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Geothermal Induced Seismicity National Environmental Policy Act Review

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BACKGROUND

WHAT IS INDUCED SEISMICITY (IS)?

Induced seismicity refers to small earthquakes (typically between a magnitude of 1.0 and 3.5 on the Richter scale) that may occur as a result of human activity.

Activities such as stimulating a geothermal reservoir or injecting fluid to replenish a geothermal reservoir may cause induced seismicity.

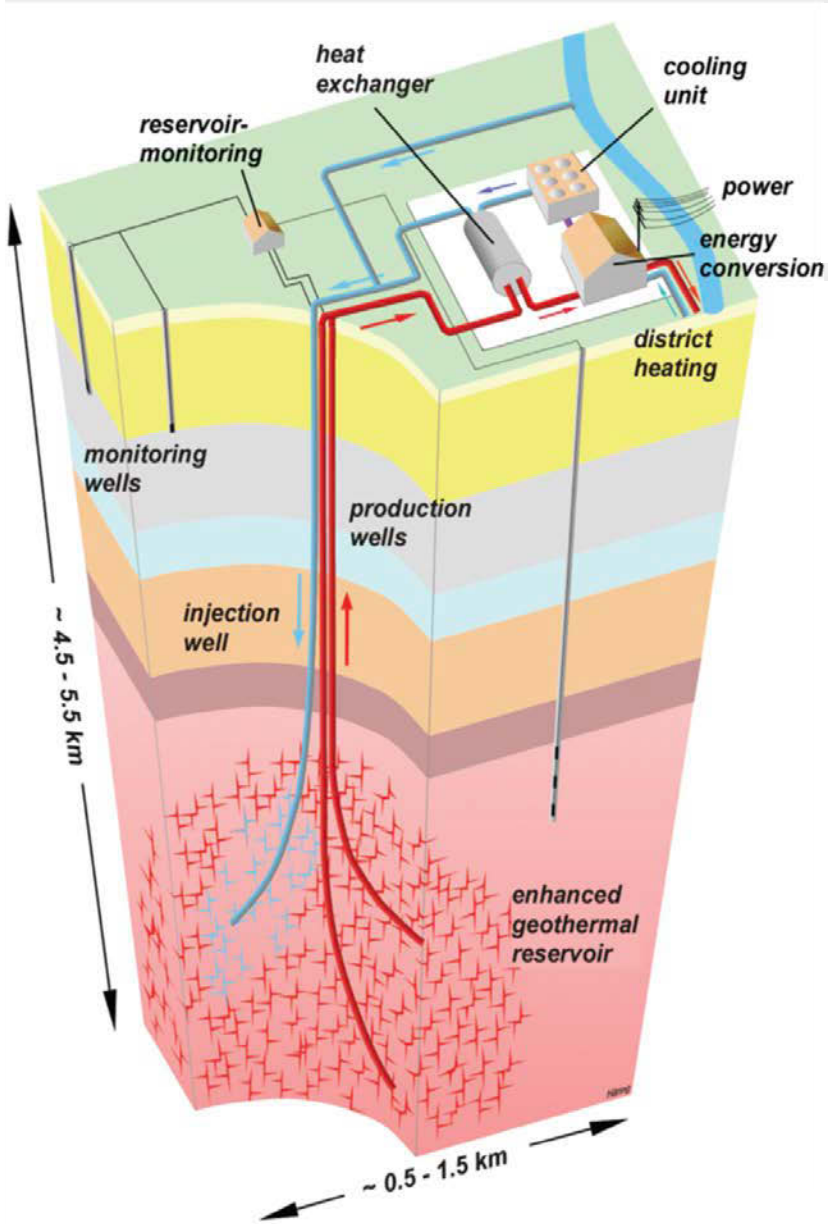


Photo source: Geothermal Explorers Ltd. 2005

BACKGROUND

WHY IS IT A CONCERN FOR GEOTHERMAL DEVELOPMENT?

