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The Ensemble Kalman Filter for real-time Groundwater Flow Modeling of the upper Limmat aquifer in Zurich (Switzerland)

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The sandy gravel aquifer of the upper Limmat valley (Zurich, Switzerland) is used for groundwater exploitation, which covers about 15% of the water demand of the city of Zurich. Water is pumped by a series of bank filtration wells along river Limmat and is recharged by basins and wells. Drinking water is produced by several production wells. To ensure drinking water quality, the inflow of potentially contaminated groundwater from the industrial part of Zurich should be avoided. In addition, the pumped groundwater should not exceed a maximum temperature. Due to infiltration from river Limmat, in late summer and autumn the pumped groundwater is sometimes too warm. In order to prevent pumping of groundwater of inferior quality in the future, the monitoring network of groundwater levels, groundwater temperature and groundwater quality was extended and adapted for real-time transmission of data. These data are used for the real-time modelling of groundwater flow, solute and heat transport with help of the Ensemble Kalman Filtering technique (EnKF).

First, a deterministically, calibrated model was developed; a 3D transient finite elements saturated-unsaturated groundwater flow model of the upper Limmat valley, together with a hydraulic model of the river Limmat. Time series of recharge and lateral inflow were constructed from meteorological data, and using a simple soil water balance model. The model was calibrated with the Pilot Points method using piezometric

head data from Mai to June 2004 and July to August 2005. The calibrated model was verified for the period December 1992- August 2005, using more than 40,000 transient piezometric head data of 90 piezometers.

As a next step, multiple stochastic realizations of the input parameters and model forcings were constructed. The hydraulic conductivities and leakage coefficients were the dominant sources of uncertainty. A statistical model for the uncertain hydraulic conductivities was constructed on the basis of a geostatistical analysis of the data, geostatistical upscaling techniques and results from the inverse modelling. The ensemble of realizations was used in EnKF to assimilate hydraulic head data from 90 locations during two years of groundwater flow modelling. It was found that EnKF gave a considerable improvement in terms of absolute hydraulic head errors, as compared with the deterministically calibrated model, also when only half of the data were used for assimilation, and the other half was used for verification. Also tests were performed with an iterative formulation of EnKF, with an augmented state vector approach that allowed for updating both transmissivities and leakage coefficients, together with the states.