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Laboratory device to investigate the heterogeneity's influence on the effective hydraulic conductivity

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Background

Groundwater flow and contaminant transport are strongly influenced by the aquifer's heterogeneity (Chao et al., 2000; Fernàndez-Garcia et al., 2004). Generally, the flow (and transport) variables, such as the effective conductivity K_{eff}, can be modelled as random space functions (RSFs) and determined by means of a self-consistent approximation (Severino, 2018). In particular, we aim at estimating the effective conductivity K_{eff} of a highly heterogeneous aquifer made of 12 different porous materials, whose K-values were experimentally measured.

Design of the experimental set up

A heterogeneous phreatic aquifer was built in the GMI Laboratory of the Department of Civil Engineering of the University of Calabria, inside a metal box (2 m x 2 m x 1 m). The thickness (0.35 m) of the aquifer was built by overlapping 7 different layers of 0.05 m, each consisting of 361 cells (19 x 19), with dimensions equal to 0.1 m x 0.1 m x 0.05 m. For each layer, each cell was filled with one of the 12 porous materials previously characterized in the lab, making the choice randomly. A central (pumping) well and 37 piezometers were located at different distances from the first according to a radial configuration.

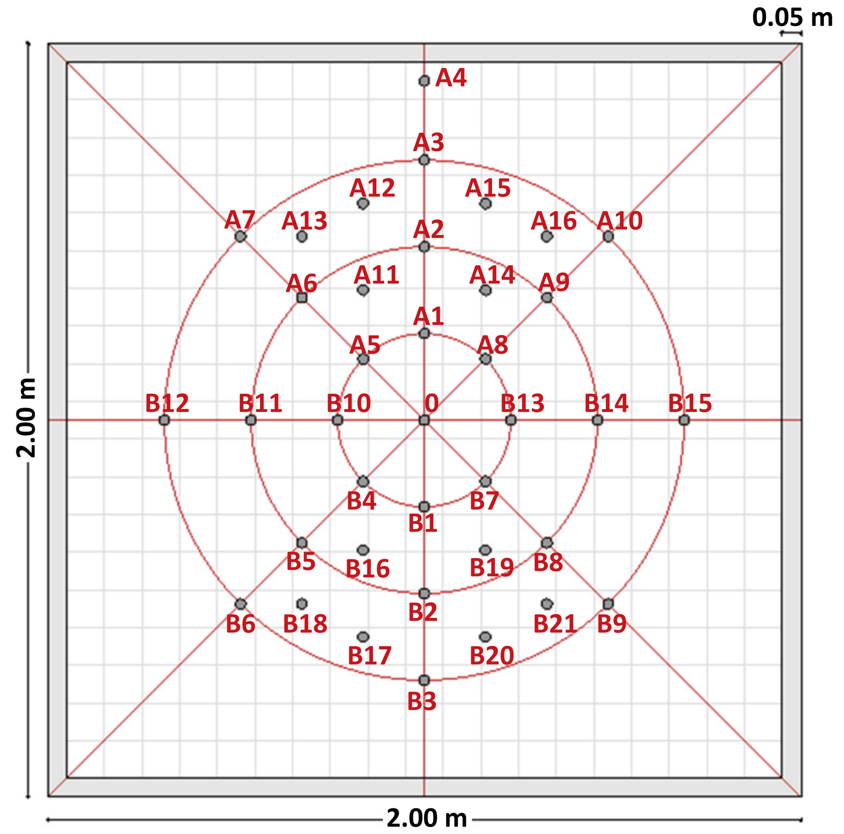

Figure 1: Planimetric scheme of the experimental device with the arrangement of the central well and of the various piezometers.

