PROCEEDINGS, Twenty-First Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 22-24, 1996
SGP-TR-151

TOUGH2/PC APPLICATION SIMULATION PROJECT FOR HEBER GEOTHERMAL FIELD, CALIFORNIA, A PROGRESS REPORT

By Timothy S. Boardman[1], M. Ali Khan[2], and Emilio Antunez[3].

[1]California Department of Conservation, Division of Oil, Gas, & Geothermal Resources, El Centro, CA 92243
[2]California Department of Conservation, Division of Oil, Gas, & Geothermal Resources, Santa Rosa, CA 95404
[3]Lawrence Berkeley National Laboratory, Berkeley, CA 94720

ABSTRACT

A numerical simulation model for the Heber geothermal field in Southern California is being developed under a technology transfer agreement between the Department of Energy/Lawrence Berkeley National Laboratory (LBNL) and the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources (DOGGR). The main objectives of the cooperation are (1) to train DOGGR personnel in the use of the TOUGH2/PC computer code; and (2) to develop a module compatible with TOUGH2 to investigate the effects of production/injection operations on the ground surface subsidence-rebound phenomenon observed in the Heber geothermal field. Initial-state calibration (undisturbed system) runs are being conducted to calibrate the model.

INTRODUCTION

The California Department of Conservation, Division of Oil, Gas, and Geothermal Resources (DOGGR) regulates the drilling, operation, maintenance, and abandonment of geothermal production/injection wells and has primary responsibility for subsidence detection and abatement policies in the Imperial Valley, Southern California.

Reservoir modeling is commonly used to predict reservoir performance. The forecast of subsidence is one aspect that interests engineers and planners, especially when a geothermal field is located in an area of developed agricultural land. The Heber geothermal field is one of the few areas in the world where the land above the geothermal reservoir is used for irrigated agriculture. The canals used to irrigate the crops are susceptible to surface ground movement.

LOCATION AND STRUCTURE OF THE HEBER GEOTHERMAL FIELD

Heber geothermal field is in the Imperial Valley near the City of Heber, California, about 3 1/2 miles north of the Mexican border (Figure 1). The Heber field is at the southern end of a network of irrigated agricultural fields extending across the valley.

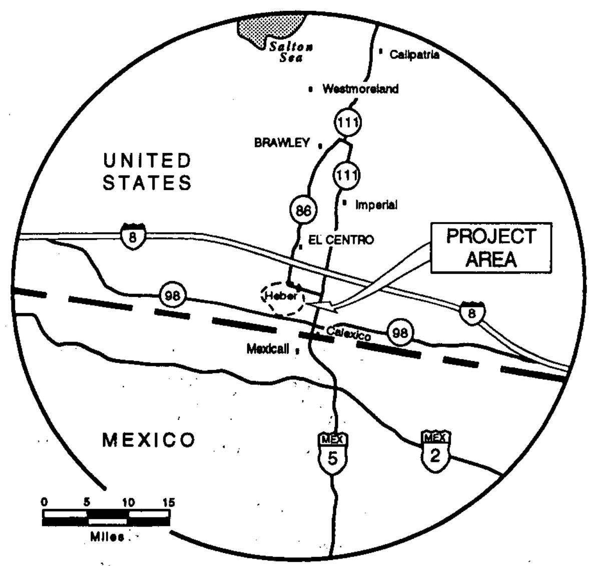

Figure 1. Location map, Heber geothermal field. *Courtesy of San Diego Gas and Electric Company, 1979.*

The Heber geothermal system produces water of moderate temperature (360° F) and low-salinity (13000-14000 ppm TDS). In cross section, the temperature plume defining the system resembles a lopsided mushroom inclined towards the northwest. The system has three major permeability units: capping clays from 500 to 1800 feet; a high-matrix-permeability, deltaic sandstone reservoir from 1800 to 5500 feet; and feeder faults and fractures in indurated sediments below 5500 feet (Figure 2). The structure of the hydrothermal system is described in more detail in a paper by James, Hoang, and Epperson (1987).

