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SENSITIVITY STUDIES OF UNSATURATED GROUNDWATER FLOW MODELING FOR GROUNDWATER TRAVEL TIME CALULATIONS AT YUCCA MOUNTAIN, NEVADA

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I. INTRODUCTION

Unsaturated flow has been modeled through four cross-sections at Yucca Mountain, Nevada, for the purpose of determining groundwater particle travel times from the potential repository to the water table.[1] This work will be combined with the results of flow modeling in the saturated zone[2] for the purpose of evaluating the suitability of the potential repository under the criteria of 10CFR960.[3] One criterion states, in part, that the groundwater travel time (GWTT) from the repository to the accessible environment must exceed 1,000 years along the fastest path of likely and significant radionuclide travel.

Sensitivity analyses have been conducted for one geostatistical realization of one cross-section for the purpose of 1) evaluating the importance of hydrological parameters having some uncertainty (infiltration, fracture-matrix connectivity, fracture frequency, and matrix air entry pressure or van Genuchten a); and 2) examining conceptual models of flow by altering the numerical implementation of the conceptual model (dual permeability (DK) and the equivalent continuum model (ECM)). Results of comparisons of the ECM and DK model are also presented in Ho et al.[1]

II. APPROACH

Hydrogeological parameters either were simulated geostatistically along the cross-section. Refer to McKenna and Altman[4] for more details on parameter development and the geostatistical analyses. For the sensitivity studies, flow simulations and particle-tracking calculations were conducted using one geostatistical realization of one east-west cross-section located in the northern half of the potential repository. No-flow, lateral boundaries are located just west of the Solitario Canyon fault and just east of the Bow Ridge fault. The lower boundary of the cross-section was the water table, which was treated as having a constant saturation of 1. The upper boundary was treated as a spatially variable constant flux estimated from shallow infiltration data from neutron moisture meter logs at 84 locations around Yucca Mountain.[5] Simulations were run to steady-state using the integrated-finite difference code TOUGH2 (SNL YMP version 3.1).

Shallow infiltration into the bedrock at Yucca Mountain is still under study. The most recent estimates are based on a multiple regression using precipitation, physiographic location (channel terrace, footslope, sideslope, ridge) and thickness of alluvium (greater or less than 3 m) as the variables. Based on this regression, which had a low r^2 of 0.27, average infiltration over the study area was 24 mm/yr.[5] This rate of infiltration distribution was much higher than has been estimated previously, thus sensitivity studies were conducted to see how a change in infiltration rate affects the saturation profiles, fluid-velocity distributions, and particle travel times through the cross-section. The infiltration reported in the most recent study[5] was used in the sensitivity studies along with an infiltration distribution 1 and 2 orders of magnitude less than that which was reported.

Fracture-matrix connectivity is another parameter for which there are little field data. For the GWTT-95 calculations using the DK model the fracture-matrix connectivity was set to be two orders of magnitude less than full connection. This reduction can be interpreted as assuming that one of every ten fractures has water flowing through it and only one tenth of the surface of these fractures actually has water flowing on it.[6] The sensitivity of this fracture-matrix connectivity was tested with two additional calculations: one reducing the full connection by 4 orders of magnitude, and a second using a 5-order-of- magnitude reduction.

Finally, the range of matrix van Genuchten a used in GWTT-95 has changed significantly from previous studies.[7,8,9] GWTT-95 calculations used more recent a values, which are thought to be more realistic because of improved measurement techniques and calibrations with field data. To evaluate the effects of the new van Genuchten a's (and therefore new characteristic curves), simulations were run using the a values from Klavetter and Peters.[10] The ECM was used in this sensitivity study to be consistent with the previous studies. Results from this simulation can be compared to those using the GWTT-95 parameters and the ECM model.[1] Of particular interest was whether lateral diversion would be observed in the Paintbrush nonwelded unit (PTn), as had been observed in other studies that used the parameters reported in Klavetter and Peters.[7]

III. RESULTS AND DISCUSSION

Matrix saturations simulated using the newly reported infiltration distributions (mean = 24 mm/yr) were much higher than measured saturations of core samples from drill hole USW-SD-9, located just north of the cross-section. To reduce the simulated saturations in an attempt to match the core data one can decrease either the infiltration rate or the fracture-matrix connectivity. Saturations most closely matched those measured from the core from SD-9 when an infiltration rate two orders of magnitude less than the reported estimations[5] was used. For this reason these modified infiltration rates were used for the GWTT-95 study.[1] It was more difficult to match matrix saturations by decreasing the fracture-matrix connectivity while using a mean infiltration rate of 24 mm/yr. Even with a reduction of fracture-matrix connectivity by 5 orders of magnitude, the matrix in the TSw, the welded units of the Topopah Spring Tuff (thermal/mechanical units TSw1 and TSw2), were highly saturated. With this decrease in the fracture-matrix connectivity the simulated matrix saturations in the Tiva Canyon Member of the Paintbrush Tuff (TCw) were much lower than the core measurements and those simulated by decreasing the infiltration rate.