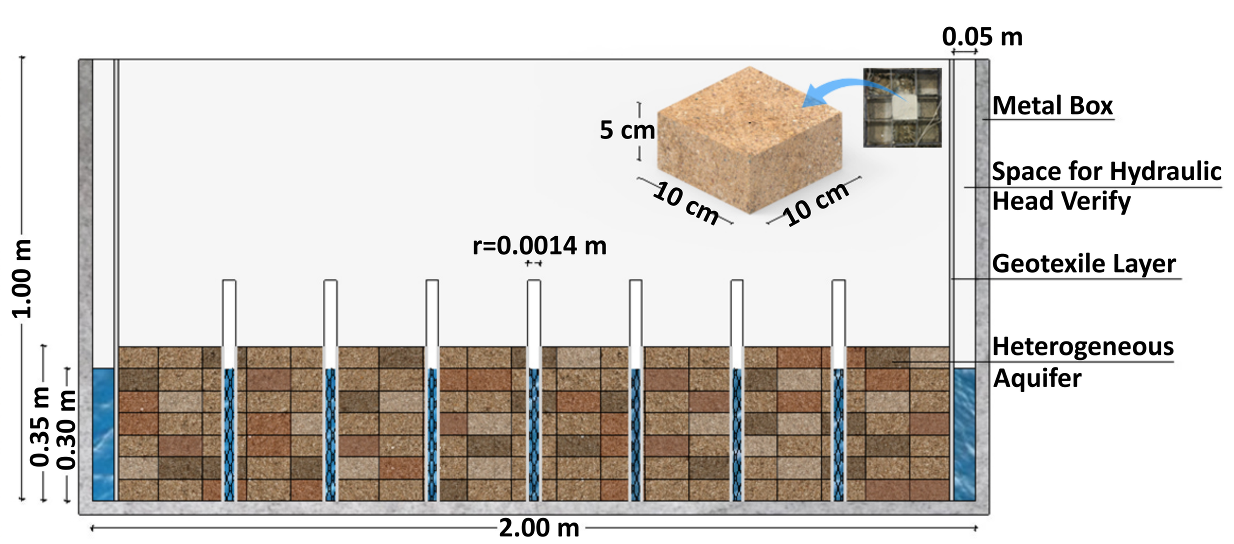

Figure 2: Section of the experimental device built in the laboratory and zoom of a generic filled cell of material.

