Application of multi-scale variography for inferring the spatial variability of the hydraulic conductivity of a sandy aquifer

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Introduction

In the framework of the disposal of short-lived low- and intermediate-level radioactive waste in a near-surface disposal facility in Dessel (Belgium), extensive characterization of the hydraulic conductivity (*K*) in the shallow Neogene aquifer has been performed, from the cm- to the km-scale.
In this work, we aim to quantify the spatial variability revealed by the different datasets across different scales, and check their compatibility.

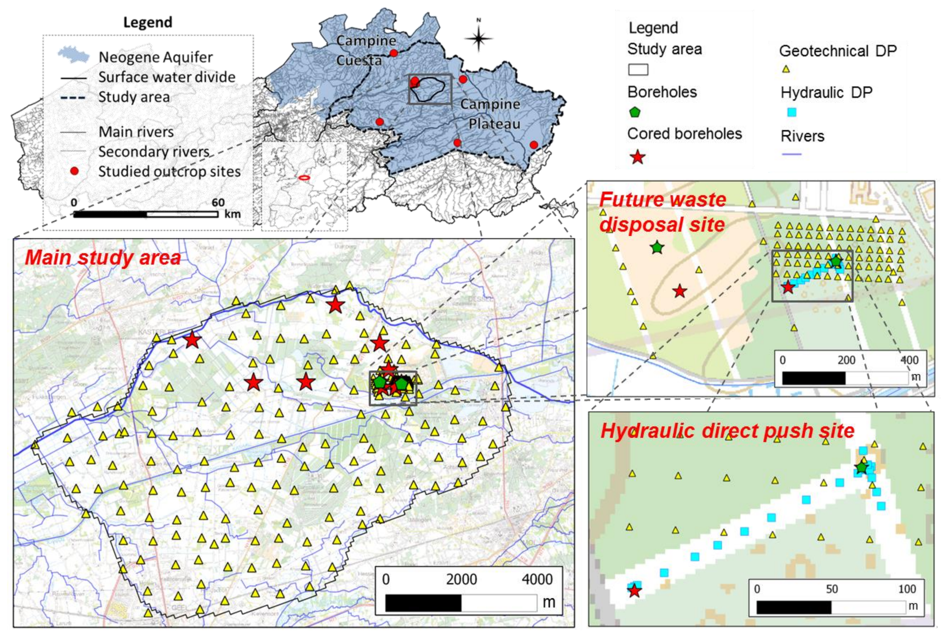

Fig 1: Study area and site investigation points.

Methods

Different methods were used to characterize *K* at different scales of investigation (either direct measurements, calibrated relative *K* values, or *K* estimates from secondary data) for an upper aquifer, aquitard and lower aquifer:

Cored boreholes

- ✓ > 400 lab *K* measurements (Mallants *et al.* 2000, Beerten *et al.* 2010)
- ✓ > 5000 air permeability measurements (Rogiers *et al.* 2014a)
- ✓ Numerous grain size analyses (Rogiers *et al.* 2012)

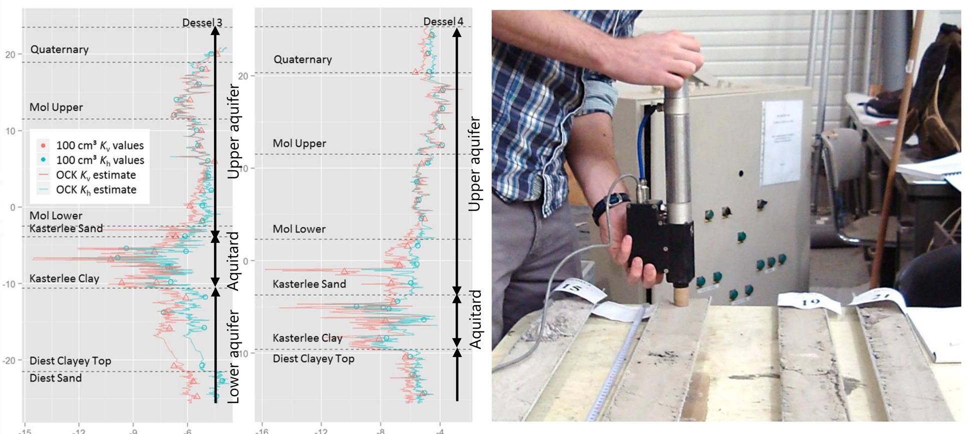

Fig 2: Example K logs for two boreholes, and illustration of the borehole core air permeameter measurements.

