Are TRISOPLAST barriers sustainable?

Appendices
Are TRISOPLAST barriers sustainable?

An evaluation of old barriers in landfill caps

Appendices

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Stefan Melchior
Bernd Steinert

Alterra-report 541-appendices

Alterra, Green World Research, Wageningen, 2003
ABSTRACT


ISSN 1566-7197

This report can be ordered by paying € 47,- into bank account number 36 70 54 612 in the name of Alterra, Wageningen, the Netherlands, with reference to report 541-appendices. This amount is inclusive of VAT and postage.

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Soil Profile Description

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Methods


Soil Profiles

![Soil Profiles Diagram]

Legend:
- Rekultivierungsschicht: Reclamation layer
- Oberboden: Topsoil
- Unterboden: Subsoil
- Entwässerungsschicht: Drainage layer
- Trisoplast-Dichtung: Trisoplast sealing
- Kunststoff-Dichtungsbahn: Plastic sealing strip

Measurement: cm

WO-W6: Durchwurzelungsintensität nach AG Boden, 1994

EUROPEAN UNION
**location:** Landfill Rotterdam Europoort  
**profile no.:** EUR 1  
**relief/ exposition:** middle slope  
**vegetation:** gras, thistel, stinging nettle, clover  
**date:** 24.09.01  
**use of the area:** landfill cover  
**weather:** cloudy, 15°C  
**editor:** Steinert  
**page:** 3

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<td>-</td>
<td>-</td>
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<tr>
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<td>-</td>
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**location:** Landfill Rotterdam Europoort  
**profile no.:** EUR 2  
**relief/ exposition:** middle slope  
**vegetation:** gras, thistle, stinging nettle, clover  
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**editor:** Steinert  
**page:** 4

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<td>koh</td>
<td>Ld5</td>
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<td>at the top w6</td>
</tr>
<tr>
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<td>gsmS</td>
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<td>ein</td>
<td>Ld2</td>
<td>w4</td>
<td>h1</td>
<td>++</td>
<td>-</td>
<td>shells, on top of the geomembrane w6</td>
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<td>h4</td>
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<td>n.p.</td>
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<td>10-70</td>
<td>recultivation layer I</td>
<td>2,5YR3/2- sub-pol</td>
<td>Ld6</td>
<td>w4</td>
<td>h4</td>
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<td>n.p.</td>
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<td>70-110</td>
<td>recultivation layer II</td>
<td>10Y2,5/x pol</td>
<td>Ld5</td>
<td>w1</td>
<td>h6</td>
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<td>n.p.</td>
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<td>at the top rust coloured spots and areas</td>
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<td>geotextile</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<td></td>
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<td>drainage layer</td>
<td>7,5YR4/6 ein</td>
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<td>h0</td>
<td>++</td>
<td>n.p.</td>
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<td>no rust coloured spots</td>
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<tr>
<td>140-146</td>
<td>Trisoplast</td>
<td>2,5Y6/1 koh</td>
<td>Ld5</td>
<td>w0</td>
<td>h0</td>
<td>++</td>
<td>n.p.</td>
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<td>no rust coloured spots</td>
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<tr>
<td>&gt;146</td>
<td>subgrade</td>
<td>2,5Y5/1 ein</td>
<td>Ld3</td>
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<td>h0</td>
<td>++</td>
<td>n.p.</td>
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soil description according to AG Boden (1994), soil colour according to Munsell (1994), * colour test with α-α-Dipyridyl, n.p.: not provable
**location:** Landfill Almere  
**profile no.:** ALM 5  
**relief/ exposition:** upper slope, SSW  
**vegetation:** reed gras, thistels, docks, coltsfoot, mugwort  
**date:** 25.09.01  
**use of the area:** landfill cover  
**weather:** cloudy, rainy  
**editor:** Steinert  
**page:** 7