The random distribution

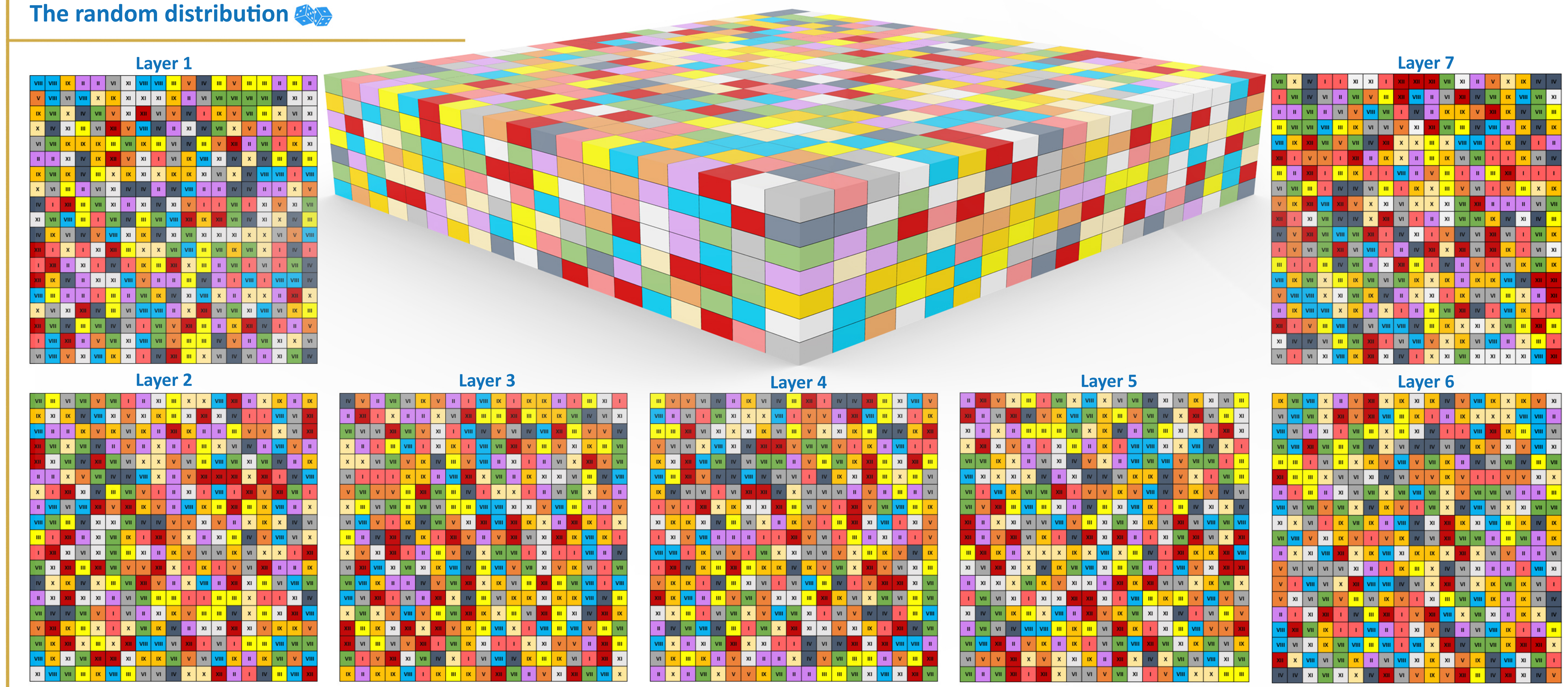

Figure 3: Layers and 3D view of the random distribution of the 12 porous materials constituting the artificial aquifer.

Characterization of materials

The 12 mixtures (TI, TII, TIII, TIV, TV, TVI, TVII, TVIII, TIX, TX, TXI, TXII) constituting the aquifer were obtained by combining different quantities of silt, sand, fine gravel and coarse gravel. In order to better characterize each material, the particle size curves were plotted and the hydraulic conductivity values were measured in the laboratory using flow cells as constant hydraulic head permeameters.

