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Using Borehole Temperature Profiles to Constrain Regional Groundwater Flow

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Starting with regional geographic, geologic, hydrologic, geophysical, and meteorological data for the Tono area in Gifu, Japan, we develop a numerical model to simulate subsurface flow and transport in a 4 km by 6 km by 3 km thick fractured granite rock mass overlain by sedimentary layers. Individual fractures are not modeled explicitly. Rather, continuum permeability and porosity distributions are assigned stochastically, based on well-test data and fracture density measurements. The primary goal of the study is to simulate steady-state groundwater flow through the model, then calculate travel times to the model boundaries from specified monitoring points, to represent leakage from a hypothetical nuclear waste repository.

The lateral boundaries of the model follow topographic features such as ridgelines and rivers. Assigning lateral boundary conditions is a major point of uncertainty in model construction. One approach is to assume that the boundary conditions associated with surface features (closed boundaries along ridgelines, open boundaries along rivers) are appropriate for the entire thickness of the model. An alternative approach ignores the local surface features and assigns lateral boundary conditions based on larger-scale geographical features (flow from mountainous regions toward the coast). The first approach results in a mostly closed model while the second approach results in a mostly open model. The two models produce vastly different spatial distributions of groundwater flow, so we would like to find a means of choosing the more realistic model.

Surface recharge is much larger for the closed model, but field recharge data are of too limited spatial extent to provide a definitive model constraint. Simulation of a long-term pumping test indicates that the pressure-transient response does not discriminate between the two models either, because the volume of water that can practically be pumped is small compared to natural groundwater flow. Temperature profiles in 16 boreholes show consistent trends with conduction-dominated (linear) temperature profiles below depths of 300 m. The open and closed models predict strongly different temperature versus depth profiles, with the closed model showing a strong convective signature produced by the large surface recharge. The open model shows more linear temperature profiles, better agreeing with measurements from the field. Based on this data we can eliminate from consideration the closed model, at least in its present form in which surface recharge penetrates deep into the model.