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# Spatio-temporal groundwater recharge assessment using a lumped-parameter distributed model of the unsaturated zone (pyEARTH-2D)

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Numerical flow models are nowadays a powerful and widely used tool for groundwater management. Their reliability requires both an accurate physical representation of an aquifer system and appropriate boundary conditions. While the hydraulic parameters like hydraulic conductivity (K) and storativity (S) are spatially dependent and time invariant, groundwater fluxes such as recharge (R), evapotranspiration from groundwater (ETg) and groundwater inflow/outflow (Qgw) can vary in both space and time. Multiplicity of combinations between parameters and fluxes leads to a non-uniqueness of model solutions which limits their reliability and forecasting capability.

We propose to constrain groundwater models at the catchment scale by the spatio-temporal assessment of fluxes in the unsaturated zone. Although the physically based models that involve the Darcy's law and the conservation of mass through the Richard's equation constitute the most appropriate tools for fluxes assessment in the unsaturated zone, they are computationally demanding and require a complex parameterization and boundary condition definition, which restricts their application to large and regional scales. We have thus chosen to develop and apply a lumped-parameter unsaturated zone model because it uses simplified representations of the physical processes and limits the number of parameters.

We present in this study the development and application of a spatio-temporal recharge model (pyEARTH-2D) coupled with the numerical flow model MODFLOW at the catchment scale. pyEARTH-2D is a lumped-parameter distributed (grid-based) model that shares the same spatial discretization of the MODFLOW model for coupling purpose. pyEARTH-2D solves the water balance in the topsoil layer using linear relations between fluxes and soil moisture on a daily basis. The partitioning of rainfall is done by taking into consideration interception, evapotranspiration, percolation, soil moisture storage and surface storage and runoff. The input driving forces (rainfall and potential evapotranspiration) and the calibration state variables (hydraulic heads, soil moisture) time series are obtained through Automatic Data Acquisition System (ADAS) monitoring network. Parameterization of the soil reservoir requires basic soil hydraulic properties (soil porosity, specific retention, wilting point, saturated hydraulic conductivity and thickness) that can be obtained by standard field survey and laboratory measurements in the different soil zones of the catchment. Data integration using a combination of techniques such as remote sensing and statistics are used to determine soil properties spatially. The transient calibration of the coupled models is typically done against: (i) soil moisture of the recharge model pyEARTH-2D; (ii) hydraulic heads of the MODFLOW groundwater model. The coupling of pyEARTH-2D and MODFLOW is done through dynamic link of the parameter estimation algorithm PEST in which the simultaneous calibration of both models takes place. For each iterative cycle, recharge output is implemented in the MODFLOW model while the depth of the water table computed by MODFLOW is returned back to pyEARTH-2D in the next time step.

The developed coupling procedure was tested in the Pisões (Portugal) and Sardon (Spain) catchments. In these two study case, the pyEARTH-2D and MODFLOW coupling approach solution was compared with the standard solution applying Recharge and Evapotranspiration packages of MODFLOW with regard to the goodness of fit and the similarity of the temporal trends between the simulated and observed hydraulic heads.

Current developments of the pyEARTH-2D recharge model focus towards: i) improving the depth-wise discretization and parametrization of the unsaturated zone to represent the several soil horizons (pyEARTH-q3D); ii) partitioning of subsurface fluxes into unsaturated and saturated zone components to be able to quantify groundwater uptake by plants and loss of groundwater by direct evaporation from water table.