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Changes in Surficial Features Associated with Geothermal Development in Long Valley Caldera, California, 1985-1997

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ABSTRACT

Since 1985, Long Valley caldera in east central California has been the site of a 40 MW binary-electric geothermal development utilizing water at temperatures near 170EC. During the course of this development, changes have occurred in surficial features, including declines in hot-spring discharge, increases in fumarolic discharge, heat-induced vegetation kills, and land subsidence. Factors responsible for such changes include seismic activity and related ground deformation, seasonal and annual variations in recharge, and changes in geothermal reservoir pressures and temperatures. To date, however, there have been no significant adverse impacts to thermal springs whose usage is important for recreational and economic reasons. A program of hydrologic monitoring has been in effect since 1988 under the direction of the Long Valley Hydrologic Advisory Committee. The monitoring data have provided useful information on the hydrothermal system and its response to development that can be used by regulatory agencies in designating permit conditions and mitigation measures for existing and future resource developments.

Introduction

Long Valley caldera in east-central California (Figure 1) is an 450 km^2 elliptical depression with a history of episodic volcanic activity over the past 760,000 years, including a most recent eruptive period about 600 years ago along the Inyo Craters Volcanic Chain. The young age of volcanic rocks in this area, together with the abundance of hot springs and steam vents, has encouraged geothermal exploration since the early 1970's and the eventual commissioning of the first geothermal power plant at Casa Diablo in 1985. Although exploration holes have encountered temperatures as high as 214EC in the caldera's west moat, the current development taps water at temperatures of about 170EC from a shallow (~ 150 m deep) reservoir in volcanic rocks on the southwestern edge of the caldera's resurgent dome (Sorey et al., 1991). Three binary power plants, operated by Mammoth-Pacific L.P., currently produce a total of about 40 MW of electricity; plant MP-1 began operation in 1985 and plants MP-2 and PLES-1 began operation in 1991. In this single-phase, closed system, all the cooled geothermal water (~80EC) from the power plants is reinjected at depths of about 600 m. Total flow rate through the plants is approximately 900 kg/s.

The Long Valley area, which includes the resort town of Mammoth Lakes and a major ski area on Mammoth Mountain, has numerous features of geologic, hydrologic, and recreational significance. Concerns over possible impacts of geothermal development on the thermal features led to establishment of the Long Valley Hydrologic Advisory Committee in 1987, with

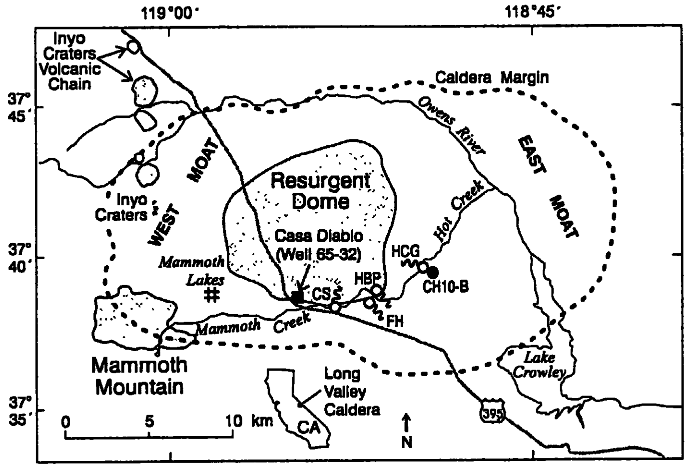

Figure 1. Map of Long Valley caldera including the geothermal well field at Casa Diablo (black square); thermal springs labeled CS (Colton Spring), HBP (Hot Bubbling Pool), and HCG (Hot Creek Gorge); springs at the Fish Hatchery (FH) containing a small component of thermal water; and observation wells CH10-B and 65-32.

membership drawn from regulatory agencies, geothermal developers, the local water district, interested land owners and operators, and various environmental organizations (Farrar and Lyster, 1990). In 1988, the U.S. Geological Survey, in cooperation with the LVHAC and Mono County began a program of hydrologic monitoring to detect changes in surface features and in observation wells that might be related to the development of both the geothermal resource and the nonthermal groundwater system. In the latter case, the Mammoth Community Water District operates wells adjacent to the upper reaches of Mammoth Creek that supply fresh water for domestic consumption.