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<td>Ld5-</td>
<td>w4</td>
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<td>n.p.</td>
<td>peat, pieces of wood, shells, rubbish, organic clay, reduction characteristics,</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>n.p.</td>
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<td>Ld1</td>
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<td>h0</td>
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<td>n.p.</td>
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<td>h0</td>
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<td>n.p.</td>
<td>rust coloured spots</td>
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<tr>
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<td>mSgs</td>
<td>10YR6/3</td>
<td>ein</td>
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<td>h0</td>
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soil description according to AG Boden (1994), soil colour according to Munsel (1994), * colour test with α-α-Dipyridyl, n.p.: not provable
**location:** Landfill Soesterberg, Amersfoort  
**profile no.:** SOE6  
**relief/ exposition:** gentle slope, N  

**vegetation:** thistles, docks, diff. trees  
**use of the area:** landfill cover, forest plantation area  
**weather:** first foggy, later clear  
**date:** 26.09.01  
**editor:** Steinert  
**page:** 8

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<td>N2,5/x</td>
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<td>Ld3-4</td>
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<td>h3</td>
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<td>Ld3</td>
<td>w0</td>
<td>h0</td>
<td>+</td>
<td>n.p.</td>
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<td>w0</td>
<td>h2</td>
<td>+</td>
<td>n.p.</td>
<td>stones, rubble</td>
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Soil description according to AG Boden (1994), soil colour according to Munsel (1994), * colour test with α-α-Dipyridyl, n.p.: not provable
appendix 2

Photo documentation

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*Methods of excavation:* Removing the drainage sand from the geomembrane (profile 1, Landfill Rotterdam Europoort)
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appendix 3

Micromorphological survey of Trisoplast- and Drainage-Layers by Thin Sections

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Methods

- Taking undisturbed sample rings from the Trisoplast layer respectively the drainage layer
- Vacuum impregnation of the hole sample rings with liquid polyester over 3 month
- Preparation of thin sections through the middle of the samples
- Fixing the thin section on glass slides (48 mm x 60 mm)
- Examination of the thin sections under a microscope with photo tube
Figure 1: Profile 1, Landfill Rotterdam Europoort, Trisoplast layer, magnification: 50×

Figure 2: Detail of Fig. 1, magnification: 143×
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Methods

Method A (SEM scanning of freeze-dried Trisopast)
- Preparation of approx. 1 g moist Trisopast sample from the sample rings
- 3 min. shock freezing in liquid nitrogen
- 72 h freeze-drying in high vacuum freeze drying equipment (Christ Alpha1-2)
- Fixing the samples on SEM stubs
- 3 min. coating surface with gold in Plasma-Magnetron-Sputter (Edwards Sputter Coater S 150B)
- Scanning with SEM (LEO 1455 VP) in high vacuum

Method B (SEM scanning of moist Trisoplast)
- Preparation of pea sized moist Trisoplast samples from the sample rings
- Fixing the moist samples on SEM stubs
- Scanning with SEM (LEO 1455 VP) in low vacuum

Advantages of method A and disadvantages of method B: High magnifications and focus in the high vacuum modus possible

Disadvantages of method A and advantage of method B: Changing the surface of the clay component of Trisoplast by shock freezing and freeze-drying

Recommendation: Systematic improvement of sample preparation of method A
Figure 1: Profile 1, Landfill Rotterdam Europoort, freeze-dried Trisoplast sample

Figure 2: Profile 1, Landfill Rotterdam Europoort, detail of Fig. 1
Figure 3: Profile 1, Landfill Rotterdam Europoort, moist Trisoplast sample

Figure 4: Profile 1, Landfill Rotterdam Europoort, detail of Fig. 3
Figure 5: Profile 2, Landfill Rotterdam Europoort, freeze-dried Trisoplast sample

Figure 6: Profile 2, Landfill Rotterdam Europoort, detail of Fig. 5
Figure 7: Profile 2, Landfill Rotterdam Europoort, moist Trisoplast sample