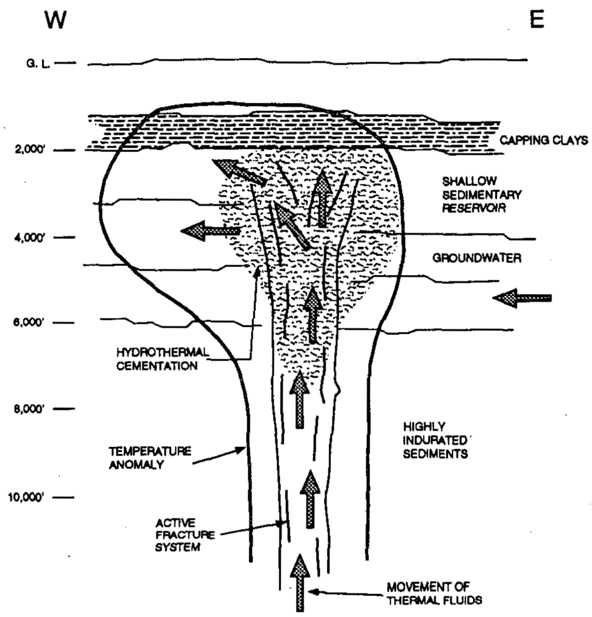

Figure 2. Heber geothermal anomaly, a fault conduit-barrier model. *Courtesy of E. D. James et al., November 1987.*

FIELD DEVELOPMENT

In 1984, Chevron Geothermal Company began developing Heber geothermal field. Anticipating ground surface deformation, the company established a subsidence monitoring network. By 1987, the geothermal field spanned over 4000 acres of mostly private land and two power plants were on line: a 52-megawatt dual-flash plant operated by Heber Geothermal Company (HGC) and a 67-megawatt binary plant operated by San Diego Gas and Electric (SDG&E). Both power-plant operators purchased geothermal fluids from Chevron.

Sixteen field production wells were drilled directionally between June 1984 and December 1986 from drilling islands at the power-plant sites. Injection well islands were located away from the power plants.

From 1985 to 1987, the HGC dual-flash power plant and the SDG&E binary power plant were operated simultaneously and severe well interference occurred. The SDG&E binary power plant was not economically feasible on a commercial scale. In the spring of 1987, fluid production peaked at 3.5 x 10^9 kilograms per month, but the reservoir could not supply the volume of fluid needed to operate both power plants fully. In periods of high production, fluids in some wells dropped below pump settings.

With poor operating results, the SDG&E binary power plant was shut down in July 1987. [The entire SDG&E binary project at Heber is described in detail by Nelson (1987).] The SDG&E binary plant owner does not have rights to the geothermal resource, and the plant awaits decommissioning or salvage.

RECENT DEVELOPMENTS

In 1991, Chevron sold the Heber geothermal field to the current owner of the field, Heber Field Company, a partnership between Ogden and Centennial, also partners in Heber Geothermal Company, lessor of the HGC 52-megawatt dual-flash power plant. Ogden Geothermal Operations, Inc. operates the field for Heber Field Company.

In 1993, Second Imperial Geothermal Company (SIGC) built a new 33-megawatt binary power plant, owned by the United States Trust Company, the project lender. The plant operator is Ogden Geothermal Operations. The new power plant is north of the defunct SDG&E binary plant.

Production wells for the new plant penetrate the reservoir in an area northwest of the original production area. The nearly vertical production wells were completed at depths between 2500 feet and 6000 feet, about 1200 feet apart. By drilling new production wells over a large area, the operator hopes to avoid well-interference problems noted in earlier projects. The completion zones for the SIGC production wells are generally those used for the 52-megawatt dual-flash power plant. Injection well completion depth is from 2500 feet to 4500 feet. Heber geothermal field currently has 22 active production wells, 23 active injection wells, and 13 observation wells (Figures 3,4,5,&6).

