ANALYSIS OF THE ENVIRONMENTAL IMPACT OF THE INJECTION OF TREATED MUNICIPAL WASTE WATERS INTO A PORTION OF THE GEYSERS GEOTHERMAL FIELD, CALIFORNIA, USA

by

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Abstract

Pressure decline within The Geysers geothermal reservoir has resulted in decreased power output from existing power plants. As a means of partially arresting these pressure declines, several field operators and the County of Lake propose to add approximately 13,000 lpm of treated municipal waste water from several small communities into 6 injection wells in the southeastern corner of the field. Water will be carried to the geothermal field via a 50- or 60-cm diameter pipeline from the vicinity of Clear Lake, a distance of about 45 km. The results of this study suggest that the proposed injection of effluent could help reducing the high rate of pressure and production rate declines without inducing significant geochemistry incompatibility or microseismicity.

1.0 INTRODUCTION

Commercial generation of electricity at The Geysers (figure 1) began in September 1960 with the start-up of Unit 1 and 2, a 12 MW(gross) power plant. During the 1960s, growth was slow, with the installed capacity only rising to 82 MW (Units 1 to 4) by 1970. However, the growth rate accelerated during the 1970s when 612 MW was brought on-line and in the 1980s when an additional 1,412 MW of generating capacity was installed (figure 2). Installed capacity in The Geysers reached a peak of 2,106 MW in mid-1991 and there are no new power plants are scheduled for construction at The Geysers.

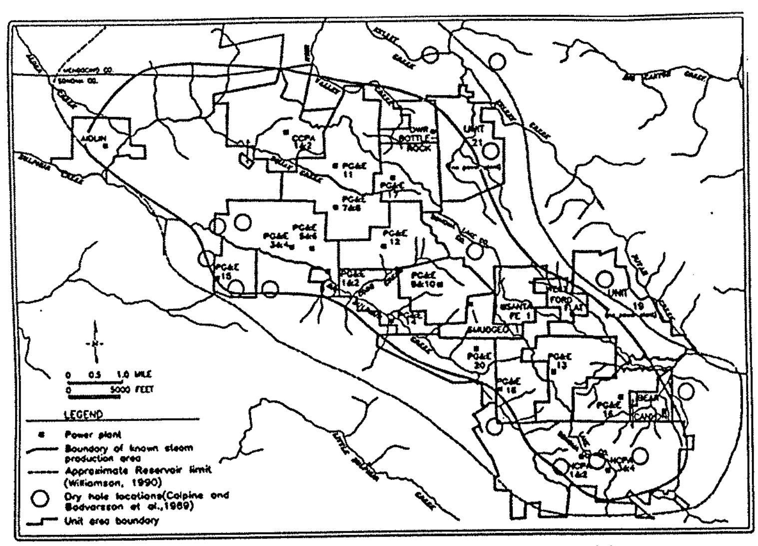

Figure 1: The Geysers Geothermal field

With the accelerated development in the 1980s, it was found that there was a significant change in well decline characteristics. In most areas, the production decline increased from an exponential rate of 6% per year to about 30% per year in 1985; since then production has continued to decline at a high rate, although there is evidence of a lessening in decline rate since 1990, possibly due to:

1. a reduction in overall production rate of about 23% from 1987 to mid-1991(figure 2);

2. local changes in injection strategy; and,

3. changes in generating strategy in some areas of the field, notably the NCPA area, by moving from base load operation to load-following.

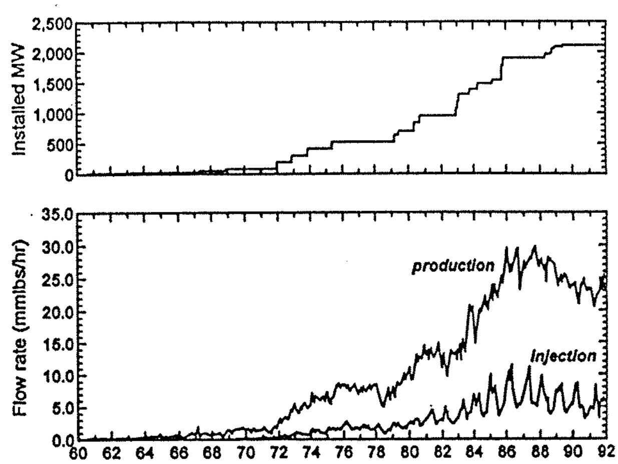

Figure 2: Development history at The Geysers

With the reduction in electrical generation, the ability of The Geysers to continue to provide significant electrical generation into the future has been questioned. The effluent injection program was designed to provide additional source of water, which could be converted to steam by the heat from the reservoir rock and thereby help to reduce the decline rate in steam pressure. It is a legal requirement (California Environmental Quality Act, CEQA) that an analysis be made of the environmental impact of this proposed activity. As part of the environmental report, we were asked to review the following issues:

1. Conceptual correlation between production and injection; and the possibility of steam production gain or loss resulting from the injection of the effluent.