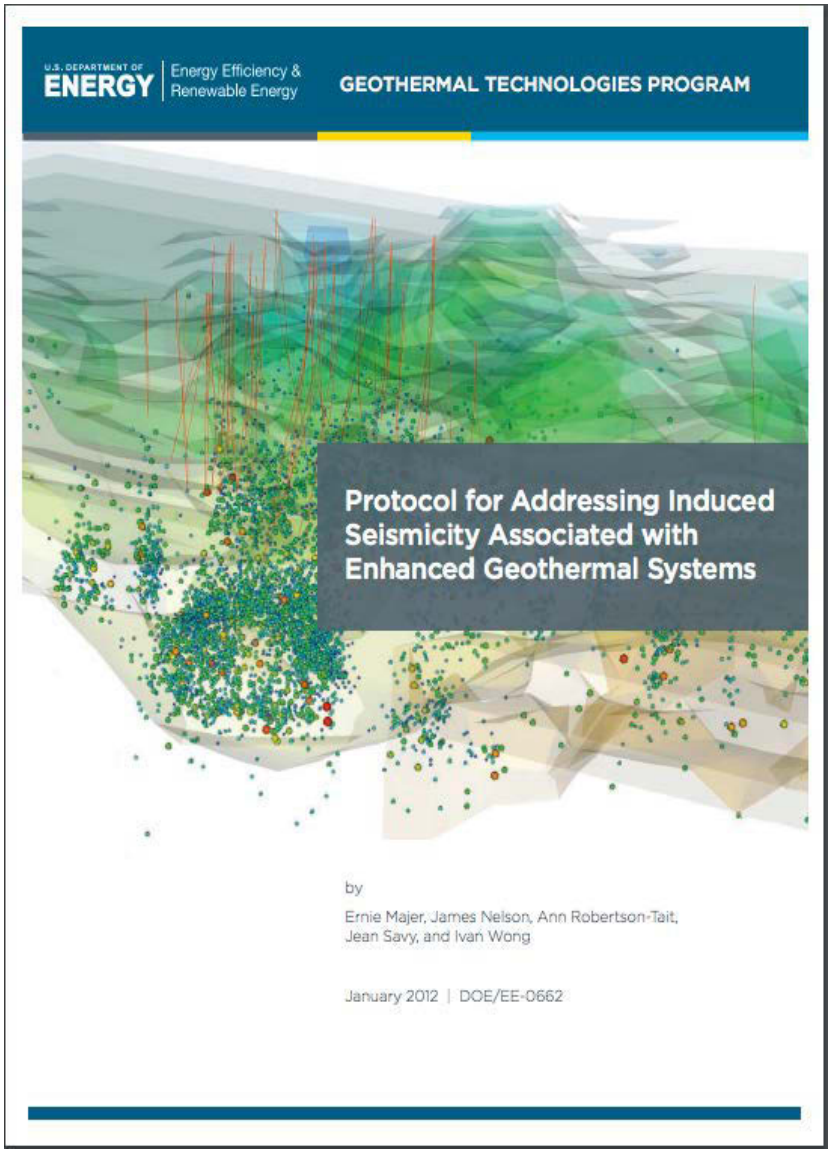
2006 Basel 1 Project
Basel, Switzerland

Basel 1 drilling rig in downtown Basel.

Image source: https://www.iwb-blog.ch/wp-content/uploads/2011/07/geothermie.gif

- Most infamous hydraulic stimulation event for creating an enhanced geothermal system (EGS) reservoir.
- Basel had known historical seismicity and the presence of nearby active faults.
- 6 days into a 21 day hydraulic stimulation project, increased seismic activity (max event of M_L 3.4) resulted in 2,700 damage claims by local residents.
- Basel 1 prematurely halted injection and eventually terminated the entire project.

