Pathline Density Distributions in a Null-space Monte Carlo Approach to estimate Groundwater Pathways for a Major Water Supply System

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A null-space Monte Carlo (NSMC) approach was applied to assess uncertainty in the calibration of the hydraulic conductivity (K) field for a three-dimensional groundwater flow model of a major water supply system in Switzerland. Different parameter realizations of the K field are generated by applying the pilot point methodology. Backward particle tracking (PT) was then applied to each calibrated model, and the resulting particles are interpreted as the spatial pathline density distribution of multiple sources. The adopted approach offers advantages over classical PT which does not provide a means for treating uncertainty originating from the incomplete description of the K field. Besides evaluating the effect of uncertainty in the K field on pathline distribution, the importance of the chosen boundary conditions for flow predictions is also investigated by applying a linear uncertainty approach.

Uncertainty in the K field is shown to strongly influence the spatial pathline distribution. Pathline spreading is particularly evident in locations where the information content of the head observations does not sufficiently constrain the estimated parameters. As demonstrated with the linear uncertainty analysis, however, the artificial recharge rates and the pumping well conditions can also significantly affect the model predictions. Explicitly accounting for uncertainty in the boundary conditions is therefore a necessity rather than a choice.

Despite the predictive uncertainty, the pumped drinking water at the study site is most likely dominated by artificially infiltrated groundwater originating from the local artificial infiltration canals and ponds. The results suggest that within the well field, the central pumping wells could be extracting regional groundwater, although the probability is relatively low. Nevertheless, a rigorous uncertainty assessment is still required since only a few realizations resulted in flow paths that support the field observations from tracer tests and on-site noble gas measurements to estimate groundwater mixing ratios.

We demonstrate that standard PT approaches without a Monte-Carlo approach will not represent the underlying subsurface uncertainty and will always underestimate well capture zones. While PT based on a single flow simulation can be used as an initial screening tool, model results and hence
water resource management decisions should not be based on only one model realization; rather, an uncertainty analysis should be carried out to provide simulations within the range of all likely system states, including uncertainties in the hydraulic K distribution.