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NYSE CPN

A GENERATION AHEAD, today

Seismic Monitoring
Advisory Committee Review

12 May 2014
Geothermal Visitors Center
Middletown, California

Reporting Period:
01 October 2013 to 31 March 2014

Craig Hartline
Senior Geophysicist
Calpine Corporation

CLEAN MODERN EFFICIENT FLEXIBLE POWER GENERATION

Seismic Monitoring Advisory Committee Meeting
Calpine Presentation Agenda
Reporting Period 01 October 2013 to 31 March 2014

- Seismicity Hotline
- Seismic Monitoring Networks
- Field-Wide Water Injection and Seismicity
- Southeast Geysers Water Injection
- Water Injection Modifications
- Strong Motion Sensor Stations and Data Analysis
- Strong Motion Triggers By Modified Mercalli Intensity and Year
- Historical Seismic Energy Release Analysis
- SRGRP #21 Report Summary
- 3D Visualization and Geological Model Building
  - Paradigm SKUA/GOCAD Seismicity Analysis Software Advances
- Ongoing Seismicity Research Collaborations
  - GFZ Potsdam
  - Lawrence Berkeley National Laboratory
  - Massachusetts Institute of Technology
  - Seismic Warning Systems
- 2014 Calpine Fact Sheet
- Calpine Community Outreach

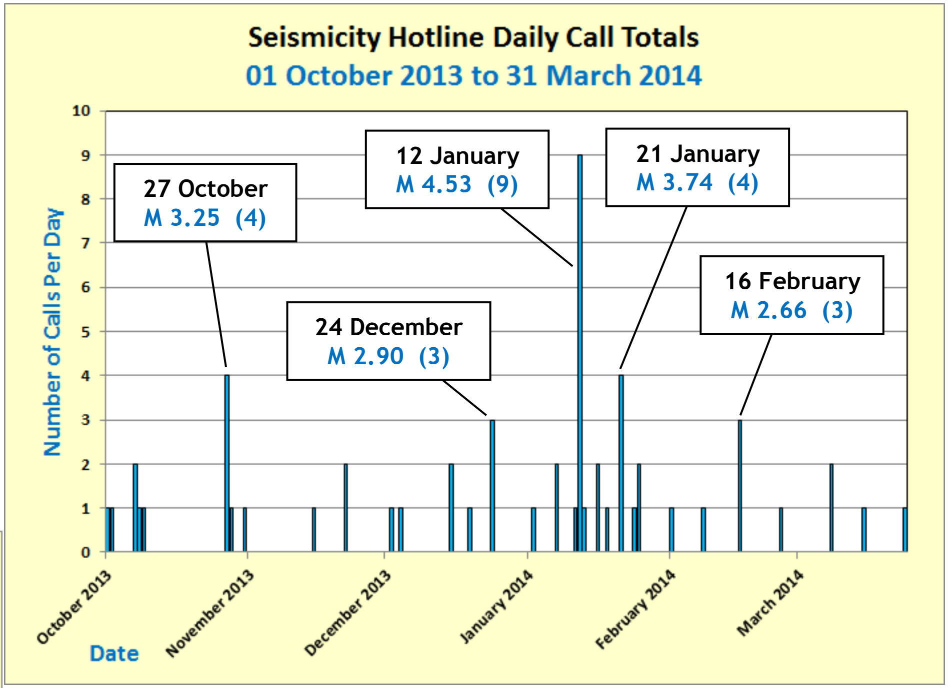
Seismic Monitoring Advisory Committee Meeting
01 October 2013 to 31 March 2014
Seismicity Hotline 1-877-4GEYSER (Toll Free)

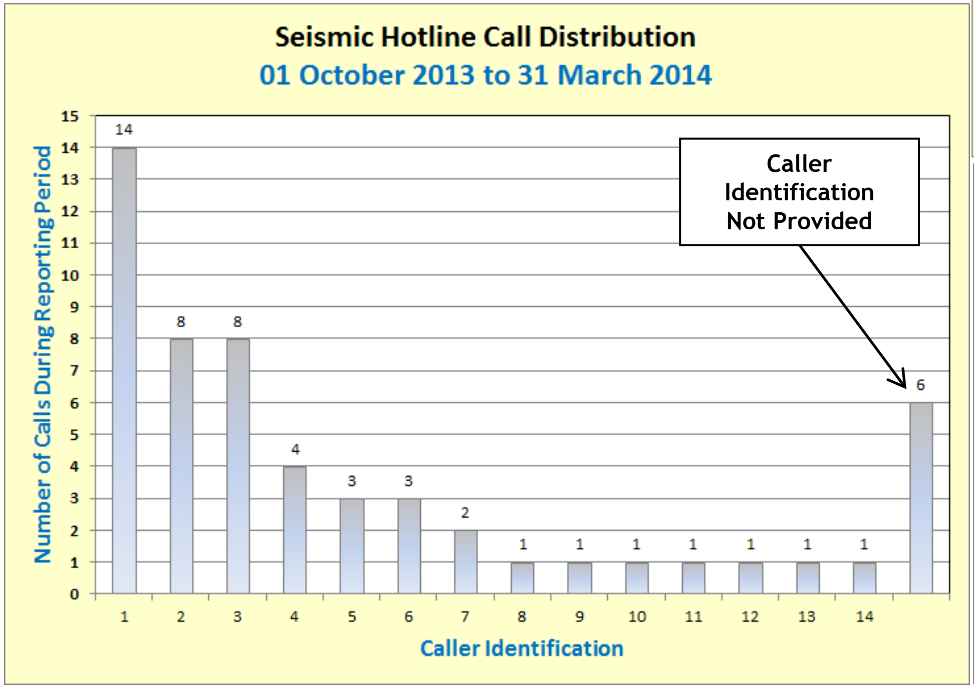
Calls transcribed, distributed and reviewed daily.

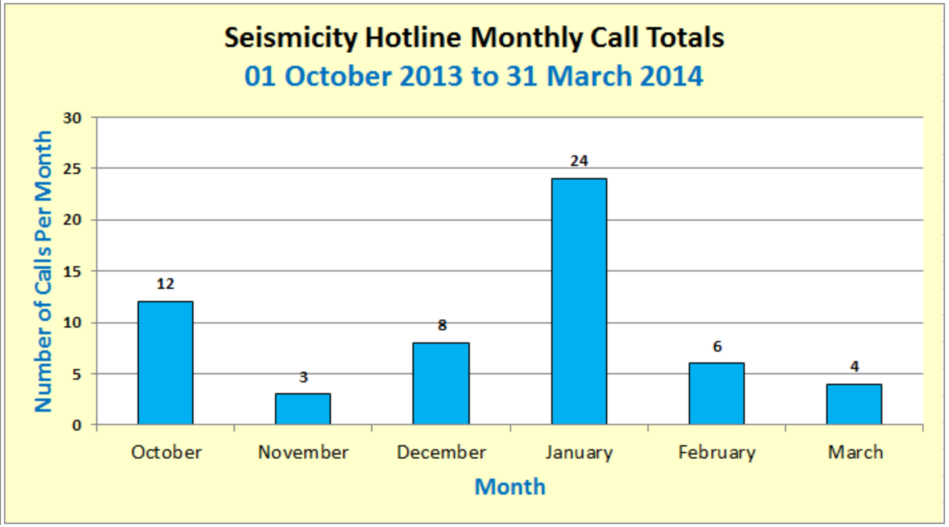
57 seismicity voicemails transcribed and reviewed.

Anderson Springs:	42 calls	3 call-back requests
Cobb:	15 calls	4 call-back requests

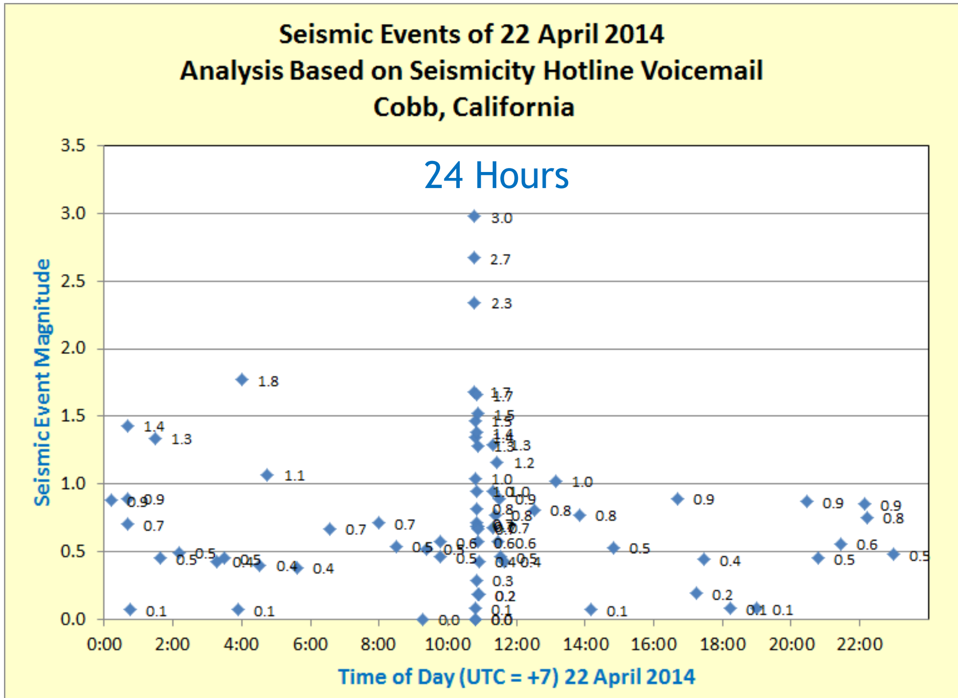
81 calls in previous reporting period.



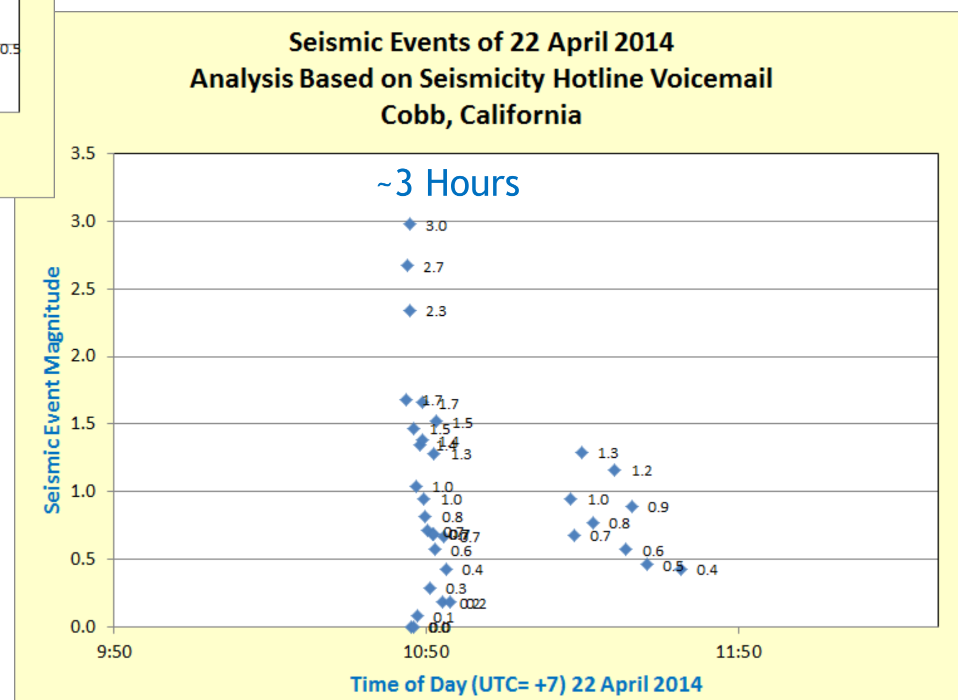




Seismic Monitoring Advisory Committee Meeting
01 October 2013 to 31 March 2014
Seismicity Hotline 1-877-4GEYSER (Toll Free)



Based on a call of 22 April 2014 from the community of Cobb, several seismic events felt in series were analyzed in detail. These events were determined to be related to energy release within a very short time and within a very limited area.



Seismic Monitoring Networks

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Permanent Monitoring / Real-Time Processing

Lawrence Berkeley National Laboratory
Installed in 2003; continued upgrades
32 stations; M 1.0 threshold
Primary Contact: Dr. Ernie Major (LBNL)

US Geological Survey
Installed in 1970's; some upgrades
6 stations; M 1.5 threshold
Primary Contact: Dr. David Oppenheimer (USGS)

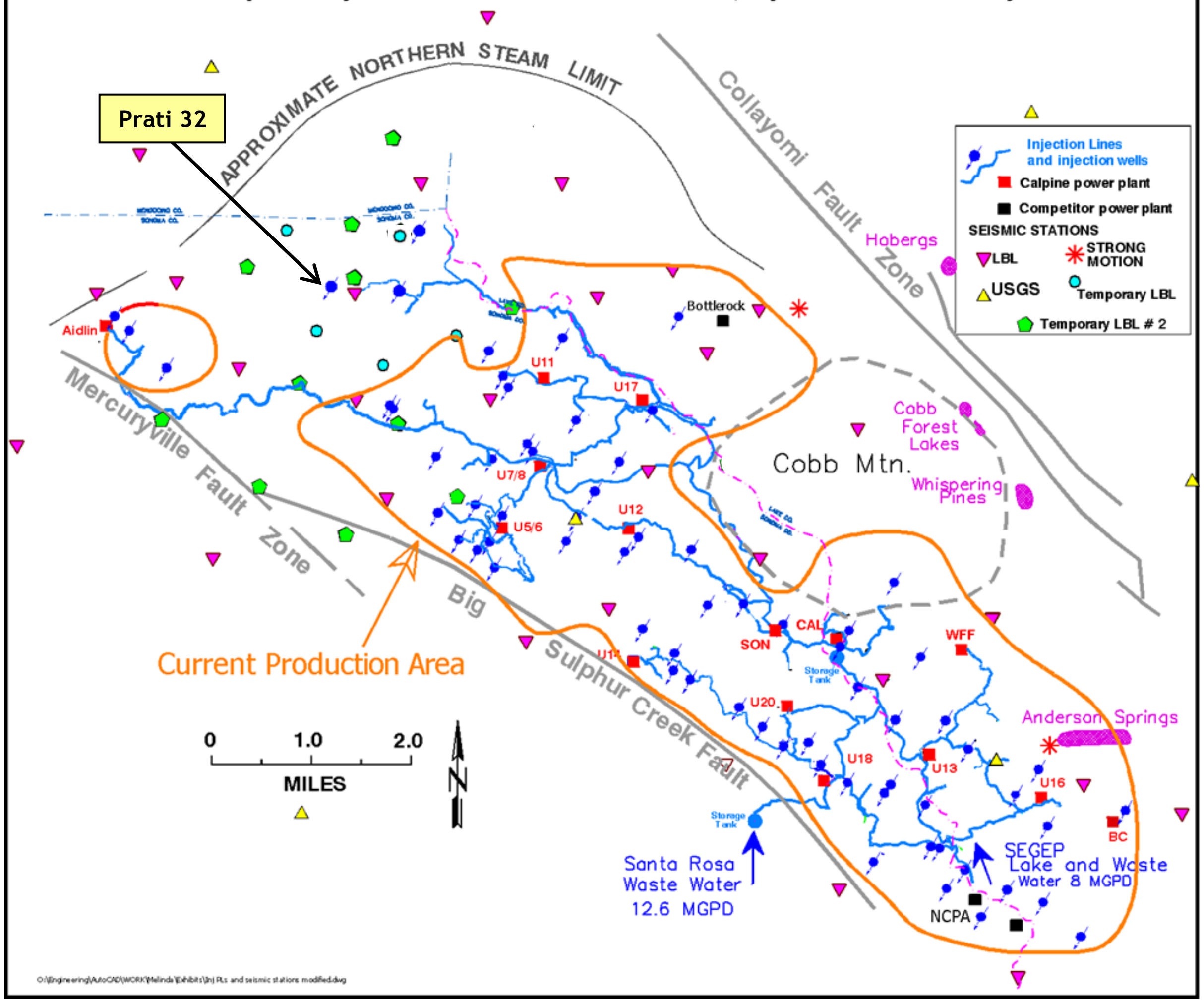
Strong motion instruments: 3
Installed in 2003; perceived shaking
3 stations; ~0.1% g threshold
Primary Contact: Jim Cullen (USGS contracted)

Project Dedicated Temporary Monitoring

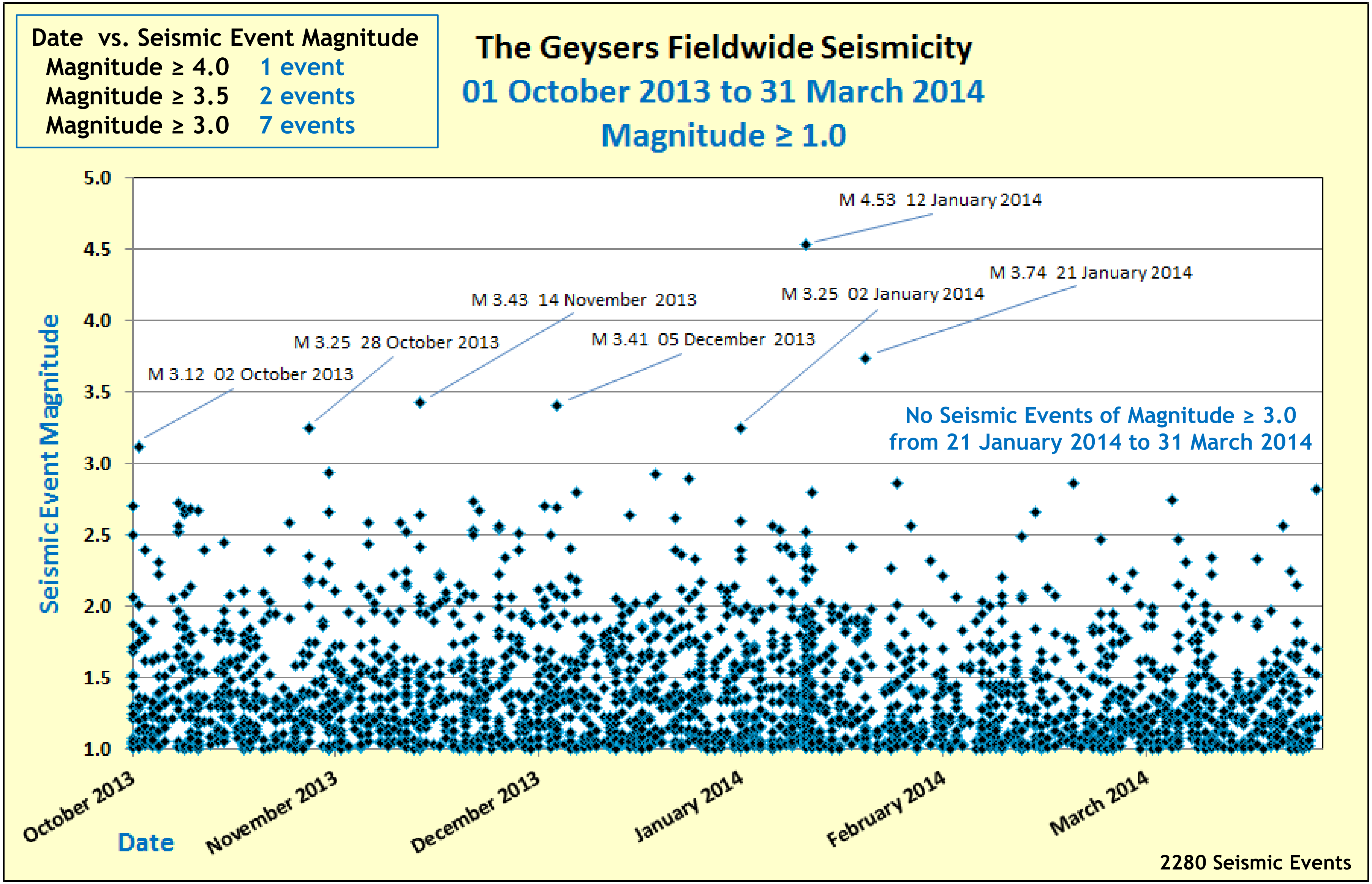
Lawrence Berkeley National Laboratory
Installed in 2010, ~ M1.0 threshold
5 stations; 4-6 months storage
Primary Contact: Dr. Ernie Major (LBNL)