IEA AND DOE IS PROTOCOLS



2012 DOE Induced Seismicity Protocol

Results of Basel 1 project and EGS induced seismicity concerns generally led to the development of an IS Protocol by the International Energy Agency (IEA) (2008) and a later update by the U.S. Department of Energy (DOE) (2012).

The IS Protocols were developed to:

- Guide geothermal developers in managing induced seismicity and applying EGS technology safely.
- Gain public acceptance for geothermal activities, particularly EGS projects.

DOE IS PROTOCOL (2012)

The 2012 DOE IS Protocol consists of **seven steps** for addressing induced seismicity issues:

1. Perform a preliminary screening evaluation
2. Implement an outreach and communication program
3. Review and select criteria for ground vibration and noise
4. Establish seismic monitoring
5. Quantify the hazard from natural and induced seismic events
6. Characterize the risk of induced seismic events
7. Develop a risk-based mitigation plan

THE NATIONAL ENVIRONMENTAL POLICY ACT OF 1969 (NEPA)

WHAT IS NEPA?

Photo: Kate Young

NEPA requires federal agencies or departments to consider the environmental impacts of **all major federal actions** significantly affecting the quality of the human environment (NEPA, Sec. 102).

Examples:

- federal funding (e.g., DOE grants),
- permit approvals (e.g., Geothermal Drilling Permit)

The NEPA review is a **procedural tool used to consider the environmental impacts** of the proposed action as well as alternatives to the proposed action before a federal agency approves or rejects it.

METHODOLOGY

GEOTHERMAL INDUCED SEISMICITY NEPA REVIEW

To understand how federal agencies have analyzed and mitigated the potential impacts of IS for geothermal projects, NREL staff analyzed four NEPA reviews, highlighting:

- The lead and participating agencies
- The action triggering NEPA review
- Noted seismic concerns with the project
- The seismicity evaluation conducted for the project
- Utilization of the IEA or DOE IS Protocols
- The level and type of seismic monitoring
- Pre-stimulation mitigation measures and planning
- Stimulation and post-stimulation mitigation measures and planning

We then obtained documentation on actual seismic events associated with these four projects to compare with anticipated seismicity and federal agency required mitigation measures.

GEOTHERMAL PROJECTS REVIEWED

	Project	Location	Review Type	Lead Agency	Participating Agencies	Review Completion
1	**Calpine Enhanced Geothermal Systems Project**	Sonoma County, CA	EA	DOE	None	June 2010
2	**Bottle Rock Power Steam Project**	Lake County, CA	EA/EIR	BLM/ Lake County	None	December 2010
3	**Newberry Volcano EGS Demonstration Project**	Deschutes National Forest Lands in OR	EA	BLM	USFS DOE	December 2011
4	**Brady Hot Springs Well 15-12 Hydro-Stimulation**	Churchill, NV	EA	BLM	DOE	January 2013

