Simultaneous estimation of groundwater recharge and hydrodynamic parameters for groundwater flow modelling

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Groundwater water resources management is a major issue because it is often the only available water resources for many countries. Moreover, the estimation of the recharge of the groudnwater is still a challenge and is a key value for accurate exploitation of the aquifer. Therefore, groundwater models have become a very usual tool for groundwater management. Aquifers are known to be very heterogeneous and groundwater recharge to be variable in space, depending mainly on the soil and vegetation covers, and in time since it is a combination of precipitation, evaporation and transpiration through the vegetation. Groundwater recharge cannot be measured. Its value varies from zero to precipitation. Two key factors are unknown: the actual evapotranspiration which depends on many factors like vegetation and meteorological data and the water flow conditions in the unsaturated zone located above the groundwater.

Groundwater survey consists in measuring water piezometric levels in different wells. Physical parameters (hydraulic conductivity, storage coefficient), aquifer geometry and boundary conditions are very poorly known for economic reasons: the parameters estimation requires the drilling and monitoring of numerous wells. Therefore, model calibration cannot be avoided.

Groundwater models are based on two equations:

- Mass conservation written in terms of piezometric head assuming constant water density:

$$S\frac{\partial h}{\partial t}+\nabla.\mathbf{q}=r$$

- and Darcy's law for energy conservation:

$$\mathbf{q}=-\mathbf{K}\nabla h$$

where h is the piezometric head, S the storage coefficient, **K** the hydraulic conductivity tensor, **q** the water flux and r sink/source terms including groundwater recharge.

Model calibration consists in fitting the measured piezometric heads by estimating the ad hoc parameters (storage term and hydraulic conductivity) and sink/source terms. Boundary conditions are rarely calibrated. It is traditionally recommended to avoid simultaneous calibration of groundwater recharge and flow parameters because of correlation between recharge and hydraulic conductivity. From a physical point of view, little recharge associated with low hydraulic conductivity can provide very similar piezometric values than high recharge and high hydraulic conductivity.

If this correlation is true under steady state conditions, we assume that this correlation is much weaker under transient conditions because recharge varies in time and the parameters do not. Moreover, the recharge is negligible during summer time for many climatic conditions due to reduced precipitation, increased evaporation and transpiration by vegetation cover.

We analyze our hypothesis through global sensitivity analysis (GSA) in conjunction with the polynomial chaos expansion (PCE) methodology. We perform GSA by calculating the Sobol indices, which provide a variance-based importance measure of the effects of uncertain parameters (storage and hydraulic conductivity) and sink/source term on the piezometric heads computed by the flow model. The choice of PCE has the following two benefits: (i) it provides the global sensitivity indices in a straightforward manner, and (ii) PCE can serve as a surrogate model for the calibration of parameters. The coefficients of the PCE are computed by probabilistic collocation. We perform the GSA on real conditions coming from an already built groundwater model dedicated to a subdomain of the Upper-Rhine aquifer (geometry, boundary conditions, climatic data, measured piezometric heads over time in several wells).

GSA shows that the simultaneous calibration of recharge and flow parameters is possible if the calibration is performed over at least one year. It provides also the valuable information of the sensitivity versus time, depending on the aquifer inertia and climatic conditions. Typically, piezometric heads are sensitive to flow parameters when recharge is negligible (summer time) and are more sensitive to recharge in winter time.

Our work shows also that the GSA method in conjunction with the PCE technique can provide practical guidance for groundwater resources survey.