Figure 8: Profile 2, Landfill Rotterdam Europoort, detail of Fig. 7
Figure 9: Profile 3, Protection pan, VOPAK petrol depot, Rotterdam, freeze-dried Trisoplast sample

Figure 10: Profile 3, Protection pan, VOPAK petrol depot, Rotterdam, detail of Fig. 9
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Figure 12: Profile 3, Protection pan, VOPAK petrol depot, Rotterdam, detail of Fig. 11
Figure 13: Profile 4, Landfill Almere, freeze-dried Trisoplast sample

Figure 14: Profile 4, Landfill Almere, detail of Fig. 13
Figure 15: Profile 4, Landfill Almere, moist Trisoplast sample

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Figure 17: Profile 5, Landfill Almere, freeze-dried Trisoplast sample

Figure 18: Profile 5, Landfill Almere, detail of Fig. 17
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Figure 21: Profile 6, Landfill Soesterberg, Amersford, moist Trisoplast sample

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Profile 6, Landfill Soesterberg, Amersford (SOE 6) 106
Methods

- Taking five undisturbed samples from each Trisoplast barrier respectively adjoining layer (sample cylinders: 4 cm high and 5 cm diameter)

- Wetting of the samples with capillary water on a wet sand layer over a period of about 6 weeks (water-level 0.5 cm below the samples resulting in a mean pressure head of 3 hPa within the samples)

- Dewatering of the samples in a pressure cell apparatus (Soilmoisture Equipment Corp., Santa Barbara, USA) in steps of 20 hPa, 60 hPa, 100 hPa, 300 hPa, 1,000 hPa, 3,000 hPa and 15,000 hPa over periods of about one day to two weeks each.

Details about the methods in:

Drainage Layer (Landfill Rotterdam Europoort, profile 1)

Individual samples
- Z207
- Z208
- Z218
- Z219
- Z226

Average and range

Matric suction head in hPa

Volumetric water content in %
Trisoplast Layer (Landfill Rotterdam Europoort, profile 1)

Individual samples
- Z203
- Z205
- Z206
- Z209
- Z211

Average and range

Matric suction head in hPa

Volumetric water content in %
Topsoil (Landfill Rotterdam Europoort, profile 2)

Individual samples:
- Z232
- Z236
- Z237
- Z238
- Z244

Average and range:

Volumetric water content in %

Matric suction head in hPa

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Trisoplast Layer (Landfill Rotterdam Europoort, profile 2)

- **Individual samples**
  - Z207
  - Z210
  - Z216
  - Z225
  - Z228

- **Average and range**

<table>
<thead>
<tr>
<th>Matric suction head in hPa</th>
<th>Volumetric water content in %</th>
</tr>
</thead>
<tbody>
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<tr>
<td>10</td>
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<td>100</td>
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<tr>
<td>1000</td>
<td>20</td>
</tr>
<tr>
<td>10000</td>
<td>10</td>
</tr>
</tbody>
</table>

Average and range values are shown with error bars.
Soil Water Retention

Trisoplast Layer
(Protection pan, VOPAK petrol depot, Rotterdam, profile 3)

Individual samples
- Z201
- Z204
- Z214
- Z223
- Z242

Average and range

Matric suction head in hPa

Volumetric water content in %
Drainage Layer (Landfill Almere, profile 4)

Individual samples
- Z230
- Z239
- Z245
- Z258
- Z295

Average and range
Soil Water Retention

Trisoplast Layer (Landfill Almere, profile 4)

Individual samples
- Z241
- Z246
- Z248
- Z282
- Z290

Average and range

Matric suction head in hPa

Volumetric water content in %
Subgrade (Landfill Almere, profile 4)

Individual samples
- Z279
- Z281
- Z283
- Z298
- Z300

Matric suction head in hPa

Volumetric water content in %

Average and range

Matric suction head in hPa

Volumetric water content in %
Soil Water Retention

Trisoplast Layer (Landfill Almere, profile 5)