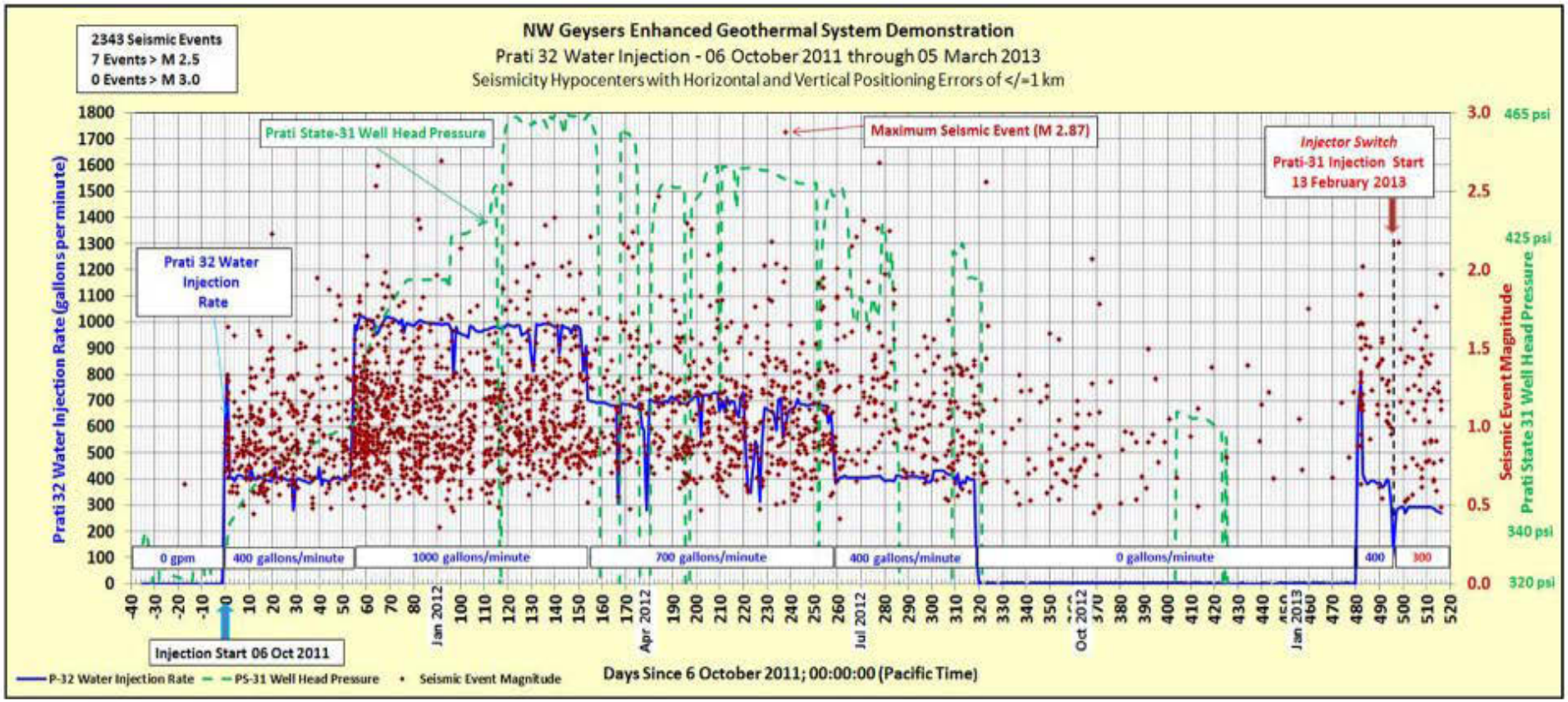
EA = environmental assessment; EIR = environmental impact report

1. CALPINE ENHANCED GEOTHERMAL SYSTEMS PROJECT EA (JUNE 2010)

- The Calpine EGS project sought to develop an EGS demonstration by injecting cool water into abandoned exploratory wells that had been converted into deep injection wells to enhance permeability of an existing high-temperature hydrothermal reservoir.
- The geothermal area had 25 historical (probable) Geysers-induced earthquakes of M4.0 and greater since 1972.
- Pre-stimulation modeling and an analysis of historical induced seismicity in the Geysers led to a prediction that seismic events were expected to be lower than M3.0, with a max predicted (but unlikely) event of M4.5.

Project Summary	
Action	Injection of cool water at 100-800 gpm to enhance permeability of an existing high temperature reservoir through alteration of existing exploratory wells
Use of IS Protocol	IEA Protocol
Monitoring	Four new seismic monitoring stations; Use of 29 existing seismic monitoring station Use of two accelerograph stations in nearby communities
Mitigation Trigger	Analyze well data to see which wells are more susceptible to induced seismicity and decrease injection rate at wells with higher levels of felt seismicity
Seismic Results	8 seismic events greater than M2.5; Largest seismic event M3.74

1. CALPINE EGS PROJECT INDUCED SEISMICITY RESULTS



- The Calpine EGS stimulation began in October 2011 with a series of stimulation activities predominately occurring through March 2013.
- Calpine was able to identify a total of 8 seismic events greater than M2.5.
- The two largest events were an M3.74 in January 2014 and an M2.87 in May 2012.
- The timing of the events greater than M2.5 did not show a strong correlation with injection rate or injection rate variability.

