HYDROLOGIC EVALUATION FOR GEOTHERMAL DEVELOPMENT - AN EXAMPLE AT COSO HOT SPRINGS, CALIFORNIA*

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ABSTRACT

Adequate hydrologic evaluations are essential to determine the economic and environmental feasibility of a proposed geothermal development. The main economic concern is the availability of cooling water. The major environmental concerns are maintenance of surface and ground-water character, effects of surface and ground-water use and effects on surface manifestations. A study done at Coso Hot Springs, California, is an example of such an evaluation. It was found that the ground-water reservoir is currently near hydrologic equilibrium and ground-water extraction will cause water table lowering in Rose Valley. Projections to 2000 indicate that water use will exceed recharge by about two thousand acre-feet/year. Pumping may affect the spatial distribution of usable ground water. A baseline of natural variations in surface thermal manifestations must be established to assess changes due to geothermal production.

INTRODUCTION

Evaluation of hydrologic resources and environmental effects may be as important as evaluation of the potential resource itself. In addition to geothermal reservoir assessment, several hydrologic aspects are often critical in determining the economic feasibility of a potential geothermal resource. These include:

1. The quantity of available cooling water--Many geothermal resources occur in arid areas. Water availability would have a great influence on the economics and feasibility of geothermal development. Even power plants that are designed to use minimal quantity of nonthermal cooling water would use on the order of 300 acre-feet per year (AF/yr) per 50 MWe power plant. Surface water sources may not be available so use may lower ground water tables. This would reduce the amount of ground water in storage and alter flow rates and direction. In certain situations, it could affect natural surface vegetation, water quality, and/or the quantity of subsurface outflow.

2. Maintenance of natural water quality.--This involves currently used water resources as well as potentially usable resources. Degradation may occur in shallow aquifers from pumping for makeup water or deeper ones from geothermal production and injection.

3. Effect on surface thermal manifestations.--Hot springs, fumaroles and steaming ground often associated with a geothermal resource may be considered valuable as scenic, recreational or spiritual resources.

At the reservoir evaluation stage, adequate data are most likely not available so assessment of potential ground-water resources and potential hydrologic environmental impacts must be based on many approximations and assumptions. A hydrologic study done at Coso Hot Springs, California, is outlined below as an example of a study to assess these issues.

QUANTITY OF AVAILABLE COOLING WATER

No surface water is available for use in the Coso area. Water is potentially available from several ground water basins. These include the alluvial-filled valleys surrounding the study area. Rose Valley is considered the prime potential source of cooling water. Rose Valley has had very limited ground-water development. Consequently, recharge, storage and specific yield have not been defined. To estimate whether the available water resources in the area are sufficient to supply the existing and proposed consumptive use, a hydrologic balance was calculated. This involved estimation of precipitation in the study area, application of a ground-water recharge-precipitation relationship, estimation of locations and quantities of subsurface inflow and outflow and consumptive water use in the area.

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Recharge

No surface water flows into Rose Valley. Rainfall on the valley floor is insufficient to percolate downward and contribute to the ground-water reservoir. Recharge to Rose Valley is derived from precipitation infiltration on the Sierra and alluvial fans abutting the Sierra, ground-water inflow from the north, percolation from irrigation and leakage from the Los Angeles Aqueduct. All sources and quantities of recharge to Rose Valley have not been definitively established. Table 1 summarizes the current best estimates for ground-water recharge and discharge in Rose Valley.

Table 1. Summary of Ground Water Recharge and Discharge for Rose Valley

Recharge	Estimated Annual Quantity (AF/yr)
Underflow from Haiwee Reservoir	600
Underflow from alluvial fans west of Haiwee Reservoir	?
From precipitation on Sierra	1,900 - 3,000
From precipitation on Coso Range	0
From precipitation on valley floor	0
Imported water	100
Irrigation	900
	3,500 - 4,600
Discharge	
Irrigation withdrawal	3100
Little Lake surface evaporation	600
Evapotranspiration, other vegetated areas around Little Lake	30
Underflow to Indian Wells Valley	45,[a]/200-500[b]
Domestic and stock withdrawal	30
Springs	30 / 190
	3,800 - 4,500

[a] Bloyd and Robson, 1971, p. 15
[b] This study

Ground-Water Inflow--

Six hundred AF/yr are derived as underflow from Haiwee Reservoir on the north end of Rose valley. There is no underflow from Owens Valley southward to Rose Valley. The major contribution to recharge is from precipitation on the Sierra; however, the quantity of rainfall on the east slope of the Sierra is not well defined. Studies of vegetation on the slope, weather patterns and snowfall indicate that precipitation on the Sierra is much higher than previously estimated; up to 20 or 22 inches at the crest.

