Geophysical Research Abstracts
Vol. 14, EGU2012-6479-2, 2012
EGU General Assembly 2012

Preferential flow and mixing process in the chemical recharge in subsurface catchments: observations and modeling

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Shallow groundwater that develops on hillslopes is the main compartment in headwater catchments for flow and solute transport to rivers. Although spatial and temporal variations in its chemical composition are reported in the literature, there is no coherent description of the way these variations are organized, nor is there an accepted conceptual model for the recharge mechanisms and flows in the groundwater involved. We instrumented an intensive farming and subsurface dominant catchment located in Oceanic Western Europe (Kerbernez, Brittany, France), a headwater catchment included in the Observatory for Research on Environment AgrHyS (Agro-Hydro-System) and a part of the French Network of catchments for environmental research (SOERE RBV focused on the Critical Zone). These systems are strongly constrained by anthropogenic pressures (agriculture) and are characterized by a clear non-equilibrium status. A network of 42 nested piezometers was installed along a 200 m hillslope allowing water sampling along two transects in the permanent water table as well as in what we call the “fluctuating zone”, characterized by seasonal alternance of saturated and unsaturated conditions. Water composition was monitored at high frequency (weekly) over a 3-year period for major anion composition and over a one year period for detailed 15N, CFC, SF6 and other dissolved gases.

The results demonstrated that (i) the anionic composition in water table fluctuation zone varied significantly compared to deeper portions of the aquifer on the hillslope, confirming that this layer constitutes a main compartment for the mixing of new recharge water and old groundwater, (ii) seasonally, the variations of 15N and CFC are much higher during the recharge period than during the recession period, confirming the preferential flow during early recharge events, iii) variations of nitrate 15N and O18 composition was suggesting any significant denitrification process in the fluctuating zone, confirming the dominance of the mixing processes in the fluctuating zone, iv) deeper parts of the aquifer exhibited seasonal variations with structured hysteretic patterns, suggesting that mixing process also occurred at greater depths and v) these hysteretic patterns were dampered from upslope to downslope, indicating an increased influence of lateral flow downslope.

A first modeling approach has been tested adding to a convection-dispersion model a mobile-immobile model, representing a mixing process between the pre-recharge water and the recharge water, and therefore taken into account the mixing processes varying from the surface to depth.As of now, we can deduce from these results that the residence times calculated from end member approaches considering the groundwater as homogeneous lumped reservoir are likely to be highly underestimated. We can also dedude that the water sampled in the shallow groundwater during the first part of the recharge period is chemically different from the water sampled after. Instrumented observatories including spatial and temporal monitoring of the hillslope groundwater are required to understand the anthropogenic and environmental processes and their interactions, to model and predict the effect and the response time of such systems under different constraints.

This work is funded by AN-08-STRA-01 (National research Agency).

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