THE TOUGH2 MODEL

After reviewing all the available data, a decision was made that a north-south grid orientation was adequate for the Heber model. Dimensions of the model were set at 14 km (N-S) by 13 km (E-W). The thickness is 3 km (10000 ft.), and is divided into 8 horizontal layers. Eight maps were constructed showing isotherms at 150, 425, 700, 1050, 1450, 1829, 3000, 3048 m (490, 1390, 2300, 3440, 4760, 6000, 9840, and 10000 ft., respectively) below sea level. The first seven elevations correspond to the middle of each layer; the last one to the bottom of the model. The purpose of these inferred temperature contours is to facilitate the construction of

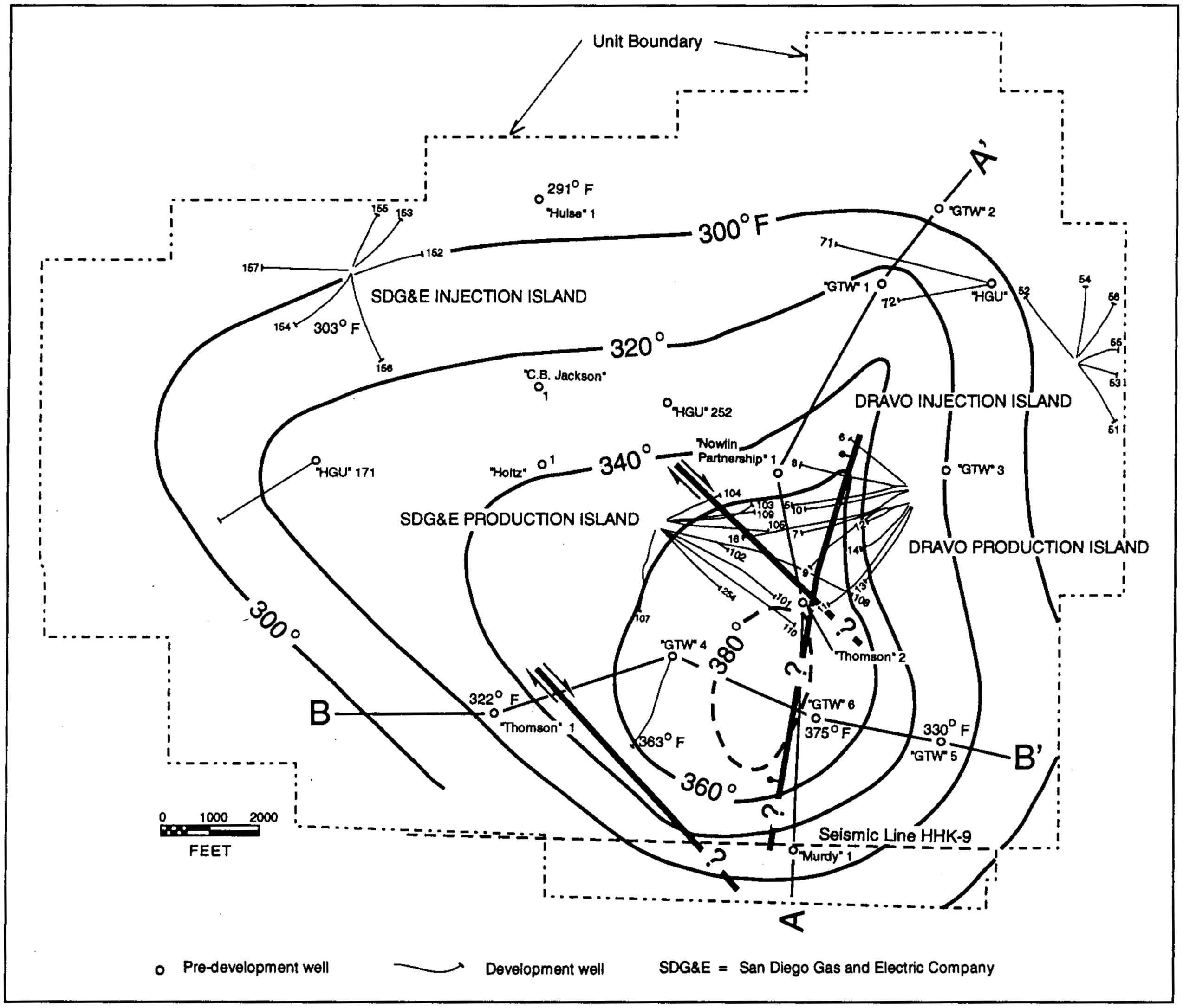

Figure 3. Well locations, structure, and temperature contours at 6,000 feet, Heber geothermal field. *Modified from James et al., 1987.*

a conceptual model for the field and to provide a guide for matching measured temperatures during the calibration of the model.

