Title
Constraining a fractured-rock groundwater flow model with pressure-transient data from an inadvertent well test

Permalink
https://escholarship.org/uc/item/644165b6

Authors
Doughty, Christine
Karasaki, Kenzi

Publication Date
2003-12-16

Constraining a Fractured-Rock Groundwater Flow Model with Pressure-Transient Data from an Inadvertent Well Test

Christine Doughty and Kenzi Karasaki
Earth Sciences Division
E.O. Lawrence Berkeley National Laboratory

Introduction

Starting with regional geographic, geologic, surface and subsurface hydrologic, and geophysical data for the Tono area in Gifu, Japan, we have developed an effective continuum model to simulate subsurface flow and transport in a 4 km by 6 km by 3 km thick fractured granite rock mass overlain by about 100 m of sedimentary rock (Doughty and Karasaki, 2001, 2002). Individual fractures are not modeled explicitly. Rather, continuum permeability and porosity distributions are inferred from well-test data and fracture density measurements. Lithologic layering and one major fault, the sub-vertical, E-W striking, Tsukiyoshi Fault, are assigned deterministically. Figure 1 shows a perspective view of the model, identifying the different material types. Within each material type, grid-block permeability and porosity are assigned stochastically.

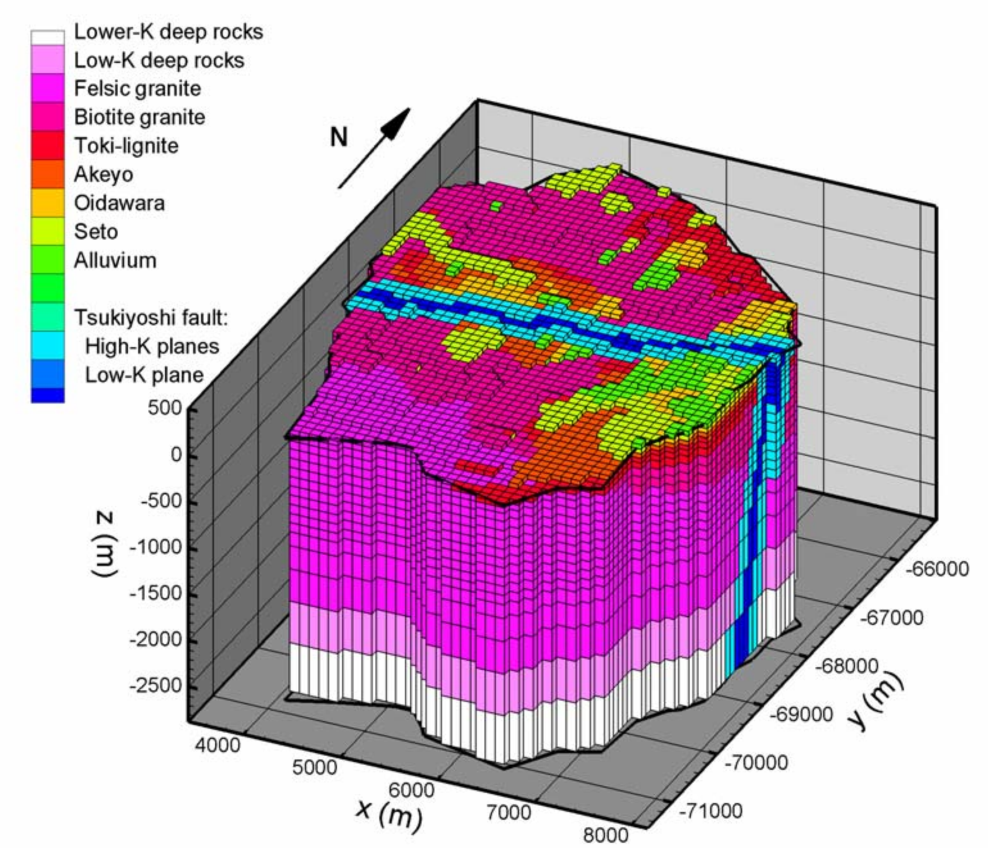

Figure 1. Perspective view of the 4 by 6 by 3 km model of the Tono area. Lateral boundaries are open (hydrostatic pressure) except for the southern model boundary, which coincides with the Toki River and is closed at depth and constant pressure at the surface; the top of the model is the ground surface

(presumed to coincide with the water table); the bottom of the model is closed.

