GEOSTATISTICAL ANALYSIS OF PRIMARY AND SECONDARY DATA IN A SANDY AQUIFER AT MOL/DESSEL, BELGIUM

B. Rogiers[1,2], **D. Mallants**[1], **O. Batelaan**[2,3], **M. Gedeon**[1], **M. Huysmans**[2] **& A. Dassargues**[2,4]

[1]Institute for Environment, Health and Safety, Belgian Nuclear Research Centre (SCK•CEN), Boeretang 200, 2400 Mol, Belgium, brogiers@sckcen.be.

[2]Dept. of Earth and Environmental Sciences, K.U.Leuven, Celestijnenlaan 200e - bus 2410, 3001 Heverlee, Belgium.

[3]Dept. of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium.

[4]Dept. of Architecture, Geology, Environment and Civil Engineering (ArGEnCo), Université de Liège, B.52/3 Sart-Tilman, 4000 Liège, Belgium.

Abstract

In the framework of the disposal of short-lived low- and intermediate-level radioactive waste in a near-surface disposal facility in Dessel, Belgium, additional extensive site characterization has been performed in 2008. The gathered data now enclose 388 hydraulic conductivity measurements on samples of 8 cored boreholes. Secondary information as grain size analysis, porosity, and borehole geophysical parameters was also gathered. In addition, the geology of the study area has also been thoroughly characterized by a set of 178 cone penetration tests (CPTs) to approximate 50 m depth. This dataset allowed to refine the hydrostratigraphical model of the region. The existing groundwater model, based on large-scale effective hydraulic properties, was updated accordingly. The next step is a small-scale probabilistic approach 1) to validate the current existing deterministic groundwater models and 2) to support design for a monitoring network. In preparation for stochastic realizations of the subsurface, a geostatistical analysis of the available primary and secondary data is performed.

Relationships between the borehole logs and the hydraulic conductivity measurements are examined. The considered logs are the caliper, gamma ray (GR), a focused electrolog (Res_FEL), and long- and short spacing resistivity logs (Res_64, Res_16). These logs are continuous, and allow to get some information about the hydraulic conductivity at the depths that were not sampled. This is especially interesting for studying the heterogeneity of the different hydrogeological units and calculating a representative hydraulic conductivity for a geological unit over its entire thickness. The correlation coefficients between the logs and the hydraulic conductivity depend strongly on the considered geological formation. For certain hydrogeological units, the caliper, gamma ray and resistivity logs show a correlation coefficient around 0.6 - 0.7 (Table 1).

Structural analysis was performed for all the hydrogeological units together. Figure 1 shows the variograms and cross-variograms that are calculated using Cressie's robust variogram estimation (Cressie, 1993) after standardization of each hydrogeological unit. Spherical models are fitted,

and a kriging and co-kriging cross-validation is performed. The method used is k-fold cross-validation with k ≈ n/2 (with n equal to the number of data points) in a way that the (almost) co-located horizontal and vertical K-measurements were always left out together (leave-two-out cross-validation). The correlation coefficient between observed and predicted values from the cross-validation increases from 0.68 for kriging to 0.77 for co-kriging with all the available secondary information.

Table 1: *Correlation coefficients between logarithmic hydraulic conductivity and secondary parameters for the different hydrogeological units. (r: correlation coefficient, n: number of points)*

Secondary parameters	Hydrogeological units								Total	
	Quaternary		Mol (Upper)		Mol (Lower)		Kasterlee			
	r	n	r	n	r	n	r	n	r	n
Caliper	*-0.27*	*12*	*0.77*	*39*	*0.22*	*68*	*0.44*	*25*	**0.42**	**144**
Res_FEL	*0.04*	*13*	*0.45*	*39*	*0.09*	*68*	*0.61*	*25*	**0.28**	**145**
GR_cps	*0.41*	*12*	*-0.59*	*37*	*-0.13*	*68*	*-0.47*	*25*	**-0.42**	**142**
Res_16	-	-	*0.67*	*28*	*0.05*	*68*	*0.44*	*25*	**0.34**	**123**
Res_64	-	-	*0.38*	*30*	*-0.33*	*68*	*-0.32*	*25*	**0.10**	**125**