Lawrence Berkeley National Laboratory
Installed in 2011, ~ M1.0 threshold
9 stations; 3-4 weeks storage
Stations Removed; Data Analysis
Primary Contact: Dr. Lawrence Hutchings (LBNL)

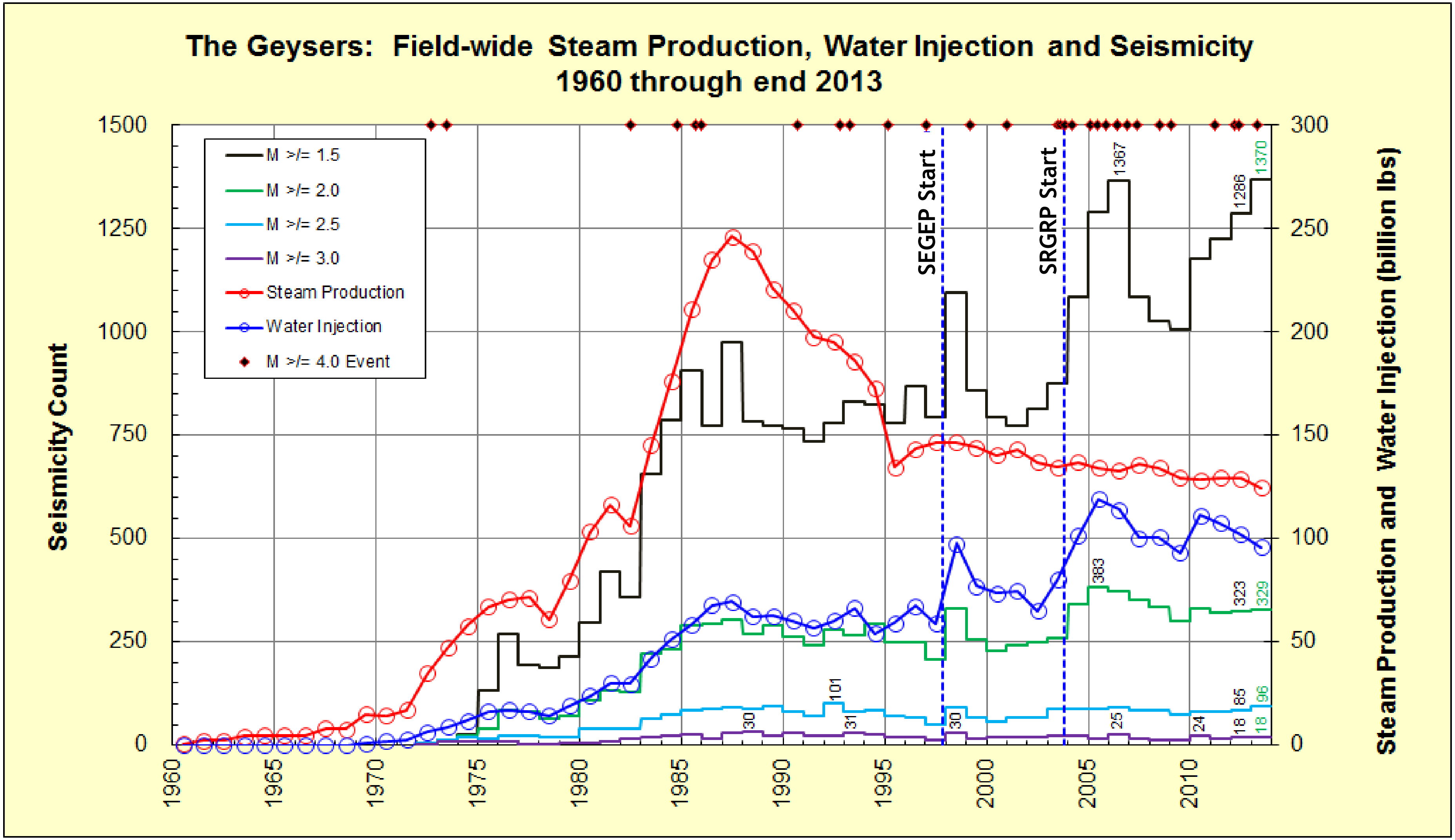
Outline of The Calpine Geysers field with seismic stations, injection wells and injection lines.



Field-wide Seismicity Analysis
01 October 2013 to 31 March 2014



Yearly Field-wide Steam Production, Water Injection and Seismicity 1960 through end 2013



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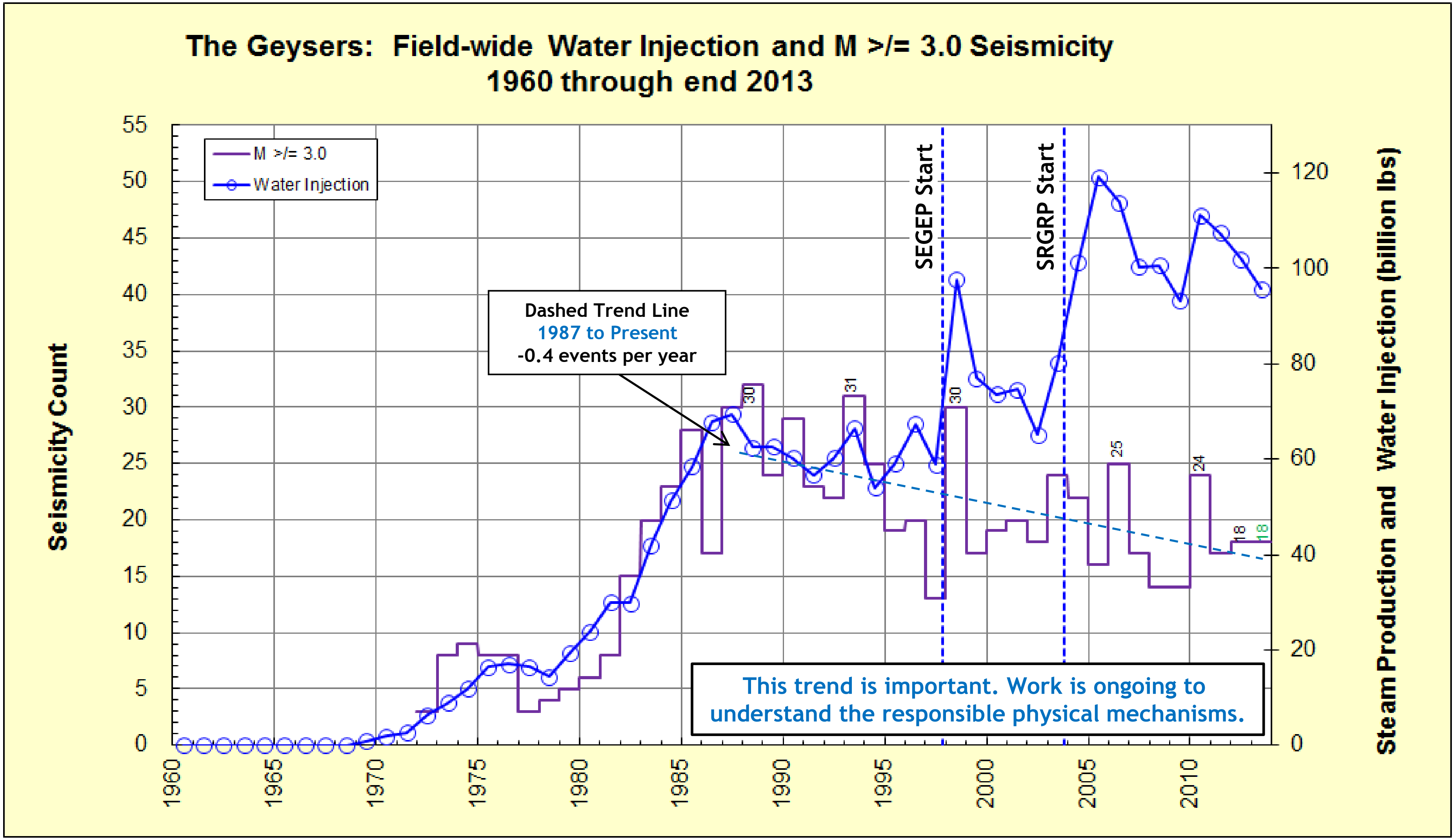
Field-wide Water Injection and M ≥ 3.0 Seismicity 1960 through end 2013



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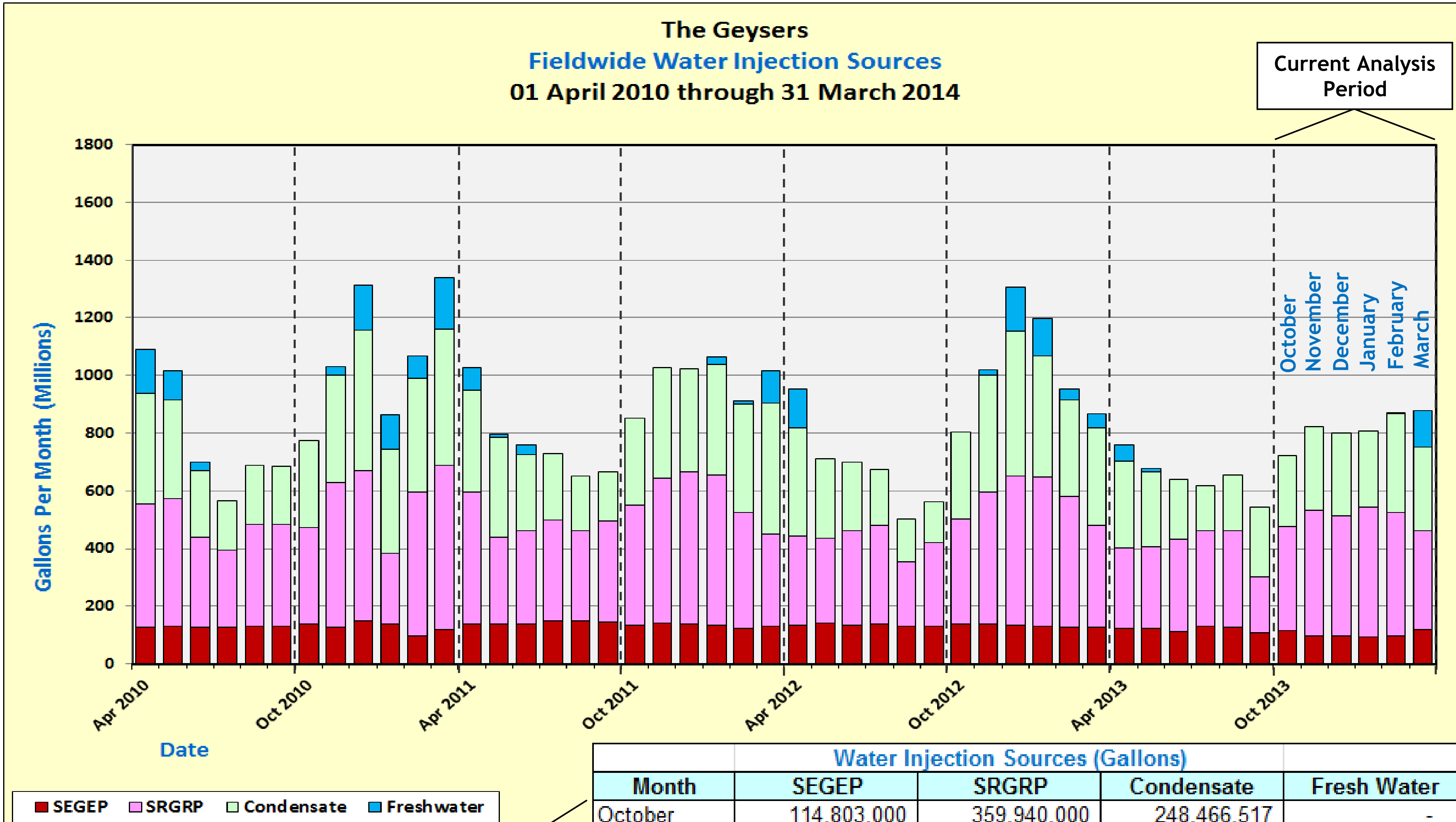
Field-wide Injection Sources
01 April 2010 to 31 March 2014



Current Analysis Period

	Water Injection Sources (Gallons)			
Month	SEGEP	SRGRP	Condensate	Fresh Water
October	114,803,000	359,940,000	248,466,517	-
November	97,330,000	435,830,000	290,175,418	-
December	97,989,000	415,010,000	286,441,285	-
January	92,568,820	450,180,000	265,978,089	-
February	97,545,210	426,960,000	342,211,384	4,690,971
March	120,871,000	339,490,000	291,875,235	124,854,614

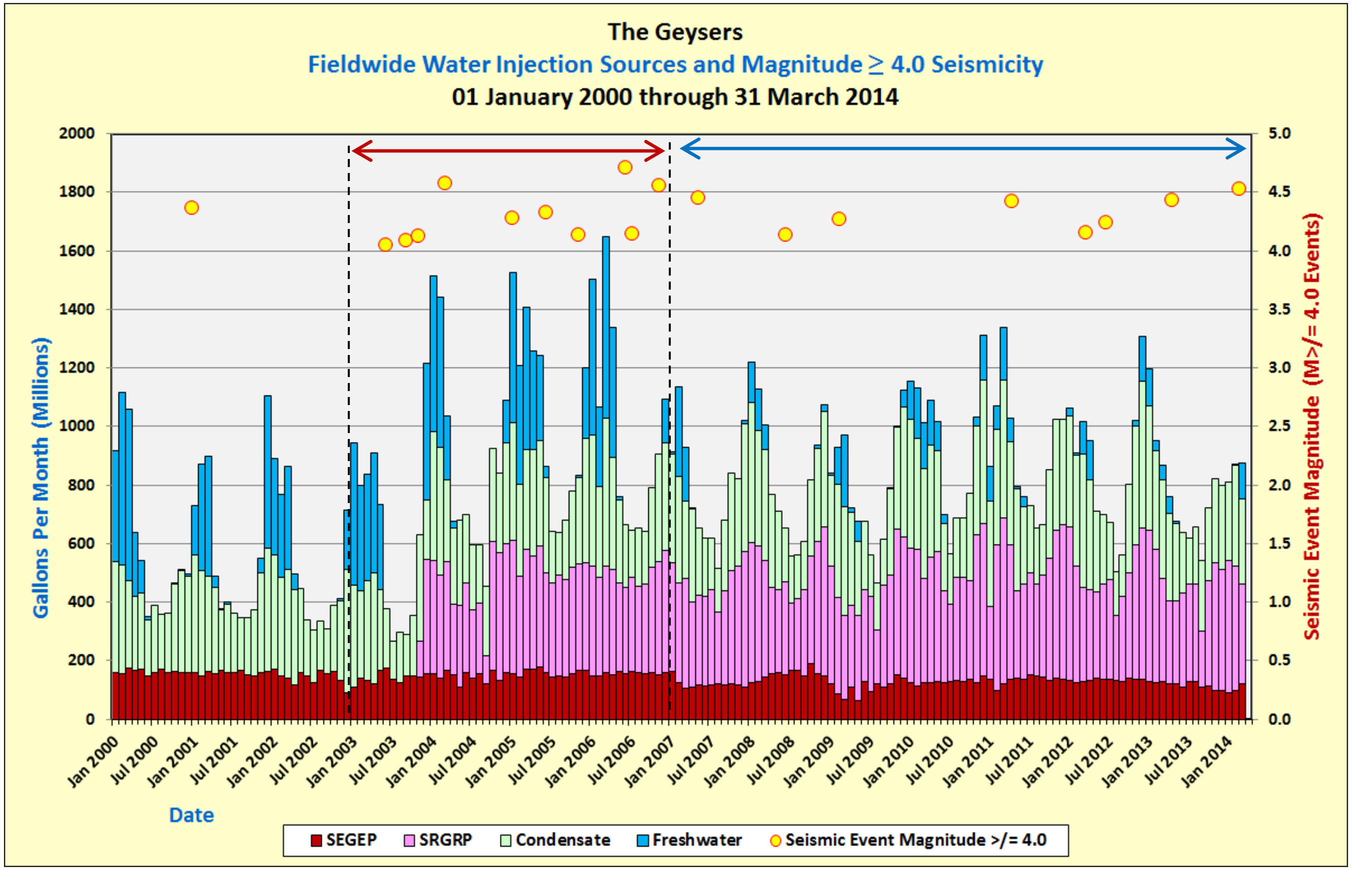
The Geysers

Field-wide Water Injection vs. M ≥ 4.0 Seismicity
01 January 2000 to 31 March 2014

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

Time Period	M ≥ 4.0 Seismic Events
2003 through end 2006	2.5 events per year
2007 through early 2014	1.1 events per year

This related trend is also important. Work is ongoing to understand the responsible physical mechanisms.