The natural-state hydraulic head distribution shows head values 30-40 m higher on the north side of the Tsukiyoshi fault, suggesting that it acts as a low-permeability impediment to regional groundwater flow from highlands in the north to a river valley in the south. Analysis of interference well-tests have suggested that the low-permeability core of the fault is bounded on either side by higher permeability zones (Takeuchi et al., 2001), creating what we call a "sandwich" structure. Many wells in the Tono area are instrumented with a multi-packer (MP) system consisting of strings of pressure probes separated by packers to hydraulically isolate various depth ranges in the wells. Several wells in the central area of the model, known as the MIU area, intersect the Tsukiyoshi fault at a depth of about 1000 m, with the pressure probes below the fault showing higher hydraulic head. The MP systems prevent the wells from acting as high-permeability conduits through the low-permeability Tsukiyoshi fault core.

Inadvertent Well Test

In November 2001, when the packers in well MIU-2 were removed in preparation for a long-term pumping test, strong pressure transients were observed in the surrounding wells. In fact, observed pressure changes in response to the MIU-2 packer removal were far larger and more widespread than those subsequently observed during the long-term pumping test, which we had planned to use for model calibration. Therefore, we decided to analyze the packer removal itself as an "inadvertent" well test, by modeling the event with different spatial distributions of permeability and porosity and comparing simulated pressure-transients with observed responses. In order to accurately simulate the response to packer removal, a local area grid refinement is done for the vicinity of well MIU-2. Following packer removal, we anticipate upward flow through well MIU-2, but we have no basis for assuming that it occurs under either constant-flow or constant-pressure conditions, precluding well-test analysis by matching pressure-transients to type curves based on analytical solutions. Unfortunately, well flow rate was not monitored. We model packer removal as a sudden increase in vertical permeability in the model column representing well MIU-2, and by allowing the well permeability to be one of our adjustable parameters, the model determines the variable flow rate that produces pressure-transients that best match the observed ones. Other adjustable parameters are the permeability and porosity values for various material types and for individual grid blocks for a few critical locations.

Figure 2 shows the wells used for model calibration to the inadvertent well test. Wells MIU-2, MIU-3, and MIU-4 all have MP systems with probes on both sides of the Tsukiyoshi fault, well MIU-1 and the two AN wells have MP systems with probes only on the south side of the fault, and the two SN wells are shallow wells without packers on the north side of the fault.

Figure 3 shows the observed pressure response to packer removal, along with the simulated response using our original (uncalibrated) model, which was constructed to reproduce the natural-state hydraulic head difference observed across the Tsukiyoshi fault. Packer removal allows fluid to flow up the well from the deeper, high head region (the footwall north of the fault) to the shallower, low head region (the hanging wall south of the fault). Consequently, pressures in the footwall decrease while pressures in the hanging wall increase. The model reproduces these responses qualitatively, but not quantitatively. The main problems with the model response are that well MIU-1, well MIU-3, and the SN wells show responses that are too small, whereas well MIU-4 and the AN wells show responses that are too big. All modeled responses tend to occur too quickly, reaching a steady-state not observed in the field data.

The calibration process consists of modifying the permeability and porosity of selected material types or individual grid blocks. Given a new property distribution, first a new steady state for packer-in-place conditions is generated, and we confirm that it reproduces the natural-state head difference observed across the Tsukiyoshi fault. Then the permeability is increased in the MIU-2 grid blocks to represent packer removal, and the 26-day pressure transients are simulated and compared to the observed values. After many repetitions of this process, the pressure-transient match shown in Figure 4 is obtained.

