TRISOPLAST®

Soil & Groundwater Protection by Polymer Enhanced Mineral Barrier

RemTech Banff 2009

Dipl.-Geol. Mike Naismith

TRISOPLAST
MINERAL LINERS

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   - Differential Settlement / Deformation
   - Properties / Durability
   - Functional Lifetime / Aftercare Costs
3. Conformity with European Directive
4. Examples
5. Conclusions

Trisoplast developed in the Netherlands

Environmental protection is crucial!

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Trisoplast® Mineral Barrier

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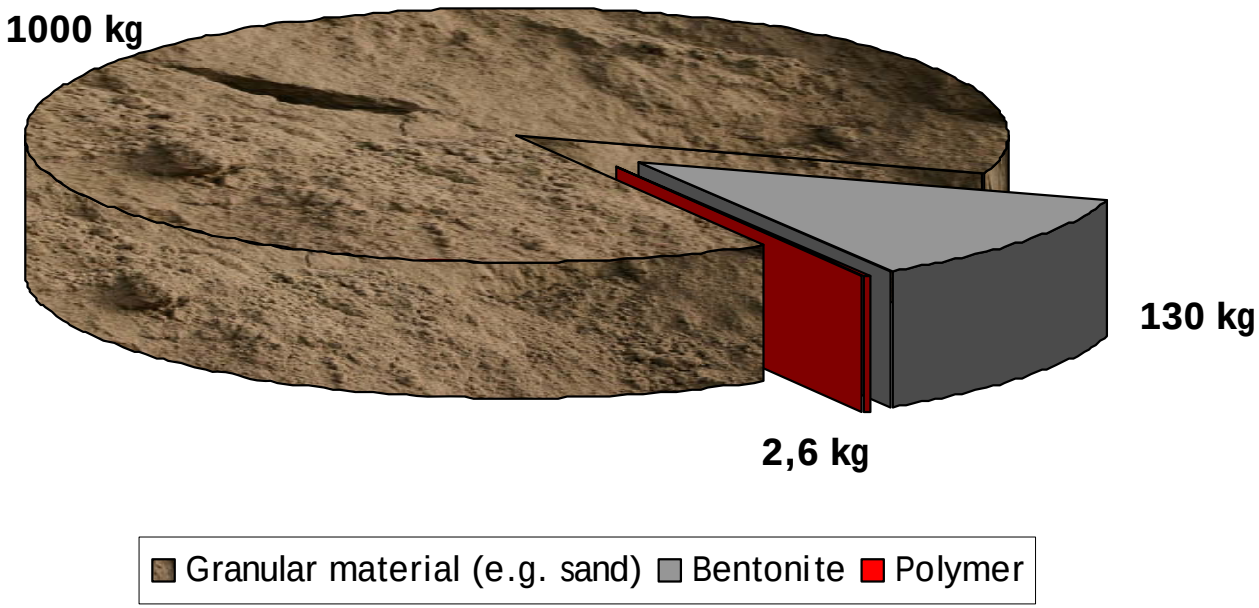
What is Trisoplast?