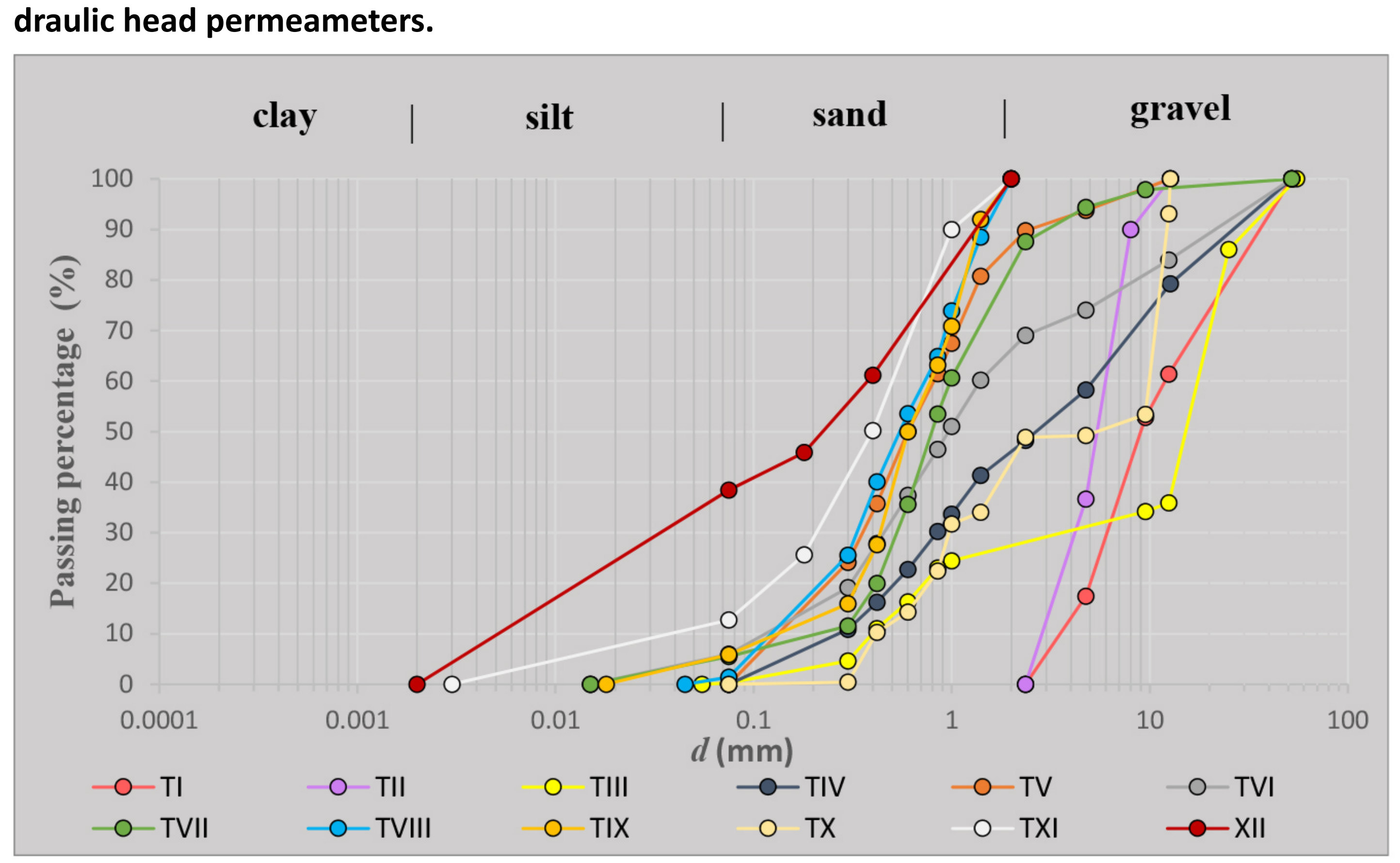

Figure 4: Particle size curves for each of the 12 mixtures constituting the aquifer.

Realization of the artificial aquifer

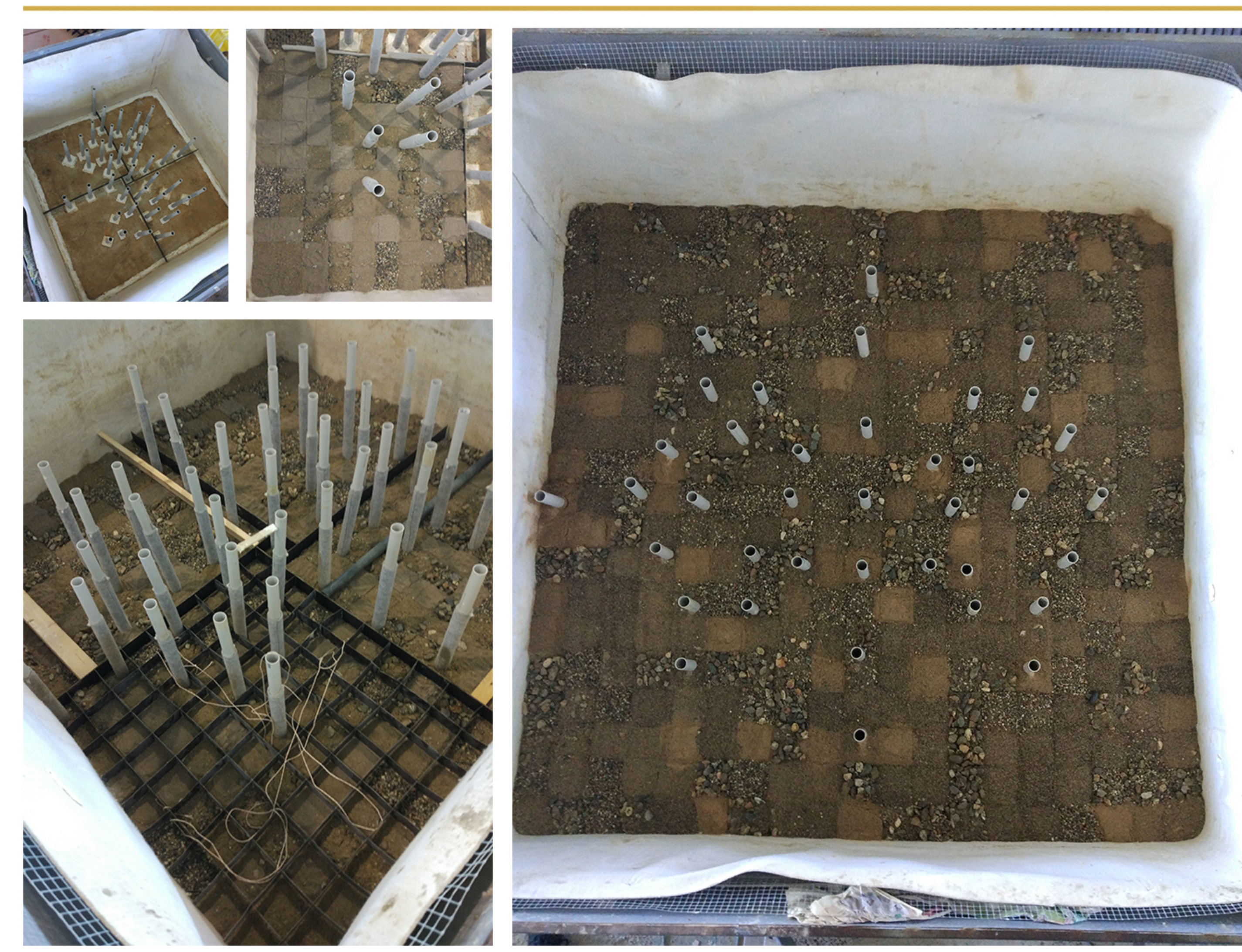

Figure 5: Photos of the construction phases and of the completed experimental device.