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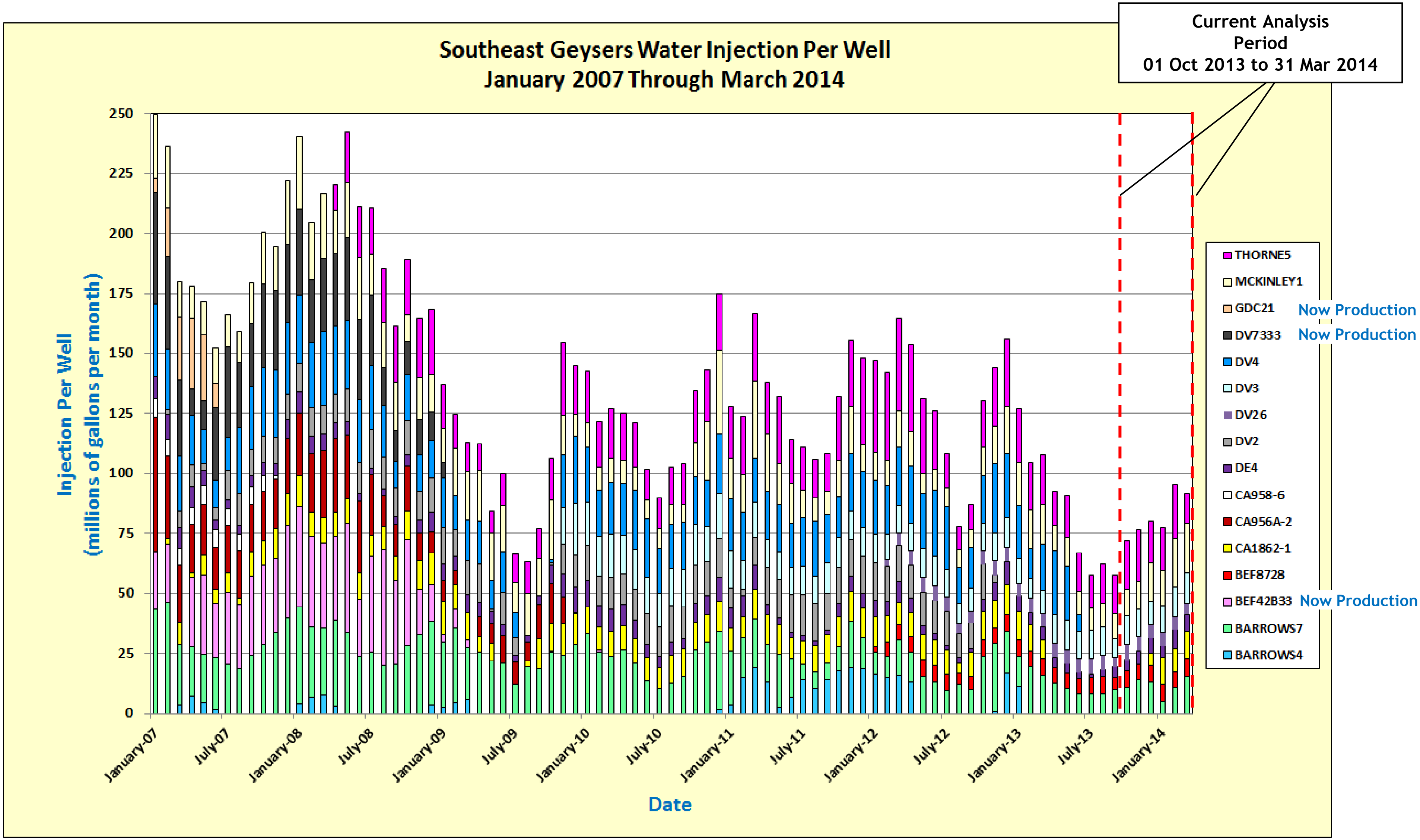
Calpine's Southeast Geysers Injection Wells

01 January 2007 to31 March 2014



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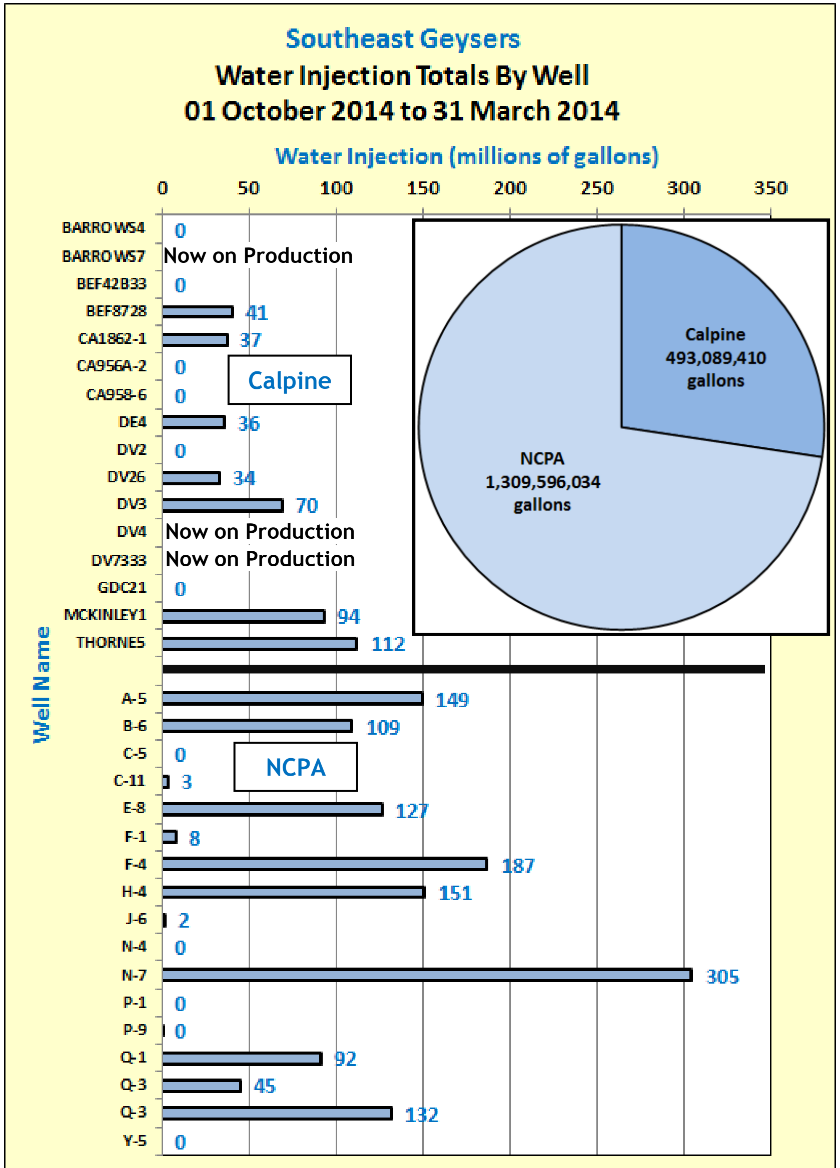
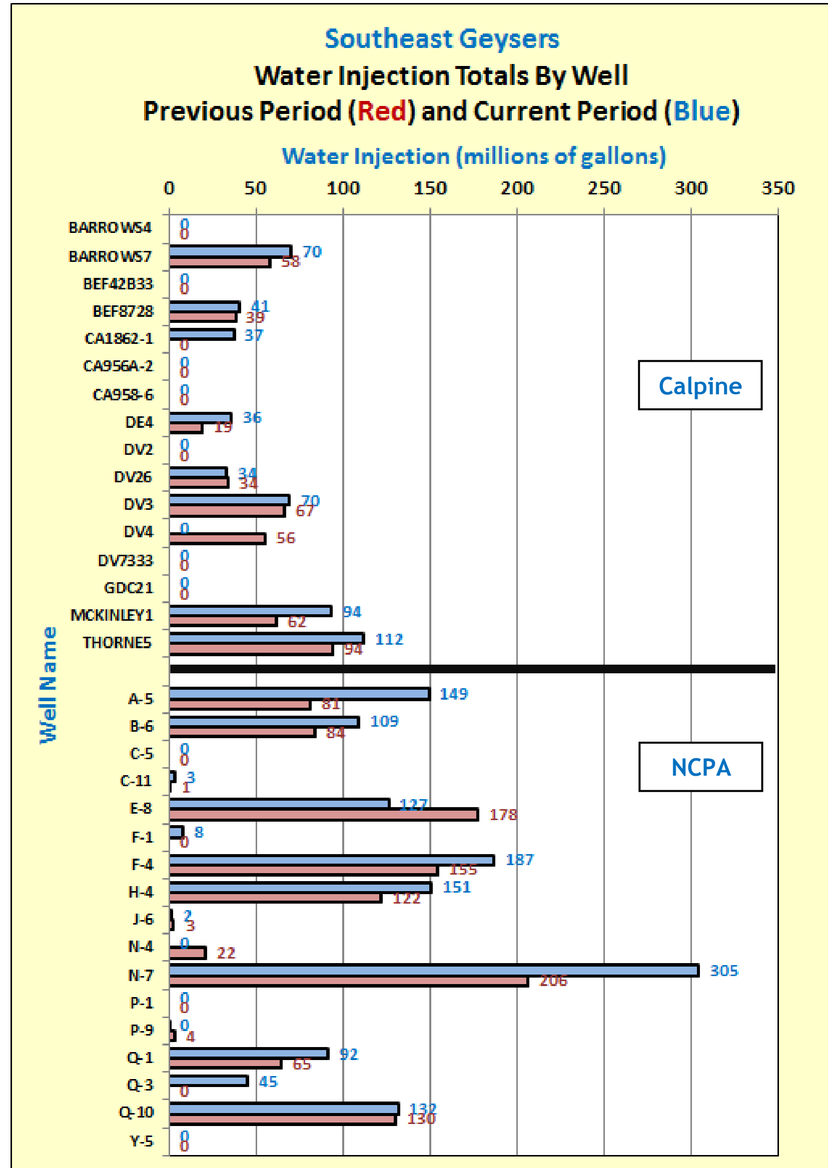
Southeast Geysers Water Injection By Well

01 Oct 2013 to 31 Mar 2014



01 Apr 2013 to 31 Sep 2014 and 01 Oct 2013 to 31 Mar 2014



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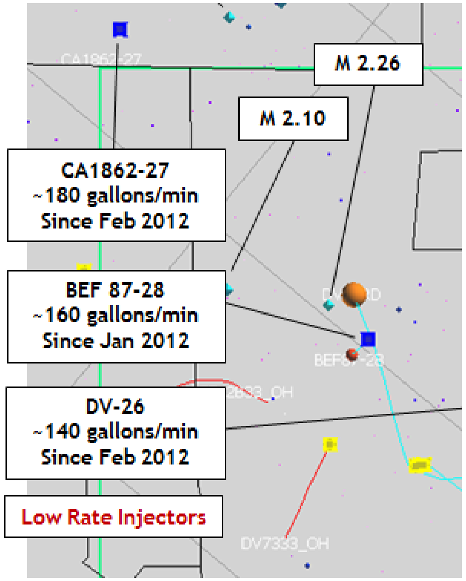
Water Injection Goals

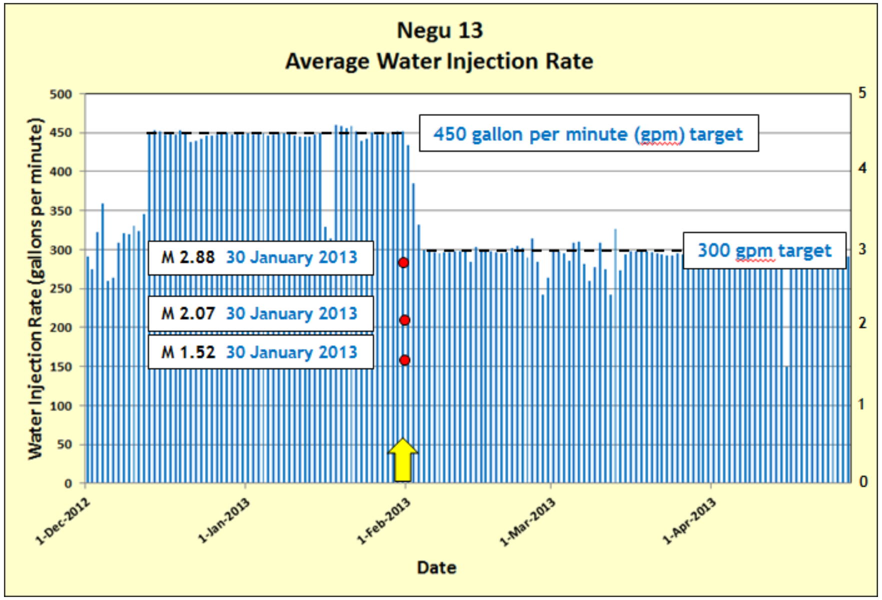
Improve Injection Distribution

- Expansion to northwest and away from communities (Wildhorse-34, Prati-9, Prati-32, Aidlin 11/12)
- Additional injection wells (LF-22 in 2013; Aidlin 13 and McKinley 16 in 2014)
- Shallow low-rate injectors (~150 gallons/minute for CA 1862-27, BEF 87-28, DV-26, 3 more in 2014)

Minimize Injection Rate Variations

- Individual wells and field-wide
- Emphasis on limited variation for wells nearest communities (Negu 13, Thorne 5)
- Suitable injection rates per well continually evaluated (dependent on local geology)
- Designed tests concerning injection rate variability far from communities (Prati 32 in NW Geysers)
- More gradual transition of SRGRP water for injection is occurring





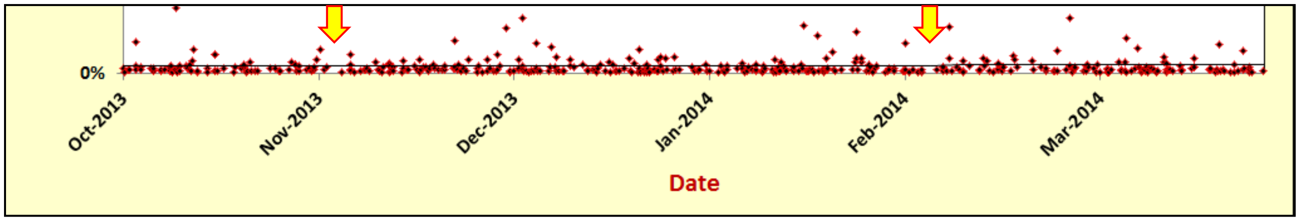
Strong Motion Sensor Stations
01 October 2013 to 31 March 2014

Anderson Springs Strong Motion

No power or communication problems noted for 01 October 2013 to 31 March 2014.

Minor triggered event gaps were noted for:

- 02 November 2013 through 03 November 2013
- 05 February 2014 through 06 February 2014



Anderson Springs ETNA Strong Motion Station

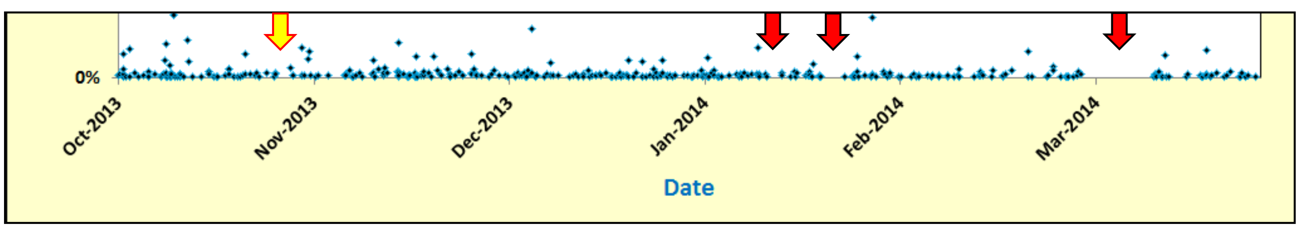
Cobb Strong Motion

Due to a persistent memory card problem the station was out of service with data loss from:

- 11 January 2014 to 14 January 2014
- 20 January 2014 through 24 January 2014
- 03 March 2014 through 13 March 2014

Minor triggered event gap was also noted for:

- 26 October 2013 through 27 October 2013

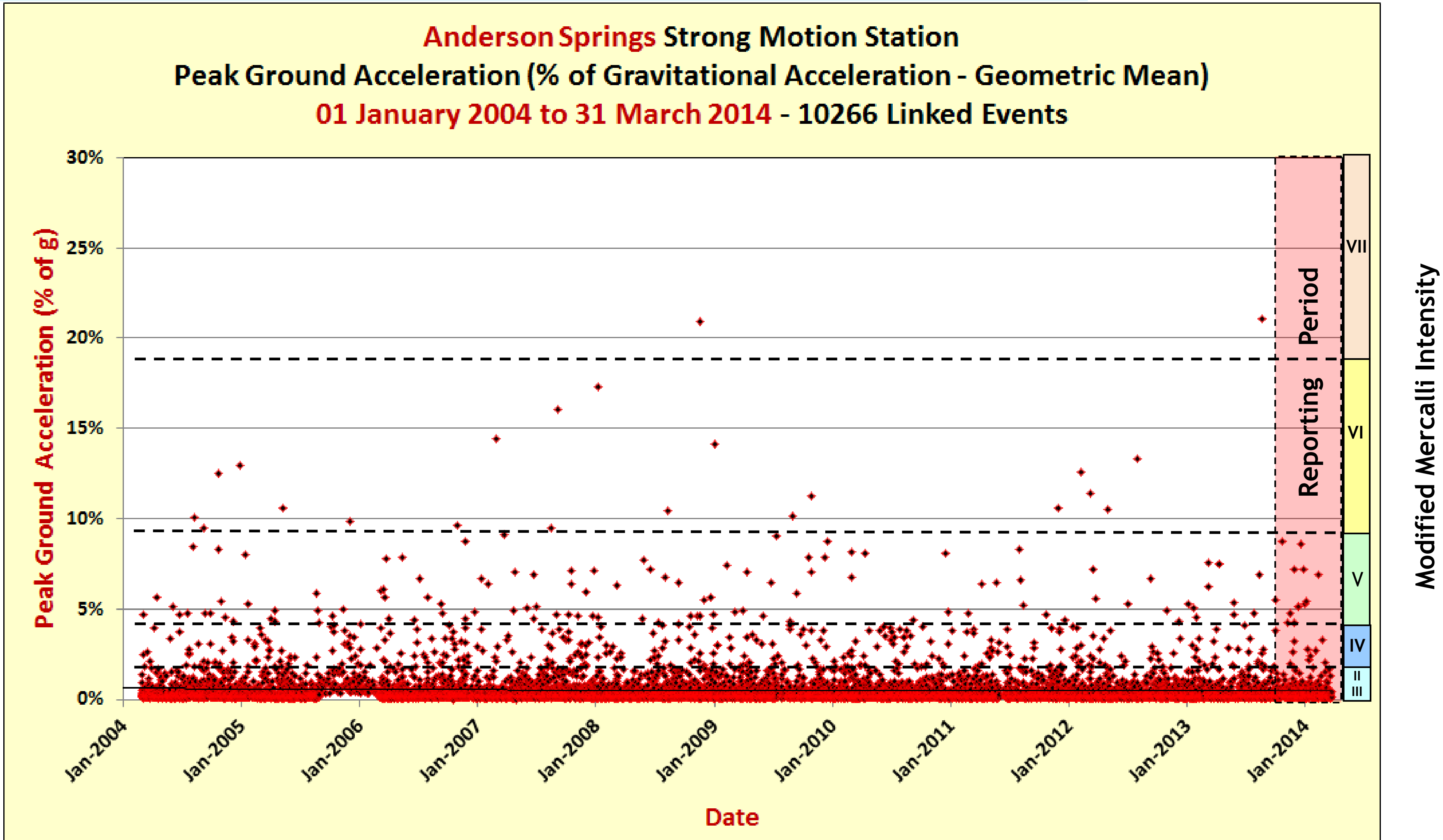


Reliability Limitations:

Rural Power
Rural Communications
Lightning Strikes
Downed Lines

Calpine is currently discussing a longer-term solution for strong motion monitoring (and seismic monitoring) with LBNL (Ernie Majer / Ramsey Haught) and the USGS (David Oppenheimer / Jim Cullen).