Trisoplast is a polymer modified mineral barrier



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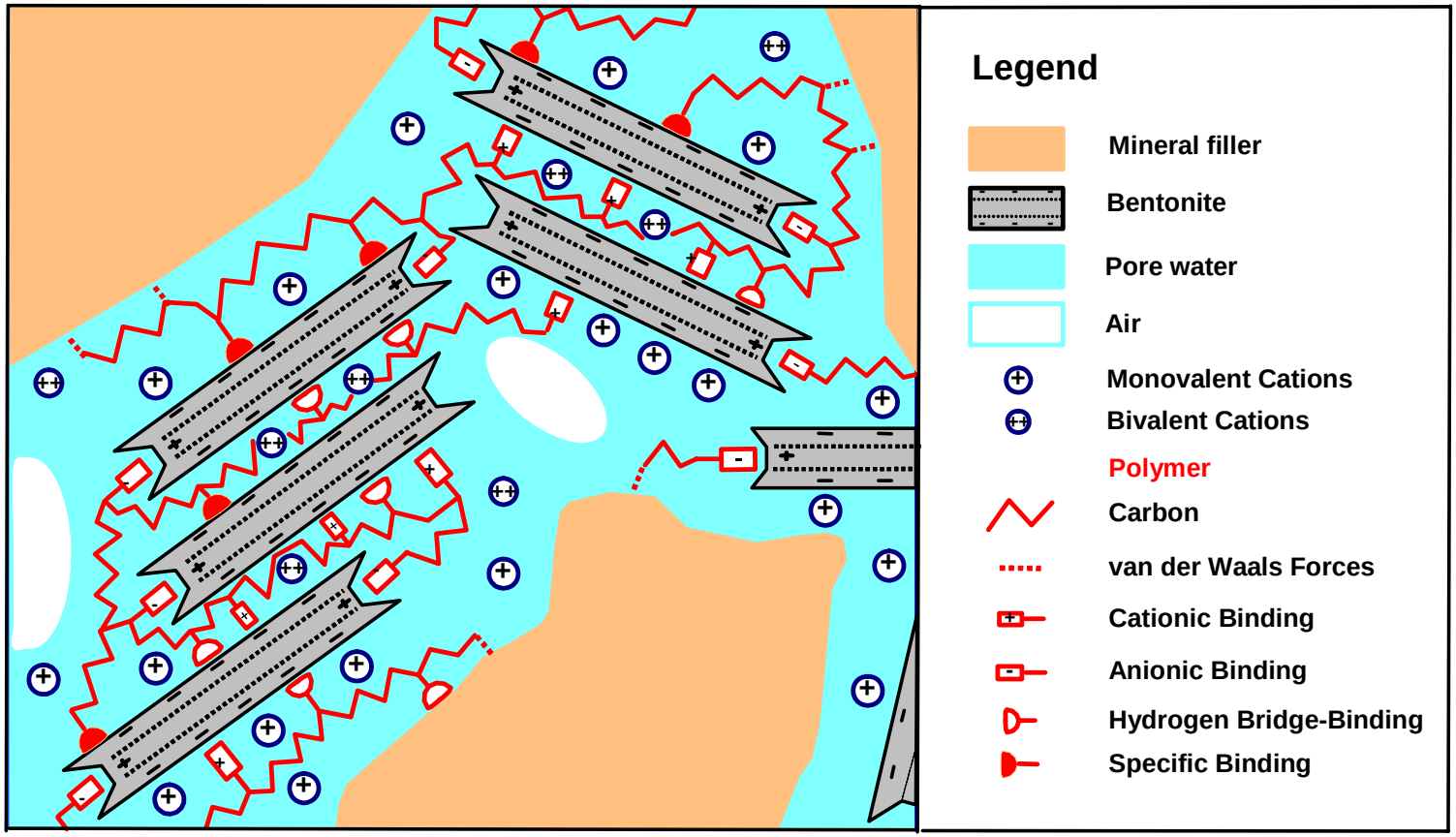
Trisoplast®: Schematic Presentation of the Interaction between Bentonite und Polymer



Mobile Mixing plant Setup in Swanscombe, UK

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Trisoplast Installation Process

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Trisoplast Installation Process

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Standard Equipment and Handwork for Small Projects

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Compaction with Roller on Slopes

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Compaction with Vibrating Plates

Trisoplast®: Surface Finish

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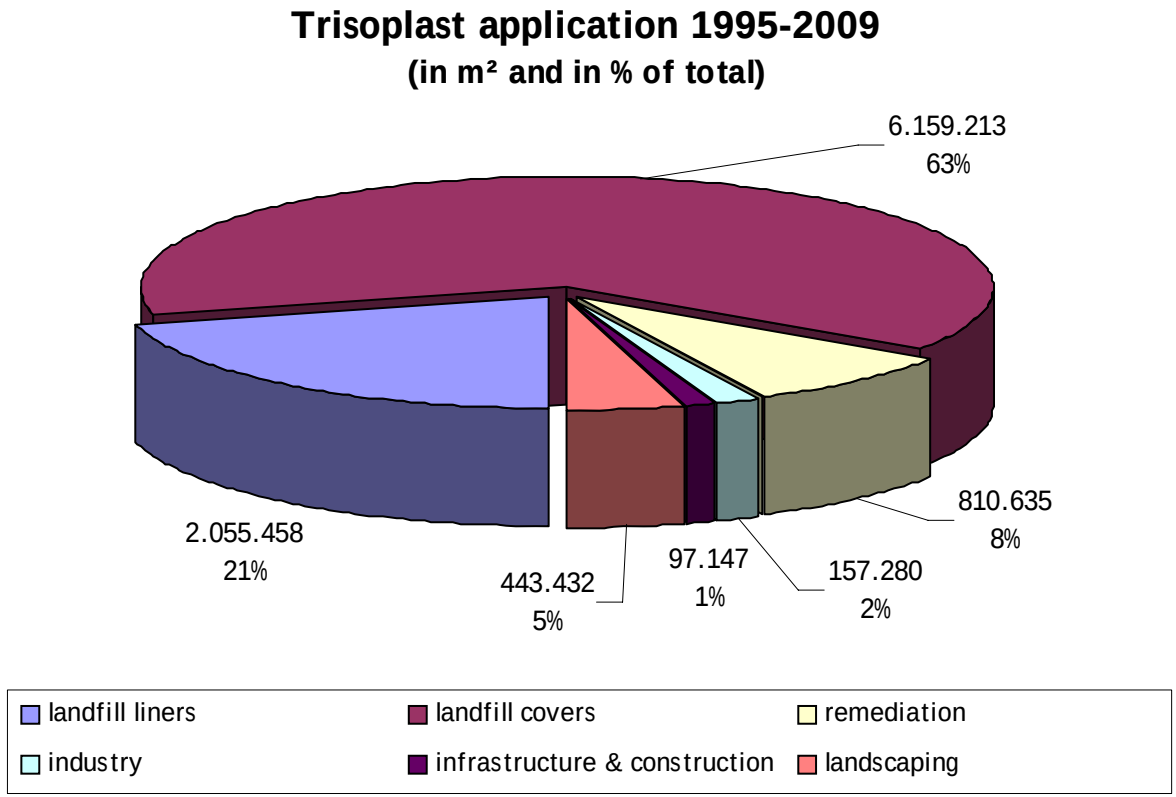
±10 Million m² of Trisoplast installed