The field gridding was accomplished by locating the well completion intervals. The surface location for each well was known, but the completion intervals were available only on directional surveys filed in DOGGR records. A correction was required to obtain the true vertical depth and location in California Coordinates for every interval in each well.

GRID GEOMETRY

Each layer is divided into 201 grid elements. Since many of the wells are directional, the nodes representing the wells are offset from the surface. The nodes represent the well entry points relevant to the simulation. A fracture zone striking southwest-northeast dominates the field's fluid flow. This fracture zone acts as a fluid conduit and is characterized by higher permeability values than the surrounding sediments. Small grid elements were positioned southwest to northeast to represent this fracture zone (Figure 7).

ROCK PROPERTIES

The values of porosity, rock density, thermal conductivity of rock, heat capacity, and permeability for each rock type in the field's lithological column were taken

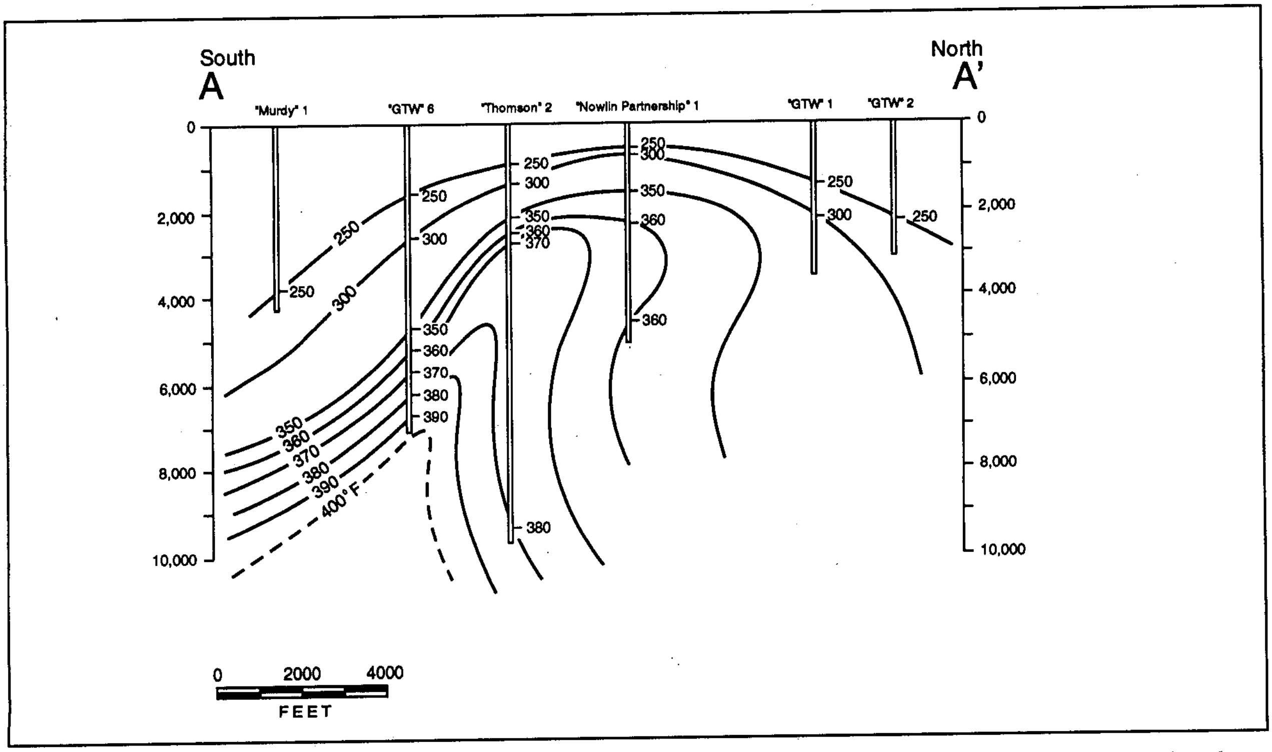

Figure 4. Temperature cross section A-A', *courtesy of James et al., 1987.* "The contours illustrate the deflection of the rising plume from south to north by groundwater movement. It is also clear from this section that the source of the thermal waters is south of current development near well "GTW" 6. The shallow matrix reservoir currently under production is at the north end of the plume. The collapse of the isotherms at the top of the plume is the result of the capping clays sealing in the thermal waters. The strong control of the fracture permeability in the indurated sediments below 5,500' is seen in temperature cross section B-B'. The plume is quite narrow east to west and most likely controlled by a narrow structure of high permeability."

