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Electromagnetic flowmeter applications for aquifer hydraulic characterization

Stefano Basirico' (1), Alberto Villa (1), Paolo Frattini (1), Giovanni Battista Crosta (1), and Alberto Godio (2)

(1) Universita' degli Studi di Milano - Bicocca, Dep. Scienze Geologiche e Geotecnologie, Milano, Italy (stefano.basirico@unimib.it, +39 02 6448 2047), (2) Dipartimento di Ingegneria del Territorio, dell'Ambiente e delle Geotecnologie - Politecnico di Torino (Italy),

Borehole flowmeter logs can provide information on direction and discharge of vertical flows, hydraulic conductivities of different aquifer intervals. Furthermore, they can give a valid support to the interpretation of environmental data (e.g. electrical conductivity, pH, temperature, dissolved oxygen) into aquifers and along each borehole, and to correctly design and analyse tracer tests for aquifer characterization.
We show the results for the application of electromagnetic flowmeter measurements in three case studies (Northern Italy). All the test sites are located in a plain area. The first case study concerns a complex aquifer, characterized by a chaotic sequence of gypsum-marls, where closely spaced boreholes have been drilled to design a remediation project. We performed both natural and forced gradient tests. The second is a single aquifer contaminated site by an oil blow out event for which a complete geophysical and hydrogeological characterization is available. The last one is a test site equipped by our department in a single highly stressed aquifer where three closely spaced boreholes have been used for a complete tracing test under "ambient" flow conditions.
At all the sites the analysis of ambient vertical flows within a borehole allows the identification of inflow/outflow zones. As an example at the first study site, we observed a large vertical ambient flow (up to 3 l/min), due to head differences between levels associated with highly permeable layers/fractures.
The collected data have been fundamental for a correct evaluation of observed changes in borehole environmental data. In fact, without the collected information on vertical flows, these changes could be misleading, compromising the hydrogeological site characterization.
A single-hole flowmeter analysis under stressed conditions (injection or pumping) can provide a high resolution vertical profile of hydraulic conductivity depending on the log sampling spacing.
By a cross-hole flowmeter analysis it is possible to check the hydraulic interconnections between the boreholes through a network of permeable layers.
Again, a complete understanding of ambient flows and interconnections provides the support for cross-hole tracer test design and evaluation. This has been experienced at different sites. In fact, flowmeter logs can provide the exact points for tracer injection and detection within the boreholes. Moreover, the water discharge at the tracer detection point can be measured allowing for a quantitative analysis of the tracer breakthrough curve and mass recovery. One clear example is presented for this type of analysis, showing how it can provide an index of reliability of the tracer test.
Finally, the detailed characterization of the aquifer system provided by the flowmeter alone or in conjunction with other techniques can support groundwater flow modelling and the design of effective clean-up strategies at contaminated sites.