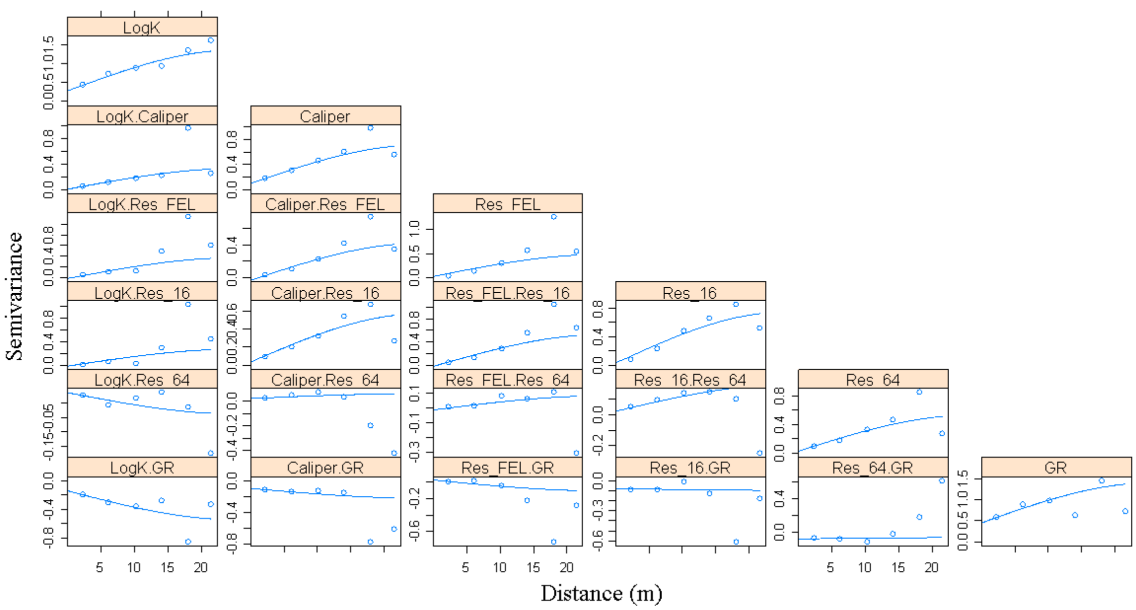

Figure 1: *Experimental variograms and cross-variograms of the hydraulic conductivity and the different borehole log parameters and their fitted spherical models***.**

Subsequently, co-kriging is used to predict continuous vertical profiles of the hydraulic conductivity. This allows to detect small contrasting layers which might have been overlooked by the discrete sampling of the cores, and are hence not represented in the hydraulic conductivity measurements. The presence of contrasting layers is checked by visual inspection of the borehole

cores. Effective K-values are finally calculated for each hydrostratigraphical layer from these continuous profiles, and compared with the values obtained from the discrete sampling.
Another source of information is the CPT campaign. This data covers the entire area of interest, and would hence be a very usefull source of secondary information. The use of CPTs in predicting hydraulic conductivity has already been demonstrated for instance by Tillmann et al. (2008). They used several CPT parameters (including gamma activity, bulk and matrix density and water content) to predict grain size distributions and calculate the hydraulic conductivity from those. The parameters recorded in the current CPT campaign comprise the point resistance and the side resistance, which only allows to search for an empirical relationship with hydrogeologic parameters. The proportion of point to side resistance is called the friction ratio, and is commonly used to make a distinction between different lithological units. Because of the mechanical character of these measurements, one might indeed expect a relationship with the hydraulic conductivity. Unfortunately, the CPTs and boreholes are not co-located. The horizontal distance between the two sources of information is between 7 m and 350 m. Despite this drawback, it is however still possible to find a relationship. The point resistance shows the highest correlation with the logarithmic hydraulic conductivity. The fitted function has an R-squared of 0.73 (Figure 2, left). The demonstrated relationship is however only valid over a broad range of hydraulic conductivity values (-7.5 to -4.5; 3 orders of magnitude). This is probably due to the distance between the CPTs and boreholes. Additional CPTs close to the boreholes are necessary to be able to infer small-scale changes. A horizontal pseudo cross semivariogram (as defined in Goovaerts, 1997) is finally calculated for the boreholes and their neighbouring CPTs (Figure 2, right).

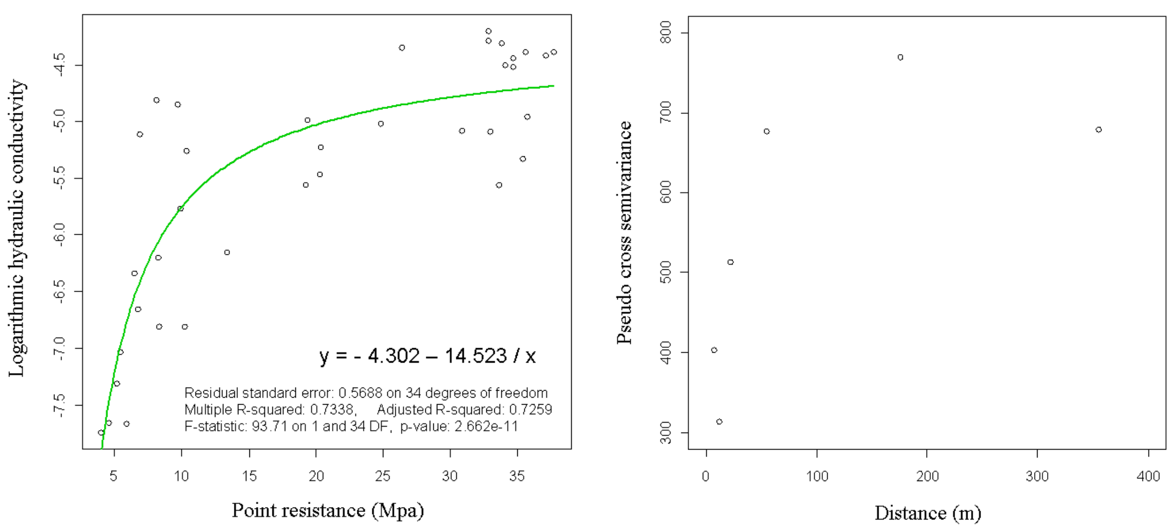

Figure 2: *CPT point resistance and logarithm of the hydraulic conductivity. Left: Scatter plot and fit. Right: Pseudo cross semivariogram***.**

Currently, only vertical information is gathered based on the vertical data profiles. Additional sampling and measurements will be performed in the future to provide information of the horizontal spatial variance and to optimize the use of secondary data. Together with the current results, these will serve as the basis for conditional stochastic simulation of groundwater flow and contaminant transport.

References

Goovaerts P (1997) Geostatistics for Natural Resources Evaluation. Oxford University Press.

Cressie N (1993) Statistics for Spatial Data. Wiley.

Tillmann A, Englert A, Nyari Z, Fejes I, Vanderborght J, Vereecken H (2008) Characterization of subsoil heterogeneity, estimation of grain size distribution and hydraulic conductivity at the Krauthausen test site using Cone Penetration Test. Journal of contaminant hydrology 95(1-2): 57-75.