H23D CC: 220 C-E Tuesday 1330h

Groundwater Remediation in Fractured Rock Posters

Presiding: **B Kueper,** Queen's University; **K Novakowski,** Queen's University

H23D-01 1330h POSTER

A method to determine the spacing and transmissivity statistics of "conductive" fractures in which the criterion disgtinguishing between conductive and non-conductive fractures is a sliding scale

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The design of clean-up applications for fractured rock strongly depends on the use of appropriate models and field measurements. Implicit in the use of discrete fracture models is that a subset of fractures have been distinguished from the remaining fractures and labelled as "conductive". Where injection tests have been used to measure permeability along boreholes, the dividing line between these two sets of fractures has traditionally been associated with investigators' ability to measure flow. For example, those sections of borehole into which the rate of injection is below the lower limit of measurement are often associated with the set of "non-conductive" fractures, while those sections into which flow can be measured have been assumed to contain at least one of the conductive set. Snow (1970) used this criteria along with the statistics of a set of transmissivity measurements to derive the mean and variance of the transmissvity of the conductive set. More recently, investigators have used this criteria along with a set of transmissivity magnitudes to derive maximum likelihood estimates of the parameters of a conductive fracture transmissivity set having an assumed gamma-distribution. In this study, provided the distribution of fracture transmissivities is strongly positively skewed, this method of distinguishment is shown to be valid, even in the case where the lower limit of flow rate detection is artificially raised above that associated with equipment. This (upward) sliding detection limit is shown to be useful in the creation of a diminishing (in population) subset of fractures with increasing mean transmissivity and decreasing variance. Using the assumption that the log-normal distribution is stable during addition of small numbers of relatively low variance random variables, the log-normal distribution is shown to be a better model of fracture transmissivity than is the gamma distribution.

H23D-02 1330h POSTER

A Semi-Analytical Model to Describe the Effect of Biofilm Development on Solute Diffusion in Low Permeability Rock

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In fractured rock environments, the process of matrix diffusion strongly influences the persistence of groundwater contamination. Biofilm growth, which occurs naturally in fractured rock, can have a significant effect on the solute transport properties of the matrix, and thus the mobility of contaminants in the system. A semi-analytical model that accounts for the presence of a biofilm has been developed from a solution of the advection-dispersion equation for solute transport in radial coordinates. The model is intended to aid in simulating radial diffusion experiments. It describes solute transport by diffusion from a cylindrical reservoir into a layered medium of finite diameter. The model accounts for linear adsorption and decay in each layer, as well as the periodic addition and/or removal of fluid of known solute concentration from the reservoir. The boundary value problem is solved using the Laplace transform method and Crout's method of LU Decomposition, and numerically inverted using the De Hoog algorithm. According to a sensitivity analysis, compared to the no-biofilm case, diffusion of conservative tracers is most sensitive to the depth of penetration of the biofilm into the matrix, as well as the effective porosity and diffusion coefficient of that penetrated zone. The model developed in this study has been used to interpret the results of diffusion experiments undertaken to investigate mass transport into intact rock samples in the presence of a biofilm and to assign average mass transport parameters to the system. Laboratory data demonstrates that the presence of a biofilm acts to limit diffusive transfer between a discrete fracture and the matrix.

H23D-03 1330h POSTER

Semi-analytical Solutions for Solute Transport in Fractured Porous Media Using a Finite Width Strip Source

