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Parameter sensitivities for helium-4 accumulation in groundwater due to in-situ production in dual porosity aquifers

Torsten Lange (1), Thomas Graf (2), and Martin Sauter (1)

(1) Georg-August-Universität Göttingen, Geowissenschaftliches Zentrum Göttingen, Applied Geology, Goldschmidtstraße 3, 37077 Göttingen, Germany (tlange@gwdg.de), (2) Gottfried-Wilhelm-Leibnitz Universität, Department of Civil Engineering, Institute of Fluid Mechanics, Appelstrasse 9A, 30167 Hannover

The accumulation of ^{4}He in groundwater is a potential water age indicator if all sources and fluxes can be quantified sufficiently accurately. However, multi-porosity characteristics of aquifers like fractured sandstone or karstic limestone are well-known phenomena that distinctively affect the spatial distribution of flow velocities, the variation of flow paths, as well as the transport of ^{4}He. The impacts on the distribution of any tracer used for groundwater age estimation are crucial and were discovered by researchers very early. A good example for dual-porosity behaviour is chalk as it usually has a high primary porosity with low pore diameters, and minor secondary porosities like fractures and others. It is obvious that a tracer is being transported differently in a dual-porosity material than in unconsolidated aquifer material.

Due to their chemical inertness, noble gases like helium are valuable complementary environmental tracers in hydrogeological studies including processes of mixing and salinization, estimation of paleo-infiltration temperatures, characterization of deep circulating systems, detection of mantle degassing along fracture systems, or estimation of groundwater age. The most frequently applied noble gas tracer is helium with its two isotopes ^{3}He and ^{4}He. While ^{3}He is more related to a degassing primordial mantle source, ^{4}He is a stable daughter isotope from uranium and thorium decay taking place mainly within crustal rocks, and it accumulates in groundwater as a function of time. Because of the accumulation mechanism, ^{4}He is a potential tracer for estimation of groundwater age if the uranium and thorium concentration in the aquifer material is known. However, those two elements are common in most types of crustal rocks. The resulting crustal ^{4}He flux must be considered as potential second source that may overlay the in-situ aquifer production.

To better understand the mechanisms of in-situ ^{4}He accumulation in dual porosity aquifers depending on five aquifer parameters, a sensitivity analysis was conducted. From a geological 3D GoCAD model, a 2D cross section through a well field southwest of Jerusalem, Israel, was extracted, where helium isotope data already exist for several deep wells. The 2D meshes were also created in GoCAD and reformatted for HydroGeoSphere, the applied flow and transport simulator. Due to the long individual model run times and the expected monitoring demand, the process was automated in terms of batch software creating all input files, running the cases, and selecting the appropriate mesh (Peclet-criterion) and maximum time step (Courant- and Neumann-criterion). The sensitive parameters are matrix and fracture porosities, fracture space hydraulic conductivity and dispersivity, as well as the head gradient.

Within the chosen parameter ranges, the ^{4}He accumulation is dominantly sensitive to the head gradient. However, the chosen parameters have different units and scales, which has to be considered for the interpretation.