2. Possibility of chemical incompatibility between geothermal fluid and the effluent. Chemical trends within the reservoir and in the produced steam after injection.

3. The influence of steam injection on the background seismic regime. The existence or non-existence of injection-induced seismicity and its potential impacts.

2.0 METHODOLOGY AND ANALYSIS

2.1 *Impacts of effluent injection on steam production*

In order to establish correlations between production and injection, a combination of flow rate, pressure and chemical data were used. Flow rates at production wells, and in particular the changes of flow rates over time, are compared with injection well flow rates and locations. Pressure declines at production wells are similarly compared with the history of injection. Chemical data are used to track the appearance of injected water which are not shared by original, native, reservoir steam.

The most direct evidence that water injected into the reservoir reappears as steam at production wells is provided by analyses of stable isotopes. A large portion of the injected water is steam condensate which has been cycled through power plant cooling towers before being piped to the injection wells. In the cooling towers some of the condensate evaporates. This causes a shift of isotope composition in the remaining condensate, and it no longer retains the isotope composition which it had when produced as steam. When the residual cooling tower condensate is injected back into the reservoir, some fraction of it boils and mixes with native reservoir steam. When this mixed steam then appears at production wells, the fraction of "injection-derived-steam" (IDS) in the mixture can be determined by comparing the isotopic composition of the mixed steam with the composition of the residual cooling tower condensate and the composition of native (unmixed) steam formerly sampled at the well.

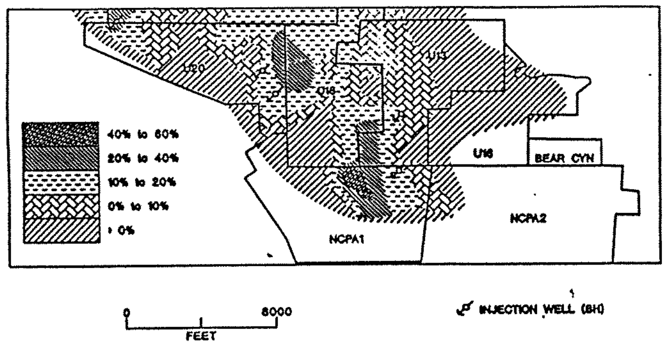

Figure 3: Flashed injectate in produced steam, 1991

The initial injection philosophy in the Southeast Geysers was to dispose of the cooling tower condensate in "peripheral" wells, away from the center of their wellfield. However, after observing the high rates of flow rate and pressure declines which started in 1986, the operators in this area (NCPA, Calpine, and UNOCAL) re-evaluated this practice, and studies were carried out to determine the reservoir response to injection in wells centrally located in the production area. These studies led to the conclusion that a properly planned strategy could: a) extract additional heat from the rock; b) have a positive effect on pressures and steam flow rates; and c) result in minimal thermal breakthrough (cooling) at adjacent production wells.

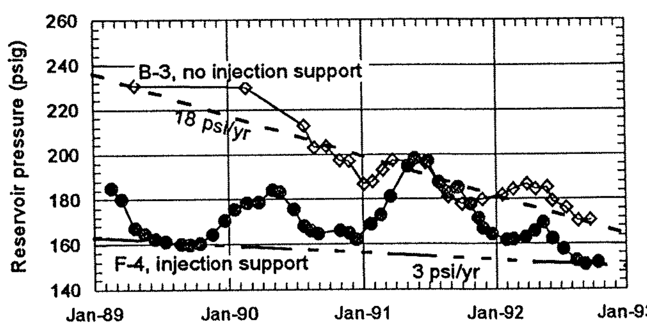

Figure 4: Pressure history for steam wells F-4 & B-3

Figure 3 is a map of the Southeast Geysers wellfield, showing percentage injectate returns (IDS) determining using stable isotope measurements as described above. The portion of the wellfield in the

NCPA leasehold with greater than 36% returns is now about one-third of the total developed area. NCPA has done analyses of pressure and flow rate decline rates, which show clear correlation between areas of reduced decline and injection wells in or adjacent to those areas. Figure 4 shows an example of two wells with and without injection support.