Ground-water recharge factors based on precipitation zones have been empirically estimated for Basin and Range areas in east-central Nevada (Table 2) (Maxey and Eakin, 1949). These rough "first approximation" recharge estimates are considered applicable to the Coso area.

Table 2. Precipitation Zones and Potential Ground Water Recharge

Precipitation Zone	Recharge to Ground Water (%)
Less than 8 inches	0
8 to 12 inches	3
12 to 15 inches	7
15 to 20 inches	15
Greater than 20 inches	25

Applying three precipitation elevation relationships to the precipitation zone recharge relation results in the following estimated potential recharge: 500 AF/yr for a regional precipitation relationship "Spane, 1978"; 1900 and 3000 AF/yr for two east Sierra slope at Rose Valley relations. It is apparent from these calculations that a small change in estimated precipitation produces a significant change in estimated potential recharge.

Discharge

The great majority of water in the Coso area is discharged through evaporation and transpiration. Ground water is discharged through irrigation, domestic and stock withdrawal, subsurface outflow, evaporation and transpiration and springs (Table 1).

Evaporative losses at Rose Valley Ranch, Little Lake and natural springs originate from the ground-water reservoir. At Rose Valley Ranch, 70 percent of the 3000 AF/yr applied for irrigation (Mower and Cordova, 1974) or 2100 AF/yr, is estimated to be consumptively used. The remainder goes to ground-water recharge. Evaporative losses from Little Lake were estimated to be about 830 AF/yr. Domestic and other consumptive uses in Rose Valley are minor.

A survey in 1975 estimated a total ground-water discharge from springs of about 30 AF/yr while observation and measurements by local residents estimate the long-term average to be closer to 200 AF/yr. This points up the necessity for long-term observation periods for accurate ground-water balance determinations. This is particularly true for precipitation measurements in arid areas where precipitation can vary greatly from year to year.

Up to several hundred AF/yr or more of ground water also discharges as underflow from Rose Valley although the quantities and paths of this underflow are not well defined.

Storage

The great majority of water available is ground water in storage. In order to estimate the quantity, the depth of alluvial fill, ground-water levels and specific yield were estimated. The thickness and volume of alluvial fill was calculated from sections constructed from a gravity survey and some drill hole control. Ground-water level contours were constructed from limited water well data and interpretation of geophysical well logs from some mineral exploration holes. Specific yields were estimated by analogy with alluvial materials in an adjacent valley. Each of these estimates lacks adequate field control so the product can be considered only semi-quantitative.

The total volume of water in storage is estimated to be 3.3 to 5 million acre-feet. Of this total, 1.4 to 2 million acre-feet is within 1000 feet of the surface. Most of the water in storage is believed to be usable. The geothermal reservoir fluid may extend into the alluvial material on the east side of the valley or saline water may occur in other locations.

Water Availability and Use

Ground water recharge in Rose Valley is estimated at 3500 to 4600 AF/yr. This roughly balances the estimated discharge of 3800 to 4500 AF/yr hence the Rose Valley ground-water basin presently appears to be near hydraulic equilibrium. Unless further study indicates greater recharge, available data and analyses suggests that additional significant ground-water withdrawal would lower the water table in Rose Valley. Water availability from lowering the water table would average about 2100 to 3200 acre-feet per foot of drawdown for the upper 1000 feet of sediments.

To assess the environmental effects on the hydrologic regime, projected water use is estimated for 1986 and the year 2000 (Table 3).

Table 3. Projected Water Use in Rose Valley

Use	Estimated Annual Quantity (acre-feet/year, rounded)	
	circa 1986[a]	circa 2000[b]
Irrigation	4,100	4,100
Domestic and stock	300	400
Geothermal	600	1,900
Total	5,000	6,600

[a] assuming completion of first 60 Mwe geothermal generating capacity and increased agricultural production.
[b] assuming 260 MWe geothermal generating capacity

The major change anticipated will be increases due to agricultural production and geothermal development. It can be seen from these projected water use estimates that geothermal use will represent about 12 percent of total water use in Rose Valley in 1986 and almost 30 percent by the year 2000. When use exceeds recharge the ground-water table will be lowered. The amount will depend on the boundary conditions assumed. In the best case analysis, average annual water table lowering will be 0.3 feet in 1986; in the worst case 1.3 feet. By the year 2000, the best case analysis results in an average annual lowering of 0.8 feet; in the worst case analysis it is 2.1 feet.