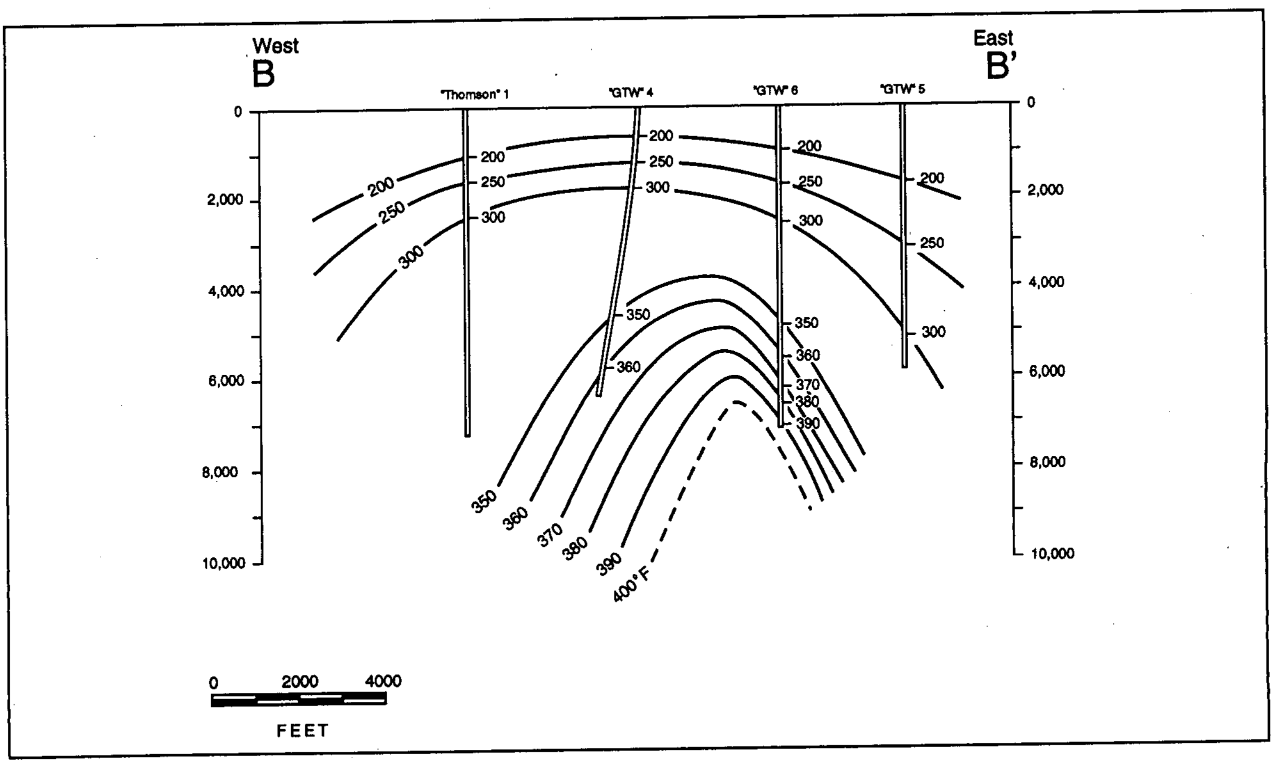

Figure 5. Temperature cross section B-B'. *Courtesy of James et al., 1987.*