Natural thermal-water discharge from the geothermal system occurs in springs located to the east of Casa Diablo, around the southern side of the resurgent dome and to the east of the dome. Fumarolic discharge occurs from vents at Casa Diablo and to the west. Concern over environmental effects of geothermal resource development is focused mainly at Casa Diablo and at springs at the Fish Hatchery and in Hot Creek Gorge (Figure 1). The Fish Hatchery springs discharge water at a composite temperature near 16EC that includes a small (~5%) thermal component. This mixture of thermal and nonthermal spring water supports a productive fish rearing operation. Springs in Hot Creek Gorge discharge at temperatures up to boiling (93EC), and provide unique opportunities for bathing in creek water heated by hot springs. Environmental changes at Casa Diablo that could cause concern include heat-induced vegetation stress, potential hydrothermal eruptions from pressure buildups in shallow steam zones, and land subsidence.

Hydrologic Changes

Operation of the geothermal well field at Casa Diablo has resulted in changes in both reservoir pressure and temperature over the 1985-1997 period. Production reservoir pressure changes are delineated by downhole pressure data for observation well 65-32 (Figure 2). The cumulative pressure decline between 1985 and 1990 amounted to ~0.1 MPa, but was followed by an additional 0.25 MPa decline during 1991 in response to increased production and deepening of injection wells (which lessened pressure support to the production zone). Between 1991 and 1997, reservoir pressure slowly declined approximately 0.07 MPa. Pressure increases in the injection reservoir of approximately the same magnitude have been observed in a deeper monitor well. The decline in production reservoir temperature over the 1985-1997 period amounted to about 10EC, compared with localized declines of approximately 80EC in the injection zone.

Accompanying these changes in production reservoir pressure, some thermal spring flow in the vicinity of Casa Diablo has ceased and been replaced by vigorous steam discharge, reflecting the establishment of boiling conditions in the shallow thermal groundwater system. A zone of steam-heated ground has developed within and adjacent to the well field and within a relatively narrow region of fumarolic vents stretching westward approximately 1 km around the south side of the resurgent dome. Fortunately, reservoir pressures have not declined sufficiently to cause boiling within the production reservoir.

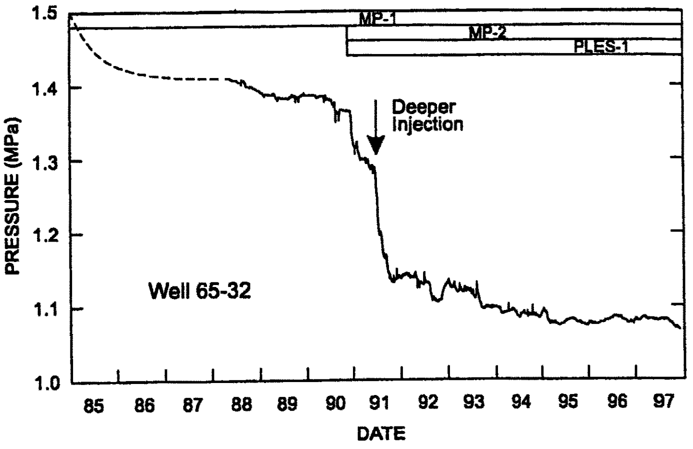

Figure 2. Pressure history for observation well 65-32 (adjacent to the geothermal well field at Casa Diablo) and periods of operation of each of three geothermal power plants (bars at top) at Casa Diablo. The pressure history for the period 1988-1997 (solid line) is based on continuous measurements made in the well (data collected by Mammoth Pacific, L.P.); the dashed line for the 1985-1988 period is based on an extrapolation of the measured pre-development pressure to the measured pressures in 1988. The sharp drop in pressure in 1991 resulted from a combination of an increase in the production rate and cooled geothermal water being injected at a greater depth.

Data from the USGS hydrologic monitoring program for sites outside the Casa Diablo area are given by Sorey and Farra (1998). Among other things, these data show that Colton Spring (2 km east of the Casa Diablo area) ceased flowing in mid 1991. At distances of about 5 km to the east of the well field declines in water level in the Hot Bubbling Pool (HBP) and in the adjacent observation well CW-3 of ~2 m correlate with the pressure record in well 65-32. Decreases in chemical flux indicate that the component of thermal water in the Hatchery spring declined ~40% after 1990. However, temperatures in the hatchery springs, which normally fluctuate seasonally by 1-2EC, have remained relatively unchanged. This situation appears to be a consequence of several factors including (1) declines in the nonthermal component of spring flow from drought condition (between 1988 and 1994) and possibly from groundwate pumpage in the Mammoth Basin, and (2) conductive heating from aquifer rocks.