Results and discussion

A pumping test was carried out by a constant flow rate of 70 L/hour. The hydraulic head data, evaluated by using the Neuman method and verified in compliance with the boundary conditions, allowed an effective hydraulic conductivity value K_{eff} to be obtained. Afterwards, this value was compared with K values measured in laboratory by permeameter for each of the 12 porous media used to build the heterogeneous aquifer considered here and with the main statistical parameters related to them.

Figure 6: Measurements through permeameter and pumping test of the hydraulic conductivity values.

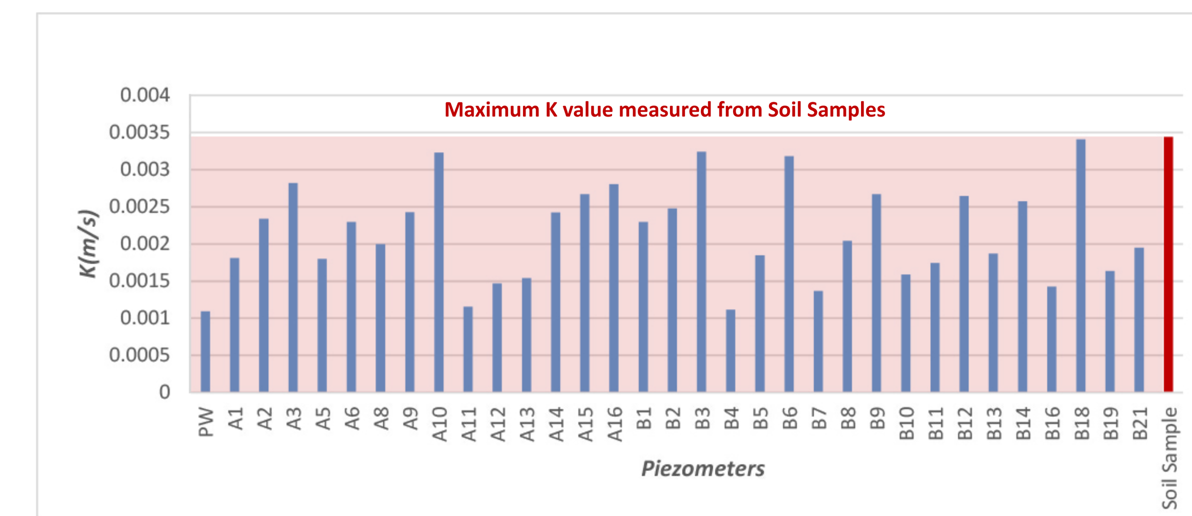

Figure 7: Comparison between the K values obtained from pumping test and the maximum k value misured from soil samples by mean of the permeameter.

Statistical parameters	Pumping test	Soil sample
N	33	12
min (m/s)	1.09×10^{-3}	2.66×10^{-6}
max (m/s)	3.41×10^{-3}	3.44×10^{-3}
mean (m/s)	2.15×10^{-3}	4.61×10^{-4}
VAR (m^2/s^2)	7.50×10^{-7}	9.46×10^{-7}
SD (m/s)	8.66×10^{-4}	9.73×10^{-4}
SE (m/s)	1.51×10^{-4}	2.81×10^{-4}
VC	0.402678	2.110
Kurtosis	-0.850616	9.478
Skewness	0.192493	3.053

Table 1: Statistical parameters of the K values obtained from pumping test and from the soil samples.

Figure 7 and Table 1 show that the values of hydraulic conductivity obtained from the pumping test are included in a range defined by the minimun and maximum values of conductivity obtained from the soil samples by mean of the permeameter. We found the K_{eff} value in a very good agreement with the expression obtained by the self-consistent approximation (Severino, 2018).

References:

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