Seismic Monitoring Advisory Committee Meeting
Anderson Springs Peak Ground Acceleration
01 January 2004 to 31 March 2014

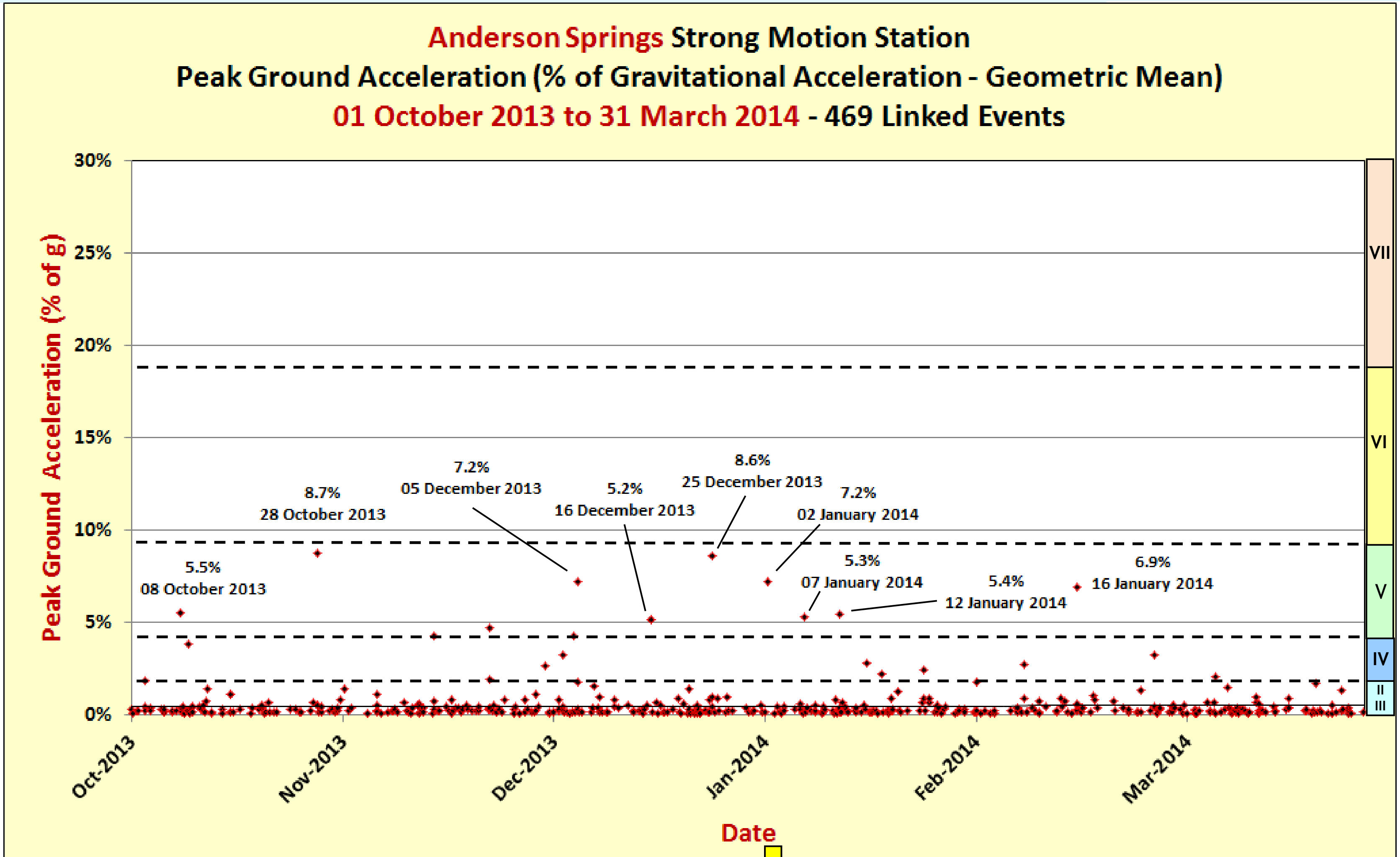


Perceived Shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	None	None	None	Very Light	Light	Moderate	Mod/Heavy	Heavy	Very Heavy
Peak Acceleration (% of g)	< 0.17	0.17 - 1.4	1.4 - 3.9	3.9 - 9.2	9.2 - 18.0	18.0 - 34.0	34.0 - 65.0	65.0 - 124.0	> 124.0
Peak Velocity (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

Seismic Monitoring Advisory Committee Meeting

Anderson Springs Peak Ground Acceleration

01 January 2004 to 31 March 2014



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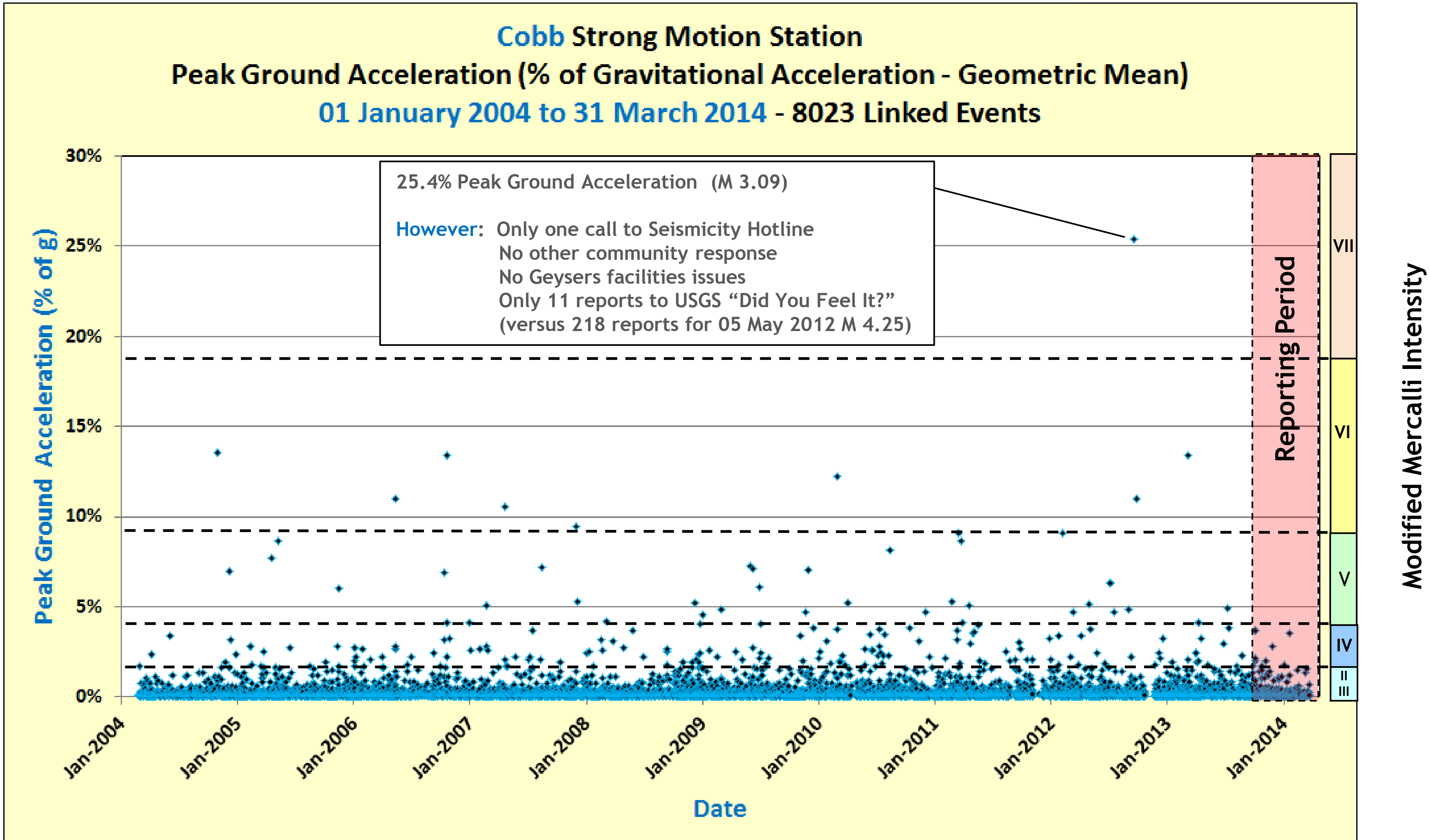
Modified Mercalli Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X

Seismic Monitoring Advisory Committee Meeting

Cobb Peak Ground Acceleration

01 January 2004 to 31 March 2014



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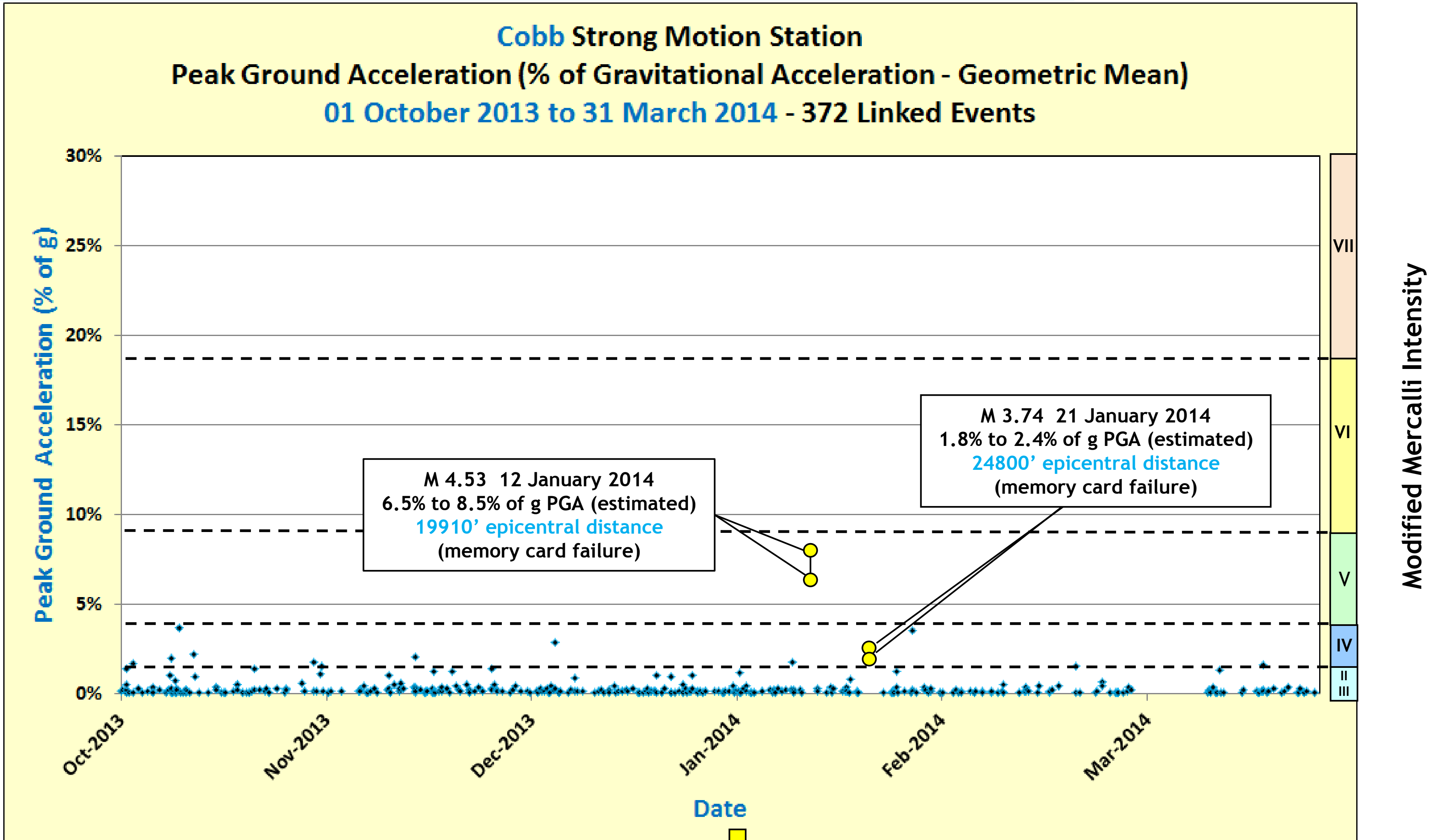
Seismic Monitoring Advisory Committee Meeting
Cobb Peak Ground Acceleration
01 January 2004 to 31 March 2014



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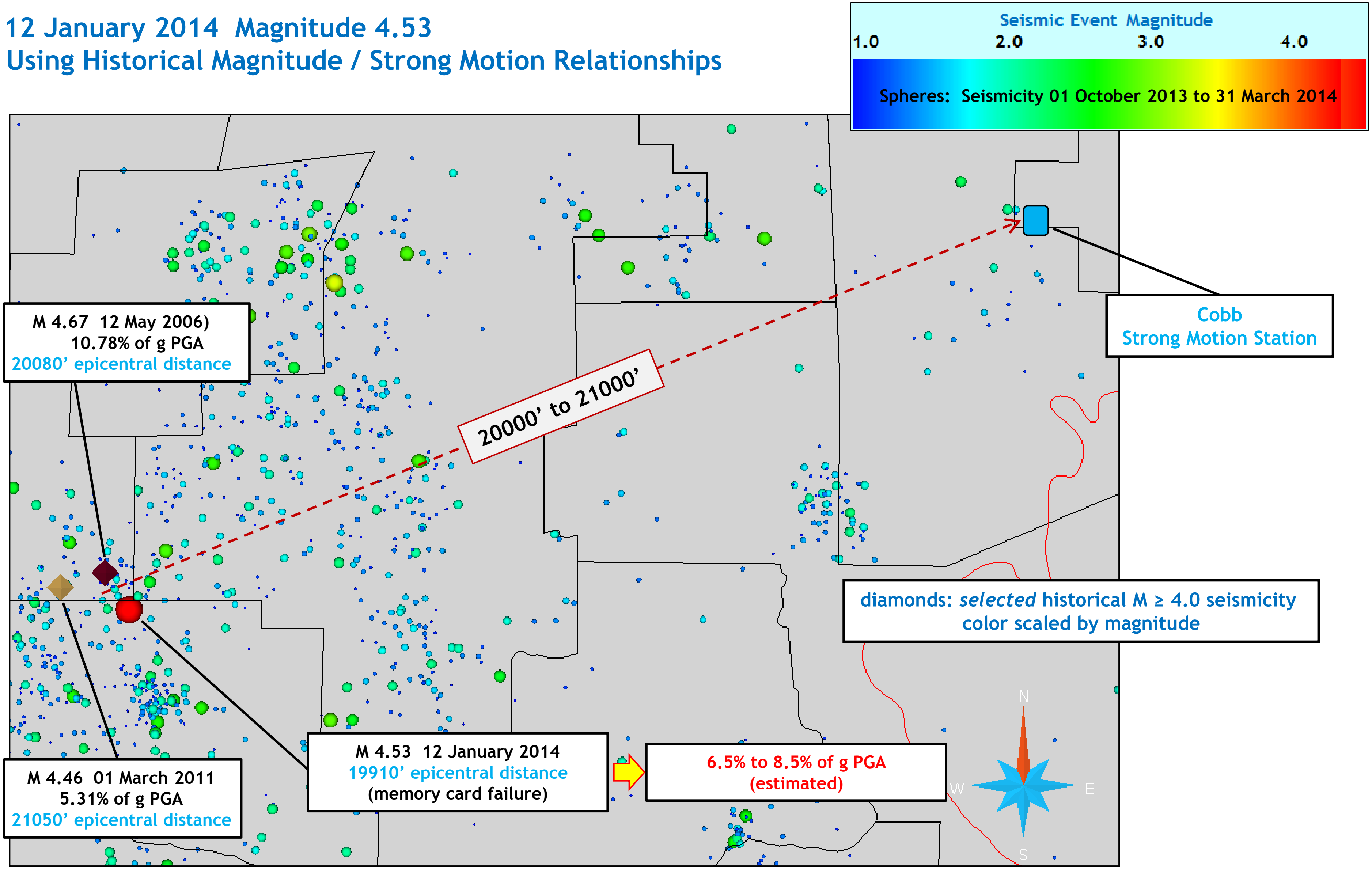
Modified Mercalli Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X

Seismic Monitoring Advisory Committee Meeting
Cobb Strong Motion
Peak Ground Acceleration *Estimation*

12 January 2014 Magnitude 4.53
Using Historical Magnitude / Strong Motion Relationships



Seismic Monitoring Advisory Committee Meeting
Cobb Strong Motion
Peak Ground Acceleration *Estimation*