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Trisoplast world-wide today

- Argentina
- Belgium
- Bulgaria
- Croatia
- Dubai
- France
- Finland
- Germany
- Ireland
- Italy
- Malaysia
- Mexico
- Portugal
- Romania
- South Africa
- Serbia
- Singapore
- Spain
- Sweden
- The Netherlands
- Ukraine
- United Kingdom

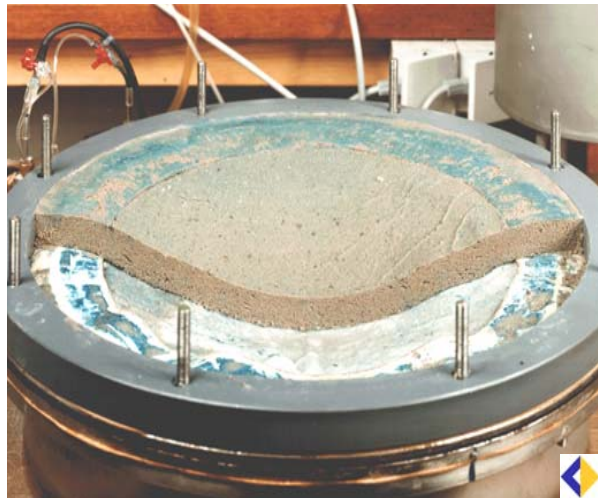
Trisoplast® is a polymer modified mineral Barrier

- **Produced / installed on site:**
  - Local personnel
  - Local Materials (only polymer delivered from NL)
  - Conventional machinery
- **Quality Controlled System:**
  - (Trisoplast Manual)
- **Know-how, Training and Support from the Netherlands :**
  - Field lab equipment and mobile mixing plant can be supplied from NL (for first references)

Properties of Trisoplast®

- **Sealing performance** Factor 100 to 1000 better than EU requirement for regular clay. *(kf 0,1 - 3 x 10-11 m/s versus 1 x 10-9 m/s)*
- **Strength:** Friction like sand and cohesion like clay. Long term slope stability of 1:2 and more can be constructed.
- **Deformability:** ability to cope with Differential Settlements due to High Plasticity, Self-Healing ability.
- **Durability** at chemical, biological and physical influences. High resistance to wet/dry cycles, cation exchange.
- **Retention of contaminants:** 9 cm layer equivalent to the 1 meter natural reference impermeable mineral layer as specified in the EU Landfill directive.

