Geophysical Research Abstracts, Vol. 8, 06920, 2006
SRef-ID: 1607-7962/gra/EGU06-A-06920

Experimental Study of Flow and Solute Transport in the Unsaturated Zone of Karst Rock in Slovenia

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The purpose of the research was to study solute (pollutants) transport in the unsaturated zone of fractured and karstified rocks, since these rocks are important aquifers in Slovenia. Fractured and karstified rocks are very heterogeneous and complex in terms of their geometry and void topology. This results in parameter variability and large uncertainties reflecting complicated hydraulic and chemical processes. Therefore, detailed studies of these processes have to be performed on a macro scale, at research field sites. Such research field site (RFS) was planned and equipped at Sinji Vrh in the western part of Slovenia. The experimental field site at Sinji Vrh, consists of surface set-up and a research tunnel, 15 m below the surface. Agrometeorological station and injection boreholes were installed on the surface. A special construction (1,5 m long segments) for collecting water seeping from the ceiling of the research tunnel was developed.

In the frame of Association of Tracer Hydrology project a multi-tracer experiment was performed at the RFS Sinji Vrh. Deuterium (90 %), potassium bromide, lithium chloride, zinc sulphate, sulfonic acid, pyranine, naphthionate, uranine, Sulforhodamine B, micro spheres and bacteriophages P22H5 were used as tracers. The aim of the tracer experiment was to quantify channel flow and fracture system flow, to determine different behaviour of conservative tracers and to study the infiltration and migration of health-hazardous human viruses, such as enteroviruses, in the unsaturated zone of fractured and karstified rock. A bacteriophage P22H5 was used as a possible model for the behaviour of health-hazardous viruses.

Tracers appeared immediately after the first significant precipitation event, respec-

tively four days after the injection. The most pronounced breakthrough appeared for uranine, deuterium and chlorine ions. This tracer experiment again confirmed the presence of fast flow through a channel above two sampling points (MP4 and MP5), where the response is rapid and the detected concentrations are high.

The peak value of δ2H (2455 ‰) and phages (3.1 E+9 pfu) appeared in the first sample after the injection in MP5 (four days after the injection and immediately after the first rain event). The highest deuterium value (306 ‰) in MP4 appeared after 21 days (18 days after the first rain event), whereas the highest phages amount in MP4 appeared after five days with the peak value of 1.1 E+8 pfu. It should be pointed out, that deuterium was injected at a high enough concentration in order to get significant concentration in fracture system, but this caused a high concentration in the fast pathways such as MP4 and MP5. In other sampling points, where water is flowing out of the rock with significantly lower hydraulic conductivity (fracture system), the δ2H composition reached up to -15 ‰. The smallest maximum was in the fracture system (-38 ‰) - the breakthrough was not obvious as it was close to the background variation (-30 to -60 ‰) in unsaturated zone water. The phages appeared at all sampling points within 22 days.

After the injection of tracers, they remain in the microfracture systems of the unsaturated zone and are rinsed by subsequent larger precipitation events even up to several years after the injection. The results from Sinji Vrh have shown that the unsaturated zone in the fractured and karstified rocks plays an important role in pollution retardation and storage. The rinsing of pollutants to deeper parts of the karst aquifer depends on the saturation rate of the soil and the unsaturated zone (precipitation events). The field experiments have shown different flow patterns depending on the fractured rock structure. In the research area some fast conduits (large fractures or faults) exist where water runs faster than in the total conductive part of the rock, as in the case of MP4 and MP5. Tracer delay in microfracture system areas was also observed.