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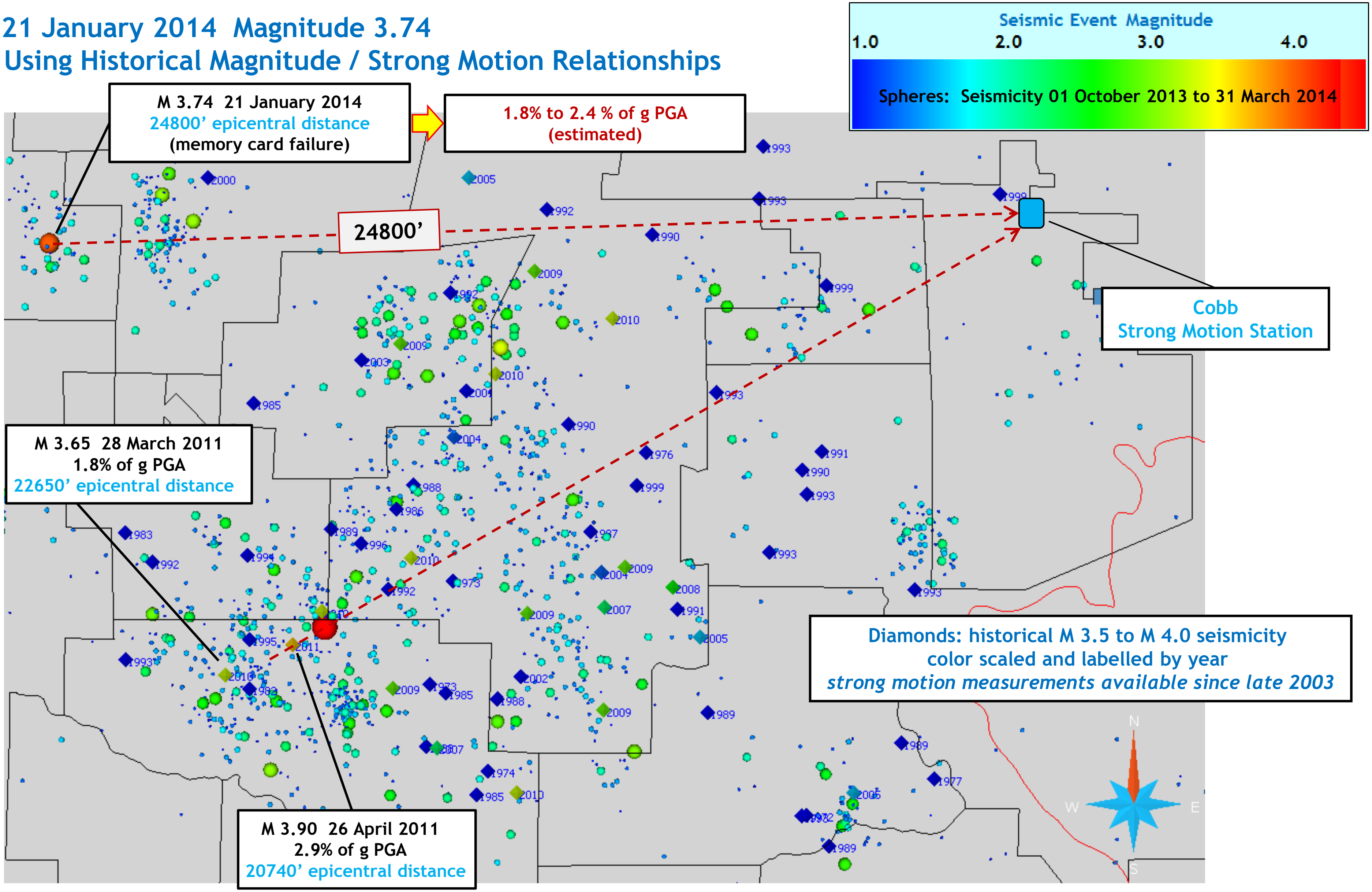
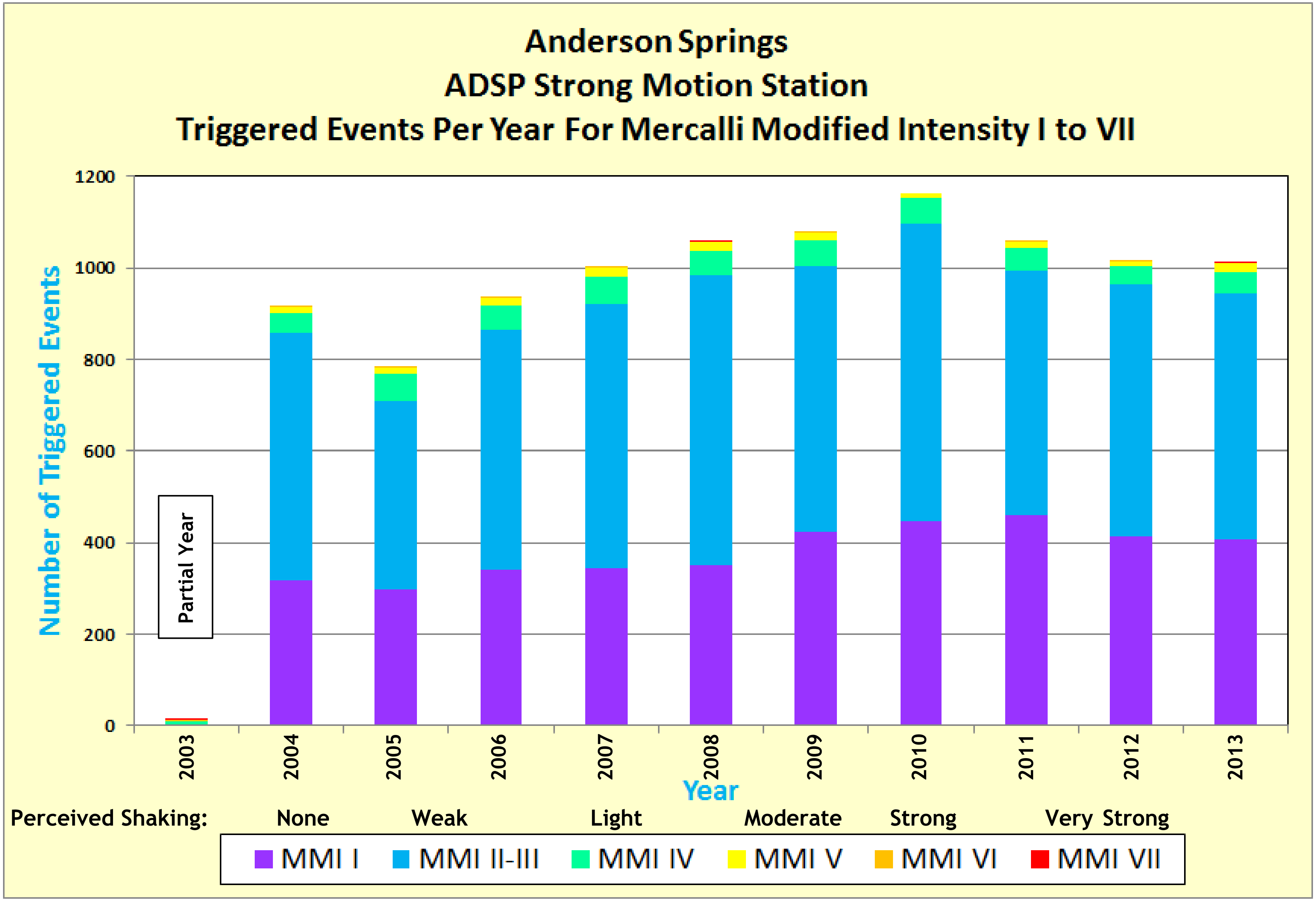
21 January 2014 Magnitude 3.74
Using Historical Magnitude / Strong Motion Relationships

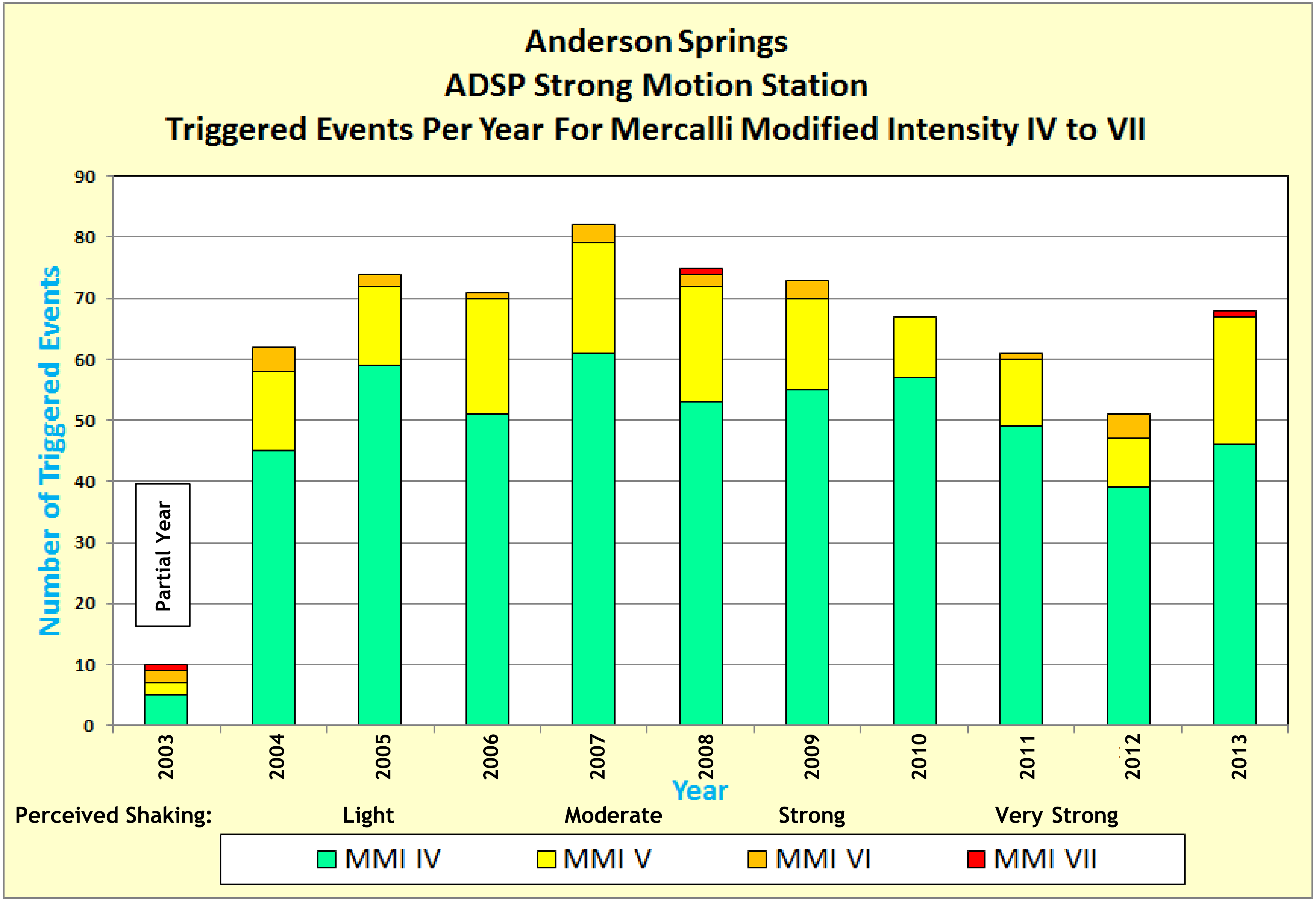


Seismic Monitoring Advisory Committee Meeting

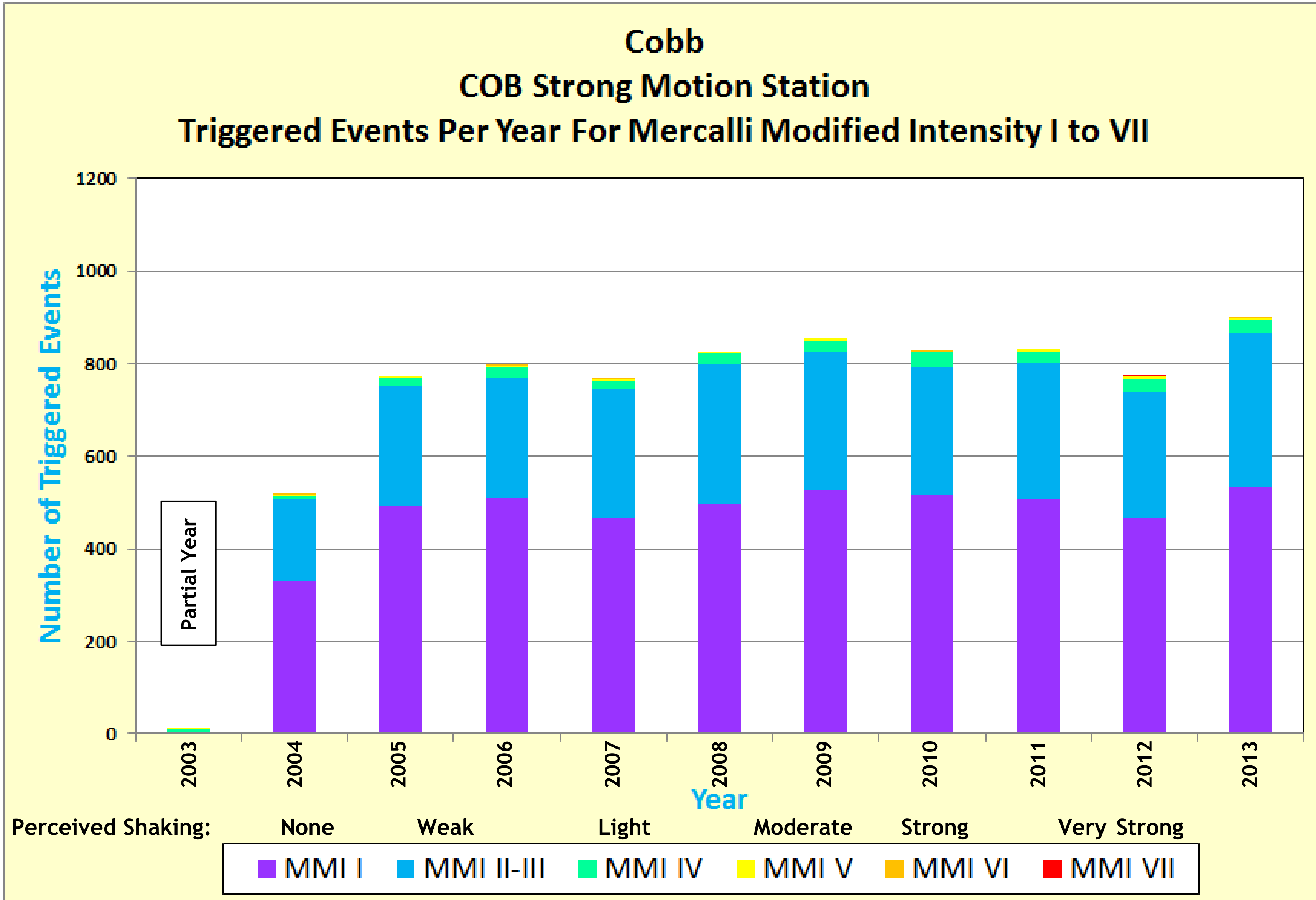
Anderson Springs Peak Ground Acceleration
Triggered Strong Motion Events Per Year Since 2003



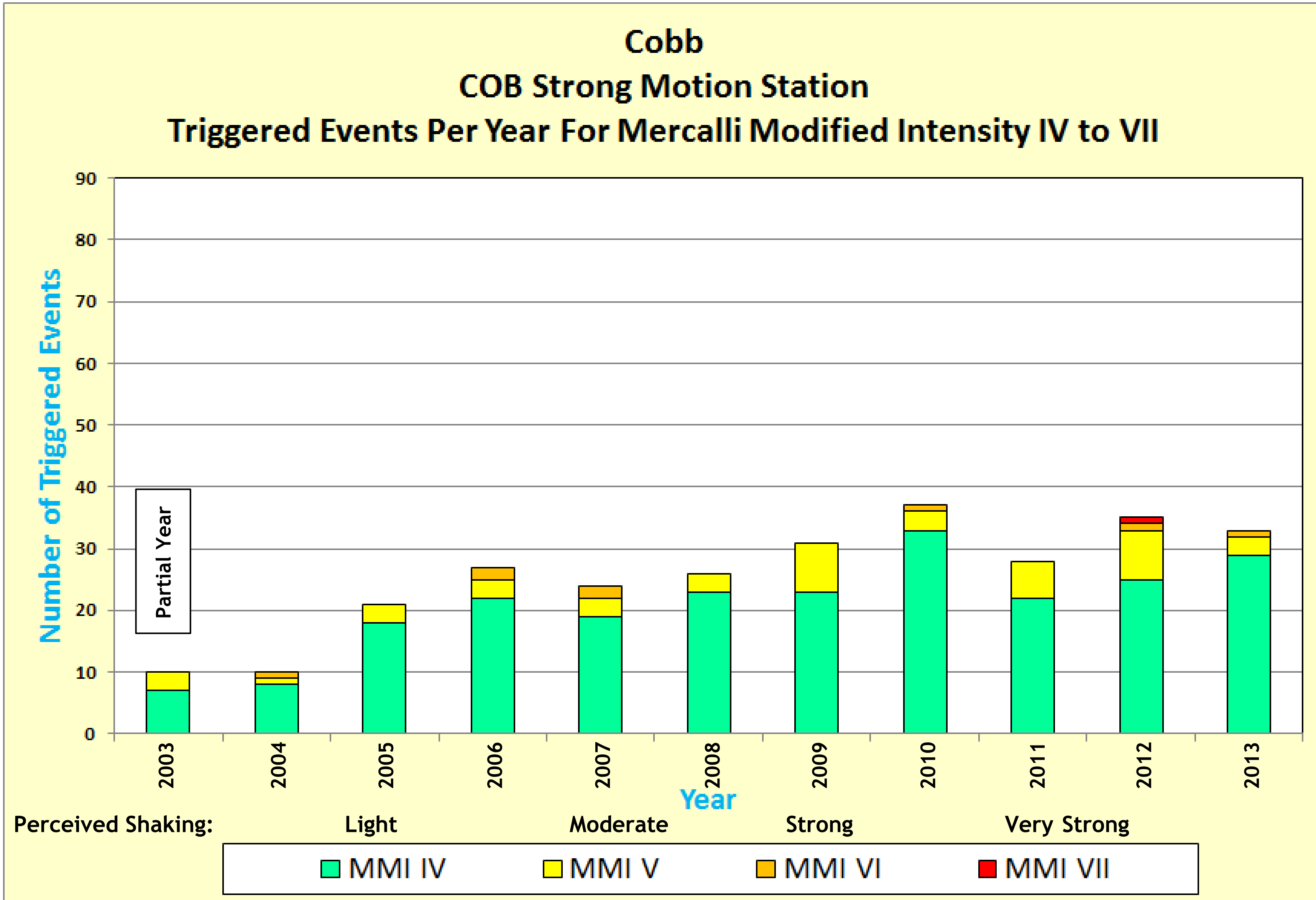
Anderson Springs Peak Ground Acceleration
Triggered Strong Motion Events Per Year Since 2003



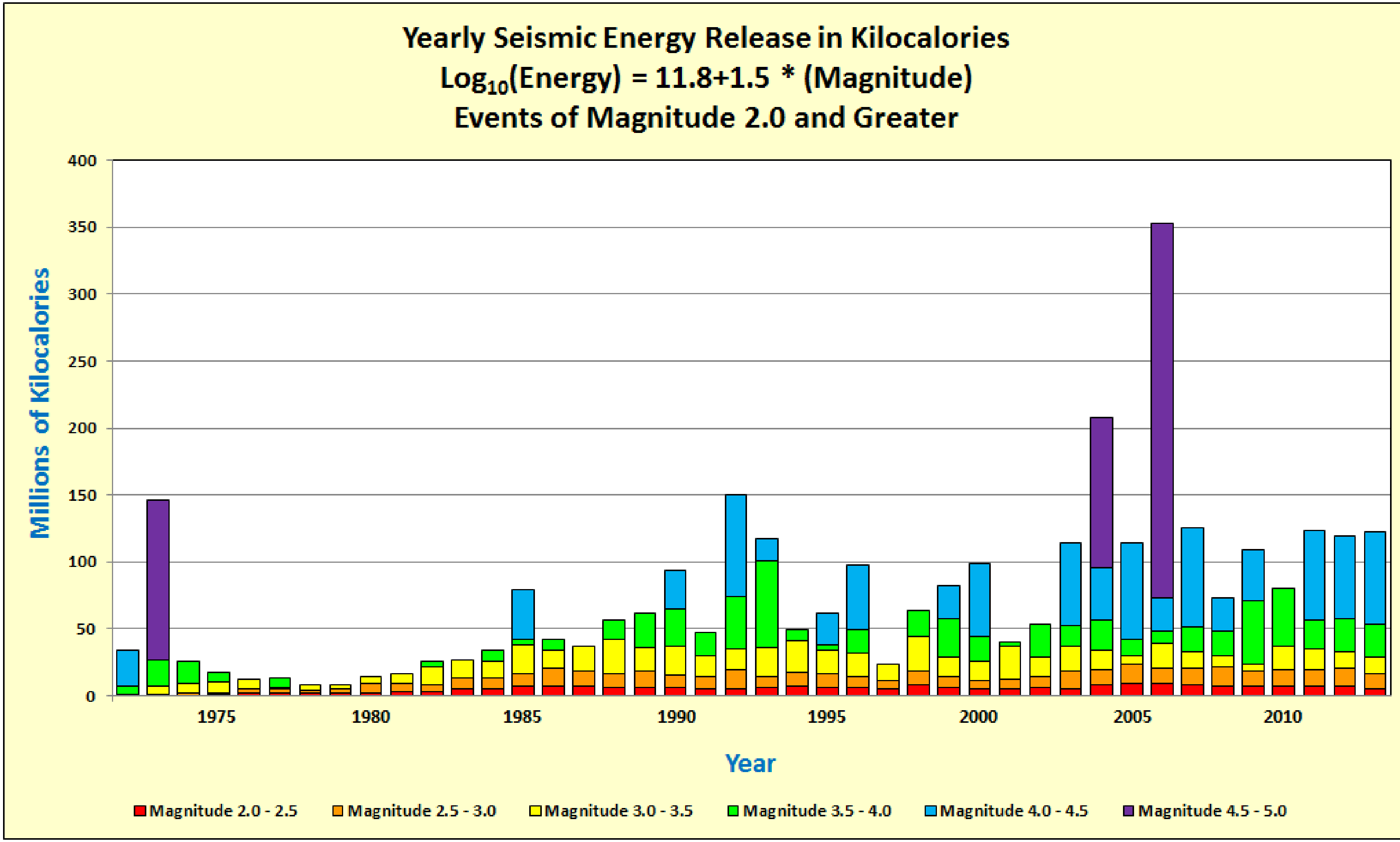
Cobb Peak Ground Acceleration
Triggered Strong Motion Events Per Year Since 2003