Individual samples
- Z229
- Z252
- Z257
- Z258
- Z267

 Average and range

Volumetric water content in %

Matric suction head in hPa

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Trisoplast Layer (Landfill Soesterberg, Amersford, profile 6)

Individual samples:
- Z403
- Z404
- Z405
- Z407
- Z413

Average and range

Matric suction head in hPa
Subgrade (Landfill Soesterberg, Amersford, profile 6)

Individual samples
- Z215
- Z287
- Z291
- Z296
- Z406

Average and range

Volumetric water content in %

Matric suction head in hPa

Volumetric water content in %

Matric suction head in hPa
Protocol for the measurement of saturated hydraulic conductivity of undisturbed samples (Alterra, Wageningen, The Netherlands) and observed permeability

Background
The saturated hydraulic conductivity, permeability, \( K_{\text{sat}} \) is defined as the constant in Darcy’s law for fluid transport in porous media:

\[
\text{Flux} = \text{permeability (K}_{\text{sat}} \text{x hydraulic gradient (m}^3\text{m}^{-2}\text{s}^{-1})
\]

The gradient is defined as the difference in hydraulic head (m water column) at the top and base of the sample, divided by the thickness of the sample or the difference of hydraulic head measured at two different levels, divided by the distance between both levels.

The permeability can be determined by measuring the flux at a constant gradient (“constant head” method) or a gradually decreasing head (“falling head”). From the observations the permeability is calculated:

1. Constant head:

\[
K_{\text{sat}} = \frac{\text{flux (m/s)}}{\{(h + d) / d\}}
\]

2. Falling head:

\[
K_{\text{sat}} = \frac{\{a \times d\}}{\{A \times T\} \times \ln \left[\frac{(h_0 + d)}{(h_t + d)}\right]}
\]

Where:
- \( a \) cross section of burette (m\(^2\))
- \( A \) cross section of sample (m\(^2\))
- \( d \) thickness of sample (m)
- \( h_0 \) height water level in burette relative to top of sample at time zero (0) and \( T \) (t) respectively (m)
- \( T \) elapsed time between two observations of the water level (s)

Materials
Required materials:
(1) *measurement set up*
1. sample with filter material;
2. burette for measuring water level
3. valve to switch from supply from Mariotte bottle (constant head) to supply from burette (falling head);
4. Mariotte bottle. The venting tube assures a constant water pressure, irrespective of the water level inside of the bottle;
5. Zero-level (reference);
6. Water level at constant head measurement
7. Vessel for collecting outflow
8. Electronic balance for weighing outflow

![Diagram of experimental set up for the permeability measurement](image)

*Fig. 1.6 Experimental set up for the permeability measurement*

(2) *Laboratory journal*
In this journal the following information has been written:
1. Sample code;
2. Sample date
3. Sample description (location of sampling, project number)
4. Name responsible person
5. Starting date of measurements
6. Readings + remarks
7. End date of measuring
8. List of all measurements + signature quality manager when approved
(3) Equipment for sampling of undisturbed sample

1. Spade
2. Sample ring, cutting ring, cover plates and clamps
3. Emballage material (plastic)
4. Gas heater for field applications
5. Pot + paraffin + spoon
6. Coarse sand / filter material

Sampling

Remove any soil and other materials at the sampling place down to the layer, which will be sampled. A working space of about one square meter is required. Smoothen the surface.

In the mean time put sufficient paraffin in the pot and heat it carefully (do not overheat!!)

Push the cutting ring as far as possible in the layer and remove sufficient material outside of the cutting ring. The idea is to cut a soil column. When the height of the column is sufficient, place the sample ring. A space of at least 1-cm should be left above the top of the soil column for the filter material. Centre the sample ring as to create a uniform space between soil column and sample ring. Fill the space with liquid paraffin. Avoid the inclusion of air!! Wait until the paraffin has regained its solid state. Remove sufficient soil as to cut out the sample.

