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Thermal modeling approach to determine aquifer heterogeneity from spatial patterns of stream-aquifer interactions

E. Kalbus (1), C. Schmidt (1), J. Molson (2), F. Reinstorf (1) and M. Schirmer (1)

(1) Department of Hydrogeology, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany, (2) Department of Civil, Geological and Mining Engineering, École Polytechnique Montreal, Canada (edda.kalbus@ufz.de / Fax: +49 341 235-2126 / Phone: +49 341 235-1986)

The groundwater discharge to a stream may vary within small distances across the streambed. At a small stream in Germany, high-resolution measurements of streambed temperatures revealed a highly heterogeneous distribution of temperatures and, correspondingly, of groundwater discharge rates. We assumed that the observed heterogeneities may be caused by the structure of the connected aquifer. Traditional subsurface investigation techniques are often not capable of providing data in sufficient resolution to capture these small-scale variations in aquifer properties. While a representative mean value of hydraulic conductivity (K) can be obtained from field data with relatively high certainty (e.g. from pumping tests), a reliable estimation of the variance of K, representing the aquifer heterogeneity, would require a large number of sampling points. We hypothesized that the heterogeneity of K can be inferred from measured streambed temperatures. A groundwater flow and heat transport model of the stream-aquifer system including stochastically generated K fields was used to analyze the relation between the variance of K and the variance of simulated streambed temperatures. From the model results we determined the required variance of K to reproduce the range of measured streambed temperatures. In subsequent simulations we assessed the influence of streambed hydraulic conductivities different from aquifer conductivities and the effects of changing boundary conditions. This study showed that subsurface characterization methods based on heat in combination with modeling

approaches constitute a valuable supplement to traditional exploration techniques.