AGENDA

SEISMIC MONITORING ADVISORY COMMITTEE

November 17, 2014 @ 9:30 a.m.
Calpine Geothermal Visitors Center
15500 Central Park Road, Middletown

I. Introductions

II. Approval of SMAC report to the Board of Supervisors of May 12, 2014 meeting.

III. Anderson Springs Report, (Jeff Gospe) and Input

IV. Cobb Area Public Input

V. General Public Input

VI. Update of SE Geysers pipeline operations (Voge, Drake)

VII. Summary of Seismic Data from USGS Network (Voge, Drake)

VIII Report by Calpine on Strong Motion Seismic Sensors (Hartline)

IX. Report by Calpine on Santa Rosa Pipeline Operations (Hartline)

X. Calpine EGS (Hartline)

XI. Report on LBNL Seismic Array (Majer) and Induced Seismicity Update

XII. Report by David Oppenheimer Seismic Data

XIII. Report on Bottle Rock Power Co. Operations

XIV. Coordination with Santa Rosa

XV. Schedule Next Meeting for Monday, May 11, 2015

XVI. Adjournment

Seismic Monitoring Advisory Committee (SMAC)

Monday, May 12th 2014 @ 9:30 a.m.
Calpine Geothermal Visitors Center
15500 Central Park Road, Middletown, California

DRAFT MINUTES

Meeting called to order by Mark Dellinger. Minutes were recorded by tape recorder and transcribed to Draft Minutes. Dellinger moved to introductions.

Present: Mark Dellinger, Committee Chairman (Lake County Special Districts), Bob Young (NCPA), Ed Voge (NCPA), Craig Hartline (Calpine), Daniel Oppenheimer (USGS via phone), Joe Austin (DOGGR), Meriel Medrano (Anderson Springs), Ernie Majer (LBNL), Jeff Gospe (Anderson Springs), Bruce Carlsen (Calpine), Danielle Seperas (Calpine), Hamilton Hess (Friends of Cobb Mountain), Cheryl Engels (Anderson Springs), Mike Sherman (City of Santa Rosa), Lester Drake (NCPA), Jody Spooner (Calpine), Benjamin Minx (DOGGR), Rick Coel (LCCDD), Brian Harms (Bottle Rock Power), Maryann Villavert (LBNL).

I. November 18, 2013 Meeting Minutes for Approval: Mark Dellinger

a. Comments: Jeff Gospe noted that the minutes were completed faster and that having the presentations visible in the minutes online is helpful. Mr. Dellinger stated that the recordings are able to capture the voices better;
b. Mr. Dellinger presented the Draft Minutes for approval and they were approved by consensus.

II. Anderson Springs Report: Jeff Gospe (5.12.14 Presentation 1)

a. Mr. Gospe presented four graphs of earthquake activity within three miles of the USGS's coordinates for Anderson Springs;
    i. Gospe observed that while there was a large increase in seismic events over the last 15 years, since 2007 the efforts of NCPA and Calpine have appreciably reduced the amount of seismic activity to a normalized range of about one event a week. The number of magnitude 2 and higher earthquakes have been reduced to 2004 levels, which is a significant decrease. Gospe stated that the average magnitude of the earthquakes is declining and based on the rate of seismic events thus far for 2014, there is the potential to have the fewest earthquakes in 13 years. The trends do show that the number of earthquakes measuring over a 3.5 have leveled off to five incidents a year since 2012 but also that the average magnitude of those earthquakes measuring over 3.5 in magnitude has increased as there has already been one over 4.0 this year and one in the high 3's. Gospe further commented that overall things

have improved and the thing that the residents care about most is the actual strong gravity motion detected on the machine to show what is felt rather than the magnitude.

ii. Questions for Jeff Gospe
   1. Bruce Carlsen: I have a question for Jeff. I am wondering if you have every tried any of the other trend-line options to fit the data?

      Jeff Gospe: No, this is just simple linear, but I leave it to the folks at LBNL or USGS or even Calpine, but I can certainly provide the raw data. It's pretty simple data. But it was interesting that the average event was pretty consistently increasing.

   2. Meriel Medrano: I'd like to say one thing. We are experiencing a lot of small earthquakes. You know, daily. Very, very small. So, that's still happening, but it's not really very bothersome.

iii. Jeff Gospe added that there has been a decline in the number of earthquakes, and the local residents are thankful for that but these efforts need to be continued.

