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GROUND WATER MONITORING METHODOLOGY FOR GEOTHERMAL DEVELOPMENT

Richard Weiss
Project Geologist

Harding-Lawson Associates
San Rafael, California 94902

ABSTRACT

The proposed ground water monitoring methodology for geothermal development specifies a seven-step monitoring system development and evaluation procedure consisting of (1) definition of baseline conditions and projected development; (2) forecast of aquifer conditions; (3) definition of necessary detection limits; (4) evaluation of alternative ground water and disposal facility monitoring techniques; (5) proposal of monitoring system and alternatives; (6) implementation of monitoring system; and (7) continuation of monitoring program and modification as necessary.

INTRODUCTION

This study, sponsored by the U.S. E.P.A., emphasizes a philosophy of "preventive monitoring" as an integral and essential component of a "detective monitoring" methodology since ground water degradation is often an essentially irreversible process and case histories of ground water contamination due to injection of waste show that many of them could have been prevented by appropriate study and planning beforehand. By utilizing this proposed methodology and by enforcing rigid specifications for injection well construction prior to injection ground water degradation can be avoided. If the preventive monitoring study shows that the injected fluid will interfer with any useful aquifer, then the initial design, location and production schedules of the offending wells must be modified before production and injection begin.

Injection of geothermal effluent into the ground is a somewhat special case of deep well injection. Some of the distinctive characteristics include effluent chemistry, quantity and temperature, and injection depth. Fluid composition may vary from a few hundred ppm to well over 250,000 ppm TDS. Within each geothermal reservoir the chemistry of the injected fluid may also vary considerably. For example, at East Mesa, California the total dissolved solids (TDS) from different wells range from less than 2,000 parts per million (ppm) in Mesa 5-1 to about 30,000 ppm in Mesa 6-1 (USBR, 1974). For most geothermal operations the quantity of fluid processed and injected will be enormous. For example, in the Otake, Japan fields 1,350 tons of fluid per hour are injected into three wells (Kubota and Aosaki, 1976). This is 10 to 100 times the quantity generally injected for oil production. Injection will generally take place in the deeper geothermal aquifer system usually more than 1,000 meters deep. The injected fluid will be significantly hotter than ambient air and may be hotter or cooler than the receiving aquifer.

Several potential pollution mechanisms must be considered in deep well injection of any waste fluid, and the proposed methodology must be able to monitor potential leaks from these mechanisms, which include: (a) surface-accidental spills; (b) cement failure; (c) casing corrosion; (d) hydrofracturing of confining formations due to high pressure injection; (e) percolation from evaporation ponds (enhanced by higher temperatures); (f) differential pore pressure resulting in intrusion of waste or simple disruption of near-surface hydraulic gradients; (g) percolation from discharge of mineralized fluid to land surfaces or drains; (h) escape of injected fluid through unknown structural or stratigraphic pathways; (i) escape of water from sheared well casings, for example, slope failure at The Geysers, California.

An additional objective of this study is to develop possible uses of borehole geophysics in ground water monitoring for potential geothermal development that may be coordinated with other more traditional monitoring approaches. Geophysical well logging may be applied in two aspects of the monitoring system. First, prior to injection it may be used for detailed definition of geologic and hydrologic properties of the strata, such as permeability, porosity, thickness of individual layers, clay content and other important structural and stratigraphic characteristics. Secondly, it may be used to monitor ground water characteristics during and prior to injection.

GENERAL METHODOLOGY

Figure 1 is a flow chart illustrating the proposed methodology. Each of the steps shown in the figure is described below.