When the sample is taken, fill the space on top of the sample with filter material and close the sample. Place the sample up side down and remove all excess granular material. Remove sufficient material to create a space of at least one-cm for filter material. Fill this space with filter material and close the sample. Transport the sample enwrapped in shock absorbing material.

Fig. 2.6 Cutting a soil column from a soil layers using the cutting ring
Permeability measurement

After installation of the sample in the set up (ambient temperature 20 centi-degrees) the test fluid is applied to the bottom of the sample (to avoid air entrapment). A constant head (1 m water column) is applied first, followed by measurements according to the falling head method. The date and time and level in the burette are recorded. Readings are done. Depending on the infiltration rate, after 24 hours the measurements are switched to the constant head method. When an outflow rate can be measured, only the constant head is applied. The permeability, $K_{sat}$ ($=\text{flux/gradient}$) is calculated and plotted. The measurements are to be continued until a zero-trend of the permeability is be observed. The trend is calculated from the last five calculated permeabilities through regression analysis and should be $0.0 \pm 0.01 \times 10^{-10} \text{ m.s}^{-1} \text{ day}^{-1}$. 

Fig. 3.6 Placing the sample ring and filling the empty space between soil column and sample ring with paraffin
Results

The results of the permeability calculations, based on the falling head approach, are listed in table 6.1a through d.

Table 6.1a Observed permeability of samples from the VBM-Maasvlakte (EUR1) site

<table>
<thead>
<tr>
<th>Elapsed time (day)</th>
<th>K-sat $1 \times 10^{-10}$ m/s</th>
<th>Elapsed time (day)</th>
<th>K-sat $1 \times 10^{-10}$ m/s</th>
<th>Elapsed time (day)</th>
<th>K-sat $1 \times 10^{-10}$ m/s</th>
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<tr>
<td>0.3</td>
<td>0.6796</td>
<td>19.2</td>
<td>0.4364</td>
<td>41.0</td>
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<td>4.2</td>
<td>0.8836</td>
<td>19.3</td>
<td>0.4852</td>
<td>42.0</td>
<td>0.2448</td>
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<tr>
<td>4.3</td>
<td>0.7889</td>
<td>25.3</td>
<td>0.5068</td>
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<td>5.2</td>
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<td>0.4927</td>
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<td>7.0</td>
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<td>0.3058</td>
<td>48.0</td>
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<td>7.2</td>
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Table 6.1b Observed permeability of samples from the VOPAK (VOP3)

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<tr>
<td>26.8</td>
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Table 6.1c Observed permeability of samples from the Almere (ALM4) site

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<th>Elapsed time (day)</th>
<th>K-sat $1 \times 10^{-10}$ m/s</th>
<th>Elapsed time (day)</th>
<th>K-sat $1 \times 10^{-10}$ m/s</th>
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<td>0.0696</td>
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<td>0.2239</td>
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<td>0.4361</td>
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<td>0.2422</td>
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<tr>
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<td>32.3</td>
<td>0.0371</td>
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<td>0.0296</td>
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<td>0.0840</td>
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<td>0.0395</td>
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Table 6.1d Observed permeability of samples from the Soesterberg (SOE6) site

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<tr>
<th>Elapsed time (day)</th>
<th>K-sat $1 \times 10^{-10}$ m/s</th>
<th>Elapsed time (day)</th>
<th>K-sat $1 \times 10^{-10}$ m/s</th>
<th>Elapsed time (day)</th>
<th>K-sat $1 \times 10^{-10}$ m/s</th>
</tr>
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<td>0.2708</td>
<td>41.0</td>
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<tr>
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<td>19.3</td>
<td>0.3528</td>
<td>42.0</td>
<td>0.2772</td>
</tr>
<tr>
<td>4.3</td>
<td>0.6684</td>
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<td>0.1287</td>
<td>46.3</td>
<td>0.0224</td>
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<td>0.1134</td>
<td>47.3</td>
<td>0.3390</td>
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<td>0.2944</td>
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<td>0.2861</td>
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<tr>
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<td>0.1695</td>
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<td>0.5426</td>
</tr>
<tr>
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<td>0.0558</td>
<td>53.3</td>
<td>0.0652</td>
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<tr>
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<td>0.0197</td>
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<td>0.0648</td>
<td>40.0</td>
<td>0.2346</td>
<td>60.3</td>
<td>0.1770</td>
</tr>
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</table>