Geotechnic & hydraulic direct push tests

- ✓ 17 direct push injections loggings
- ✓ 6 hydraulic profiling tool logs
- ✓ 6 direct push slug tests (Vienken *et al.* 2012)
- ✓ > 250 cone penetration tests (CPTs) (Rogiers *et al.* 2014b)
- ✓ > 100 dissipation tests (interpreted using Teh & Houlsby 1991)

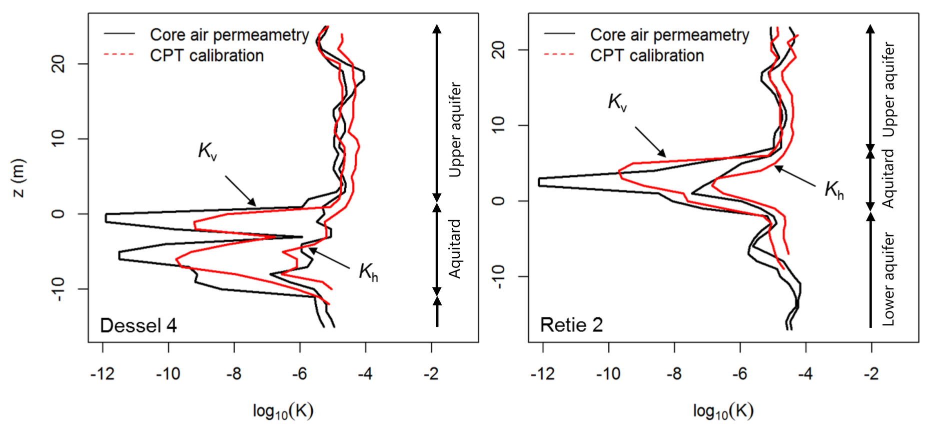

Fig 3: Two examples of CPT-based K estimate logs.

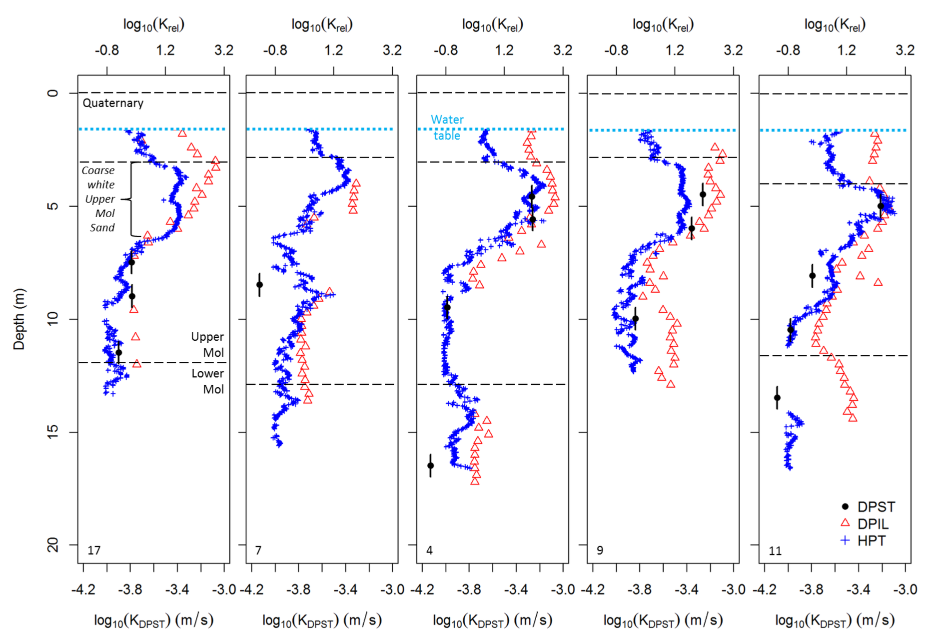

Fig 4: Data of 5 hydraulic direct push tests (upper aquifer).

