Estimating field-scale soil hydraulic properties through joint inversion of cross-borehole GPR travel times and hydrological measurements

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Ground-penetrating radar (GPR) measurements are highly sensitive to transient and non-uniform water distributions. Although GPR travel times are ideal for inclusion in inverse methods that allow for estimation of soil hydraulic parameters, this field of research is at an early stage of development. In the present work, multiple-offset cross-borehole GPR travel times and additional hydrological measurements are used jointly to estimate field-scale soil hydraulic parameters through inversion. The current implementation of our approach allows not only for estimation of the soil hydraulic parameters, but also for estimation of the petrophysical model (in this case, the constitutive model relating the dielectric constant to the porosity and water saturation) and the spatial correlation model of permeability. The usefulness of the approach must be examined for any particular application of interest, because many factors, including flow conditions and measurement configurations, affect parameter sensitivity. We choose to examine the scenario of a point injection of water and the simultaneous collection of nearby borehole measurements. In a 2-D synthetic example, we see that small errors in the petrophysical model result in substantial errors in estimates of the uniform soil hydraulic parameters. This finding is of particular relevance, since in many GPR applications a universal petrophysical model (i.e., non-site-specific) is assumed, or a field-scale model is implemented despite its having been derived at laboratory scale. However, adverse effects from incorrect or unknown petrophysical models are shown to be alleviated by jointly estimating the petrophysical model with the soil hydraulic parameters. Additionally, we consider an example with a heterogeneous permeability distribution, and explore the possibility of estimating its spatial correlation model. Finally, the approach is applied in a 3-D setting to real field data collected at the Hanford DOE site in Washington. This work was supported in part by the U.S. Dept. of Energy under Contract No. DE-AC03-76SF00098.