Cobb Peak Ground Acceleration
Triggered Strong Motion Events Per Year Since 2003



Seismic Monitoring Advisory Committee Meeting
Field-wide Seismicity Analysis
Yearly Seismic Energy Release Since1972 (Historical M ≥ 2.0 Events)



Field-wide data provided by Calpine Corporation to URS Corporation

- LBNL / USGS Seismicity
- Strong Motion Measurements
- SRGRP Well Monthly Injection Volumes
- Seismicity Hotline Reports

Draft report completed by 06 May 2014

Final report with Calpine/URS revisions complete by ~ 20 May 2014

NCSN seismicity results consistent with Environmental Impact Report projections:

Since SRGRP initiation:	
M ≥ 1.5	~ 50% increase
M ≥ 2.0	~ 25% increase
M ≥ 2.5	slight increase
M ≥ 3.0	~ 25% decrease

Seismicity

Calpine 3D Visualization and 3D Model Building

Seismic event magnitude is dependent on:

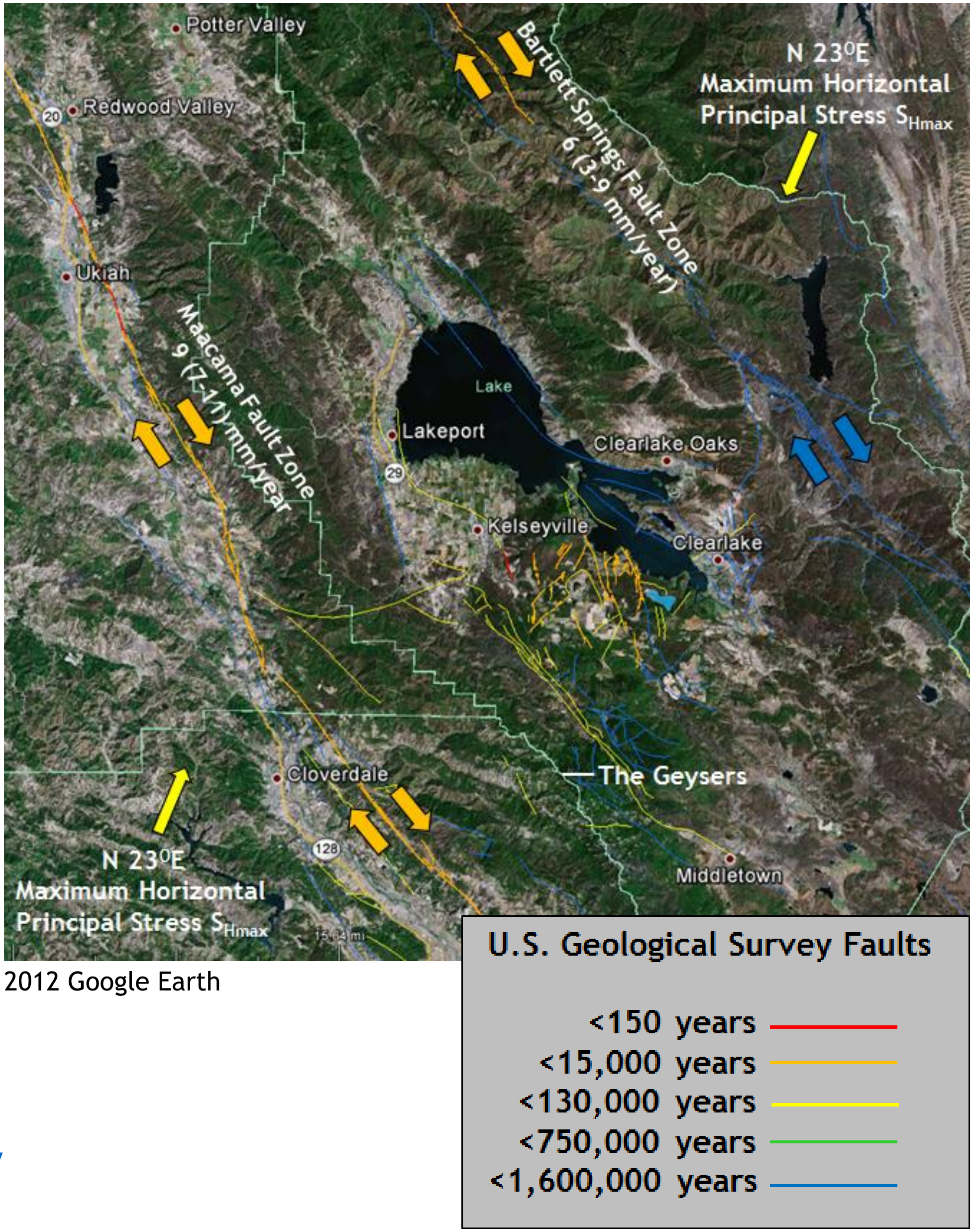
- Fault Area
- Average Slip
- Rock Rigidity

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.

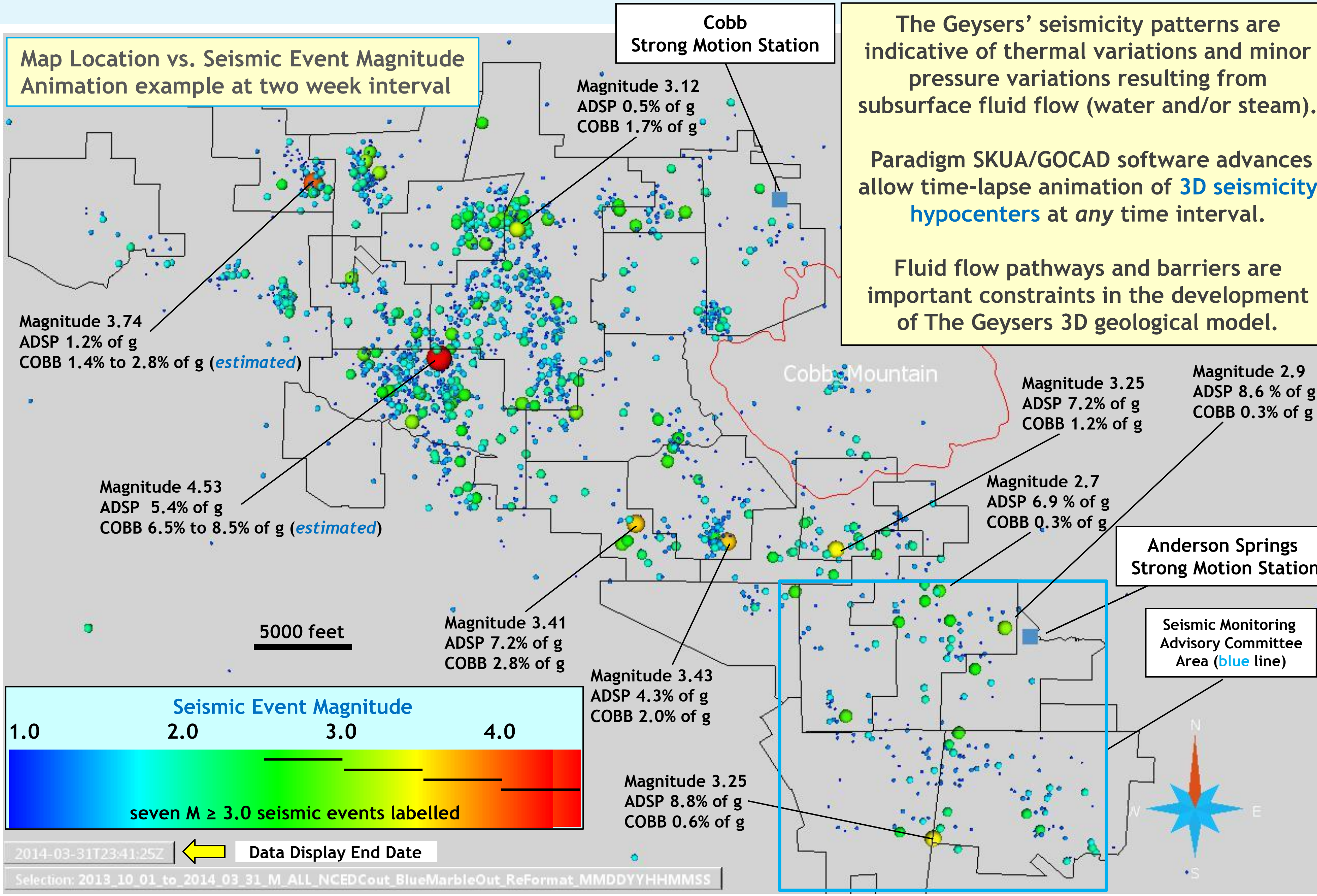
This 3D structural model (including pre-existing fault zones and fractures) will assist in understanding induced seismicity at The Geysers.



2012 Google Earth

* California Geological Survey, United States Geological Survey

Seismic Monitoring Advisory Committee Meeting
Field-wide Seismicity Analysis
01 October 2014 to 31 March 2014



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

Paradigm SKUA/GOCAD software advances allow time-lapse animation of 3D seismicity hypocenters at *any* time interval.

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

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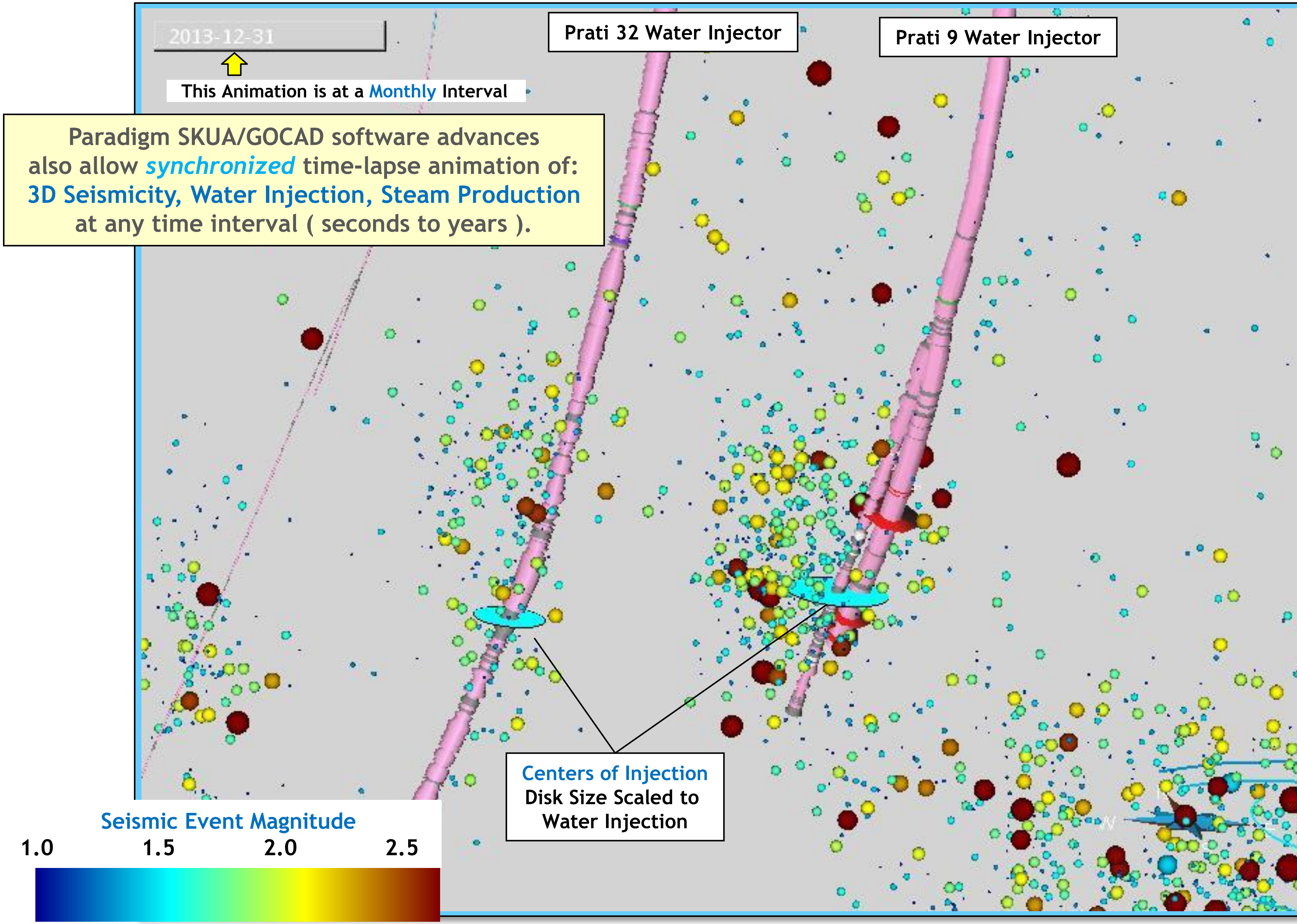
Water Injection and Induced Seismicity Animation
January 2102 through December 2013

CALPINE NYSE CPN

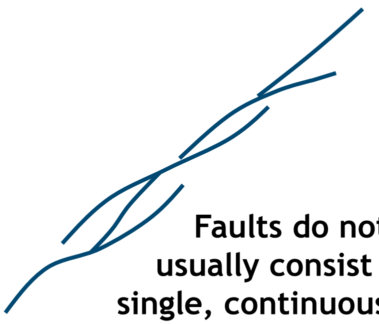
Paradigm SKUA/GOCAD software advances also allow *synchronized* time-lapse animation of:
3D Seismicity, Water Injection, Steam Production
at any time interval (seconds to years).



Seismic Monitoring Advisory Committee Meeting
Calpine 3D Visualization and 3D Model Building

CALPINE

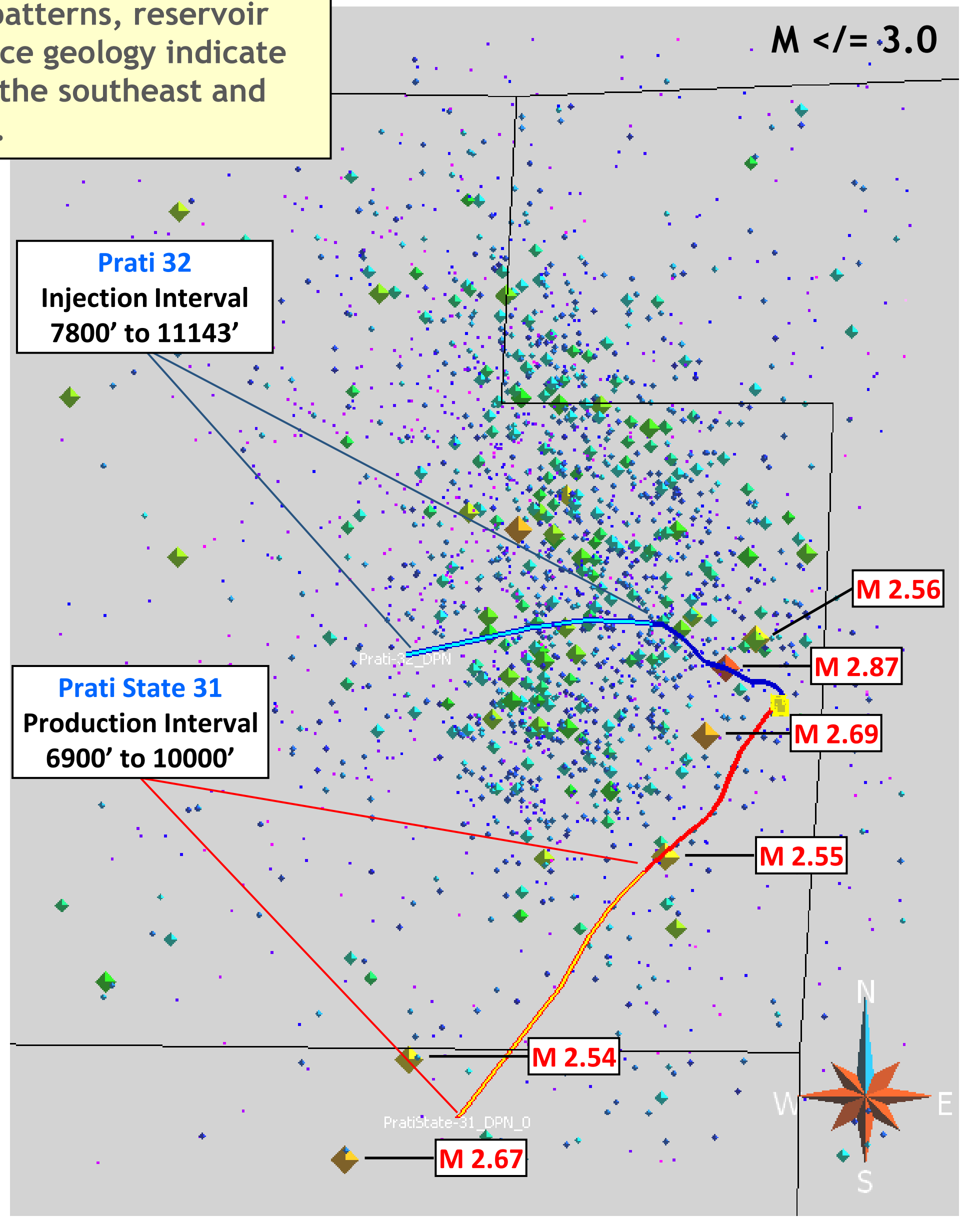
In this example, seismicity patterns, reservoir pressure variability and surface geology indicate hydraulic discontinuities to the southeast and northeast .