Similar beneficial effects were also seen in Calpine production wells located near the injection points. Before the start-up of the nearby injection well, typical flow rate was declining at a rate of about 30% per year; immediately after the injection well came on-line, the decline rate was reduced to about 13%.

The beneficial effects of interior injection in the UNOCAL leasehold is clearly shown on figure 3. Returns of up to 20%-40% as flashed injectate in produced steam were seen in parts of Unit 18 and Unit 20. Dramatic flow rate decline improvement were also reported for wells in these two Units with typical flow rate decline change from 25% to 6% before and after injection started, respectively.

Except for instances where the rate of injection has been unusually high for a prolonged period of time, communication of unflashed injected water and the steam production wells has not been a major problem (Enedy and others, 1992). High downhole superheat was measured in wells near the injection areas and there has been no noticeable thermal degradation caused by the interior injection. Superheat measurements taken before and after the interior injection program indicated that reservoir superheat in most of the production wells in the Southeast Geysers has been gradually increasing despite nearby injection. This is not surprising since the amount of vapor extracted from the reservoir far exceeds the quantity of water injected.

The proposed effluent injection would increase the current injection rate by more than twofold. Based on the results from studies conducted by the operators in the Southeast Geysers, it appears that well decline rates would continue to be lessen. Assuming that complete effluent injection could be achieved without cooling, it is likely that the recovery rate of flashed injection water will be doubled within several years.

2.2 Impacts of effluent injection on the chemistry of reservoir fluid

The potential chemical effects of injection, and attendant effects on the physical condition of the reservoir, can include:

- dilution of non-condensable gas (NCG) and shifts of gas composition and stable isotope composition;

- local enhancement of reservoir porosity/permeability as a result of solution of the rock minerals by the injection fluids; and,

- local loss of porosity/permeability as the injection fluids deposit scale or react with rock minerals.

- local loss of porosity/permeability due to injection of corrosion products.

Crecraft and Koenig (1989) calculated that heating injected effluent water in reservoir rock to 240°C without boiling produces a net increase of porosity, because the volume of quartz dissolved exceeds the volume of other minerals precipitated (dolomite, minor anhydrite, traces of hematite and hydrous magnesium silicate). However, within a descending plume of injected water, which has an interface with steam, there is likely to be an interior region of carbonate deposition at lower temperature, an intermediate zone of quartz dissolution (at higher temperature), and an outer zone where all solutes (including quartz) are deposited, because the liquid vaporizes. The present injection of condensate has the same potential to mobilize quartz and no problems have occurred.

Carbonate deposition may occur at about 100 ppm-wt, which produces about 250 m^3/yr of solids at 5.36 million gallons injection per day (year 2023), and at the same injection rate the deposition of all effluent salts at a theoretical concentration of about 400 ppm-wt will amount to roughly 1,000 m^3/yr. If the flow into a single injection well is 1,000 gpm, the total deposition near that well will be about 270 m^3/yr. Injection experience at the Southeast Geysers suggests that injected water vaporizes completely within about 300 ft of the wellbore. If all vaporization occurs within a cylinder with 5% porosity, 1,000 ft-tall and 300-ft in radius, then at 270 m^3/yr the pore volume will fill up in 1,500 years, assuming an unlimited supply of heat to vaporize the injectate.

Because the salts deposition (including carbonate) is not likely to be uniform within the pore volume near the injection well, the real effect of this deposition is highly speculative. At some point in time a build-up of injected salts appears likely to interfere with liquid movement, but the timing and severity of this effect is not subject to a reliable prediction.

The potential volume of corrosion products is considered too small to effect the reservoir, but corrosion damage to injection wells (and the pipeline?) is likely to occur if the effluent injectate is not treated to remove dissolved oxygen.

Other possible effects of injection include silica deposition fed by the addition of Clear Lake diatoms to the injection flow, and biological growths downhole allowed by cooling and a feed of effluent organic and nutrients. Evaluations were not attempted due to lack of data, but strong effects of these types appear unlikely,

2.3 Potential impacts of effluent injection on seismicity

Seismicity associated with the development of the Geysers Geothermal Field (GGF) was not documented until 1972, because the seismographic networks did not have the capability to do so. As a result, no adequate baseline exists to identify local seismicity before geothermal development was initiated. By 1972, the highly sensitive seismographic network operated by the U.S. Geological Survey in northern California (CALNET) was routinely providing hypocentral locations (epicenters and focal depths) of most events with local or "Richter" scale (M) of ≥ 1 in the GGF. Additional data from UNOCAL, the Lawrence Berkeley Laboratory (LBL), and the Lawrence Livermore National Laboratory (LLNL) were also used by various researchers in analyzing the correlation between geothermal development and seismicity in the GGF.