Phreatophytic vegetation in the Coso area is insignificant so the effects of water table lowering would not affect surface vegetation. The major impact would be loss of water in storage, possible lowering of the water level in Little Lake and possible degradation of natural water caused by changes in hydraulic gradients due to pumping. The latter is discussed in the following section.

MAINTENANCE OF NATURAL WATER QUALITY

Water quality is generally good in the Coso area, except for the thermal waters and the surface water in Little Lake. Water characteristics on the east side of Rose Valley or at depth are not known.

In the Coso area, three characteristic water types are:

a. A predominantly calcium carbonate water with total dissolved solids (TDS) content of several hundred milligrams per liter (mg/l). It is typically associated with runoff from the granitic mountains.

b. An acidic sodium sulfate water with TDS content from about 200 to 2000 mg/l. It is typically associated with the surface thermal manifestations.

c. An alkaline sodium chloride water with a TDS content around 6000 mg/l. It is only found in the geothermal reservoir.

Areas of presently nonusable ground water in Rose Valley may increase or decrease depending on:

a. the location and extent of nonusable water;

b. the hydraulic relationships between the geothermal reservoir and the ground-water reservoir;

c. geothermal production and injection design; and

d. the cooler ground-water extraction locations in Rose Valley.

Geothermal fluid may be released at the surface via accidental spills, blowouts or leakage from surface facilities. Geothermal fluid may be released beneath the surface via well failure or unforeseen structural or stratigraphic pathways. Ground and/or surface water may be degraded by escape of noxious drilling muds from the well, sump or from leaching of drilling mud residues. Communities may develop around geothermal developments; septic systems for these communities, if not properly designed and installed, may degrade ground or surface water. If proper ground water and geothermal reservoir development techniques are employed, including proper well construction design, natural water quality will not be degraded.

Although it is premature to define specifics, in general, chemical and thermal pollution of ground-water aquifers during injection of waste can result from: a) improperly constructed or deteriorated injection wells or nearby abandoned wells, b) escape through structural or stratigraphic pathways, c) hydrofracturing, accidental spills, d) leaks or percolation at the ground surface. However, the greatest risk of fluid escape is through the injection well itself (Talbot, 1972).

EFFECTS ON THERMAL MANIFESTATIONS

Disturbance of the surface manifestations at Coso Hot Springs would be considered a serious infringement upon native American values. The acid sulfate fluid from the springs is distinctly different from the sodium chloride fluid found in the deeper geothermal reservoir. However, the hot spring fluid is wholly or partly composed of steam condensate derived from the reservoir.

The Coso Hot Springs are not springs in the traditional sense but rather areas where steam condensate accumulates over near-surface impermeable clay layers (Austin and Pringle, 1970). The fluid levels, concentration and temperature of the springs all vary with precipitation, temperature and the quantity of shallow ground water (Spane, 1978). In the winter, when precipitation is greater, the fluid levels in the mud pots rise and the temperature of the fluid decreases. In the summer, evaporation increases and contribution from shallow ground water stops. This lowers the fluid levels and allows the fluid temperature and concentration to increase. Possibly pure shallow ground-water contributes to the hot springs at times. The precise mechanism and relation between all hydrologic, chemical and climate parameters are not presently known. Better definition and understanding of these relationships may provide more insight into the mechanism of the hot springs and its relationship to the geothermal reservoir.

Lowering of the water table and altering natural flow in the geothermal reservoir may affect the amount of steam condensate reaching the hot springs. This effect is impossible to quantify at this time. However, it is anticipated that the effects of geothermal development will be less than if the hot springs were fed directly and solely by geothermal reservoir fluid for two reasons:

a. Steam is much less viscous and dense than water. It will rise above the water table and flow more pervasively than water.

b. Shallow ground water contributes to the hot springs. This contribution will not be affected by geothermal development.

Detailed and comprehensive monitoring of water levels, water and air temperatures, precipitation, quantity of flow and chemical composition will be required to establish a baseline that will define natural temporal variations in the hot springs. These may then be compared with post-production variations.

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