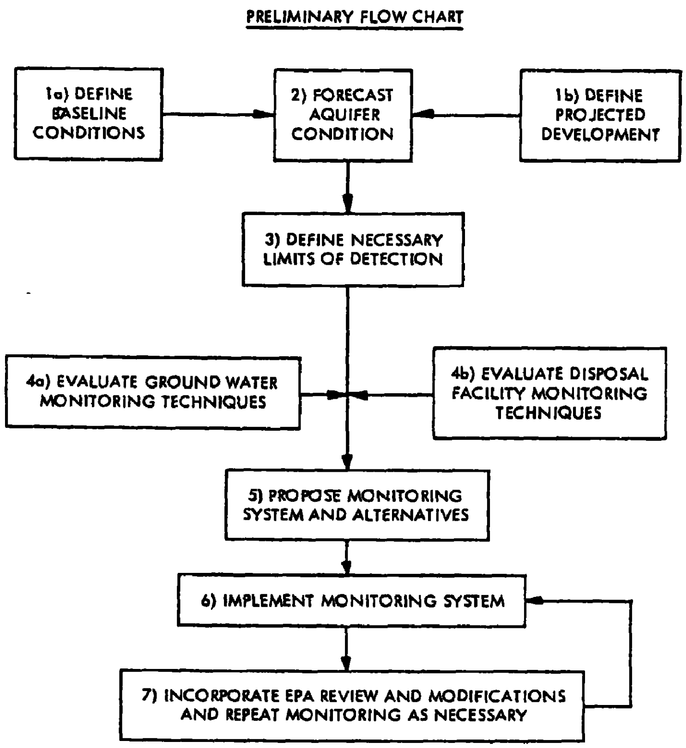

Fig. 1 Proposed Ground Water Monitoring Methodology for Geothermal Development

Define Baseline Conditions

Baseline conditions are those that exist prior to injection. To determine hydrologic changes that may occur during injection, baseline conditions must be established, including:

a. chemical characteristics of nongeothermal ground water and surface waters;
b. chemical characteristics of geothermal ground water;
c. geology and hydrology of the area;
d. location and well completion data for all wells around the geothermal site;
e. land use and sensitivity;
f. mechanics and characteristics of the geothermal system.

Determining the chemical characteristics of nongeothermal ground water and surface water will include, in addition to standard chemical analyses, available historic data which will be synthesized to identify changes with time, location or depth. A characteristic "chemical signature" for each water type from each recharge source will be sought.

In determining the chemical characteristics of the geothermal water, we must sample geothermal wells, as well as springs, and insure that we have a representative sample of the reservoir. Data analyses should cover the possibility of mixing with nongeothermal waters.

Geologic descriptions should include potential structural and stratigraphic pollutant pathways and boundaries, aquifer locations, depths, and areal extents. Well pumping tests and geologic data can provide information on the transmissivity and permeability of the aquifers. Contour maps of ground water depths and elevations for each aquifer can be prepared from water level and topographic data. Precipitation, evapotranspiration, soils, land use and water level data can be combined to describe natural ground water recharge. Irrigation and recharge data can be used to describe artificial ground water recharge. Stream flow and water level data can be used to define natural ground water discharge. Water level and transmissivity data can be used to determine directions and velocities of ground water flow. A hydrologic budget can be prepared to get an overview of the magnitude of water movement in the area.

A water well canvass will establish locations, owners, perforated intervals, well construction, water and well use, the amount of pumping and any other relevant well data for all wells around the site. Each well's suitability for use as a monitoring well, or as a potential conduit for cross aquifer pollution due to poor well construction will be evaluated. Land use and particular land sensitivities will be observed, e.g. ecologic, agricultural, subsidence, or slope stability factors as they may relate to the ground water program.

The hydraulics, temperature gradient, reservoir characteristics of the geothermal system will be defined and the system will be modeled. Of particular importance is the determination of how the geothermal ground water system is related to the nongeothermal ground water system.

To finalize the baseline data acquisition phase we would evaluate each data category for completeness. For example, are the hydrologic characteristics adequately defined? is the geographic and depth distribution of wells sufficient for adequate monitoring? is the temporal distribution of historic chemical data sufficient to establish patterns of temporal variation in water quality? Determination of data completeness will include consideration of current EPA or other regulations as well as considerations of current and potential ground water use in the area. If necessary, further data acquisition to insure an adequate baseline would be recommended. The limitations of the data that exists would be explicitly defined.

Define Projected Development

The type and magnitude of potential development will be defined, including descriptions of the heat extraction and waste disposal processes. Chemical effects of these processes such as silicification or carbonate deposition on potential pollutant pathways must be considered along with potential ground water pollution. The proportions of potential geothermal water production and injection to natural ground water system flow should be determined. The chemical characteristics of the post-process geothermal fluids must be compared with those of natural geothermal fluid and nongeothermal ground water. Local geologic and hydrologic factors at the site must also be defined. For example, landsliding has been a major consideration in planning geothermal facilities at The Geysers.