Studies of induced seismicity in The Geysers by various investigators, Bufe and Ludwin (1980), Eberhart-Phillips and Oppenheimer (1984), Stark (1990), Enedy and others (1993), Smith et al. (1994), and personal communication with operators personnel suggested that inducement of seismicity by injection water clearly does occur in the GGF, although it is not the only mechanism. Production is also believed to be a cause of induced seismicity, but probably chiefly at relatively shallow depths. Stark (1990) determined that injection-related seismicity is most apparent at depths greater than about 4,000 feet below sea level. The observations of seismicity drawn from studies in the Northwest and Central Geysers, suggest a strong relationship of injection and production activities to increased seismicity. Additionally, the initiation of geothermal production has been followed by and increase in seismic events within a relatively short period. In the long term (e.g., 8-10 years) there is good correlation between the annual number of seismic events and mass of steam withdrawn in production. These findings support the general observations and perceptions of local residents that more earthquakes have been occurring since geothermal development has started in the Geysers.

The patterns of seismicity in the Southeast Geysers are not as clear as those in the Northwest and Central Geysers. There is no apparent cluster of seismic events, although production and injection has been ongoing in the area during the same period of studies referenced for the Northwest and Central Geysers. Additionally, the relationship between injection and seismicity is not revealed in the consistent patterns at the wells, causing some geologists to suggest the possibility that the response of the local reservoir rocks to injection/production may be controlled by local geology substantially different than that in the Northwest and Central Geysers.

The above considerations make it difficult to predict the effects of the effluent injection project on seismicity in the Southeast Geysers. The evidence suggest that there is a good potential for the project on the whole and in long term to increase seismic events. The evidence also suggests that if such effects do occur, they likely would become evident relatively soon after the initiation of effluent injection. If increased seismicity may become evident, it may/may not be revealed in well defined pattern (cluster) of seismicity in the Southeast Geysers.

The evidence suggests that the effect of effluent injection is likely to be primarily an increase in microseismicity, that is earthquakes below magnitude 3, which is approximately lower limit for the earthquakes felt by people. Additionally, the magnitude of earthquakes induced by the project probably would be no greater than Richter Magnitude 4.2. While larger magnitude earthquakes may occur from natural causes in the Southeast Geysers, there is no evidence at present to suggest they would be linked to injection/production activities. It is important to note that seismic events under M 4.5 do not cause damage to structures unless, perhaps, they are already in a weak condition. These felt earthquakes may contribute to general concern and feeling of unease among local residents about earthquakes. However, the frequency of earthquakes between M 3.0 and 4.2 is relatively small and assuredly many of these events are attributable to natural, regional earthquakes. A frequency of Richter Magnitude 4.2 from The Geysers source area would likely occur once or perhaps twice during the designed life of the project.

Induced seismicity in the GGF does not represent a change in long-term seismicity (say 100 years) in the study area. Rather, it represents a hastening of release of natural tectonic stress, built up through regional plate-tectonic forces. Therefore, an increase of seismicity in coming decades (say, 10-30 years) should be followed by a decrease thereafter with respect to a natural seismicity level unaffected by geothermal activities, including fluid injection. Moreover, it is not possible to distinguish naturally occurring from induced seismicity for earthquakes of magnitude larger than about 3.5. This is because these larger shocks occur infrequently in the GGF (not more than one per year, on average), and are widely scattered, such that there is no possibility of testing their possible association with major changes in geothermal fluid injection or withdrawal.

3.0 CONCLUSIONS

1. The proposed injection of effluent could double the recovery rate of injection derived steam (IDS) within several years in Calpine, NCPA, and Units 18&20 of UNOCAL leaseholds.

2. The added injection water would slow the rate of steam production decline in the area where pressure and steam rate declines have been most severe.

3. The effluent is compatible with the chemistry of reservoir geothermal fluids and, therefore, would not have significant adverse impacts on geothermal field and power plant operations.

4. The project would result in increased microseismicity in the project area and vicinity, but probably would not induce larger earthquakes that pose a substantial threat to public safety and substantial damage to structures.

4.0 ACKNOWLEDGMENT

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