2. BOTTLE ROCK POWER (BRP) STEAM PROJECT EIR/EA (DECEMBER 2010)

- Project occurred in a geothermal area with known seismicity.
- GeothermEx (developer's contractor) evaluated historical geothermal injection data (1970-2009) at nearby Francisco Geothermal Lease (FGL) to establish potential induced seismicity that could occur at Bottle Rock.
- GeothermEX could not find consistent correlation with injection at the FGL and seismic rates, but did predict the BRP Steam Project may incur:
  - 1-4 events/month of M>2.0, and
  - 1-2 events/month at M>2.5.
- Based on GeothermEx's analysis, BLM concluded that potential induced seismicity from the BRP Steam Project was a "less than significant impact" that did not require mitigation.

Project Summary	
Action	Drill new wells to expand existing hydrothermal power plant from 18 MW to 55 MW
Use of IS Protocol	No
Monitoring	Installation of new seismometer and utilization of existing system of seismometers
Mitigation Trigger	None stated. BLM and Lake County can re-evaluate if seismic events greater than M3.0 occur.
Seismic Results	No conclusive evidence of increased seismicity

2. BRP STEAM PROJECT INDUCED SEISMICITY RESULTS

First Phase of Stimulation (March to April 2011)

- Review by project operator and hired consultants
- Used earthquake maps and consultant's earthquake processing system
- No conclusive evidence for an increase in earthquake activity as a result of the stimulation.

Second Phase of Stimulation (April 2014)

- Review by project operator and hired consultants
- Increase in the frequency of seismic events identified
- "Little evidence" to support that increase was direct result of stimulation.