In Hot Creek Gorge (~10 km east of Casa Diablo), wher total thermal-spring discharge is calculated from measurement of chemical flux in the creek, no significant changes in spring flow have been detected. Measurement precision there is “15% Similarly, water-level measurements in a nearby thermal monitor well (CH-10B) show no clear correlation with pressur changes at Casa Diablo.

Topographic Changes

Leveling data collected along or adjacent to Highway 39 (Figure 3) show a dip in the vicinity of Casa Diablo beginnin

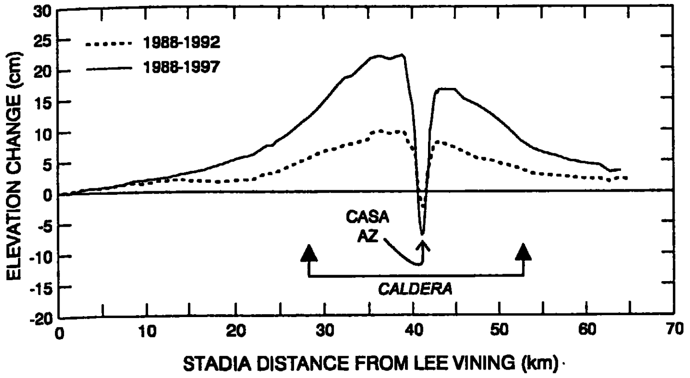

Figure 3. Elevation changes along U.S. Highway 395 with respect to Lee Vining, showing uplift of the caldera floor and a region of relative subsidence centered at bench mark CASA AZ adjacent to the geothermal well field at Casa Diablo.

in 1986 superimposed on a general pattern of uplift begun in 1980 (Sorey et al., 1995; Langbein et al., 1995). The uplift reflects extensional deformation associated with an ongoing episode of magmatic intrusion and seismicity in the central part of the Long Valley caldera. The effect of relative subsidence at Casa Diablo is clearly seen in the 1988-1992 period, when bench mark Casa AZ, adjacent to the well field, subsided 0.12 m relative to benchmarks on the resurgent dome but outside the wellfield area which rose about 0.10 m. In the 1992-1997 period, Casa AZ subsided an additional 0.11 m relative to adjacent areas on the resurgent dome. Details of the deformation history around Casa Diablo, including tilt on an L-shaped bench-mark array and elevation changes in a bench-mark array within the well field itself, were presented by Sorey et al. (1995). Their analysis supports the inference that topographic changes at Casa Diablo are mainly caused by declines in production reservoir pressure and injection reservoir temperature. Over the entire 1975-1997 period, the Casa Diablo well field has risen approximately 0.38 m while the surrounding area has risen 0.72 m, suggesting a cumulative relative subsidence at Casa Diablo of 0.34 m.

Discussion

Topographic and hydrologic changes have accompanied geothermal development in Long Valley caldera. After over 13 years of development, pressure reductions within the shallow geothermal system have been partly responsible for declines in water levels in wells and declines or cessation of hot-spring discharge within a distance of about 5 km from the Casa Diablo area. Total pressure reduction at Casa Diablo is about 0.4 MPa. No significant adverse impacts have been detected at the Fish Hatchery or Hot Creek Gorge, both areas where natural thermal-water discharge is important for recreational and economic reasons.

The Long Valley Hydrologic Advisory Committee and the hydrologic monitoring program it administers have played a role in the successful development of both the thermal and nonthermal resources in this area. The combination of resource development and monitoring has resulted in the collection of valuable information on the hydrologic system and its response to both natural and man-made changes. The LVHAC and has provided the opportunity for this information to be presented and discussed, while maintaining the proprietary nature of data collected by the geothermal operator. Participation in the LVHAC by regulatory agencies such as the Bureau of Land Management and the Forest Service has allowed for informed decisions regarding the imposition of permit conditions and mitigation measures. Such decisions are likely to become even more important if additional resource developments are to be permitted.

Acknowledgments

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