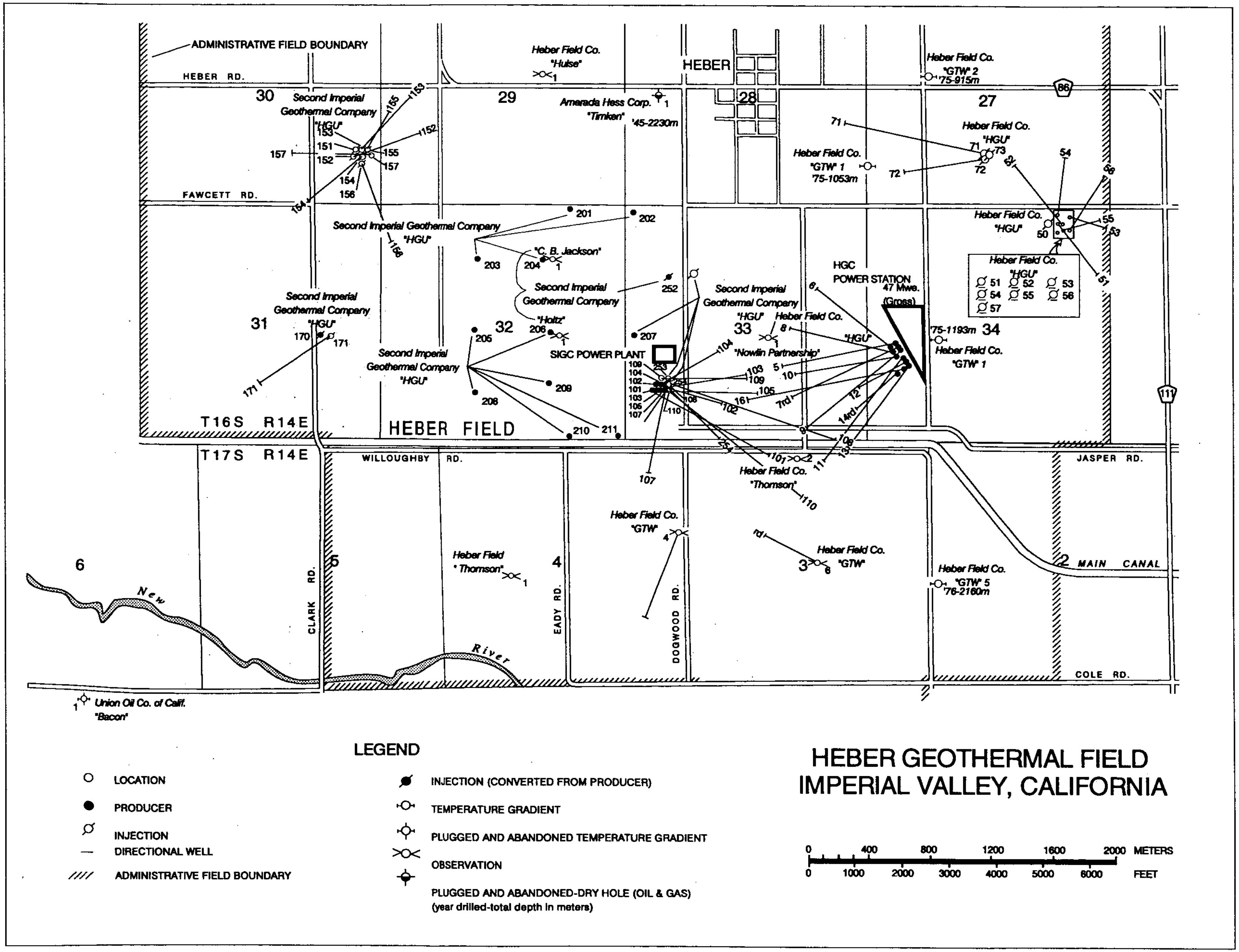

Figure 6. Well locations in Heber geothermal field. Down-hole tracks are shown for the directional wells.