Image source: http://www.bottlerockpower.com/index.html

3. NEWBERRY VOLCANO EGS DEMONSTRATION PROJECT EA (DECEMBER 2011)

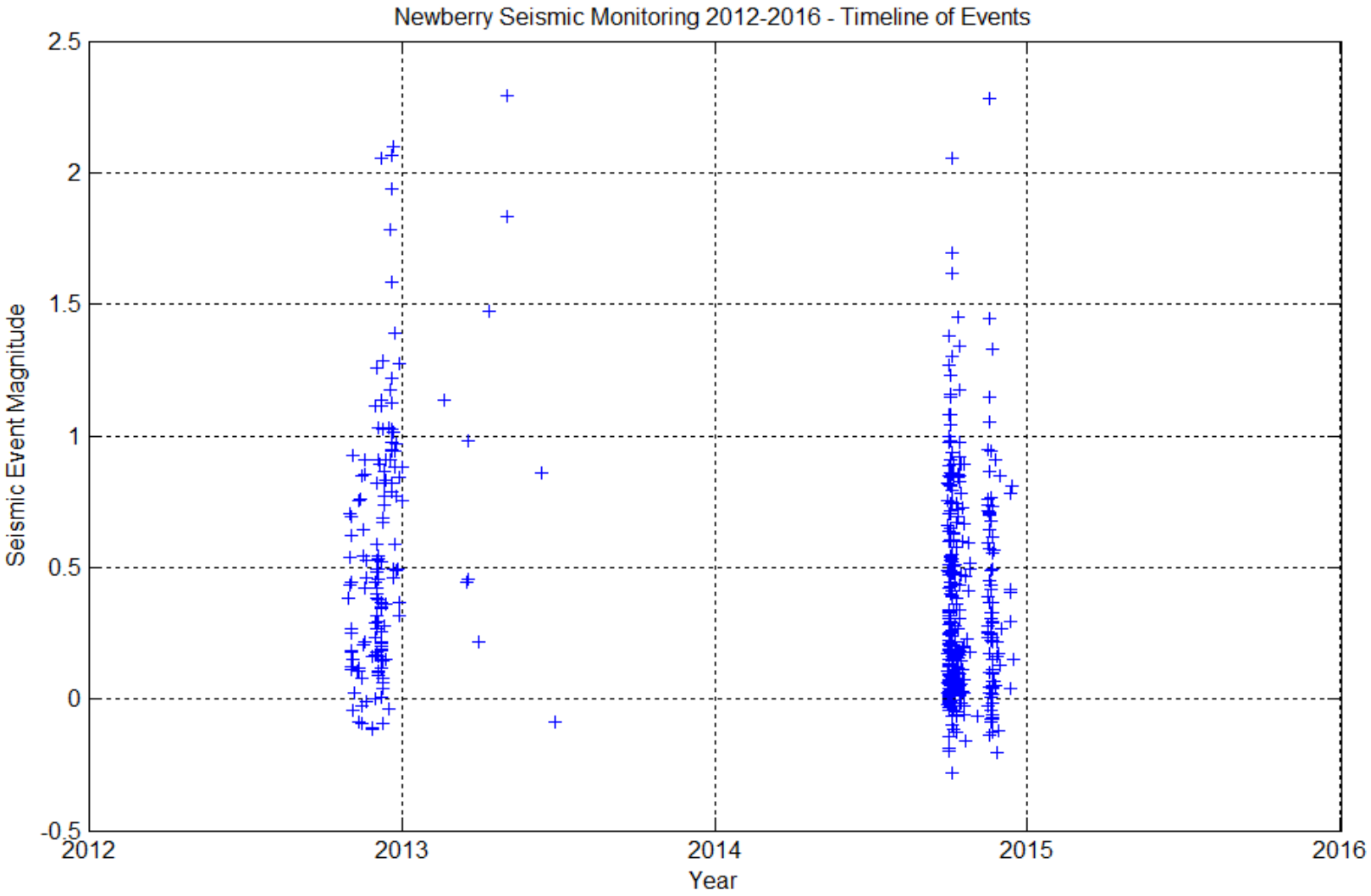
The Newberry Seismic hazards and risk evaluation estimated a probable upper bound of M3.5 to M4.0

The Newberry EGS Demonstration Project included extensive communication and outreach, monitoring, and mitigation measures with the BLM requiring the developer to:

- Provide notice in local newspapers, which includes contact information for citizens to request additional information or report concerns.
- Hold monthly public meetings.
- Install rock fall hazard ahead signs that include information on reporting damage.
- Install new avalanche warning signs.
- Conduct structural engineering analysis to determine the vulnerability of 52 key assets near the site.
- Install crack monitors on a bridge and monitor cracking at a nearby dam.

Project Summary	
Action	EGS test project using hydro-shearing to stimulate the reservoir with injection pressure of 1,160 to 2,500 psig at 6,500 to 10,000 feet
Use of IS Protocol	IEA IS Protocol and components of the Draft DOE IS Protocol
Monitoring	Two new seismic monitoring stations; 20 pre-existing seismic monitoring devices installed at wells, boreholes, and surface stations
Mitigation Trigger	M1.0 shallower than 6,000 feet detected by at least 6 monitors or any seismic event greater than or equal to M2.0
Seismic Results	174 total seismic events; Largest seismic event M2.39