III. Northern California Power Agency (NCPA): Ed Voge (5.12.14 Presentation)
   a. Mr. Voge stated that his presentation covered the last 6 months of operations for NCPA, since the last meeting, focusing on the southeast Geysers area and the relationship between injection, production, and seismic activity. The Southeast Geysers Effluent Pipeline delivers an average of 7.9 million gallons a day over the last 6 months, and since 1997 has delivered 47.8 billion gallons of water to The Geysers.

      i. Maintenance in early February reduced gallons per minute by 20% for two and a half weeks (from 5,462 to 4,300);
      ii. Curtailing injection at The Geysers in light of drought starting May 1st. Normally the injection water is 65% fresh water from the lake, 35% secondary treated waste water. However, from May 2014 to May 2015, the fresh water amount will be approximately 1/3 the normal amount (from 5,500 to 1,800 gallons a minute);
      iii. Steam production peaked at 100 billion pounds of steam mass withdrawn in 1987, has decreased to 40 billion pounds of steam in 2013;
      iv. Steam production is on a steady decline. Water injection increased 12% in this period over the previous six month period, as did the

seismic activity, averaging 14 seismic events per month previously and 16 per month during this period on the NCPA lease. In past 6 months, 97 events magnitude 1.5 or greater in the Southeast Geysers, and only one magnitude 3 or greater. Based on amount of seismic events over last six months, should have average amount of magnitude 1.5 and above for the year. However, because there will not be as much water injected because of the drought, that number might go down;

v. Across The Geysers area, 2013 had 1,342 seismic events over 1.5 magnitude, which is close to the peak of 1,384 in 2006.

IV. Calpine Corporation: Craig Hartline (5.12.14 Presentation 3)

a. Craig Hartline discussed the seismicity and water injection for the area of The Geysers operated by Calpine.
   i. The Seismicity Hotline is checked daily with the exception of Sunday, and calls are transcribed and reviewed. Since the last meeting, 57 calls regarding seismicity were received; there were 42 calls from Anderson Springs, 15 from Cobb. The call count was down from 81 calls in the previous period. The most calls came in January with nine calls after a 4.53 magnitude earthquake; and, four calls after a 3.74 earthquake. Hartline stated that the calls are helping Calpine geologists pinpoint what is going on and then by using 3D geology, to determine where events are happening in space and time.
      1. Hartline reports that Calpine is transferring the toll-free line outside of The Geysers system to prevent further outages due to local phone system failures.
   ii. Seismic Events: During this reporting period, there was a total of one greater than magnitude 4; a total of two greater than 3.5 magnitude; and a total of seven greater than 3.0.
   iii. Steam production is down slightly for 2013 as compared to previous years, as is injection due to drought conditions and the wildfire that occurred at Calpine's McCabe (Unit 5/6).
   iv. Water injection and seismicity were coupled until the mid-90s, and since then there has been a reduction in the seismic events greater than a magnitude of 3, even while water injection has been occurring.
   v. There has been a minor decrease in the wastewater from Santa Rosa, at about 93% of previous years' allocation. There have been situations where after peak injection there is slightly stronger seismicity, so with less water it will be interesting to see what happens to the seismicity levels.

vi. In this reporting period, there has been less variability in the amount of water for injection, due to an insignificant amount of fresh water and more uniform condensate related to the weather conditions.
vii. Between 2003 and 2006, there were 2.5 magnitude 4.0 or higher earthquakes per year, but since 2007, there has been an average of 1.1 per year. Work is ongoing to understand the physical mechanisms responsible for this trend in order to mitigate seismicity to as much as possible while maintaining production.
viii. The Calpine portion of the Southeast Geysers is closest to the community of Anderson Springs, and as such Calpine is injecting less in those areas. Calpine is expanding its water injection activities toward the northwest and away from the communities, and adding injection wells to distribute the water more broadly and uniformly. Three new water injection wells have been drilled with plans for 3 more in 2014/2015. There is an emphasis on limiting the water injection flow rate variation for wells in the closest proximity to the communities.
ix. Calpine constantly evaluates to find suitable injection rates per well, with an emphasis on making the process more gradual.
x. The strong motion instruments have been in use to evaluate seismicity as it is felt in the communities.
    1. The Anderson Springs station is working, but there have been some issues with the strong motion station in Cobb with a memory card problem that caused the station to go out of service for several days in January and March. The issue is being addressed.
    2. During this period, there were a limited number of high Modified Mercalli Intensity (MMI) responses measured in Cobb. However, due to instrument outages, Mr. Hartline provided information on estimated Cobb strong motion responses for a magnitude 4.53 seismic event on 12 January 2014 and a magnitude 3.74 seismic event on 21 January 2014.
    3. The 4.53 magnitude seismic event was estimated in the range of 6.5 to 8.5% of g, or in the MMI category V which is consistent with moderate perceived shaking and light potential for damage.
    4. The 3.74 magnitude seismic event was estimated in the range of 1.8 to 2.4% of g, or in the MMI category IV which is consistent with light perceived shaking and very light potential for damage.
    5.
    6. There is a slight decline in the number of triggered events per year for MMI I-VII from a peak in Anderson Springs in

2010, though there is a small increase in events in the MMI range IV-VII in 2013. This is being watched closely.

