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The characterization of a point bar-channel aquifer analogue: from geostatistical simulation to solute transport through hydrofacies connectivity

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Ground water flow and solute transport are controlled by the geological structure and the corresponding heterogeneity and anisotropy of the hydraulic conductivity (K) field. In alluvial aquifers, a complete interdisciplinary characterization of the reservoir is important for reliable predictions. The reconstruction of the subsurface heterogeneity cannot be limited to honor point (e.g., well stratigraphic logs) data, but should also account for the presence of connected high K hydrofacies, which might form preferential flow paths. To explore these concepts an aquifer analogue, at the scale of the point-bar/channel depositional element of a meandering river, was studied. The analogue, exposed in a gravel pit, belongs to the historical sediments of the terraced meandering valley of the Lambro River (Po plain, Northern Italy). The study has been conducted in five steps.

(1) Architectural and sedimentological modelling was based on 31 stratigraphic logs collected along five quarry faces (four in E-W direction and one in N-S direction) and a geophysical survey, whereas the hydrostratigraphical characterization was obtained by permeability analysis of 28 samples. Facies mapping was performed in the field and supported by the analysis of the photo-composition of the quarry faces to obtain the geometry, the hierarchy and the internal architecture of sedimentary bodies. Permeability measurements on undisturbed samples and estimates based on the grain-size distribution were compared with bibliography values and used to merge the facies into four hydrofacies: least permeable (very fine sand and silt-clay respectively from topmost channel-fill, silt/clay plugs, drapes and balls), low permeable (sand from point-bar and channel fill bedforms), medium permeable (sandy gravel e gravelly sand from point bars) and most permeable (lower part of lateral accreted units).

(2) For a test volume of $11.4\,\mathrm{m} \times 11.4\,\mathrm{m} \times 2.85\,\mathrm{m}$ 50 equiprobable simulations of the hydrofacies distribution have been obtained with SISIM (Sequential indicator simulation) and MPS (Multiple point simulation) on a grid of voxels of $20\,\mathrm{cm} \times 20\,\mathrm{cm} \times 5\,\mathrm{cm}$. Conditioning data have been extracted from the hydrofacies maps of two crossing quarry faces.

(3) The connectivity of the four simulated hydrofacies has been quantified with total and intrinsic indicators: the former measures the degree of connection within the entire volume, whereas the latter measures the degree of connection of a facies within itself and is therefore less dependent on the proportion of the facies in the total volume.

(4) Finite-difference modeling of groundwater flow has been applied to compute the equivalent hydraulic-conductivity tensor.

(5) Numerical experiments of convective transport of non-reactive solutes have been performed, in order to map the preferential flow paths and to compute the dispersion tensor with a Lagrangian approach and the longitudinal dispersion with an Eulerian approach.

The results show that a multidisciplinary approach permits to reproduce the heterogeneity of this aquifer analogue, so that the results (strength and weaknesses of different geostatistical simulation methods, relationship of connectivity indicators with flow and transport parameters, etc.) obtained for this case study can be generalized to aquifers characterized by similar geological situations.