3. NEWBERRY VOLCANO INDUCED SEISMICITY RESULTS



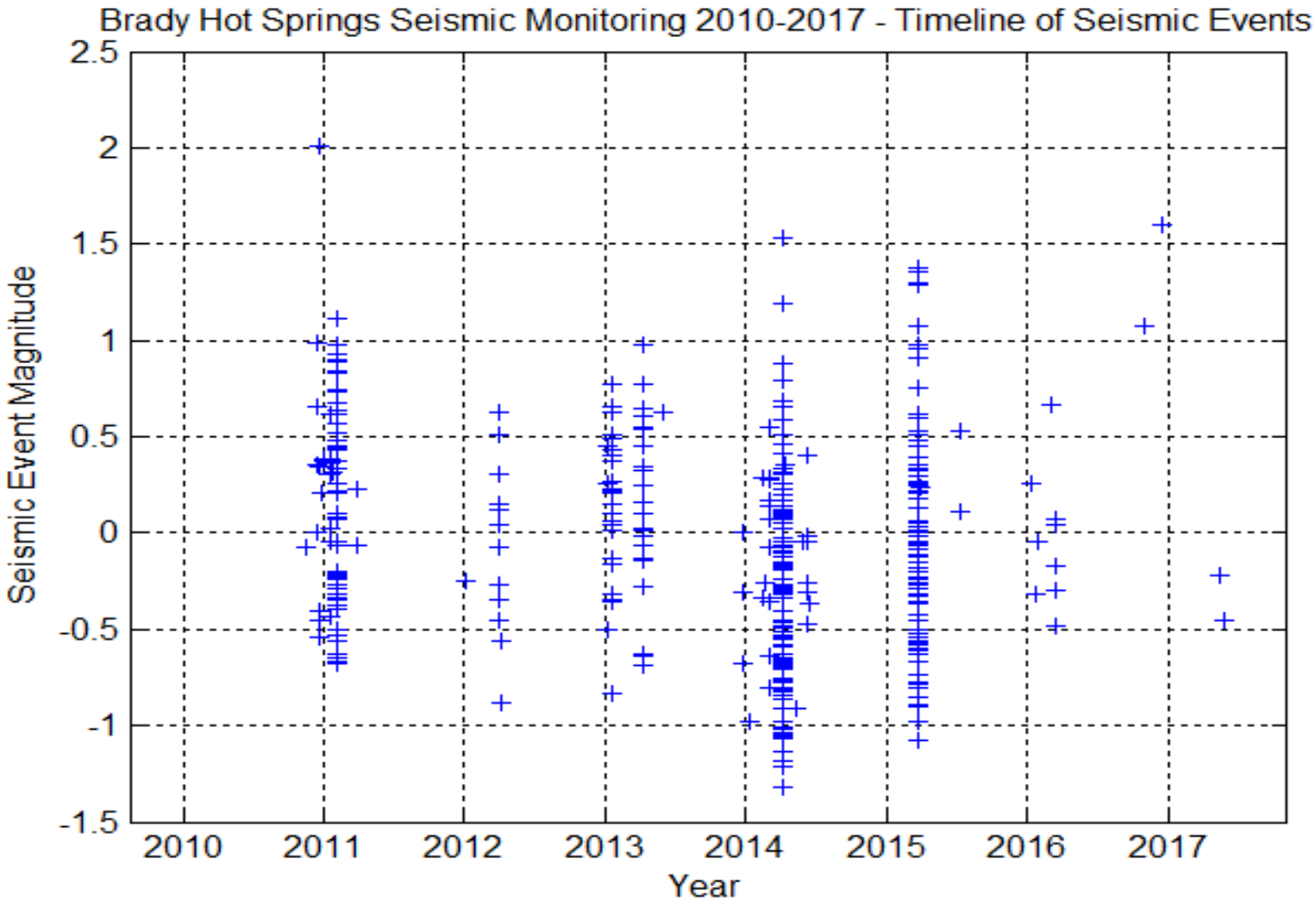
The largest event, a M2.39 reading, occurred on the last day of the first phase of stimulation and the well was shut-in later that day.

