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Quantification of groundwater storage heterogeneity in a hard rock aquifer using near-surface ERT and IP geophysical techniques

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Characterization of groundwater aquifers plays an important role in addressing the increasing demand for freshwater and low carbon energy. Specifically, hard rock aquifers that have been neglected in the past due to their overall low productivity, are increasingly recognised as important aquifers for local water supplies, sustaining environmental flows, and low enthalpy geothermal resources. Groundwater flow and, more so storage, in these aquifers are still poorly understood creating a necessity to quantify their properties and role in sustaining human and ecosystem needs. This study aims to quantify groundwater storage properties, and their spatial variability, in weathered/fractured hard rock aquifers using near-surface geophysical techniques and further evaluate the associated uncertainties. To do so, we analysed 2D electrical resistivity tomography (ERT) and induced polarization (IP) data in combination with 1D magnetic resonance sounding (MRS) and borehole geophysical logging from a metamorphic rock catchment in Gortinlieve, Ireland. The geophysical data comprised a challenging dataset that includes information at different resolution scales: a low-resolution ERT profile of 1,3 km of length, a high-resolution ERT+IP profile of 70 m of length, 8 MRS logs distributed along the study area, borehole logs (gamma ray, temperature and caliper) and petrological analysis at borehole locations. Aquifers storativity data derived from application of petrophysical model to the geophysical data showed good accuracy and reasonable uncertainty of estimated properties. ERT porosities derived from Archie´s model revealed that this model overestimates the porosity for the study site whereas estimates derived from the Waxman & Smits (WS) model, which accounts for the influence of the cation exchange capacity (CEC) of clay minerals on the ERT measurements, were closer to specific yield values obtained from pumping test in boreholes, MRS water content estimates and the typical ranges of hard rock aquifers. The superiority of WS over Archie demonstrated that the clay content cannot be neglected when characterizing storage properties in weathered/fractured basement rock aquifers. Water content profiles from MRS corroborated the results with a particularly good match at three locations across the study area characterised by deep weathering/fracturing associated with regional fracture zones. Results demonstrated that the methodology provides a reasonable estimate of storage heterogeneity which is consistent with weathering/fracturing patterns as described in accepted conceptual models of hard rock aquifers. To further challenge the ERT porosity models, we tested an alternative approach based on the differential effective medium (DEM) theory applied to time-domain IP data to recover CEC and porosity tomograms. Preliminary results show promise, through yielding porosity values close to both 2D WS porosities and 1D MRS water contents and, importantly, the approach may provide a

mean to bypass the requirement for having direct clay data of the study site. Taken together, the results confirmed that near-surface geophysical techniques are key instruments to assess groundwater conditions in hard rock aquifers and quantify the spatial heterogeneity of their storage properties at larger scales. The approach can be applied in similar hard rock environments affected by weathering and fracturing.