HYDROLOGIC CHANGES ASSOCIATED WITH GEOTHERMAL DEVELOPMENT IN LONG VALLEY CALDERA, CALIFORNIA

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ABSTRACT

Long Valley caldera in east-central California is the site of a 40 MW binary-electric geothermal development utilizing water at temperatures of 170°C. Environmental impacts of this development include declines in hot spring discharge, increases in fumarolic discharge, vegetation kills from steam-heating, and land subsidence. A program of hydrologic monitoring to detect such changes has been in effect since 1988 under the direction of the Long Valley Hydrologic Advisory Committee. This committee has provided a useful forum in which monitoring data, both public and proprietary, can be discussed and consensus reached regarding the factors responsible for observed changes and the need for mitigation measures to minimize or prevent significant adverse impacts to existing thermal features.

INTRODUCTION

Long Valley caldera in east-central California (Fig. 1) is an 450 km^2 eliptical 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 abundance of hot springs and steam vents, has encouraged geothermal exploration since the early 1970's, culminating in commissioning of the first geothermal power plant at Casa Diablo in 1985. Although exploration holes have encountered temperatures as high as 214°C in the caldera's west moat, the current development taps water at temperatures near 170°C from a shallow (~150 m deep) reservoir in volcanic rocks on the southwestern edge of the caldera's resurgent dome. Three binary power plants 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. Cooled geothermal water from the power plants is reinjected at depths of ~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 areas thermal features led to the establishment of the Long Valley Hydrologic Advisory Committee (LVHAC) in 1987, with membership drawn from regulatory agencies, geothermal developers, the local water district, interested land owners and operators, and various environmental organizations. In 1988, the LVHAC commissioned the U.S. Geological Survey to begin a program of hydrologic monitoring in order 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 County Water District operates wells adjacent to the upper reaches of Mammoth Creek to 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. Concern over impacts of resource development is focused mainly on springs at the Fish Hatchery and in Hot Creek Gorge (Fig. 1). The Fish Hatchery springs discharge water at a composite temperature near 16°C that includes a small (~10%) 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 (93 °C), and provide unique opportunities for bathing in creek water heated by hot-spring inputs.

HYDROLOGIC CHANGES DETECTED

Operation of the geothermal well field at Casa Diablo has resulted in changes in both reservoir pressure and temperature over the period 1985-1996. Production reservoir pressure changes are delineated by downhole pressure data for production well MBP-4 (Fig. 2). The cumulative pressure decline between 1985 and 1990 amounted to 0.06 MPa, with an additional 0.23 MPa decline between 1991 and 1993 in response to increased production and deepening of injection wells (which lessened pressure support to the production zone). Pressure increases in the injection reservoir of approximately the same magnitude have been observed in deeper monitor wells. The decline in production reservoir temperature over the 1985-1993 period amounted to about 10 °C, compared with localized declines of ~80 °C in the injection zone.

Accompanying these changes in production reservoir pressure, 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. Colton Spring, located 2 km east of the well field 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 well with the pressure record in well MBP-4. Measurements also indicate that the component of thermal water in the Fish Hatchery springs declined ~30% after 1990. Temperatures in the hatchery springs have remained relatively constant, however, as a consequence of drought-related declines in nonthermal spring flow and possibly to effects of groundwater pumpage in the Mammoth Basin.

In Hot Creek Gorge (~10 km east of Casa Diablo), where total thermal-spring discharge is calculated from measurements of the increase in 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) have shown no clear correlation with pressure changes at Casa Diablo.

DISCUSSION

The monitoring data for Long Valley caldera document various hydrologic changes resulting from over 10 years of geothermal development. In general, these changes are most significant within a distance of about 2 km of the well field at Casa Diablo, and are as yet undetectable at distances as far as 10 km. Changes in spring flow and temperature at the Fish Hatchery and Hot Creek Gorge from the combination of geothermal and groundwater resource development has not resulted in any significant adverse impacts. For the most part, this situation is a result of the fortuitous combination of existing levels of resource development and the hydraulic properties of the aquifer systems involved.

The LVHAC and the hydrologic monitoring program it administers have also played an important role in the successful development of these resources. The monitoring data have been useful in identifying changes, both naturally occurring changes and development induced changes. The LVHAC has provided the opportunity for these data to be presented and discussed, while maintaining the proprietary nature of data from the geothermal well field. In many other cases of resource development with environmental consequences, this forum does not exist and, instead, adequate disclosure of information and interpretations only happens after costly legal proceedings have been initiated.

In the case of Long Valley caldera, the LVHAC acts in an advisory capacity for regulatory agencies such as the Bureau of Land Management and the U.S. Forest Service who must make decisions regarding permit conditions and the need for mitigation measures to reduce or eliminate development-related adverse impacts to thermal springs. Although such measures have not yet been needed, this situation may change in the future if additional developments are permitted. It is anticipated, however, that the LVHAC will play a valuable role under such conditions in allowing development to proceed in a manner that continues to provide adequate environmental protection.