4. BRADY HOT SPRINGS WELL 15-12 HYDRO-STIMULATION EA (JANUARY 2013)

- Ormat analysis found:
  - historical geothermal operations at the Brady Hot Springs field are associated with microseismic events (M>2.0),
  - there has been some natural earthquake activity in the area (M<4.0).
- To quantify potential seismic hazards, Ormat leveraged results of a nearby geothermal project that employed well stimulation that showed low seismicity between M0.11 – M0.77.
- BLM required the project to install:
  - 15 micro-seismic monitoring stations to detect and map induced seismic events
  - A ground motion sensor in Fernley, Nevada (the only community within 30 miles of the well).

Project Summary	
Action	EGS test project at existing production well and well pad; Hydraulic stimulation at 1,400 psig at 4,000 to 5,000 feet
Use of IS Protocol	DOE IS Protocol
Monitoring	Fifteen new microseismic monitoring stations (6 on surface, 9 in boreholes at depths up to 300 ft); Use of existing ground motion detector in nearest town
Mitigation Trigger	M2.5 or a single reading of 0.002g PGA ; 10 readings per day over 0.0002g PGA
Seismic Results	403 total seismic events; No seismic event M2.5 or greater

4. BRADY HOT SPRINGS INDUCED SEISMICITY RESULTS



While seismic monitors recorded a total of 403 seismic events, only one event was greater than M2.0 and no events were greater than M2.5 (the established mitigation threshold).

GEOTHERMAL PROJECT SUMMARY TABLE

	Project	Action	Use of IS Protocol	Monitoring	Mitigation Trigger
1	**Calpine Enhanced Geothermal Systems Project EA.**	Injection of cool water at 100-800 gpm to enhance permeability of an existing high temperature reservoir through alteration of existing exploratory wells	IEA Protocol	Four new seismic monitoring stations; Use of 29 existing seismic monitoring station Use of two accelerograph stations in nearby communities	Analyze well data to see which wells are more susceptible to induced seismicity and decrease injection rate at wells with higher levels of felt seismicity
2	**Bottle Rock Power Steam Project EIR/EA**	Drill new wells to expand existing hydrothermal power plant from 18 MW to 55 MW	No	Installation of new seismometer and utilization of existing system of seismometers	None stated. BLM and Lake County can re-evaluate if seismic events greater than M3.0 occur.
3	**Newberry Volcano EGS Demonstration Project EA;**	EGS test project using hydroshearing to stimulate the reservoir with injection pressure of 1,160 to 2,500 psig at 6,500 to 10,000 feet	IEA IS Protocol and components of the Draft DOE IS Protocol	Two new seismic monitoring stations; 20 pre-existing seismic monitoring devices installed at wells, boreholes, and surface stations	M1.0 shallower than 6,000 feet detected by at least 6 monitors or any seismic event greater than or equal to M2.0
4	**Brady Hot Springs Well 15-12 Hydro-Stimulation EA**	EGS test project at existing production well and well pad; Hydraulic stimulation at 1,400 psig at 4,000 to 5,000 feet	DOE IS Protocol	Fifteen new microseismic monitoring stations (6 on surface, 9 in boreholes at depths up to 300 ft); Use of existing ground motion detector in nearest town	M2.5 or a single reading of 0.002g PGA ; 10 readings per day over 0.0002g PGA

CONCLUDING THOUGHTS – KEY TAKEAWAYS

Case-by-case mitigation plans (no "one size fits all" solution)

Mitigation for each project varies based on the results of historical seismicity at the site, the surrounding community, and the seismic potential.

Use of the DOE IS Protocol resulted in more comprehensive analysis

Projects that used some form of the DOE IS Protocol resulted in more comprehensive analysis, including more detailed communication and mitigation plans.

Active monitoring and daily reports during stimulation

Actively monitoring all seismic activity in the project area and providing daily reports during stimulation keeps the BLM, DOE, and/or cooperating agencies and other stakeholders well informed of the seismicity occurring at the project site and the frequency at which seismic activity triggers mitigation requirements.

Thank You!

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