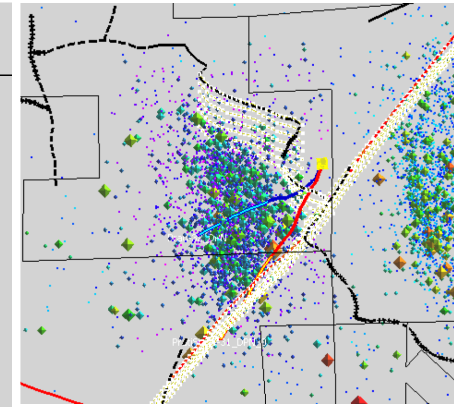
Faults do not usually consist of a single, continuous fracture.

Geologists use the term *fault zone* when referring to the zone of complex deformation.

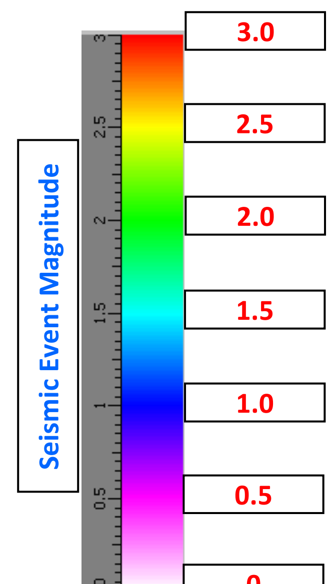
Seismicity analysis can assist in constraining *fault zones*.



Six M >/= 2.5
Seismic Events Appear to
"define" a hydraulic discontinuity
to the southeast. the Boundary



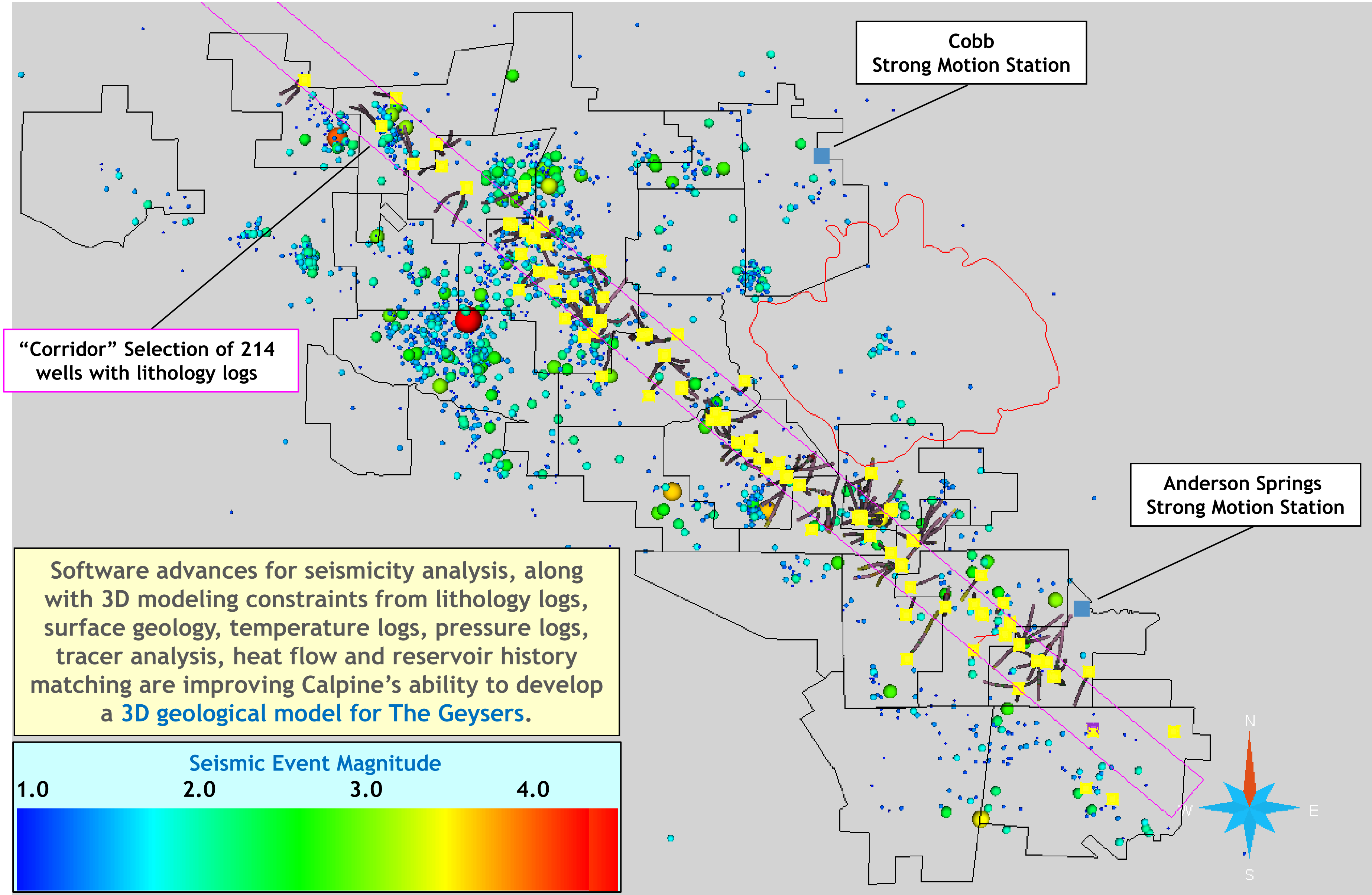
Prati 32 and Prati State 31 Area
Fault Zone Interpretation
Oblique View (west of vertical)



Seismic Monitoring Advisory Committee Meeting

Field-wide Seismicity Analysis

01 October 2014 to 31 March 2014



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 geological model for The Geysers.

Seismic Event Magnitude

1.0 2.0 3.0 4.0

Seismic Monitoring Advisory Committee Meeting

Field-wide Seismicity Analysis

01 October 2014 to 31 March 2014

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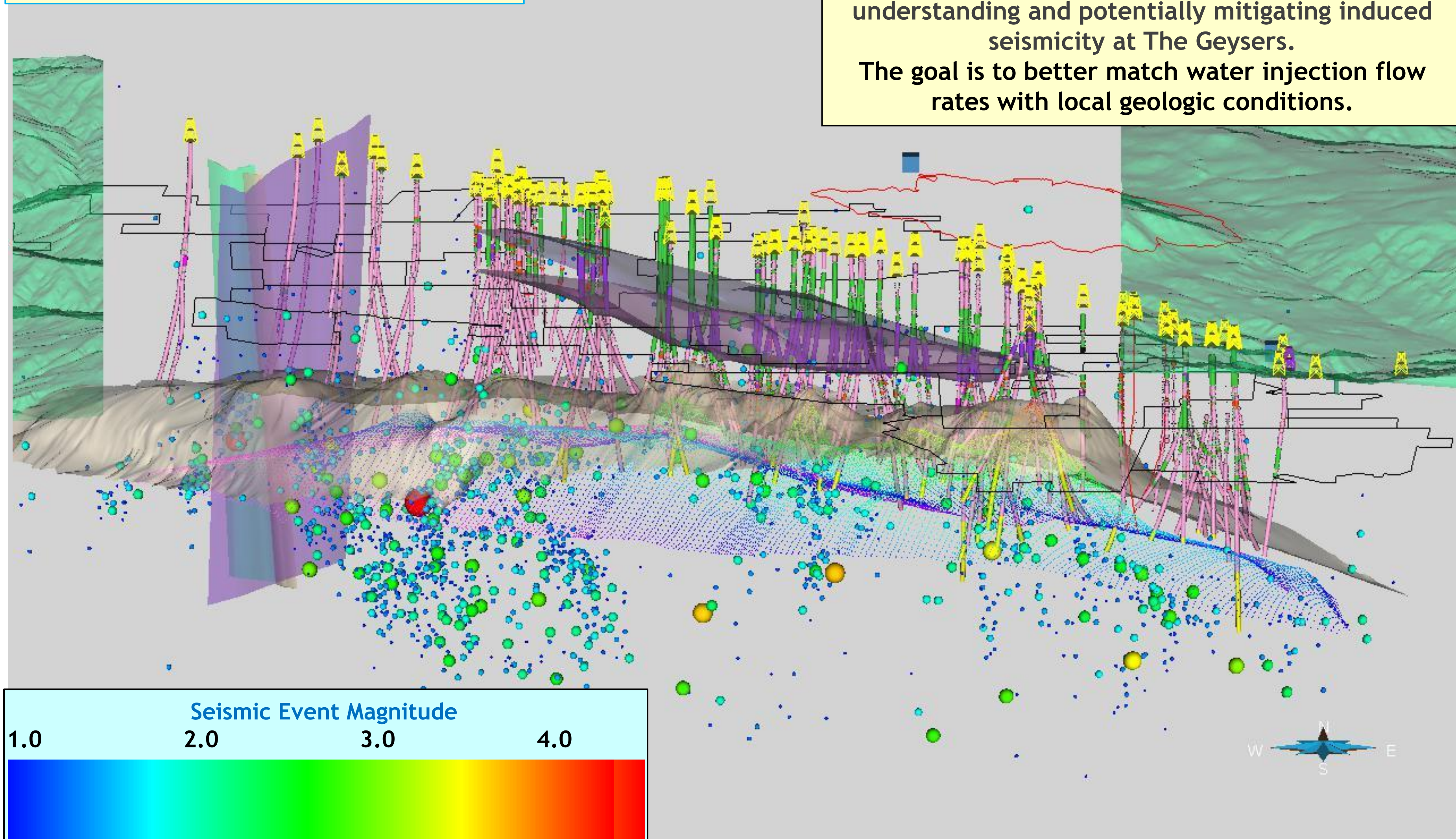
3D Seismicity Hypocenters
Events scaled and colored by magnitude
Animation example at a monthly interval

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 geologic conditions.



Additional Seismic Monitoring and Research
Induced Seismicity Research Collaborations

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)

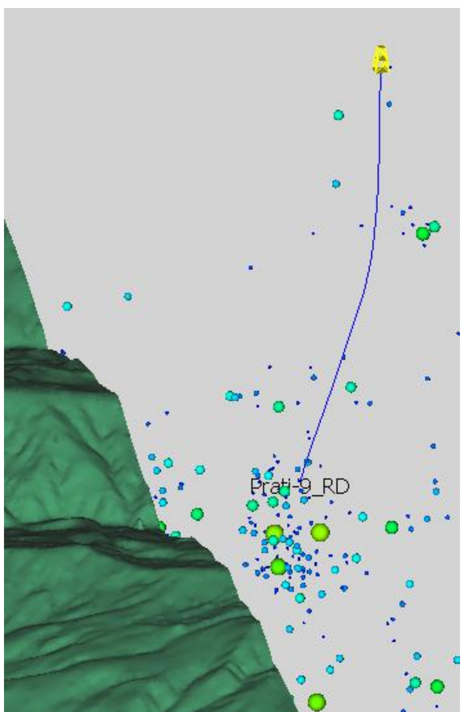
Induced seismicity mechanisms at The Geysers geothermal field

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

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]

Detailed analysis of Prati 9 water injection and associated 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

Induced Seismicity Research Collaborations

Lawrence Berkeley National Laboratory, Berkeley, California, USA (1)
Calpine Corporation, The Geysers, Middletown, California, USA (2)

Reservoir structure and properties from geomechanical modeling and microseismicity analyses associated with an Enhanced Geothermal System at The Geysers, California

Pierre Jeanne[1], Jonny Rutqvist[1], Craig Hartline[2], Julio Garcia[2], Patrick F. Dobson[1], and Mark Walters[2]

Calpine Corporation, The Geysers, Middletown, California, USA
U.S. Department of Energy

Phase II Interim Report: Characterization of the Northwest Geysers Enhanced Geothermal System Demonstration Project, The Geysers, California (DE-FC36-08G018201)

Julio Garcia, Craig Hartline, Mark Walters, and Melinda Wright

http://www1.eere.energy.gov/geothermal/pdfs/egs_factsheet.pdf

Detailed studies of relatively isolated systems of water injection and induced seismicity in the northwest Geysers, including the Enhanced Geothermal System (EGS) Demonstration Project, are contributing to the understanding of induced seismicity at The Geysers.

Selected Wells:

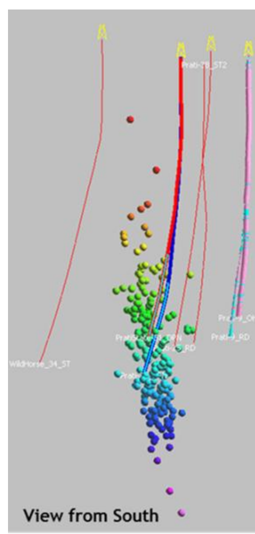
Prati State 31

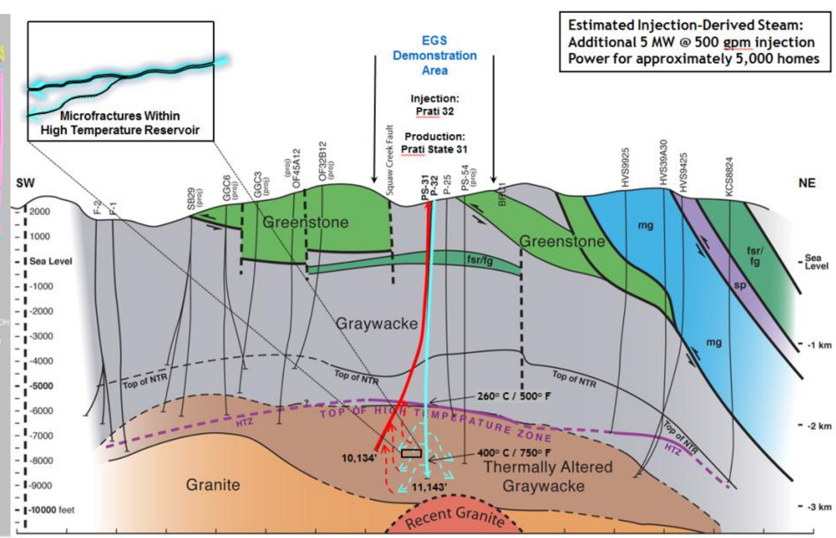
656 °F 1983

Prati 32

600 °F 1985

750 °F 2010 - Deepened





Additional Seismic Monitoring and Research

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

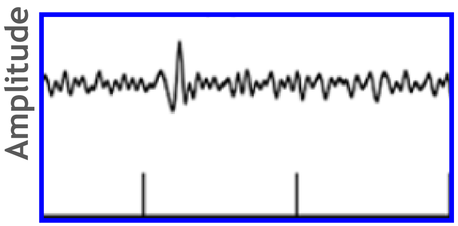
Calpine is collaborating with Lawrence Berkeley National Laboratory (LBNL) concerning additional borehole seismic monitoring research at The Geysers.

A three-component station was installed at 500’ depth for site MSA-8 (DEB - Davies Estate Borehole)

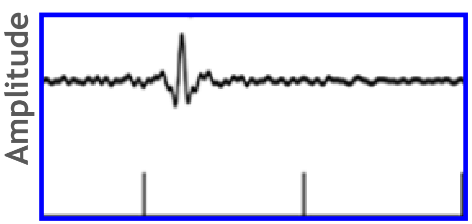
2-3 additional borehole seismic monitoring stations are planned over the next months.

Why is this important? Improved seismic data = better seismicity analysis (signal:noise ratio↑)

