

ABSTRACT

Characterization of climatic and geomorphologic forcings of the last five million years and modelling of their effects on a complex aquifer system, the Paris Basin.

The recent evolution of sedimentary basins depends upon a wide range of natural processes, primarily driven by climate and geomorphologic variations. From a hydrodynamic point of view, many changes occurred in the recharge due to past climate oscillations and in boundary conditions because of sea-level variations, river incision, general uplift, etc. It is therefore relevant to determine their implications on groundwater systems and to explore the possibility that the resulting significant changes in the past flow pattern may still have an impact on the present status of the system, which would thus not be in steady state as generally assumed. Here we investigate the response of the Paris Basin aquifer system to variations in hydrodynamic boundary conditions induced by climate and geodynamic changes over the last five million years (My), trying to determine how long the system could keep the memory of these past changes. To this end, a three-dimensional transient modelling of the multi-layered Paris Basin groundwater system has been developed using the code NEWSAM (Paris School of Mines). The geometry and the distribution of the hydrodynamical parameters derive from previous studies on a basin model, NEWBAS (Paris School of Mines), built to simulate the 248 My geological history of the Paris Basin.

To reconstruct the changes in the forcings of the model with time, the approach was to develop separate models of i) the geomorphologic evolution of the Paris Basin and ii) its paleoclimate. Firstly, geomorphologic changes are deduced from digital elevation model analysis, which allows to measure both incision rates in stream channels since approximately 1 My and the average uplift rate in the basin due to the Alpine orogeny. Secondly, climate forcing results from a suite of palaeoclimate modelling experiments using the LMDZ atmospheric general circulation model (Pierre Simon Laplace Institute) with a refined spatial resolution centered on Paris, for three representative regimes: the present, the extreme cold of the Last Glacial Maximum (LGM, 21 ky) and the Mid-Pliocene warm period (~3 My). The temporal evolution of climate variables is based on the fluctuation in oxygen isotopes recorded in a deep ocean core (ODP 659), which determines the division of the Plio-Pleistocene epoch into subperiods. Mean properties of the climate system for each phase are extrapolated from simple reparameterizations of the three simulations and translated into net recharge using a distributed soil balance reservoir model, MODSUR (Paris School of Mines). Simulated rates of groundwater recharge are eventually combined with temporal fluctuations derived from the geologic record in sea-level, in the occurrence of permafrost and in uplift and incision rates to specify boundary conditions for the computational model of groundwater flow in the basin.

Attempts at validating the simulated climate variables with pollen-based data over Europe indicate an underestimation of both cooling and precipitation during the LGM whereas Pliocene temperature results compare well with climate reconstructions, and even better when vegetation changes are included in experiments. To assess the impact of using high-resolution models on simulated climate sensitivity, three approaches to obtain a spatial resolution of about 60 km over the European region have been compared under LGM conditions. Model resolution cannot account for the discrepancy between model results and data, although the precipitation pattern is reproduced with a generally better accuracy by increasing the resolution. However precipitation biases encountered in the Pliocene simulation are in the range of their low-resolution counterpart responses.

The transient calculations simulate the evolution of piezometric heads in the system over the last 5 My. Superficial aquifers adjust quickly to perturbations while boundary-induced transient effects are suggested in aquitards and deep aquifers as well as evidence of cross formational flow direction inversion. Results clearly show that the system is not at equilibrium at present and that it would require a few tens of thousands years to reach steady state, depending on hydrodynamic properties and forcing scenarios. Sensitivity analysis illustrates the important causes of the persistence of transient effects and in particular, the largest influence of recharge variations, due to permafrost.