Continuous Research by Independent Institutes



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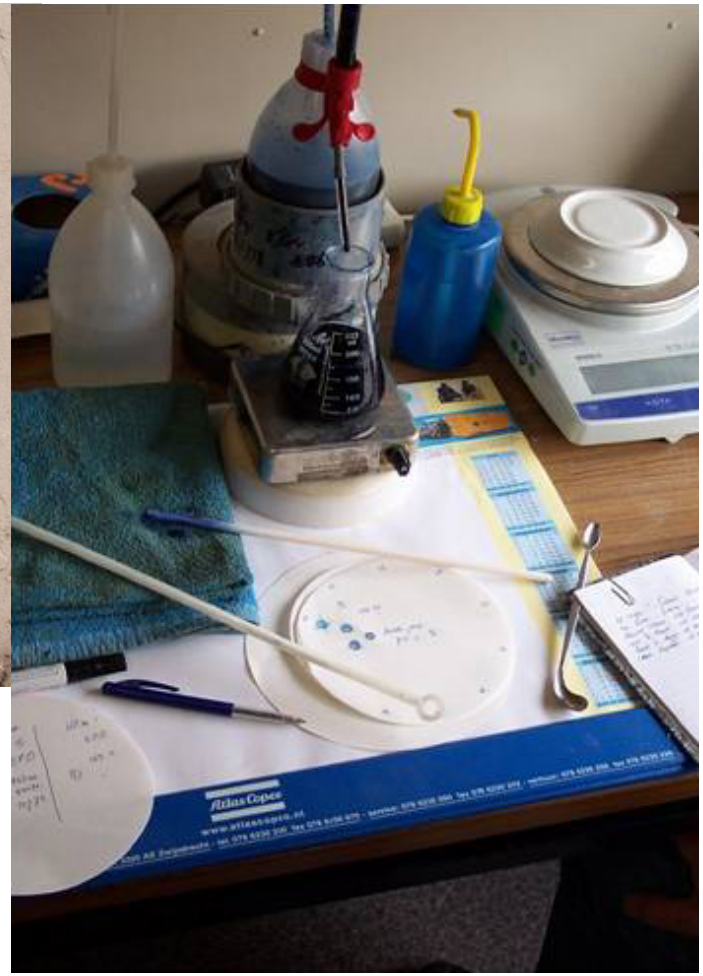
Quality Control Testing Trisoplast®



Percolation rates of different Landfill Barriers at Installation

	Trisoplast		GCL	BES	Geological Barrier / CCL		
Barrier thickness d [m]	0.07	0.09	0.01	0.25	1.00	1.00	5.00
Hydraulic conductivity k [m/s]	3×10^{-11}	3×10^{-11}	3×10^{-11}	1×10^{-10}	1×10^{-7}	1×10^{-9}	1×10^{-9}
Hydraulic gradient i [-]	14.3	11.3	94.0	4.7	1.9	1.9	1.2
Percolation rate q [mm/a]	**14**	**11**	**89**	**15**	**6,086**	**61**	**37**

According Darcy (0.3 m hydraulic head, -0.63 m below barrier = field capacity)

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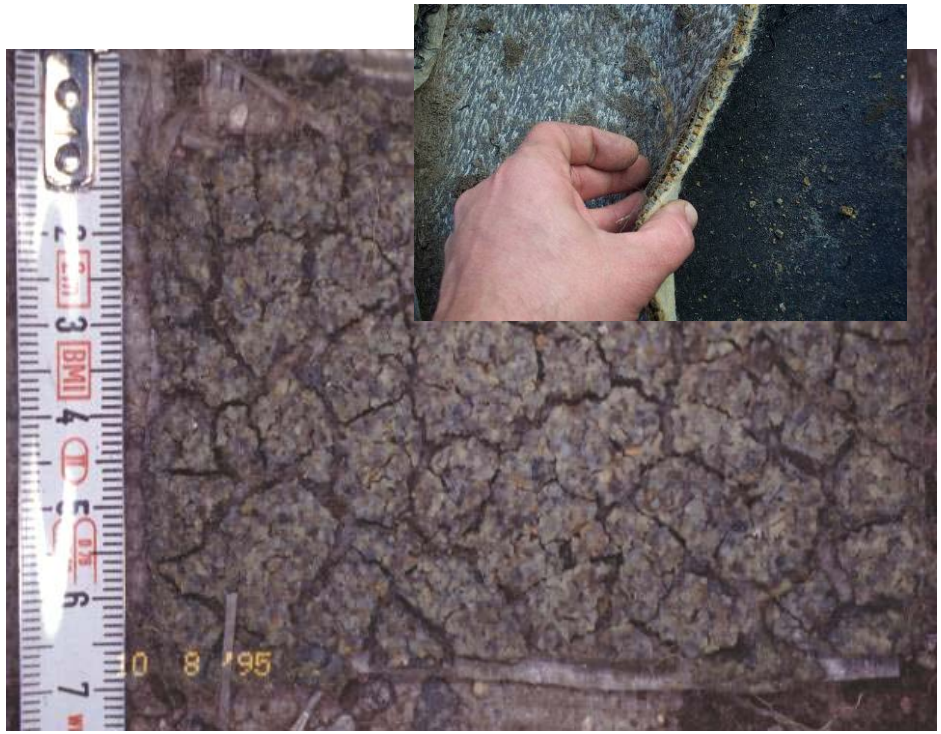
Desiccation Damage Clay Dominated Liners

Compacted Clay Liner (CCL)



Geosynthetic Clay Liner (GCL)

Melchior October 1995,
Excavations Field Trial Georgswerder, Hamburg

Research and field excavations by Albrecht, Benson, Melchior, Holzlöhner, Philip, Döll, etc.