Outcrop analogue studies

- ✓ > 1200 air permeability measurements on a selection of 15 outcrop analogues of the aquifer sediments, of which most were performed on regular grids, suitable for variographical analysis (Rogiers *et al.* 2013)

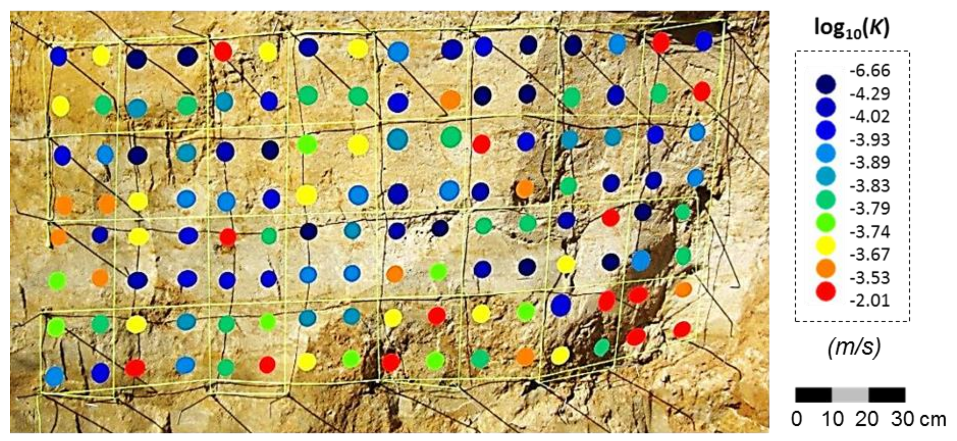

Fig 5: Air permeability-based K estimates at a Kasterlee Sands outcrop (upper aquifer).

Two-point experimental variography was performed to quantify spatial variability for the upper aquifer, aquitard and lower aquifer within the Neogene aquifer.

Results

Upper aquifer

- ✓ Spatial variability of the CPT and borehole data correspond well.
- ✓ Hydraulic direct push data (Mol Sands) corresponds well to the Mol Sands outcrop data. Both represent the most homogeneous unit in the area.
- ✓ The upper aquifer clearly consists of different units going from heterogeneous to very homogeneous sands. This is clearly illustrated by the different outcrop datasets.
- ✓ The experimental variograms including different units (CPTs, boreholes, grain size) are somewhere in between.

Aquitard

- ✓ The outcrop and CPT data are very compatible, and correspond in a lesser degree with the borehole data as well.
- ✓ The grain size and dissipation tests data are considered less reliable, though they show some spatial correlation.
- ✓ Nuggets and sills of the variogram envelopes are different in this case because of the pronounced layered structure of this unit.

Lower aquifer

- ✓ The CPT data lies somewhere between the borehole and grain size data.
- ✓ Difficult to detect horizontal spatial correlation.
- ✓ The representativity of the outcrop can be questioned as it seems to be too heterogeneous for such small lag distances.

