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A non-linear Bayesian approach for upscaling local-scale permeability measurements based on local- and regional-scale hydrogeophysical data

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Geophysical methods have the potential to bridge the inherent gap in terms of spatial resolution and coverage that exists between traditional hydrological methods, such as core analyses and tracer or pumping tests. Recently, significant progress has been made regarding the quantitative integration of geophysical and hydrological data at the local scale. Extending this approach to the regional scale does, however, represent a major, and as of yet largely unresolved, challenge, which we address through a workflow involving the following interrelated steps: (i) definition of the large-scale structure of the aquifer in terms of the prevailing hydrostratigraphic units and their large-scale geophysical properties, (ii) detailed local-scale characterizations of the permeability and pertinent geophysical properties at isolated, but representative locations within the aquifer, and (iii) upscaling of this local-scale information to the regional scale. The overall objective of this research is to develop methodologies that are capable of providing regional, aquifer-scale permeability models that are sufficiently detailed and accurate to allow for a faithful reproduction of the pertinent flow and transport phenomena. To this end, we have developed a strategy for the stochastic integration of low-resolution, regional-scale, electrical resistivity tomography (ERT) images from surface-based measurements with high-resolution, local-scale downhole measurements of the permeability and electrical conductivity. We use a non-linear Bayesian procedure consisting of the following steps: (i) estimation of the prior permeability distribution by linear interpolation of downhole permeability data, (ii) definition of a kernel density function describing the in situ relationship between the downhole, high-resolution electrical conductivity and permeability measurements, (iii) evaluation of the permeability likelihood function by combining the existing established relationship inferred from collocated ERT data and downhole electrical conductivity measurements with the previously inferred kernel probability density function, and (iv) sequential update of the prior distribution based on the estimated likelihood function. Numerical tests on realistic, highly heterogeneous aquifer models indicate that this procedure allows for obtaining remarkably faithful estimates of the upscaled, regional-scale permeability structure wherever adequate ERT images are available.