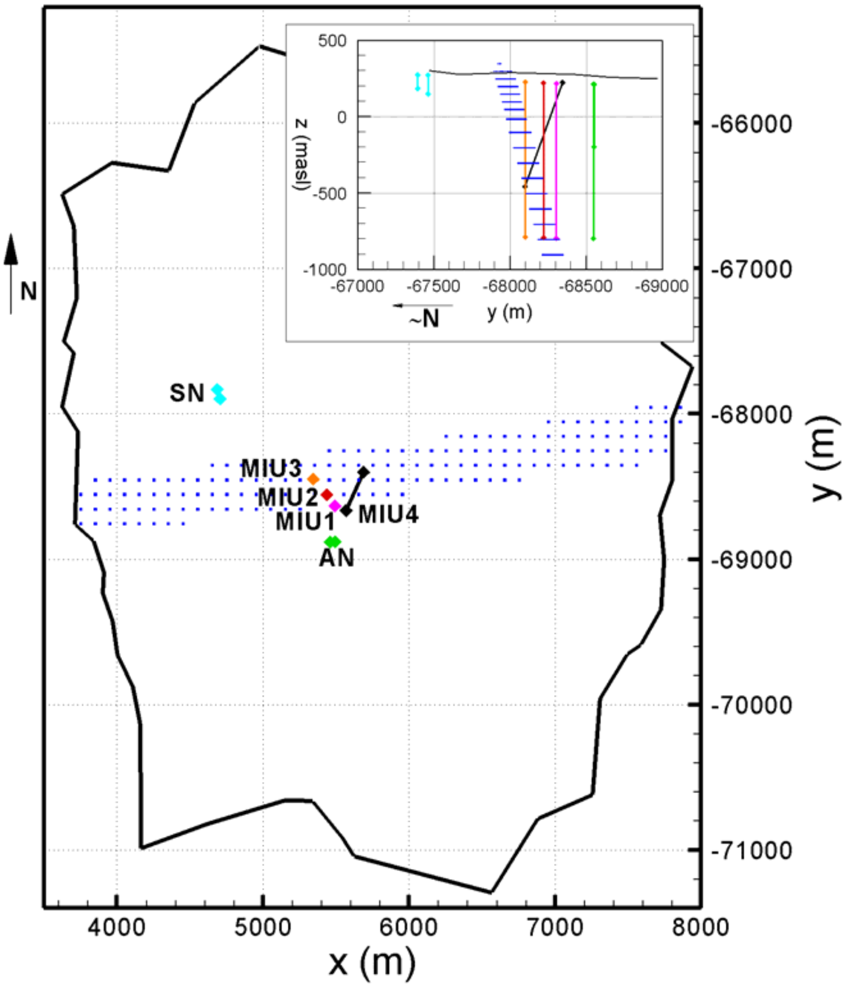

Figure 2. Plan view of the model showing the locations of the MIU-area wells. The blue shaded region is a horizontal projection of the Tsukiyoshi fault plane from the surface to a depth of 1000 m. The inset shows a vertical cross-section perpendicular to the strike of the Tsukiyoshi fault (roughly north-south).

Calibration Results

In general, it is not possible to get good matches to the large rapid pressure responses in wells MIU-1 and MIU-3 unless there is a relatively large flow rate up the wellbore (at least 400 L/min). This large flow rate requires that the footwall sandwich layer permeability be increased. Fault core permeability must be decreased to lessen certain responses in wells MIU-3 and MIU-4. Bulk granite permeability is correspondingly decreased to maintain the ratio between bulk and fault core permeability that produces the observed steady-state head difference across the fault. Lower bulk granite permeability also serves to lessen the response in the AN wells. However, in the vicinity of the SN wells, granite permeability must be increased to enhance the response there. Porosity is increased in all materials to slow the pressure responses.