7. In Cobb there is a slight increase in the overall count for MMI I-VII in 2013, though the lower intensities are not necessarily felt. There has been a slight decline in MMI IV-VII in 2013.

xi. There are efforts underway to create a Three Dimensional Geological and Geophysical Model for The Geysers geothermal field. It will include pre-existing fault and fracture zones, which will assist in understanding induced seismicity at The Geysers. This combined with new Paradigm SKUA/GOCAD software can create animations tying seismicity at a given display interval with the injection/production rates helps to understand the relationship.

xii. Seismicity patterns, reservoir pressure variability, and surface geology can indicate hydraulic discontinuities. At the Prati 32 water injection well, these constraints define hydraulic discontinuities to the southeast and northeast of the injection well.

xiii. Calpine releases reports at regular intervals, at the request of the DOE, to discuss the work that is being done for the Enhanced Geothermal System (EGS) Demonstration Project in the northwest Geysers.

xiv. Calpine is working on a collaboration project with MIT to put Global Positioning System (GPS) instruments in place to allow for continuous monitoring of the local surface deformation movements and as part of a larger program to better understand West Coast regional deformation..

xv. A new seismic warning system calibration program is in the works for natural earthquakes due to modified legislation and restored funding. The primary goal is the automated control (and shutdown) of natural gas, electricity and water supply for refineries, chemical plants, public schools and medical facilities when a significant natural earthquake occurs. eRsearchers will soon be placing test sensors within The Geysers. The smaller earthquakes typical of The Geysers will be used to calibrate the instruments (avoiding false positives), while data from larger natural earthquakes beyond The Geysers will allow calibration for the automated shutdown of systems.

b. Calpine Corporation's SMAC presentations can be found at Calpine Corporation's www.geysers.com, 'Recharging the Geysers', 'Seismic Monitoring Advisory Committee (SMAC)';

c. Questions for Hartline

i. *"Craig, the exhibit that showed the well bores and the discs... So that you replace the disc representing the volume injections at the shoe of the casing. Essentially the top of the injection interval."*

Hartline: "We have determined the center of injection for each well based on the depth of steam entries (fractures), and the significance of that steam entry. This is seen as pressure increases during drilling. we determine where the center of injection actually is for that particular well and then post that at the measured depth on the well. So that's our estimated center of injection point. The disc is a graphic representation meant to show the monthly flow volume. A series of these fractures are encountered during the drilling and we do some averaging to determine where that placement should be."

V. Laurence Berkeley National Labs Presentation: Ernie Majer (5.12.14 Presentation 4)

a. Mr. Majer summarized that LBNL has 32 permanent stations at The Geysers, as well as 5 temporary stations around the EGS well at Prati 32/31, which are providing data for the EGS program and the DOE.
   i. All stations functioned through the winter, and they have the stations on a maintenance program to ensure everything keeps working;
   ii. Since 2002, all data has been transferred to the Northern California Earthquake Data Center, which was over 500,000 Seismic Events;
   iii. This monitoring program is able to continue because the DOE granted a no-cost extension to the program for 2 more years, which was possible because there were still funds left for that time. The DOE recognizes the importance of The Geysers program and the EGS program in general, as well as the community involvement so the hope is there will not be a problem securing funds to maintain these evaluation efforts in the future;
   iv. The Alta Rock 500 foot boreholes have been abandoned by Alta Rock and make very good seismic stations. LBNL wanted to take them over, but have been dealing with a contingency, placed when they were first drilled, that they would put a bond on each one as an abandonment fee. LBNL volunteered to take over the bond, but the DOE is not allowed to pay that type of money. Calpine stepped in and worked out a deal with Alta Rock to take ownership of the boreholes to allow LBNL to continue their research. They plan to place stations at the top and bottom of the boreholes to see the difference in seismicity. The idea is to monitor the smaller magnitudes, to see if there is greater deviation between the top and the bottom of the boreholes in seismic activities of smaller magnitude than the larger magnitude;
   v. LBNL is interested in looking at fractures sizes and the maximum fracture potential. The public wants to know what the largest potential magnitude is for an earthquake at The Geysers. This

depends on the biggest fault as well as how the energy is being released. Studying the boreholes gives the opportunity to explore that;

vi. Borehole installation will be completed this summer, and the data will continue to flow to the Northern California Earthquake Data Center which is supported by the USGS and the Berkeley Seismographic Station.

