Air permeametry on outcrop analogues: a composite image of the Neogene aquifer, Belgium.

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- Methods
- Results
- Conclusions
Contents

- Introduction
  - Research context
  - Neogene aquifer
- Methods
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Research context

- Saturated hydraulic conductivity \( (K_s) \)
  - one of the most important parameters
  - determining groundwater flow and contaminant transport
  - in both unsaturated and saturated porous media

- In-situ \( K_s \) measurements
  - remain very complex and scale-dependent
  - air permeameters have being used effectively in the field as an indirect method to determine \( K_s \)

- Case study: Neogene aquifer, Belgium
  - important groundwater resource
  - subject to hydrogeological assessments in the framework of potential future disposal of radioactive waste
Neogene aquifer - Location
Neogene aquifer - Geology

- Coarse to fine sands
- Distinct clayey zones
Neogene aquifer – Selected outcrops

- Availability
- Accessibility
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- Introduction
- Methods
  - Air permeameter measurements
  - Validation in the lab
  - Numerical upscaling
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Air permeability measurements

- Tinyperm II
  air permeameter
  New England Research &
  Vindum Engineering 2011

- Equation from literature
  to convert $k_a$ to $K_s$
  Iversen et al 2003
Validation in the lab

- Kopecky ring samples of different lithologies
- Constant head permeameter tests
Numerical upscaling

- Derive one single K tensor with flow conservation
- Approaches
  - Permeameter-type setup
    - Prescribed head at in- and outflow boundaries
    - No-flow at parallel boundaries
  - Combination of 4 boundary condition setups
    - Prescribed head everywhere
    - 4 flow directions

\[
- \begin{bmatrix}
  \nabla h_x & 0 & \ldots & 0 \\
  0 & \nabla h_z & \ldots & 0 \\
  \ldots & \ldots & \ldots & \ldots \\
  0 & 0 & \ldots & \nabla h_x \\
\end{bmatrix}
\begin{bmatrix}
  K_{xx} \\
  K_{zz} \\
  K_{xz} \\
\end{bmatrix} =
\begin{bmatrix}
  \bar{q}_{x1} \\
  \bar{q}_{x2} \\
  \bar{q}_{x3} \\
\end{bmatrix}
\]

- e.g. Zhou et al 2010; Li et al 2011
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Air permeameter measurements

Quaternary

Pliocene

Miocene

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Air permeameter measurements

Quaternary

Pliocene

Miocene

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Air permeameter measurements – 2 examples

**Poederlee Sands**

**Diest Clayey Sands**
### Air permeameter measurements

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<thead>
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<th>ID</th>
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<th>log(_{10}(K_s)) (m/s)</th>
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<tr>
<td></td>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>a</td>
<td>Kleine Nete point bar sands</td>
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<td></td>
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<td>b</td>
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<tr>
<td>c</td>
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<td>f</td>
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<td>h</td>
<td>Bottom Poederlee Formation 2</td>
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<td>Hukkelberg stratigraphical boundary</td>
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<tr>
<td>j</td>
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<td>k</td>
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<tr>
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<tr>
<td>o</td>
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Validation in the lab

R² = 0.92

Line of perfect agreement
Numerical upscaling – 2 examples

Poederlee Sands

Diest Clayey Sands
## Numerical upscaling

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<th>Permeameter setup</th>
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<td>log$<em>{10}(K</em>{xx})$</td>
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<td>-3.86</td>
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</tbody>
</table>
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Conclusions

- A handheld air permeameter is an efficient tool to characterise hydraulic conductivity
- It offers access to spatial variability on scales that are not feasible by classical core-based techniques
- Validation shows that the $K_s$ estimates are within one order of magnitude from the laboratory analyses results
- Complex stratigraphical settings can be effectively characterised if outcrops of the different components are available
Acknowledgements

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- Sibelco and Terca Nova are acknowledged for the permission to access their quarries. Via Kempen is acknowledged for the permission to access the Kempense Noord-Zuidverbinding road construction yard.
Centimeter-scale secondary information on hydraulic conductivity using a hand-held air permeameter on borehole cores

Introduction

- Saturated hydraulic conductivity ($K_z$)
- One of the most important parameters
- Determining groundwater flow and contaminant transport
- Both natural and constructed porous media
- Sensitivity analysis of $K_z$ is key to obtaining effective transport parameters and explaining $K_z$ measurements or inverse estimates at the larger scale
- Use of borehole cores is common at McDonald's, Belgium (Fig. 1); EarthJet, Belgium (Fig. 1); and EarthJet, Belgium (Fig. 1)
- Sensitivity of $K_z$ to lithological or mineralogical variations
- Two approaches: 1) measure $K_z$ from constant-head permeameter tests in the lab
- $K_z$ vs. $K_v$ for different sand samples
- T-Nielsen sand sample with distinct clay layers, with varying geological context

Methods

- Measurements
  - Use of the TinyFern II hand-held air permeameter device (Fig. 2a)
  - New measurement on the dry borehole core samples at 1 cm resolution, performed within 1 hour (Fig. 2b)
  - Equation of Liu et al. (2019) to convert air permeability to a $K_z$ estimate, since perfect non-destructive measurement of hydraulic conductivity in real-world scenarios cannot be expected
  - Additional measurements to quantify measurement error and operator influence (Fig. 4)
- Calibration with the lab $K_z$ measurements with a linearized-effects model, with random effects for both the randomly-numbered factors
- Statistical analysis
  - Comparing the lab measurements and air permeameter estimates after standardization
  - Fitting an intrinsic model of compression
- Results
  - The relative differences between the geophysical data correspond to the lab analysis observations
  - A systematic bias and smaller range of $K_z$ values is predicted using the equation from Liu et al. (2019)
  - Measurement error as well as the systematic bias introduced by the operator are small compared to the intrinsic $K_z$ variability (compare Figs. 3a and 3b)
  - The difference between lab measurements and air permeameter estimates is 0.74 and increases after calibration to 2.3 (see Fig. 2)
  - After standardization of the data, an initial model of compression was fitted to the experimental variances with two nested variance models (Fig. 6): One for a short range (2.4 m) and one for the larger range (12 m)
- Predictions are presented in Fig. 7, and show a clear shift in scale, as well as clear zones of lower $K_z$ values in the areas for which core samples were missing, important uncertainty remains, as indicated by the large confidence intervals
- Cross-validation results (Fig. 8)
  - Performance metrics: ME = 1.75; ME = 0.91; ME = 0.31
  - Performance coefficients: ME = 0.98; ME = 0.97; ME = 0.97
  - Especially the low $K_z$ range predictions are improved

Conclusions

- Hand-held air permeameter measurements on uncleaned borehole cores provide a very cost-effective way to obtain high-resolution $K_z$ data
- Even core data that have been lying open to air and have been subject of several investigations during a few years, provide useful information
- Without calibration, relative analysis $K_z$ estimates can be obtained, and equations from literature provide absolute $K_z$ estimates (e.g., Liu et al. 1995)
- Calibration with laboratory measurements improves the accuracy, and is recommended for core data and measurements of this scale

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References


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Thank you for your attention!

Questions?

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References