A TRIPLE-POROSITY DUAL-PERMEABILITY MODEL FOR ASSESSMENT OF RADIONUCLIDE TRANSPORT IN TRANSIENT VARIABLY SATURATED FRACTURE FLOW CONDITIONS

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Assessment of radionuclide transport in fractured rock environments over large length and time scales is challenged by the small scale process of diffusion. To address combined fracture flow and matrix diffusion effects in site-scale assessment, a t riple-porosity dual-permeability flow and transport model is developed to consider three effective pore spaces – (1) fracture, (2) matrix flow, and (3) m atrix effective transport. In assessment of radionuclide transport from a underground nuclear test source situated in variably saturated and fractured zeolitic tuff, the triple-porosity dual-permeability model produces realistic ranges of bul k fracture and matrix flow, radionuclide breakthrough, and fracture concentration consistent with observed radionuclide concentration data.
In a fractured rock environment with low fracture frequency, the diffusion process between fractures and matrix material (matrix diffusion) can dominate transport behavior. However, coarse grid resolution of site scale numerical models prevents direct model-based assessment of fine scale matrix heterogeneities such as flow banding and clay alteration. Alternatively, an additional grid block property of "matrix effective transport porosity" is added to a dual-permeability model recognizing that fine scale pore-structure heterogeneities effectively limit diffusive penetration into the matrix. Model results coupling the matrix effective transport porosity parameter with linear sorption produce fracture concentrations consistent with observational data for both sorbing and non-sorbing radionuclides, suggesting that the "matrix effective transport porosity" also relates to the accessible volume of reactive minerals in the matrix.
The tri-porosity dual-permeability model can be viewed as a h ybrid between a single-continuum model with effective flow and transport porosities and a dual-permeability model with distinct fracture and matrix flow properties. While single continuum and "dual porosity" models can account for matrix diffusion, lack of distinct advective components for fracture and matrix flow presents difficulties in environments where contribution of matrix and fracture flow varies with rock type. A dual permeability model is instrumental to assessment of flow across interfaces, particularly in transitions between matrix and fracture dominated flow. While the triple-porosity dual-permeability model does not explicitly capture details of small-scale matrix-diffusion processes, it enables site-scale assessment of uncertainty derived from combined effects of fracture-matrix flow, matrix diffusion, and sorption into matrix materials.
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