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Changing the scale of hydrogeophysical aquifer heterogeneity characterization

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Contaminant remediation and management require the quantitative predictive capabilities of groundwater flow and mass transport numerical models. Such models have to encompass source zones and receptors, and thus typically cover several square kilometers. To predict the path and fate of contaminant plumes, these models have to represent the heterogeneous distribution of hydraulic conductivity (K). However, hydrogeophysics has generally been used to image relatively restricted areas of the subsurface (small fractions of km^2), so there is a need for approaches defining heterogeneity at larger scales and providing data to constrain conceptual and numerical models of aquifer systems.

This communication describes a workflow defining aquifer heterogeneity that was applied over a 12 km^2 sub-watershed surrounding a decommissioned landfill emitting landfill leachate. The aquifer is a shallow, 10 to 20 m thick, highly heterogeneous and anisotropic assemblage of littoral sand and silt. Field work involved the acquisition of a broad range of data: geological, hydraulic, geophysical, and geochemical. The emphasis was put on high resolution and continuous hydrogeophysical data, the use of direct-push fully-screened wells and the acquisition of targeted high-resolution hydraulic data covering the range of observed aquifer materials. The main methods were: 1) surface geophysics (ground-penetrating radar and electrical resistivity); 2) direct-push operations with a geotechnical drilling rig (cone penetration tests with soil moisture resistivity CPT/SMR; full-screen well installation); and 3) borehole operations, including high-resolution hydraulic tests and geochemical sampling. New methods were developed to acquire high vertical resolution hydraulic data in direct-push wells, including both vertical and horizontal K (K_v and K_h).

Various data integration approaches were used to represent aquifer properties in 1D, 2D and 3D. Using relevant vector machines (RVM), the mechanical and geophysical CPT/SMR measurements were used to recognize hydrofacies (HF) and obtain high-resolution 1D vertical profiles of hydraulic properties. Bayesian sequential simulation of the low-resolution surface-based geoelectrical measurements as well as high-resolution direct-push measurements of the electrical and hydraulic conductivities provided realistic estimates of the spatial distribution of K on a 250-m-long 2D survey line. Following a similar approach, all 1D vertical profiles of K derived from CPT/SMR soundings were integrated with available 2D geoelectrical profiles to obtain the 3D distribution of K over the study area.

Numerical models were developed to understand flow and mass transport and assess how indicators could constrain model results and their K distributions. A 2D vertical section model was first developed based on a conceptual representation of heterogeneity which showed a significant effect of layering on flow and transport. The model demonstrated that solute and age tracers provide key model constraints. Additional 2D vertical section models with synthetic representations of low and high K hydrofacies were also developed on the basis of CPT/SMR soundings. These models showed that high-resolution profiles of hydraulic head could help constrain the spatial distribution and continuity of hydrofacies. History matching approaches are still required to simulate geostatistical models of K using hydrogeophysical data, while considering their impact on flow and transport with constraints provided by tracers of solutes and groundwater age.