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In this paper, transient and steady-state analytical solutions are derived to investigate three-dimensional solute transport in a fractured porous medium. The system consists of evenly spaced, parallel discrete fractures, where solute transport in the fracture is governed by advection-dispersion and the matrix diffusion occurs in the adjacent rock matrix. Transverse dispersion, decay in a finite strip source, and aqueous phase decay in the advection-dispersion equation are also included. Solutions are derived using Laplace and Fourier transforms, and inverted by interchanging the order of integration and utilizing a numerical Laplace inversion algorithm. The application of the solutions to an example site consisting of bedded sandstone impacted with trichloroethylene (TCE) demonstrates the significant influence of source width and transverse dispersivity on plume development. Break-through curves for source widths of 15 m or greater exhibit the same shape, but there is considerable variation in break-through curve attributes for source widths between 1 m and 10 m. Source width significantly affects steady-state plume development, where increasing the width from 1 m to 10 m resulted in a three order of magnitude increase in the down-gradient displacement of the 10 mg/L concentration contour. When considering a base case of longitudinal dispersivity equal to 0.3 m and transverse dispersivity equal to 0.03 m, increasing transverse dispersivity to 0.3 m yields a 3 fold reduction in break-through concentration at 100 m down-gradient from the source. Increasing both longitudinal and transverse dispersivity from the base case values to 1.0 m and 0.1 m, respectively, resulted in a 43% reduction in concentration at the same down-gradient location. The application of decay mechanisms significantly influences contaminant impact and can rapidly mitigate long-term back-diffusion processes. To investigate the influence of decay mechanisms, several cases were considered for modest decay half-life values. For the example site, the absence of decay processes resulted in a steady-state concentration of 180 mg/L at a location 100 m down-gradient from the source. Using a source decay half-life of 3 years reduces the impact, with 5 ppb levels achieved at approximately 3600 years. The inclusion of a source decay half-life of 3 years and an aqueous phase decay half-life of 5 years further mitigates the impact, with 5 ppb concentrations achieved at approximately 50 years.

H23D-04 1330h POSTER

A Sensitivity Analysis of Well Capture Zones in Discretely Fractured Rock

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A Discrete Fracture Network (DFN) model was created using FracMan® to assess what input parameters are most influential in determining the aerial and vertical extent of capture at an existing pump-and-treat system in southwestern Ontario. Two separate three-level factorial designs were conducted; the first evaluated the effect of changing bedding plane fracture parameters P32, mean aperture and mean size on area and depth of capture keeping vertical fracture properties at the base case values. The second evaluated the effect of changing vertical fracture parameters P32, mean aperture and termination % on area and depth of capture keeping bedding plane fracture properties at the base case values. Analysis of Variance (ANOVA) tables and significance analysis was carried out for each of the factorial design analyses data. The effects of mean bedding plane fracture aperture and P32, respectively, were found to significantly affect area and depth of capture and accounted for the greatest percentage of variance in mean area and depth of capture for all simulations in the factorial design. In general, as mean bedding plane fracture aperture and P32 increase, the mean area and depth of capture, respectively, decreases. Mean bedding plane fracture size accounted for only a small percentage of the overall variance in mean area and depth of capture. The interaction effects between bedding plane fracture P32 and mean bedding plane fracture aperture, mean bedding plane fracture size and bedding plane fracture P32 and mean bedding plane fracture size and mean bedding plane fracture aperture, respectively, were found to significantly affect capture zone area. The interaction effect between bedding plane fracture P32 and mean bedding plane fracture aperture was also found to significantly affect the depth of capture. Mean vertical fracture aperture and vertical fracture P32, respectively, were found to significantly affect capture zone area and accounted for the greater percentage of variance in mean area of capture for all simulations in the factorial design. Termination % only accounted for a small percentage of the overall variance in mean area of capture. In general, as mean vertical fracture aperture and vertical fracture P32 increase, respectively, the mean area and depth of capture decreases. Neither vertical fracture P32, mean vertical fracture aperture, nor termination % was found to significantly affect depth of capture. However, the interaction effect between vertical fracture P32 and mean vertical fracture aperture was found to significantly affect the depth of capture and accounted for the greatest percentage of variance in mean depth of capture for all simulations in the factorial design. The interaction effect between vertical fracture P32 and mean vertical fracture aperture was also found to significantly affect capture zone area.

H23E CC: 520 C Tuesday 1330h

Groundwater and Climate Change I

Presiding: **D M Allen,** Simon Fraser University; **G van der Kamp,** National Water Research Institute

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H23E-01 1330h

Groundwater Supported Evapotranspiration within Glaciated Watersheds under Conditions of Climate Change

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We analyze the effects of geology and geomorphology on surface water/groundwater interactions, evapotranspiration, and runoff generation under conditions of long-term climate change. Our analysis uses hydrologic data from the glaciated Crow Wing watershed in central Minnesota, USA, as well as saturated/unsaturated mathematical modeling. Analysis of historical water table (1970-1993) and lake level (1924–2002) records indicate that larger amplitude, longer period fluctuations occur within the upland portions