Changing both the infiltration rate and the fracture-matrix connectivity also affected the flow velocities and, therefore, the particle travel times in the system. Again, changes in the infiltration rate had a greater impact on the system than changes in fracture-matrix connectivity as exemplified by particle travel times along the cross-section (Figure 1). The reduction in fracture-matrix connectivity did not have as strong an effect on particle travel times because, whereas fracture saturations did increase, the fracture porosity was high enough that this increase in saturation did not significantly affect the flow velocities.

Lateral flow was observed in the PTn when the Klavetter's and Peters' a values are used, whereas the flow is primarily vertical throughout the system when using the GWTT-95 parameters and the ECM.[1] There are two factors influencing the lateral flow in the PTn. First the characteristic curves corresponding to the use of the Klavetter's and Peters' data are significantly different than that for the GWTT-95 data, so that lateral diversion can occur under drier conditions.[11] Second, the effects of using a combined fracture/matrix characteristic curve for the ECM significantly decreases the suction pressure in the TSw, again resulting in lateral flow in the PTn under drier conditions. This sensitivity study has shown that it is a combination of both effects that leads to the lateral diversion observed when the Klavetter's and Peters' van Genuchten a values are used with the ECM.

IV. CONCLUSIONS

Sensitivity studies have shown that infiltration rate to the bedrock has a strong influence on the saturations of the system, flow velocities, and therefore groundwater particle travel times. While fracture-matrix connectivity also has some effect on the system the overall effect on the particle travel times is not as strong. Understanding infiltration at Yucca Mountain, currently a highly uncertain parameter, is therefore extremely important for accurate flow modeling.

The modeling of lateral flow diversion within the PTn is dependent on both the characteristic curves of the PTn and whether DK or ECM model is used. With this better understanding of how the air entry pressure in the PTn and numerical implementation of a conceptual model controls whether water flows laterally in the PTn in numerical models, field observations of lateral diversion are needed to determine the most accurate van Genuchten parameters and the most appropriate model for the system.

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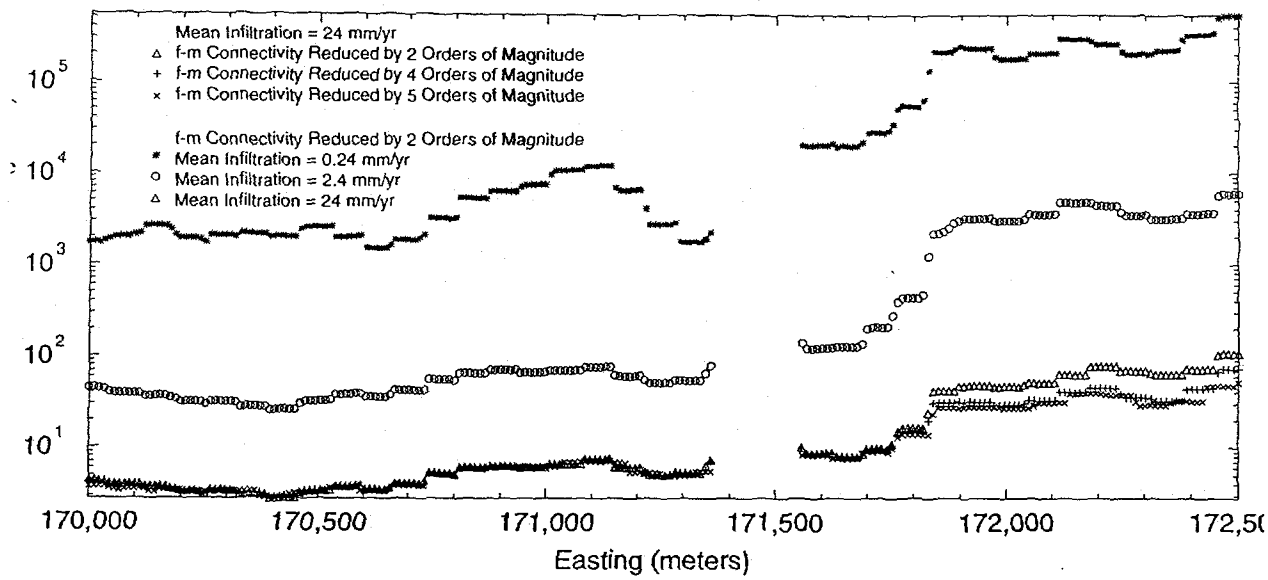

Figure 1: Groundwater particle travel times across a cross-section showing sensitivity of the travel times to infiltration and fracture-matrix connectivity. Particle movement is simulated without dispersion.