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Non-invasive investigation of the saturated/unsaturated zone with magnetic resonance sounding – a field example at the testsite Fuhrberger Feld near Hannover, Germany

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Magnetic resonance sounding (MRS) is a non-invasive geophysical method for groundwater prospection that uses the principle of nuclear magnetic resonance (NMR) in the Earth's magnetic field. Its unique property distinct from other hydrogeophysical methods is the direct sensitivity to the amount of water, i.e. to the amount of ^{1}H nuclei in the subsurface. Because MRS is normally used to investigate the water content of the saturated zone and to characterize aquifer structures, the standard application is optimized for 1D-measurements in depths from several to several tens of meters. However, our investigations show that MRS has also the potential to contribute substantially to the study of groundwater recharge if the sensitivity of the method for the unsaturated zone and for the transition to the saturated zone is increased by using a modified measurement setup and adjusted interpretation schemes.

We conducted MRS test measurements with the focus on the very shallow subsurface in the range of some few decimeters down to the groundwater table in a depth of 3 m. The test site is located in the area Fuhrberger Feld about 30 km north-east of Hannover, Germany, which comprises an unconfined sandy aquifer of 20 to 30-m thickness. Previous studies have discovered the soil physical characteristics of the site with tension infiltrometer measurements and tracer irrigation experiments in the field, as well as with water retention measurements in the laboratory. In addition, several infiltration experiments with dye tracer were conducted and monitored with electrical resistivity tomography (ERT), tensiometers and TDR devices.

For the MRS measurements at the testsite, a serious challenge was the intense electromagnetic noise consisting of large spiky radio signals and harmonic components, respectively. A special combination of new processing techniques was developed to isolate and interpret the NMR signals with amplitudes of approximately 5 to 14 nV. The standard inversion of the MRS data shows the ground water table at the correct depth and furthermore, increased residual water in the topsoil, which is verified by the water retention measurements in the lab. However, the amount of water at shallow depth down to 30 cm is difficult to quantify and to allocate exactly in depth due to the limited resolution properties of the method in this depth range. A new inversion scheme that parameterizes the capillary fringe using the van-Genuchten model was applied to the data. These results are in good agreement with the laboratory measurements.

In order to develop MRS as a method for monitoring groundwater recharge processes, we combine hydraulic simulations and MRS forward modeling. Our numerical experiments suggest that the common MRS measurement scheme must be modified to enable faster repetitions, i.e., to resolve fast infiltration processes accordingly in time. For such modifications one must accept losses in the spatial resolution of the method. Compared to non-invasive ERT measurements with a 2D or 3D resolution in the decimeter range, the resolution properties of MRS are much worse. However, the direct sensitivity of the MRS method to the water content is an important benefit, whereas the quantification of water with ERT methods remains a serious problem. Therefore, we anticipate therefore that combining both methods could be the key for non-invasive monitoring of groundwater recharge in the future.