Forecast Aquifer Condition

Forecasting the interaction between geothermal and nongeothermal aquifers before production and injection begin may enable us to avoid potential problems. By incorporating possible pollutant mechanisms and pathways in our ground water and geothermal model, we would aim to predict the water quality and quantity changes in the geothermal reservoir and in the ground water system due to the production and injection of varying quantities and qualities of fluid. Hopefully, many of the geologic and hydrologic parameters necessary for this model would be supplied by detailed geophysical borehole logging.

Limits of Detection

The monitoring system will be designed to detect chemical changes in the ground water. These changes will occur in a spatial and temporal matrix. The necessary sensitivity of detection in chemistry, time and space must be specified for each area and is a function of:

a. Chemical contrast of geothermal and nongeothermal fluids
b. Environmental sensitivity to particular constituents
c. Natural variations in water characteristics
d. Hydrologic factors
e. The relative size of the development
f. Characteristics of potential pollutant pathways
g. Water use and well distribution density in the area
h. Available analytic techniques
i. EPA and other regulatory constraints

Analysis of these parameters will aid in determining sampling frequency, distribution and density of sample points, significant chemical and physical parameters, and sampling and analysis methods to be utilized. Where ground water is used extensively, we would be more concerned about rapidly detecting minute changes in quality, whereas where ground water quality is poor and it is not used we may accept larger variations and less frequent sampling.

Ground Water and Disposal Facility Monitoring Techniques

Once the monitoring parameters have been defined the most appropriate monitoring techniques must be selected, e.g. standard water sampling and analyses, geophysical well logging, electromagnetic probes, surface geophysics, etc. The applications, sensitivities, accuracy and cost of these techniques, taken individually or in combination will be considered.

For the water sampling we want to specify field determination of volatile constituents and evaluate standard lab chemical analysis techniques; e.g. wet chemical, atomic absorption, mass spectrography, pH, specific conductance.

The techniques and parameters which most closely reflect our needs and our budget will be determined.

Geophysical well logs can be interpreted to determine the lithology, geometry, resistivity, formation factor, bulk density, porosity, permeability, moisture content and specific yield of water bearing rocks and to define the source, movement and chemical and physical characteristics of ground water. However, log interpretation techniques used for geothermal wells often provide inaccurate answers since log interpretation technology has been developed for petroleum reservoirs which generally have different physical characteristics than geothermal reservoirs. One aspect of this particular study is to define how geophysical well logs can accurately and economically be used in ground water monitoring for geothermal systems development. A few sample applications are briefly noted below.

One important capability of geophysical well logging is continuous vertical profiling of water quality with depth. With this vertical profile temporal changes in water quality and rates of dispersion in individual layers could be detected. Salinity of the formation water can be determined from electrical resistivity and SP logs in uncased holes or it can be calculated from pulsed neutron logs in cased holes. Disposal of geothermal waste water may be monitored using temperature logs which detect the movement of a fluid which is either hotter or cooler than the aquifer. Gamma ray logs may be used to detect movement of contaminated water behind well casings.

Most monitoring of deep well disposal has been done through monitoring of the disposal facility itself as opposed to monitoring the area around the disposal facility. This type of monitoring has included measuring the volume of disposed fluid, chemical and physical properties of the fluid, and fluid pressures at the wellhead and annulus, as well as periodic inspection of surface and subsurface facilities, determination of permeable boundaries and periodic geophysical well logging.

Propose Monitoring System and Alternatives

Detecting temporal and spatial changes in ground water characteristics within the established limits of detection is the goal of the proposed monitoring system. Designing a site specific monitoring system may be done using a matrix evaluation technique specifying an algorithm or relative weighting for each factor and parameter to arrive at an optimum balance of cost versus confidence.

Generally, sample points will be more concentrated around and down-gradient from potential pollutant sources, i.e., disposal wells. Sample frequency should be greater near and down-gradient from the source than further away. Initially, some comprehensive chemical analysis (e.g. multispectrographic analysis) of sample water should be done to determine which trace minerals need to be specified for detailed wet chemical or atomic absorption analysis.

Recommendations to achieve the proposed monitoring system may include installing additional observation holes, specifications for the sampling frequency and pattern, specifications for sampling and analysis techniques to be used and chemical constituents to analyze for. We may find that adequate detection limits can be achieved economically by carefully selecting frequency, density and types of sampling and analysis.

Implement Monitoring System

Implementing the monitoring system will involve data collection at specified frequency and locations, and data synthesis, interpretation and display. Past data will be reviewed and correlated with the new data. Modifications will be recommended for the system as necessary.

References

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