Investigation of Unsaturated Flow Patterns in Fractured Rock Using an Integrated Modeling Approach

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RESEARCH OBJECTIVES

Characterizing percolation patterns in unsaturated fractured rock poses a significant challenge to modeling investigations, because of the heterogeneous nature of unsaturated media and the many variables impacting unsaturated flow. The primary objective of this work is to quantitatively characterize percolation patterns in the fractured rock of the unsaturated zone (UZ) of Yucca Mountain, using an integrated modeling methodology.

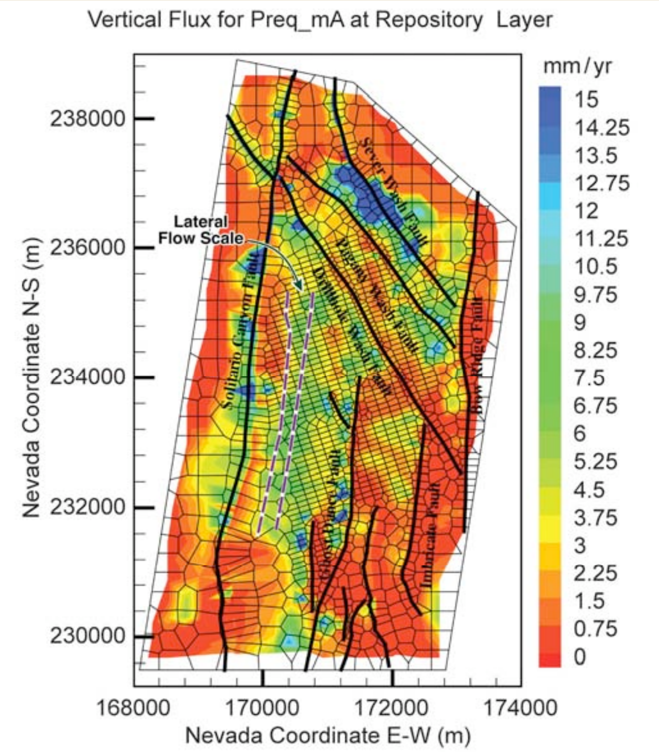

Figure 1. Simulated percolation fluxes at the repository horizon, using the present-day, mean infiltration scenario, base-case model results.

APPROACH

The integrated modeling approach combines a wide variety of field data into a comprehensive three-dimensional numerical model for flow pattern analyses. It takes into account the coupled processes of fluid and heat flow and chemical isotopic transport in Yucca Mountain's highly heterogeneous, unsaturated fractured tuffs. The fractured rocks are represented by a dual-permeability media. The main activities of study include (1) UZ model description; (2) model calibration using pneumatic, moisture, and geochemical data; (3) simulated percolation pattern analysis; and (4) assessment of percolation patterns and flow behavior using thermal and geochemical data.

ACCOMPLISHMENTS

An integrated modeling approach was used in a large-scale field study characterizing percolation patterns in the UZ of Yucca Mountain, The developed model integrated different field-observed data, such as moisture, gas pressure, chloride, and temperature data, into one single 3-D UZ flow and transport model. This combined model calibration provided a consistent cross-check or verification of model results, as well as better insight into UZ flow patterns. The integrated modeling effort also provided consistent model predictions for different but interrelated hydrological, pneumatic, geochemical, and geothermal processes. Most importantly, such an integrated approach improved the capability and credibility of numerical models in characterizing subsurface flow and transport processes.

The important findings from this study were: (1) at Yucca Mountain, water may not flow directly downward in a thick, heterogeneous unsaturated zone, but rather may be diverted laterally towards the east, along the sloping layers, and focused into major faults; and (2) lateral flow diversion occurs mainly at the Calico Hills formation (CHn), the stratigraphic unit below the repository horizon, resulting from the presence of perched water or thick low-permeability layers. Under the current hydrogeological conceptualization, faults act as major flow paths through the CHn or below the repository horizon. In addition, the modeled percolation fluxes show that fracture flow is dominant in the welded tuff, both at the repository horizon and at the water table, while the matrix carries the majority of water percolation through the nonwelded tuff. Figure 1 shows the simulated flux distribution at the repository horizon.

SIGNIFICANCE OF FINDINGS

The integrated modeling approach provides a practical modeling tool for characterizing flow and transport processes in complex subsurface systems and results in better understanding of percolation patterns and flow behavior through the Yucca Mountain UZ.

RELATED PUBLICATIONS

Wu, Y.-S., G. Lu, K. Zhang, L. Pan, and G. S. Bodvarsson, Analyzing unsaturated flow patterns in fractured rock using an integrated modeling approach. LBNL-54006. Hydrogeology Journal, 15, 553–572, 2007.

ACKNOWLEDGMENTS

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