Estimation of Hydraulic Conductivity for a Heterogeneous Unsaturated Soil Using Electrical Resistivity and Level-Set Methods

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Abstract

The estimation of the soil saturated hydraulic conductivity (Ks) is crucial in understanding water flow and transport of contaminants. There are many hydrological techniques available for helping to determine this parameter (constant head method, in-situ soil analysis, etc...) While these techniques can provide quality data points, they are often limited by sparse data sampling and scale. Therefore estimation of the conductivity model may lack spatial resolution and may not represent the complexity of the true model. Geophysical methods have being used successfully in many instances in locating the water table level and the migration of liquid flow through the use of monitoring electrical resistivity tomography (ERT) surveys and time-lapse inversions. Here we present a technique for estimating Ks in an unsaturated medium using infiltration test and time-lapse ERT.

First, progression of the infiltration front is detected by ERT at two times (Ti, Ti+1). Secondly, the level-set method is used to reconstruct the infiltration front between times Ti and Ti+1. Thirdly, the flow paths are estimated by propagating the fronts in their normal direction allowing an initial estimate of the hydraulic conductivity. Finally, through a process of iterative scheme of forward modeling, the hydraulic conductivity and the front propagation are reconstructed. This iterative scheme minimizes the difference between the measured and the calculated infiltration front velocity. Richards' equation is used for solving the forward hydrogeological model and van Genuchten analytic formulas are used to define the water retention model. Spatial variations in van Genuchten parameters (α, n, l) are assumed to be small therefore the van Genuchten parameters are kept constant throughout the forward and the inverse process.

A COMSOL Multiphysics® simulation reflecting the subsurface that one might encounter in an urban region, is used to test and validate the proposed technique. The model consists of sand and subsoil that are separated by a vertical contact. The problem is scaled down by setting the saturated hydraulic conductivity to respectively 10 m/s and 1 m/s, and the measurement time set in the order of seconds. Two different approaches in detecting the water infiltration front are used. The first approach is to determine the water infiltration front directly from the hydrogeology modeling where water saturation (Se) is 0.1. The second approach is to determine the water infiltration front from electrical resistivity tomography (ERT) time-lapse inversion. Resistivity

models are obtained by converting hydrogeology models through a modified Archie's law. The forward calculation for the hydrogeology and resistivity models are accomplished through the use of COMSOL Subsurface Flow Module and AC/DC Module.

For the first approach, the reconstructed Ks match those in the synthetic model (Figures 1 and 2). The reconstructed Se and infiltration fronts also match those observed at each measured time (Figure 3). The water infiltration are set to be constant along the entire surface of the model, no horizontal flow is assumed at the model boundaries and the van Genuchten parameters are pre-determined through time-lapse TDR measurements. The results from the second approach using time-lapse ERT method is currently under testing.

Reference

1. Archie, G.E., The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics, American Institute of Mineral and Metal Engineering, Technical Publication, 1442, Petroleum Technology, 8-13, (1942).

2. Osher, S., and Sethian, J.A., Fronts Propagating with Curvature-Dependent Speed: Algorithms Based on Hamilton-Jacobi Formulations, Journal of Computational Physics, 79(1), 12-49, (1988).

3. van Genuchten, M.Th., A Close-Form Equation For Predicting The Hydraulic Conductivity Of Unsaturated Soils, Soil Science Society of American Journal, 44, 892-898, (1980).

Figures used in the abstract

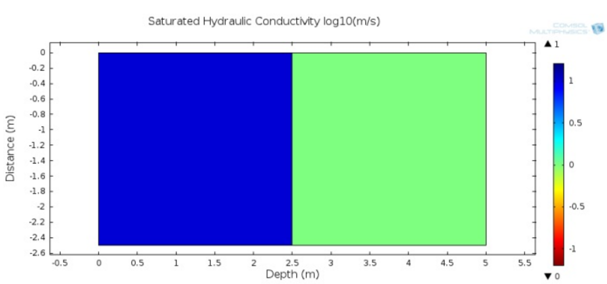

Figure 1: Synthetic hydraulic conductivity model. The saturated hydraulic conductivity (Ks) for the sand and the subsoil are respectively 10 m/s (left) and 1 m/s (right).

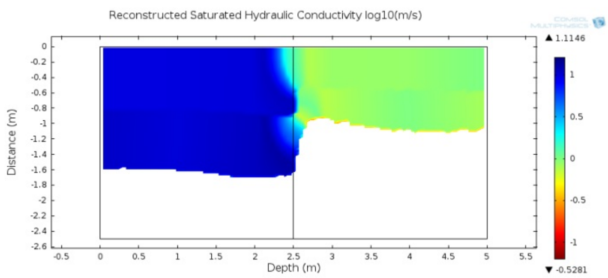

Figure 2: Reconstructed saturated hydraulic conductivity model from hydrogeological inversion using a uniform infiltration at ground surface from time 0 to time 2.

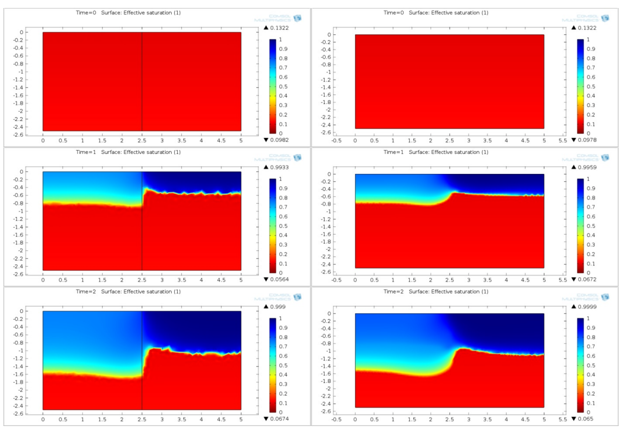

Figure 3: Comparison between modeled (left) and interpreted (right) water saturation at time t = 0 s (top), t = 1 s (middle) and t = 2 s (bottom).