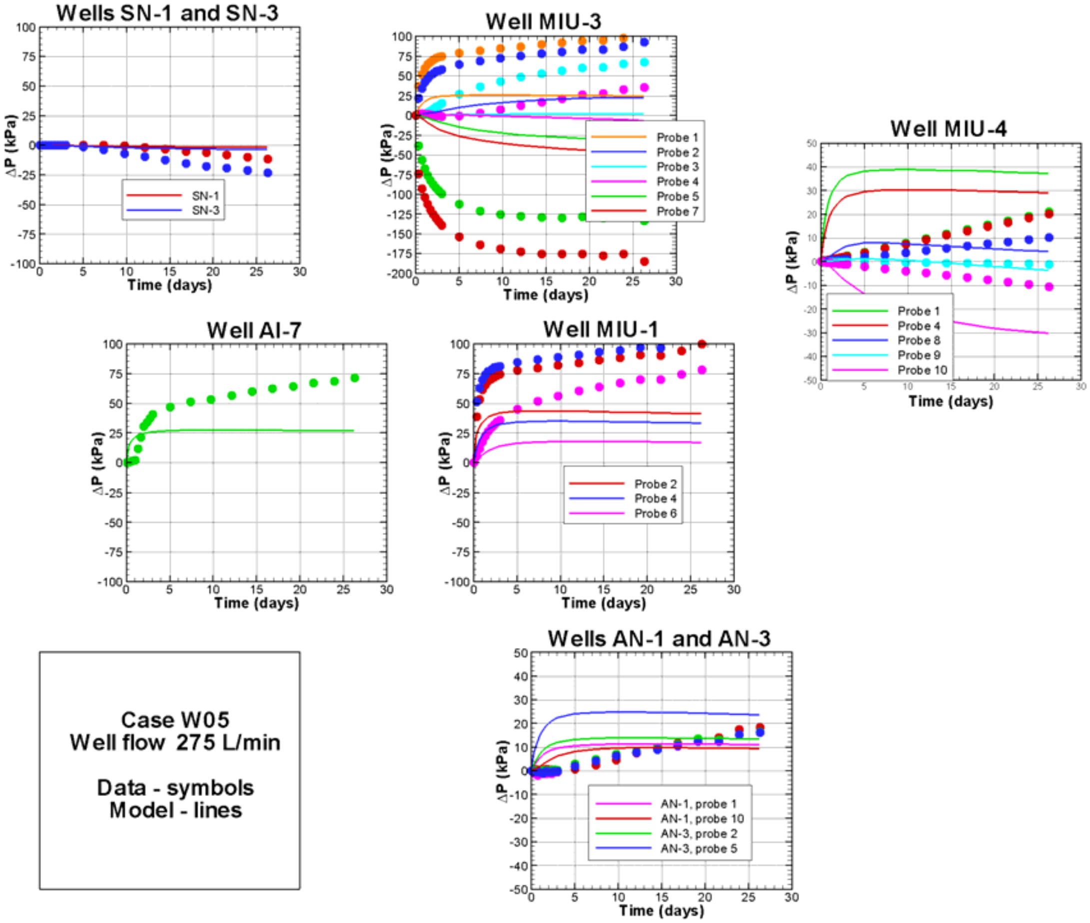

Figure 3. Observed and modeled pressure responses to packer removal in well MIU-2: uncalibrated model. The arrangement of plots on the page roughly corresponds to well location in plan view. For MP wells, probe depth increases with probe number. Well AI-7 is a shallow well near well MIU-2.

After the calibration process is complete, the calibrated model is used to predict travel times from specified monitoring points to the model boundaries. The model changes arising from the calibration process (primarily decreases in permeability and increases in porosity) serve to lengthen the travel times through the model by a factor of about 100, a significant change.

Conclusions

Analyzing the pressure-transient data resulting from the removal of the Well MIU-2 packer has proved to be a useful means of improving estimates of fracture porosity, which has always been considered one of the least well constrained model parameters. A key benefit is the large flow rates that are attainable, due to the large steady-state pressure difference across the Tsukiyoshi fault. This enables large pressure signals to be generated, which in turn enables large spatial regions to be analyzed. One difficulty of using well-test data to try to infer porosity is that field-scale rock compressibility is still an unknown. It is difficult to determine rock compressibility independently from porosity since pressure-transient responses just depend on their product through specific storage. One possibility might be to do a tracer test in a local area to infer porosity, then do a well test focusing on the same area to enable rock compressibility to be better inferred from specific storage.

Acknowledgments

We thank S. Finsterle and K. Ito for reviewing this paper. This work was supported by Japan Nuclear Cycle Development Institute (JNC) and Taisei Corporation of Japan through the U.S. Department of Energy Contract No. DE-AC03-76SF00098. We are particularly indebted to A. Sawada of JNC and Y. Ijiri of Taisei Corp. for useful discussions. We would also like to thank S. Takeuci and H. Saegusa for making the field data available, and K. Ito for providing the grid refinement program.

