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Modelling radionuclide transport for time varying flow in a channel network

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Abstract

Water flowrates and flow directions may change over time in the subsurface for a number of reasons. In fractured rocks flow takes place in channels within fractures. Solutes are carried by the advective flow. In addition, solutes may diffuse in and out of stagnant waters in the rock matrix and other stagnant water regions. Sorbing species may sorb on fracture surfaces and on the micropore surfaces in the rock matrix. We present a method by which solute particles can be traced in flowing water undergoing changes in flowrate and direction in a complex channel network where the solutes can also interact with the rock by diffusion in the rock matrix. The novelty of this paper is handling of diffusion in the rock matrix under transient flow conditions. The diffusive processes are stochastic and it is not possible to follow a particle deterministically. The method therefore utilises the properties of a probability distribution function for a tracer moving in a fracture where matrix diffusion is active. The method is incorporated in a three dimensional channel network model. Particle tracking is used to trace out a multitude of flowpaths, each of which consists of a large number of channels within fractures. Along each channel the aperture and velocity as well as the matrix sorption properties can vary. An efficient method is presented whereby a particle can be followed along the variable property flowpath. For stationary flow conditions and a network of channels with advective flow and matrix diffusion, a simple analytical solution for the residence time distribution along each pathway can be used. Only two parameter groups need to be integrated along each path. For transient flow conditions, a time stepping procedure that incorporates a stochastic Monte-Carlo like method to follow the particles along the paths when flow conditions change is used. The method is fast and an example is used for illustrative purposes. It is exemplified by a case where land rises due to glacial rebound. It is shown that the effects of changing flowrates and directions can be considerable and that the diffusive migration in the matrix can have a dominating effect on the results.

Keywords: Radionuclide transport; Transient flow; Network models; Matrix diffusion; Monte-Carlo methods

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1. Introduction and background

In many countries studies are underway to support the Performance Assessment (PA) of repositories for nuclear waste. Models that can simulate flow and radionuclide transport in fractured rocks under stationary flow conditions have been developed. Over the long times of interest for PA, flow conditions are expected to change and there is a need for coupled flow and solute transport models that can account for changing flow conditions. (See, for example, Robinson et al., 2003)

The water flowrates and directions in deep lying fractured rock change with time when the boundary conditions change. This occurs in Sweden due to the land uplift that takes place in Scandinavia subsequent to de-glaciation events and in the longer term may occur due to new glaciations. To calculate the transport of radionuclides from a deep lying repository for nuclear waste, the changing flow field must be accounted for. We wish to study the flowrate and flowpath changes induced by the land rise and quantify their impact on the radionuclide transport from a final repository for nuclear waste. Both the travel time and eventual discharge locations are of interest. In fractured rocks, such as Swedish granites, the water flows in the fractures, but nuclide migration is strongly influenced, actually dominated, by diffusion in and out of the stagnant waters in the porous rock matrix and sorption therein (Neretnieks, 1980). It is the main aim of this paper to devise a method that can be used to simulate radionuclide transport in fractured rocks under changing flow conditions.

1.1. Short overview of work on transient methods and Fracture/Channel Network models

There are a large number of papers that describe flow and transport in porous media under transient flow conditions. They are based on following the trajectories of the flowing water. We extend the methods that follow a particle trajectory to also include the random movement of the particles due to molecular diffusion in stagnant water in a porous rock matrix adjacent to the flowing water. This cannot be done by conventional particle tracking. Our method is aimed at being used in complex three dimensional channel networks where the particles may travel through a multitude of different flowpaths with different properties. For background a short overview is presented below of recent literature describing particle tracking under transient conditions as well as some work describing central aspects of flow and transport in fracture and channel networks.

For a porous medium the flow equations and the coupled solute transport equations formulated as Advection–Dispersion AD equations are solved simultaneously. The equations are fully coupled in the sense that flow influences transport and e.g. salt concentration influences the flow due to density effects. Heat effects are also frequently included. Chemical reactions and retardation due to sorption are sometimes included. A solute can be followed by tracking flow vectors or by particle tracking.

Zurmuhl (1998) solved the AD equation for transient flow by numerical methods and applied the model to follow HTO movement in soils. Kolditz et al. (1998) give an overview of a number of numerical codes with the capability to solve transient flow and transport especially for density driven flow. They also discuss and compare different iteration schemes. Vasco and Finsterle (2004) superimpose a particle tracking technique on a numerical code and describe how to compute the trajectories directly from the output of a numerical simulator. Prommer et al. (2000) compare some numerical codes to simulate tracer transport under transient conditions and account for biochemical reactions of the tracers. Bhallamudi et al. (2003) also solve flow and AD