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On the value of including transient data in the delineation of the capture zone of a well

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Most often the unknown variation of the hydraulic conductivity distribution is considered as the main source of uncertainty within the aquifer characterization process. Thus, in the last decade a lot of research effort has been devoted to the stochastic description of aquifer management tasks like the delineation of wellhead protection zones. In such approaches, typically, a steady state approach has been applied. However, in alpine environments time series of groundwater heads and of internal and external boundary conditions generally show significant transient behaviour. Depending on the local conditions, the transient groundwater features may be related to time and space varying recharge events or substantial interaction with a river.

In this paper we argue that despite of the influence of the hydraulic conductivity variability the transient nature of groundwater flow may have not been adequately considered in the delineation of wellhead protection zones. The flow direction of any particle is not only influenced by the local variation of hydraulic conductivities but also by temporary changing groundwater flow direction due to changing hydraulic gradients which are in turn related to fluctuating groundwater discharge. Thus, in one case a particle might be captured by the well but missed in another instant. As a consequence, local variations of groundwater flow direction will not average out, even not in a regional setting or over long periods. Moreover, it has been shown that the delineated captured zone of a well under the steady state assumption can be considered a good indication of average flow conditions but direction and shape of the capture zone might considerably fluctuate with changing flow conditions. In alpine environments it is not unusual that groundwater flow directions significantly change on a time scale comparable to the required subsurface flow time to avoid bacteriological pollution (which is

60 days in Austria).

In order to prove our hypothesis we process a large number of conditional conductivity realizations of an Austrian aquifer through a groundwater flow model and keep only those that match the observed heads within a predefined range. This procedure is completed for low, high and average groundwater flow conditions that are defined as the 10% and 90% percentile and the median of the well groundwater level time series, respectively. This time period is representative of the observed groundwater head fluctuations. The width of the capture zone at a specific upstream control section is retained for the selected realizations. For comparison, groundwater flows model are run for the same realizations using transient boundary conditions. Again, only those realizations are kept that meet the observed head time series within a predefined range. Then, particles are released from the same upstream control section as in the steady state cases and the largest distance between the outermost particles that are caught by the well is kept. Evaluating the combined width distribution of the steady state cases and that of the transient cases it can be seen that the spread (and thus the uncertainty) about the capture zone width has considerably decreased if transient boundary conditions are applied.

Put in a broader perspective we suppose that the uncertainty about the shape and location of a well capture zone due to the unknown variability of the hydraulic conductivity distribution can be reduced by making use of transient boundary conditions (if appropriate). In the later case, the combination of boundary conditions and system parameters have not only to match the observed system state at one time instant (the representativeness of which can always be disputed) but during a consecutive period of time comprising the transient aquifer characteristics. Of course, the uncertainty in aquifer management decisions can only be decreased if the change of applicable hydraulic stresses can be adequately described in time and space. For this purpose process models depicting the soil water balance or statistical approaches can be used, among others. Yet, the variations of internal or external boundary conditions have anyway to be represented within the groundwater model in order to setup a useful predictive tool.