vii. Work on an advanced stoplight system is in process. This involves induced seismicity related to geothermal operations worldwide. It dictates that when there are a certain number of events, or events of a certain size in a proximity to buildings or the public, geothermal operations will decrease or halt injections. It did not work in previous applications, but the new programs are physics based stoplight systems. Mr. Majer attended the International Program for Geothermal Technology conference, and the members countries are putting together a proposal on advanced stoplight systems to implement. This program will start this summer and continue for the next couple years;

viii. The DOE is working on a Cross-Cutting Subsurface initiative. This research into the subsurface will have many different applications, including providing information about seismicity. This program will start this year, but will evolve into a much larger program that the Secretary of Energy wants to implement starting in 2015, ramping up in 2016. This will likely address such issues as hydraulic fracturing, which is relevant not only in California but in the Midwest as well with the induced seismicity concern growing in that area. The research is coming not only from a seismicity mitigation standpoint, but from a standpoint of understanding why seismic events happen, and how what is going on in the reservoir affects energy extraction for oil and gas as well as geothermal. Hopefully geothermal will be able to take advantage of this research to gain a greater understanding of seismicity.

VI. Phone Comments:

a. Mr. Oppenheimer noted that there is a technique called double difference that is used to obtain a precise location for earthquakes. USGS has been working with the Lamont Geophysical Observatory at Columbia University, and has implemented that code into the production system. That data will be available shortly from the Northern California Earthquake Data Center website. The double difference technique allows the viewer to see how earthquakes tend to coalesce on to clear fractures, which are presumably imaging the rupture default itself.

Oppenheimer explained how once an earthquake occurs, the USGS looks for earthquakes in the vicinity to grab wave forms, and cross correlates the wave forms to estimate the arrival time. It allows the seismologists to use the property of repeatability of earthquake wave forms to pinpoint the earthquake locations. This is very useful to determine the structural elements of the reservoir, especially in terms of injection and fluid flow and the ability to compute locations in real time, a few minutes after a seismic event. This has real implications for mitigation of seismicity.

b. Mr. Oppenheimer further commented that the USGS is recording earthquakes at The Geysers from 32 seismic stations. They never recorded earthquakes below a magnitude of 1, causing the USGS' magnitude algorithms to fall apart. They are working on code to compute a moment magnitude for very small earthquakes. It is in testing, but he hopes to have it by the next SMAC meeting. It will measure magnitudes below 1, the seismic events that residents will not feel, but that provide useful information for the USGS about the energy release of tiny earthquakes;

c. Questions for Mr. Oppenheimer

i. Hartline: "*David, I appreciate the comments and to answer your one question, when we're looking at the current seismicity period, I haven't been using the double difference data, but there are some cases where I've been reaching back into the double-difference data catalog. This includes one study being completed with GFZ Potsdam. It's good to be reminded of that, that's the way to go and I'm glad you're making some progress with that. Very good.*"

Oppenheimer: "So, the caveat for anybody who does retrieve the data in this format, and it's probably going to be available this week or next -we're just wrapping up some testing –you don't get a solution for every earthquake. But I would imagine that at The Geysers almost every earthquake is probably going to be locatable using this technique. So, if you see earthquakes missing, that's not anything to get alarmed about. The technique doesn't guarantee a location every time."

VII. Bottle Rock Power Update: Brian Harms (no presentation)

a. Harms stated that Alta Rock Energy became an investor in Bottle Rock Power at the beginning of this year.

b. Harms stated Bottle Rock is doing lots of activities, such as stimulations on some wells, using some of the low levels of induced seismicity that would be expected during the stimulation. Harms said that they are seeing small

seismic events, less than a magnitude 1 and very locally. He will provide a report at the next meeting once some of the work has been done.

Next Meeting: The next SMAC meeting will take place on November 17th, 2014 at 9:30 a.m. at the Calpine Geothermal Visitor Center. Meeting was adjourned by Chairman Dellinger at 11:25 a.m.