5 power plants in Lake County: Bear Canyon, West Ford Flat, Big Geysers, Quicksilver and Calistoga.
- 29,000 acres (45 square miles)

- 333 steam wells
- 60 injection wells
- Deepest well: 12,900 feet, or over two miles
- Average well depth: 8,500 feet
- Total Calpine Geysers wells drilled to date: 587
- Today's Average Grassroots Drilling Time: 85 days (75 days drilling + 10 rig up/down)
- 2013 Average Steam Production per well: 36,690 pounds per hour
- Average Reservoir Steam Temperature: 359 degrees Fahrenheit
- Average Flowing Steam Pressure: 76.6 PSIG
- Most recent steam well drilled: Aidlin-10, January 13, 2014
- Most recent injection well drilled: LF-22 , August 27, 2013

- 15 operating geothermal plants
- Steam pipelines: 80 miles
- Injection water lines: 69 miles
- 21kV power lines: 70 miles
- Project roads: over 167 miles

World's largest geothermal power producer

18% of California's renewable electricity generation
39% of USA geothermal electricity generation

- Two large-scale wastewater injection projects
  - Santa Rosa Geysers Recharge Project Average: 11.73 MGD
  - Calpine Southeast Geysers Effluent Pipeline Average: 3.88 MGD
  - Calpine + Northern California Power Agency Average: 8.39 MGD

- 2013 Average Load: 685.2 net megawatts
- 2013 Generation: 6,002,660 net megawatt hours
- 2013 Average Unit Availability: 96.0%