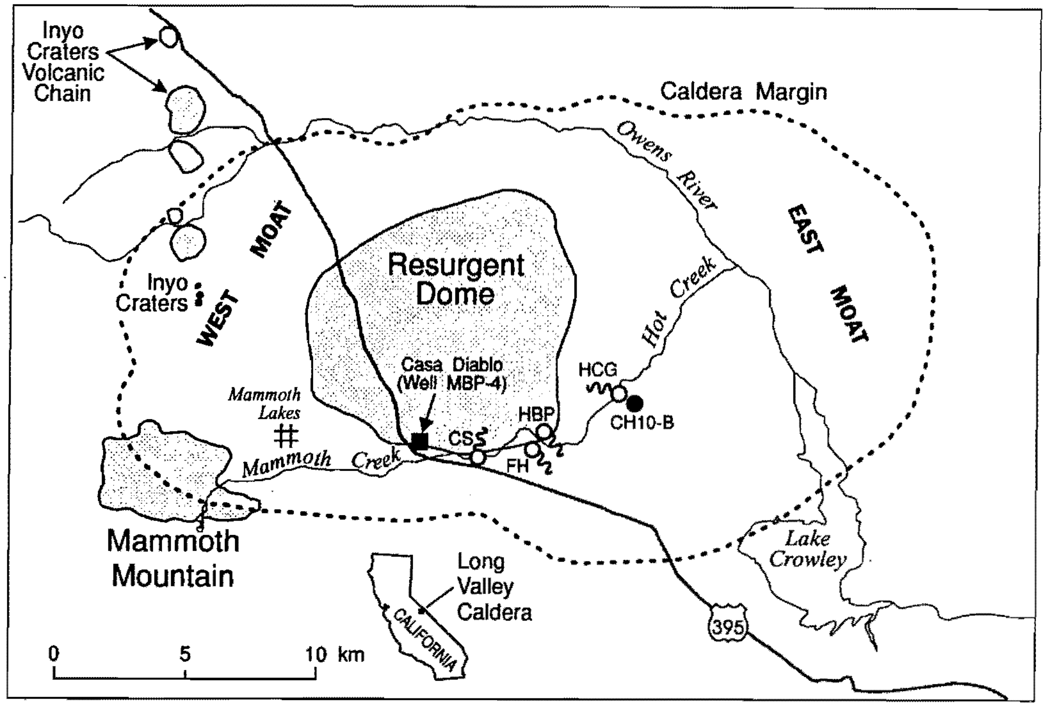

Figure 1. Map of Long Valley caldera showing locations of various features noted in text, including the geothermal well field at Casa Diablo and thermal springs labeled CS (Colton Spring), HBP (Hot Bubbling Pool), FH (Fish Hatchery), and HCG (Hot Creek Gorge).

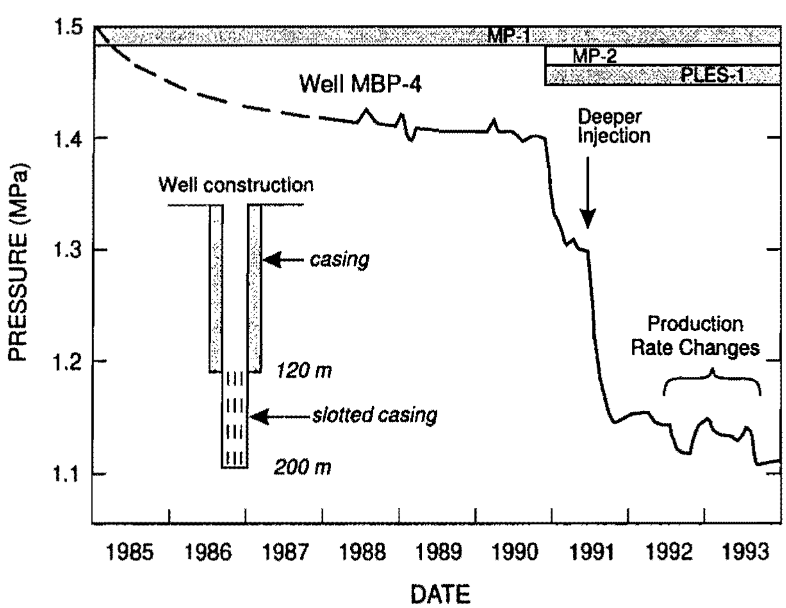

Figure 2. Pressure history and completion diagram for well MBP-4 and periods of operation of each of three geothermal power plants (bars at top) at Casa Diablo. The pressure history for the period 1988-1993 is based on continuous measurements made in the well (solid line); the dashed line for the 1985-1987 period is based on a combination of measured pre-development pressure and numerical simulations. Production rate changes noted during 1992-1993 were of the order of ±15%.