Geophysical Research Abstracts, Vol. 8, 09187, 2006
SRef-ID: 1607-7962/gra/EGU06-A-09187

Groundwater age and environmental radioisotope response to deep water abstractions: the possibility of early warning, and the scope of process-oriented control

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Long-term threats to water quality arising from the exploitation of deep groundwaters at regional scale have been revealed by Seiler (1983, 2000); ways to tackle with them, relying on an early-warning system, have been proposed by Seiler and Lindner (1995), Seiler (2001), Ghergut et al. (2001).

Here, the possibility of early warning and of a process-oriented control for deep groundwater abstractions is examined anew. First, it is explained in terms of a time-scale contrast between the transport of 'polluting' and that of 'monitoring' species. Second, it is investigated numerically for two hydrogeologic situations, one with mild and one with marked permeability change over depth; the environmental-radioisotope response to deep water abstractions is predicted as a function of pumping rate, duration and depth, and of aquifer heterogeneity. Third, it is substantiated by a direct computation of groundwater age fields and of their unsteady evolution induced by deep water abstractions.

Early warning is possible because the concentrations of certain solute species present in the aquifer water and accessible to monitoring (like environmental radioisotopes) respond to a deep water abstraction long before the 'pollutant' species have reached the pumping depth. Process-oriented control is possible only as long as their concentration changes correlate unambiguously with the pumping rate or the cumulative amounts abstracted. The time scope of such process-oriented control can be deter-

mined by analyzing the IBVP for the transport of each species involved, which, in conjunction with the applied hydraulic stress, represents a coupled, linear perturbation problem for each species taken independently.

An intrinsic measure of the maximum-possible signals available for a process-oriented control (independent upon a particular solute's metering technique, detection accuracy and sensitivity) is provided by the direct computation of unsteady groundwater-age fields under exploitation conditions; there will also be characteristic age repartition density functions, as well as characteristic abstraction-induced shift patterns for the shallow aquifer layer, the confining layer and the deep (exploited) layer.

The time scope of a process-oriented control, before environmental-radioisotope responses under different pumping regimes approach a common plateau, is found to comprise at least 4-5 decades for aquifers with an average transport-effective porosity over 10%.

Concrete opportunities for applying this control tool are discussed with reference to a comprehensive monitoring program carried out by the BAYERISCHES LANDESAMT FÜR WASSERWIRTSCHAFT (Bavarian Water Resources Survey, Munich) for exploited deep aquifers in the Upper Freshwater Molasse.