Surface Sensor - More noise



Borehole Sensor - Less noise



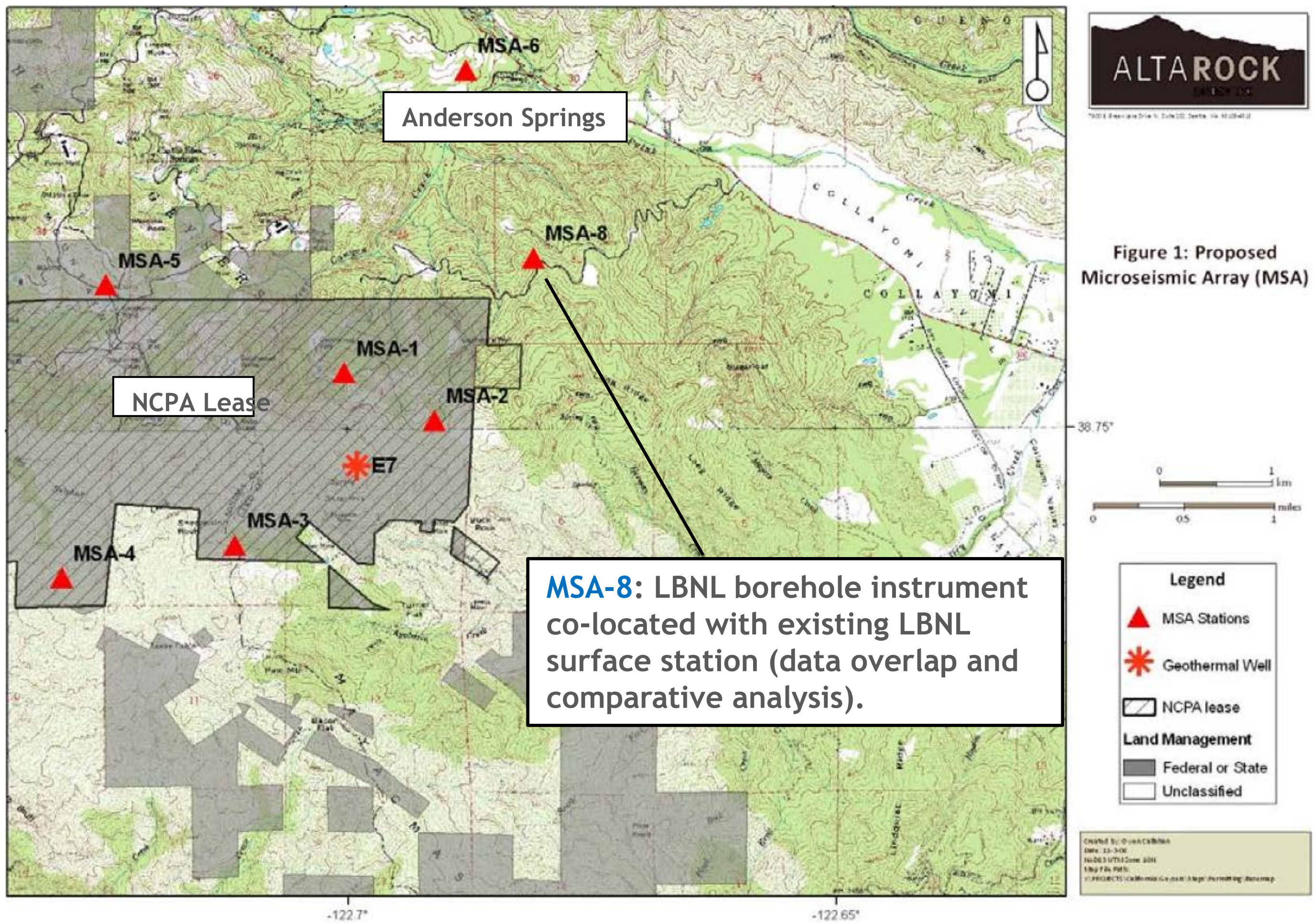


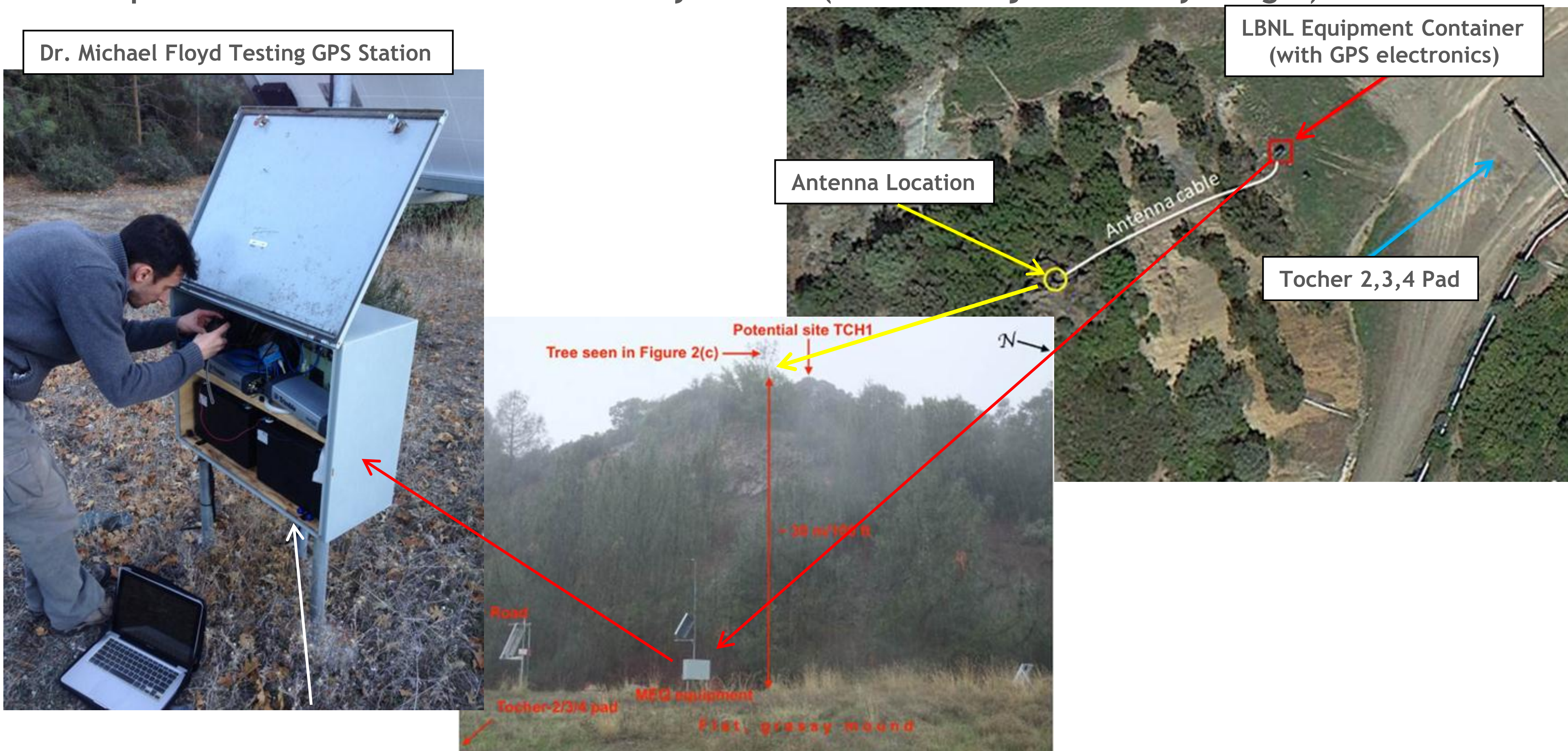
Figure 1: Proposed Microseismic Array (MSA)

Global Positioning System (GPS) Research Collaboration
Massachusetts Institute of Technology
University of California Riverside

Goals: Continuous monitoring of The Geysers' local surface deformation
Additional data to better understand West Coast regional surface deformation

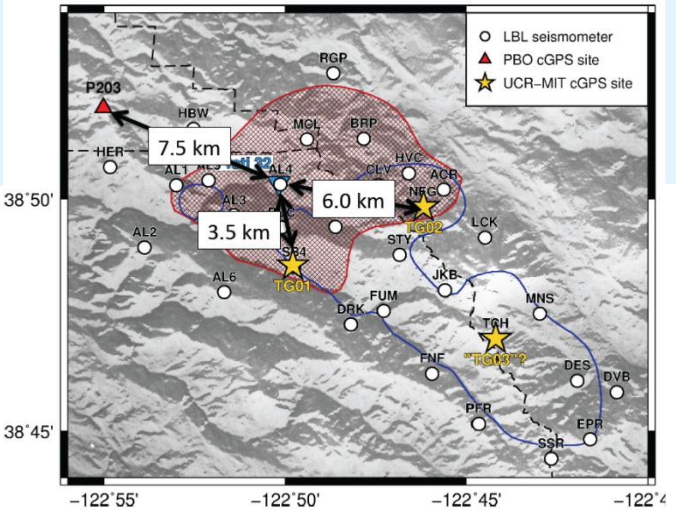
Primary Contacts: Dr. Michael Floyd (MIT) and Dr. Gareth Funning (UC Riverside)

A third Geysers' GPS station was installed 14 December 2013 on a rock outcrop near Tocher 2,3,4 pad.
GPS station co-located with LBNL seismic monitoring station TCH.
Shared power and communications - courtesy of LBNL (Dr. Ernie Majer / Ramsey Haught).



Global Positioning System (GPS) Research Collaboration
Massachusetts Institute of Technology
University of California Riverside

CALPINE



Why is this important?

Surface subsidence previously observed at The Geysers with:

- Terrestrial leveling observations (Logren, 1981)
- Episodic GPS measurements
- InSAR (Interferometric Synthetic Aperture Radar)

Maximum subsidence rate ~40 mm/year (1.6"/year) at field center
Total subsidence ~1 meter (~39") at field center
Subsidence is related to mass loss and pressure decline from steam production
Water injection designed to minimize/halt pressure decline and approach reservoir mass balance.

The detailed investigation Induced Seismicity in Energy Technologies (National Research Council, 2012) identified mass balance as a very important consideration for minimizing induced seismicity. (although The Geysers seismicity is complicated by thermal effects).

Recent monitoring results - significant decrease in subsidence rates:

- InSAR (Vasco et al., 2013)
- Continuous GPS Monitoring (Floyd and Funning, 2013)

Primary GPS data[1] transferred via radio telemetry and established communication networks to:

- Northern California Earthquake Data Center (NCEDC)
- Massachusetts Institute of Technology (MIT)
- University of California Riverside (UCR) - Archival

Secondary GPS data[2] manually downloaded for detailed analysis of seismic events ("GPS seismology")

1 Primary Data: 2 cycles per minute or 0.0333 cycles per second
2 Secondary Data: 600 cycles per minute or 10 cycles per second

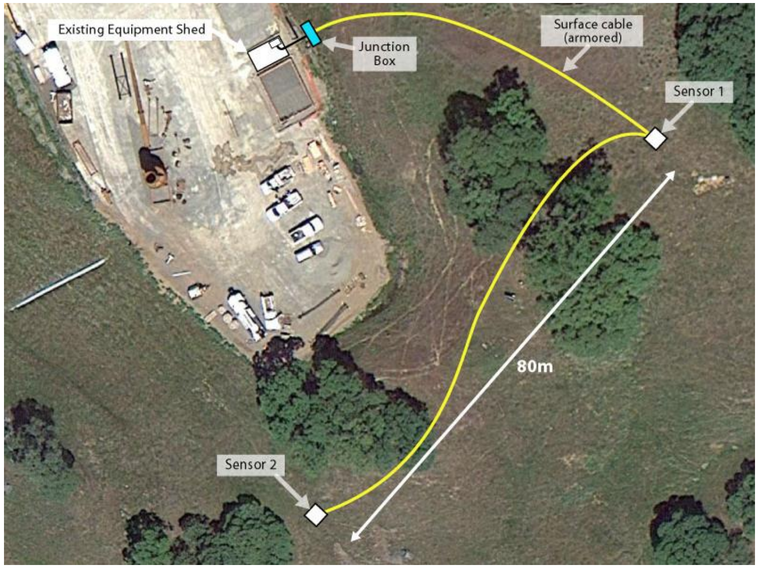
Additional Seismic Monitoring and Research
Installation in May/June 2014 (restored funding; legislation finalized)

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

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.

Goal:
Refinement of event detection software to:
- Avoid false positives (caused by human activity)
- Distinguish between:
  - smaller earthquakes
    - (which should be ignored)
  - larger earthquakes
    - (warning and automated shutdowns)



Seismic Monitoring Advisory Committee Meeting

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%

Geysers Community Relations Overview

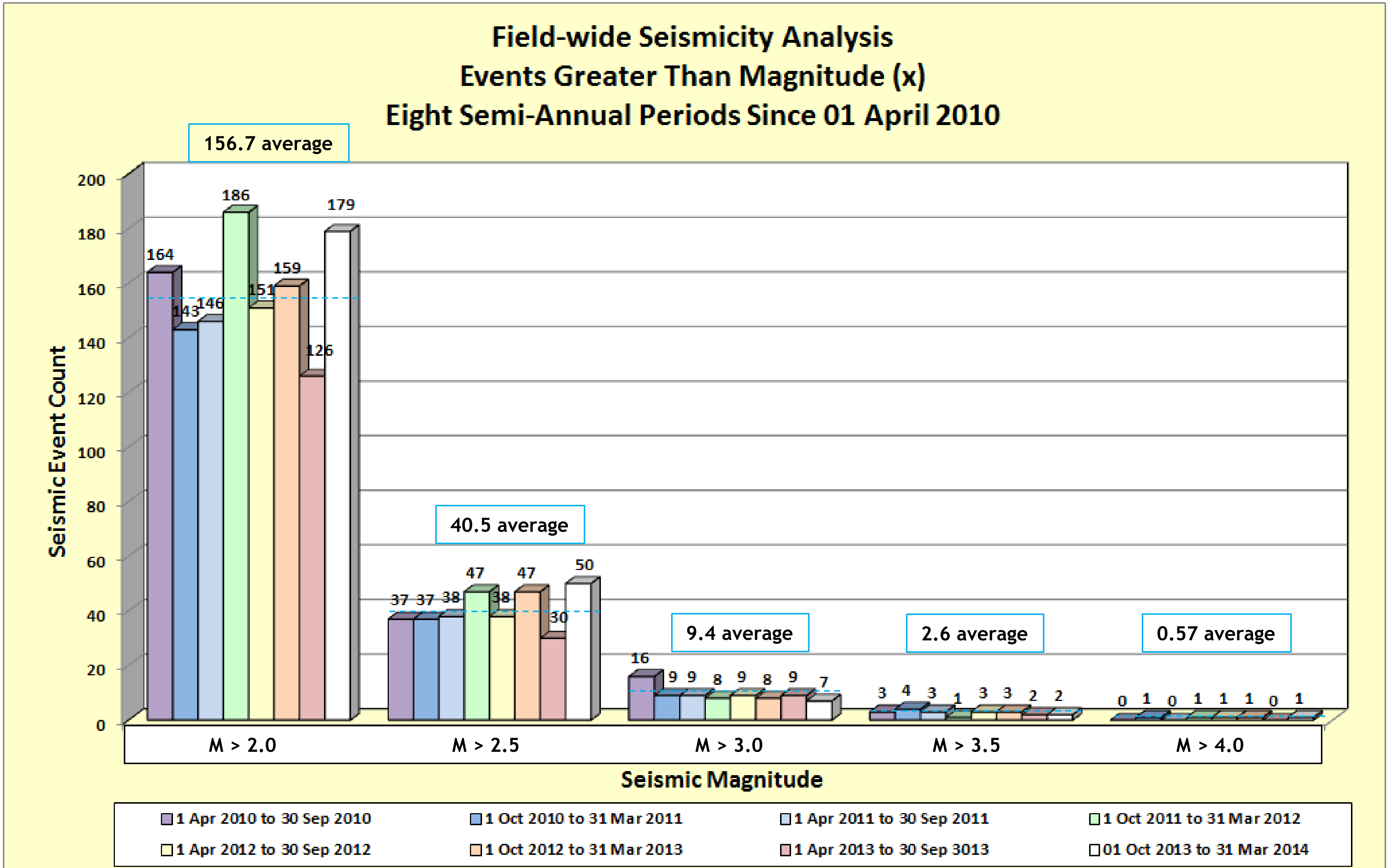
- Seismic Monitoring and Advisory Committee (SMAC) Biannual Meetings
  - Field Activity and Seismicity Update to Community, Industry and Academic Representatives
  - Presentations Available Upon Request and Posted at www.geysers.com
- Seismic Hotline: 877-4-GEYSER, 707-431-6161 *(alternate number if 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

Seismic Monitoring Advisory Committee Meeting

Field-wide Seismicity Analysis

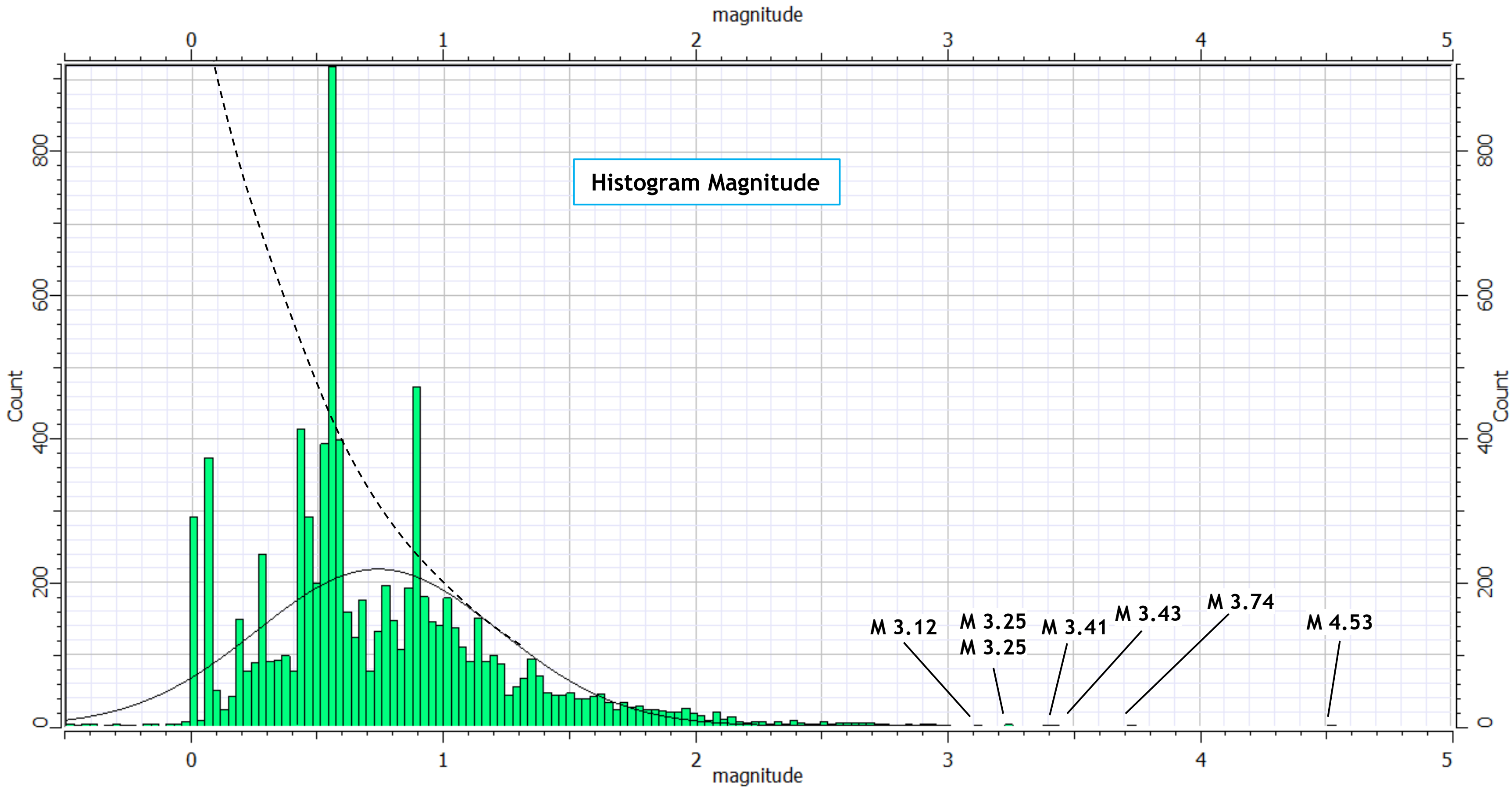
01 October 2013 to 31 March 2014

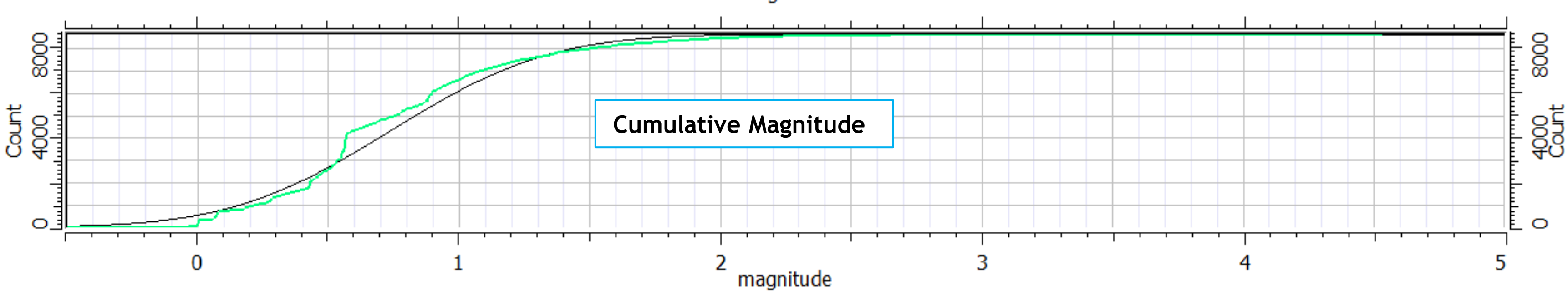
CALPINE NYSE CPN



Access Query CSH Monthly Count, M> X

Seismic Monitoring Advisory Committee Meeting
Field-wide Seismicity Analysis
01 October 2014 to 31 March 2014





CALPINE NYSE CPN

Northern California Seismic Network Seismicity Data

Southeast Geysers Seismicity Results as of 31 March 2014

Comparison of pre-SEGEP and post-SEGEP (equivalent annual rates in parentheses)

Time Period	Pre-SEGEP	SEGEP	Current Period
Dates	Nov 1995 - Oct 1997	Nov 1997 - Oct 2013	Oct 2013- Mar 2014
Time Span (yrs)	2	16.41	0.5
Seismic Events:			
M>=1.2	330 (165)	5202 (317)	146 (292)
M>=2.0	46 (23)	744 (45)	23 (46)
M>=3.0	10 (5)	40 (2.4)	1 (2)
M Maximum	3.70	4.30	3.25