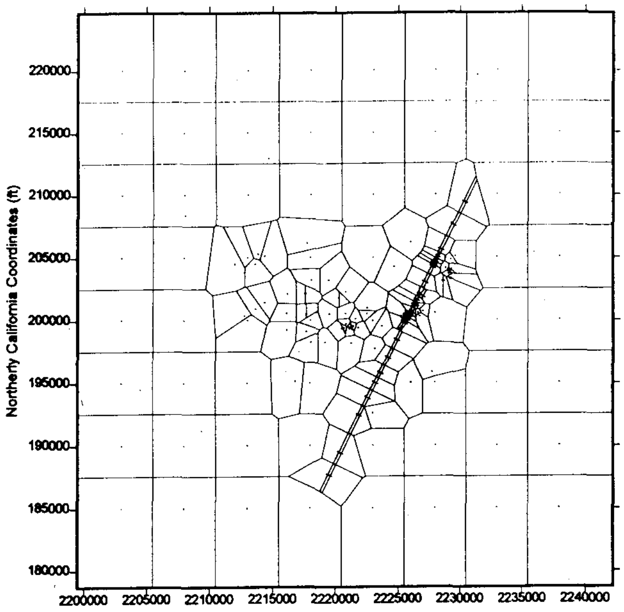

Figure 7. Areal gridding for the Heber geothermal field.

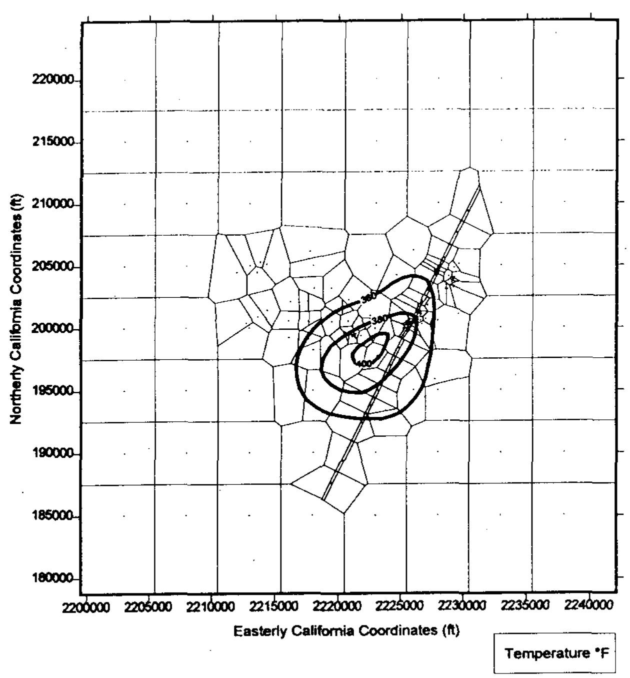

Figure 8. Areal gridding for the Heber geothermal field and temperature contours at 9850 ft. depth.

from published literature or data available to us.

BOUNDARY AND INITIAL CONDITIONS

The model has closed boundaries on all sides. It is open at the bottom to simulate the recharge that is as-

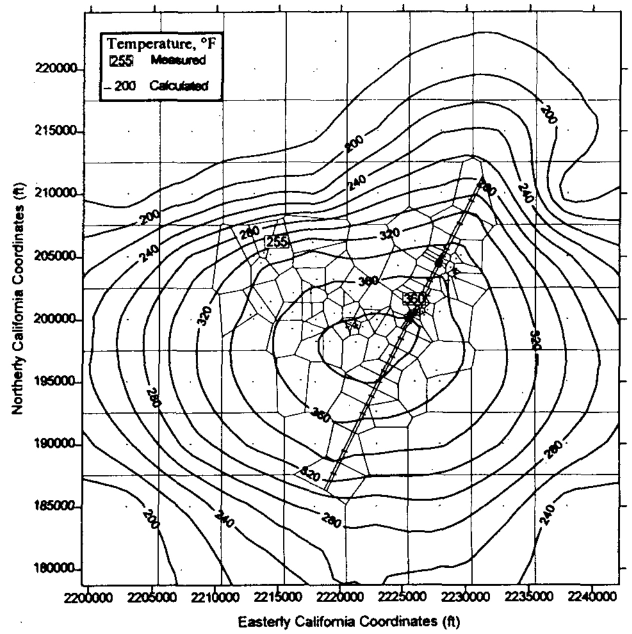

Figure 9. Areal gridding for the Heber geothermal field, layer 3. Calculated temperature contours at -2300 ft. msl.