At time 0 day, water is applied to the bottom of the sample. The sample itself is unsaturated, so likely relatively high gradients exist. The calculation procedure is based on the assumption of complete saturation and an outflow at a fixed level, which underestimates the actual gradient and overestimates the permeability. When, however saturation proceeds, the gradients become more or less equal to the assumed one and the calculated permeability reflects the real saturated permeability. The VOPAK sample was almost fully saturated at the beginning of the measurements, so initially the gradients are not elevated.
Chemical Analysis of Topsoil and Drainage Layer

Contents

Methods .......................... 116
Samples .......................... 116
Results profiles 2 and 4 .......... 117
Methods

- Taking disturbed samples
- Measuring pH-Value in water and CaCl₂-solution
- Measuring the ion concentration of Fe, Al and Mn after oxalat-and dithionit-extraction according to Schlichting, Blume & Stahr (1995): Bodenkundliches Praktikum.
- Measuring the total content of Fe, Al and Mn according to S7 DIN ISO 11466.

Samples

<table>
<thead>
<tr>
<th>profile</th>
<th>layer</th>
<th>sample no.</th>
<th>lab no.</th>
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<tbody>
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<td>topsoil</td>
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<td>11402</td>
</tr>
<tr>
<td>EUR 2</td>
<td>drainage layer</td>
<td>2/28</td>
<td>11403</td>
</tr>
<tr>
<td>ALM 4</td>
<td>drainage layer without rusty coloured areas</td>
<td>4/7</td>
<td>11404</td>
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<tr>
<td>ALM 4</td>
<td>rusty coloured areas of the drainage layer</td>
<td>4/9</td>
<td>11405</td>
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</tbody>
</table>
Melchior + Wittpohl  
Ingenieurgesellschaft  
Karlottenstraße 6  
D 20357 Hamburg  

18.12.2001  
Auftrag 7688  
Probeneingang 12.12.2001  

<table>
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<td>4/7</td>
<td>4/9</td>
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<td>pH-Wert H2O</td>
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<td>8.32</td>
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</tbody>
</table>

Extrakt  
| Oxalat Fe | 3523 | 517 | 518 | 2555 mg/kg |
| Dithionit Fe | 4644 | 800 | 548 | 2801 mg/kg |
| Oxalat Mn | 207 | 29 | 17 | 19 mg/kg |
| Dithionit Mn | 265 | 65 | 32 | 33 mg/kg |
| Oxalat Al | 252 | 41 | 36 | 32 mg/kg |
| Dithionit Al | 383 | 63 | 86 | 81 mg/kg |

Königswasser  
aufschluß S7 DIN ISO 11466  
| Fe | 16155 | 4248 | 2376 | 5318 mg/kg |
| Mn | 333 | 95 | 58 | 55 mg/kg |
| Al | 10286 | 2145 | 1703 | 1490 mg/kg |

Angaben bezogen auf TS  
Oxalatextrakt nach Schlichting Blume Stahr 1995  
Dithionitextrakt nach Schlichting Blume Stahr 1995  
Messung: ICP-OES DIN EN ISO 11885 (E22)
### Chemical composition of pore water

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample location</th>
<th>Layer code</th>
<th>pH</th>
<th>Tot. conc. (meq/l)</th>
<th>SAR</th>
<th>Cationen (mg/l)</th>
<th>Anions (meq/l)</th>
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</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Ca</td>
<td>K</td>
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<td>120.35</td>
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<td>0.68</td>
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Below geotextile