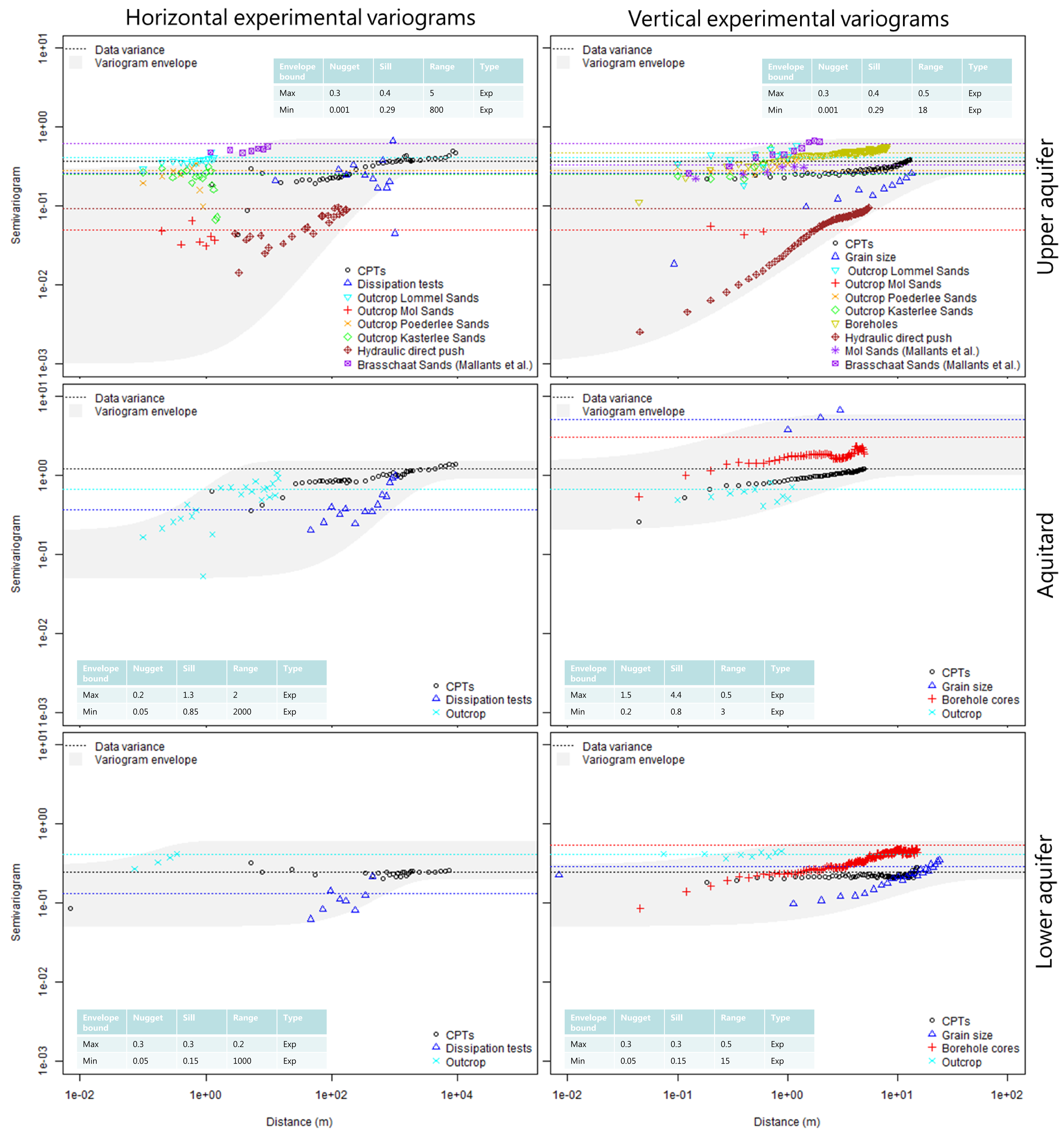

Fig 6: Multi-scale variography.

Conclusions

Overall the CPT, borehole and grain size data seem to be compatible and show slightly different absolute semivariances.
The hydraulic direct push data confirm the homogeneity of the Mol Sands within the upper aquifer.
Dissipation test data is the least informative on spatial variability, and data of a single outcrop is not very representative for an aquifer unit.
It is clear that considerable uncertainty exists on *K* spatial variability, and that stationary units should be mapped, or non-stationary techniques should be used for modelling the studied sandy aquifer.

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