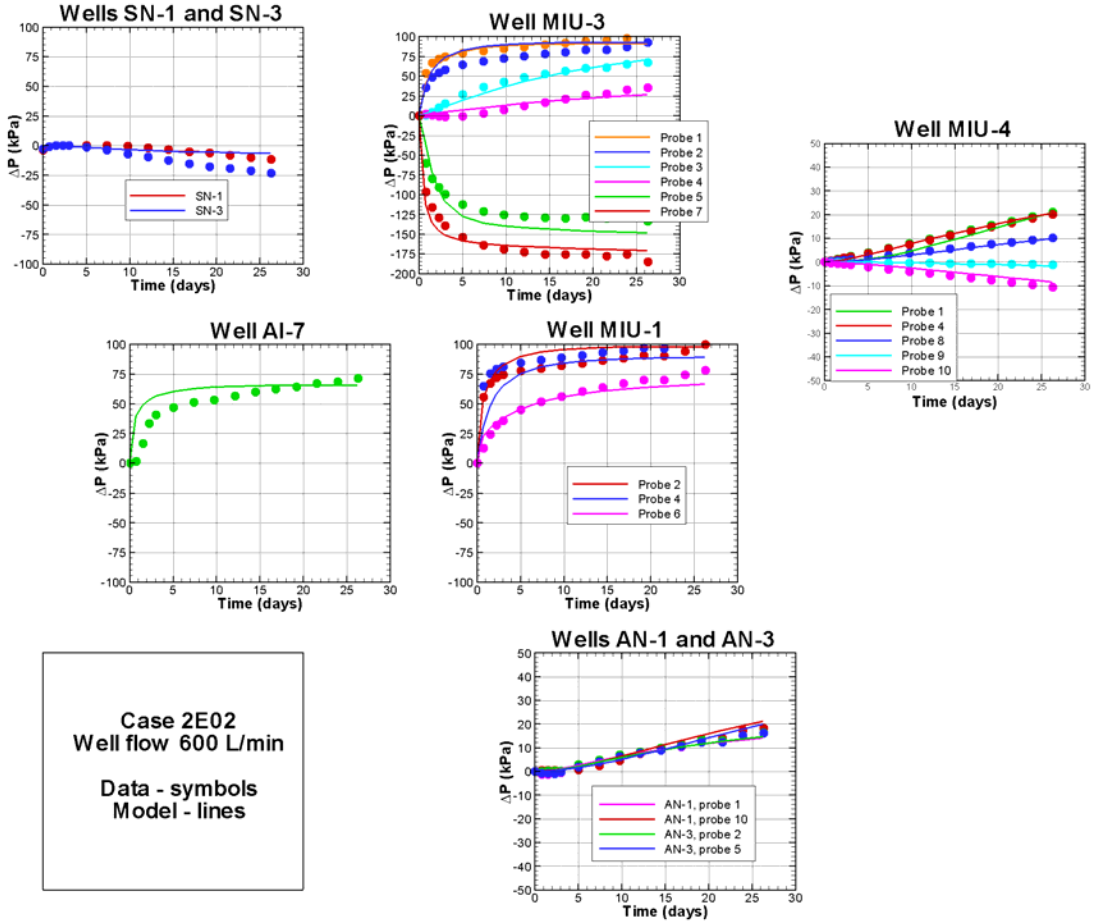

Figure 4. Observed and modeled pressure responses to packer removal in well MIU-2: calibrated model.

References

Doughty, C. and K. Karasaki, Evaluation of uncertainties due to hydrogeological modeling and groundwater flow analysis: Effective continuum model using TOUGH2, Rep. LBNL-48151, Lawrence Berkeley National Lab., Berkeley, Calif., 2001.

Doughty, C. and K. Karasaki, Evaluation of uncertainties due to hydrogeological modeling and groundwater flow analysis: Steady flow, transient flow, and thermal studies, Rep. LBNL-51894, Lawrence Berkeley National Lab., Berkeley, Calif., 2002.

Takeuchi, S., M. Shimo, N. Nishijima, and K. Goto, Investigation of hydraulic properties near the fault by pressure interference test using 1000 m depth boreholes, The 31st Japanese Rock Mechanics Symposium, pp. 296-300, 2001.