Geophysical Research Abstracts
Vol. 17, EGU2015-3856, 2015
EGU General Assembly 2015

Supplementing environmental isotopes with time series methods to date groundwater

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A popular method to estimate the transit time of groundwater is to fit the predictions of a lumped parameter model (LPM) to environmental isotope measurements. The fitting, or inverse modeling, procedure consists in rejecting all parameters (or parameter combinations for more complex LPMs) that exceeds a given error threshold. In many usual cases where this does not lead to a single acceptable solution, additional and independent data can prove useful to further eliminate some of the remaining solutions.
In the case study presented here, groundwater transit times have been estimated by combining tritium, temperature, and discharge measurements.
Tritium measurements from a series of contact springs draining the Luxembourg Sandstone aquifer were used to estimate the two parameters of an exponential piston flow model. The piston flow parameter gives the transit time of tritium through the thick unsaturated zone of the aquifer, while the exponential component corresponds to its mean transit time in the saturated zone. Due to the limited extent of the tritium time series and the fact that tritium activity has nearly returned to its background concentration, the solution of the inverse modeling was not unique.
The discharge measurements were then used to reduce the number of retained parameter combinations by estimating independently from tritium the transit time through the unsaturated and saturated zones. The former was calculated from the time lag between a time series of net annual recharge over ten years and the fluctuations in discharge over that same period, while the latter was calculated from the discharge recession during the dry season. Although both methods necessitate relatively long time series of at least a few years, they reduce dramatically the range of estimated transit times.
Another possibility is to use the temperature signal measured in spring water. The amplitude damping and its shift relatively to air temperature (which we used as proxy for the temperature of recharge water) is a function of soil depth, soil thermal properties, and aquifer transit time. Contrarily to the method using discharge, one complete year of temperature measurement is enough, but the calculated transit times are very sensitive to the soil depth parameter, whose value is not easy to estimate. Nevertheless, as for the discharge method, combining the tritium measurements with independent temperature measurements proved useful to constrain the estimated transit times.