sumed to come from below the present production areas. The top of the model is in contact with a constant pressure and temperature block at atmospheric conditions (0.1 MPa and 25°C). The closed boundaries in the system are justified because there is no evidence of lateral recharge and the presence of subsidence and rebound effects, suggesting low horizontal permeability around the production and injection areas.

At initial conditions, single pressure and temperature values were assigned to all elements in the same layer (layers 1 to 7). These values were taken from field static pressure and temperature logs. An inferred fixed temperature distribution and single value pressure were assigned to the bottom layer (layer 8) (Figure 8). Pressure and temperature distributions on the overlying layers will be brought to concurrence with the measured undisturbed pressures and temperatures in the field (prior to production) using initial conditions in layer 8 as building blocks. The constructed inferred temperature contours for each layer will be used for matching purposes.

CURRENT STATUS OF THE PROJECT

Initial-state (undisturbed system) runs are being conducted to calibrate the model. The purpose of these runs is to provide a first cut in the calibration of the model. The runs involve a trial-and-error procedure to match the measured temperatures and pressures prior to production. After analyzing the results of a run, the permeability values are modified for the different rocks to get a better match. The pressure and temperature distribution calculated by the simulator at the end of a run are used as initial conditions for subsequent runs. This process ends when the calculated and measured temperature and pressure match within reasonable limits.

The initial-state calibration will be refined further when the model is calibrated to match the production data. At the end of this second calibration stage, the model will be calibrated and ready to be used for forecasting purposes.

Figure 9 presents an example of an intermediate run during the initial-state calibration of the model.

SUMMARY AND FUTURE WORK

- A numerical model of the Heber geothermal field was constructed by engineers of the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources under the supervision of personnel from Lawrence Berkeley National Laboratory.
- The Heber model is currently being initial-state calibrated by DOGGR engineers.
- Once this step is concluded satisfactorily, the calibration of the model will be refined by including the production history. This history has to be reproduced by the numerical model before it can be considered calibrated and useful for prediction purposes.
- Currently a TOUGH2-compatible module is being written by LBNL to include subsidence-rebound effects in the simulation.
- The technology transfer and cooperative agreement will allow DOGGR engineers to conduct numerical simulation exercises in-house and predict subsidence as part of their regulatory roles.

ACKNOWLEDGEMENTS

The authors would like to thank Richard Thomas from the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, and Marcelo Lippmann from Lawrence Berkeley National Laboratory for their comments and suggestions. This work was supported, in part, by the Geothermal Division of the US Department of Energy under contract No. DE-AC03-76SF0098.

REFERENCES

Boardman, T.S., 1996. Subsidence and uplift at Heber Geothermal Field, California. Department of Conservation, Division of Oil, Gas, and Geothermal Resources, The Geothermal Hot Line, January 1996. Vol. 22 No. 1 (In Press).

James, E.D., Hoang, V.T., and Epperson, I.J., 1987. Structure, Permeability and Production Characteristics of the Heber, California Geothermal Field. Proceedings, Twelfth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford California, p. 267-271.

Lippmann, M.J., and Bodvarsson, G.S., 1985. The Heber Geothermal Field, California: Natural State and Exploitation Modeling Studies. Journal of Geophysical Research, Vol. 90, No. B1, p. 745-758.

Nelson, T.T., 1987. Heber Binary Project. Geothermal Resources Council Trans., Vol. 11, p. 459-463.

Salveson, J.O., and Cooper, A.M., 1979. Exploration and Development of the Heber Geothermal Field, Imperial Valley, California. Geothermal Resources Council Trans., Vol. 3, p. 605-608.