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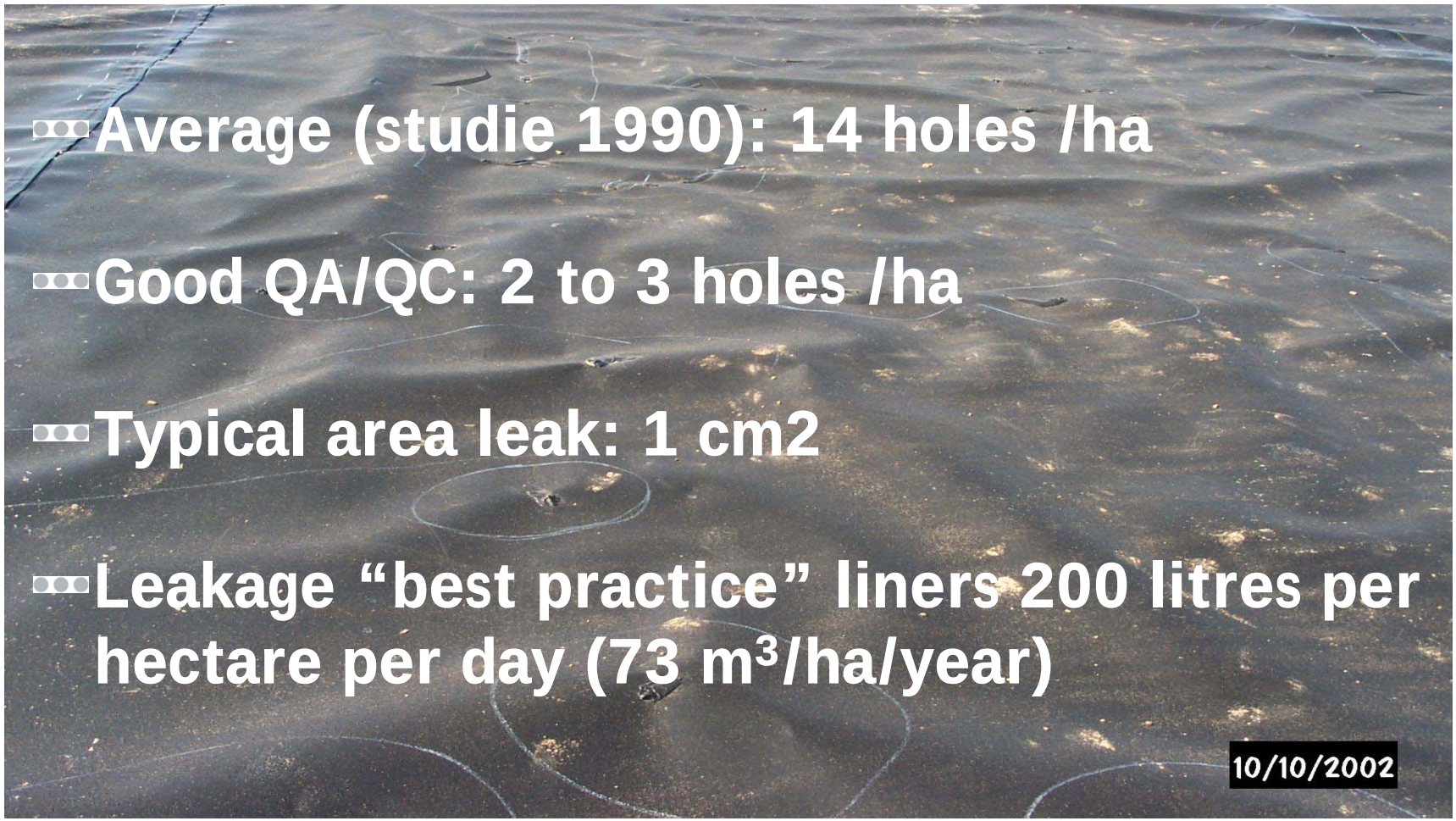
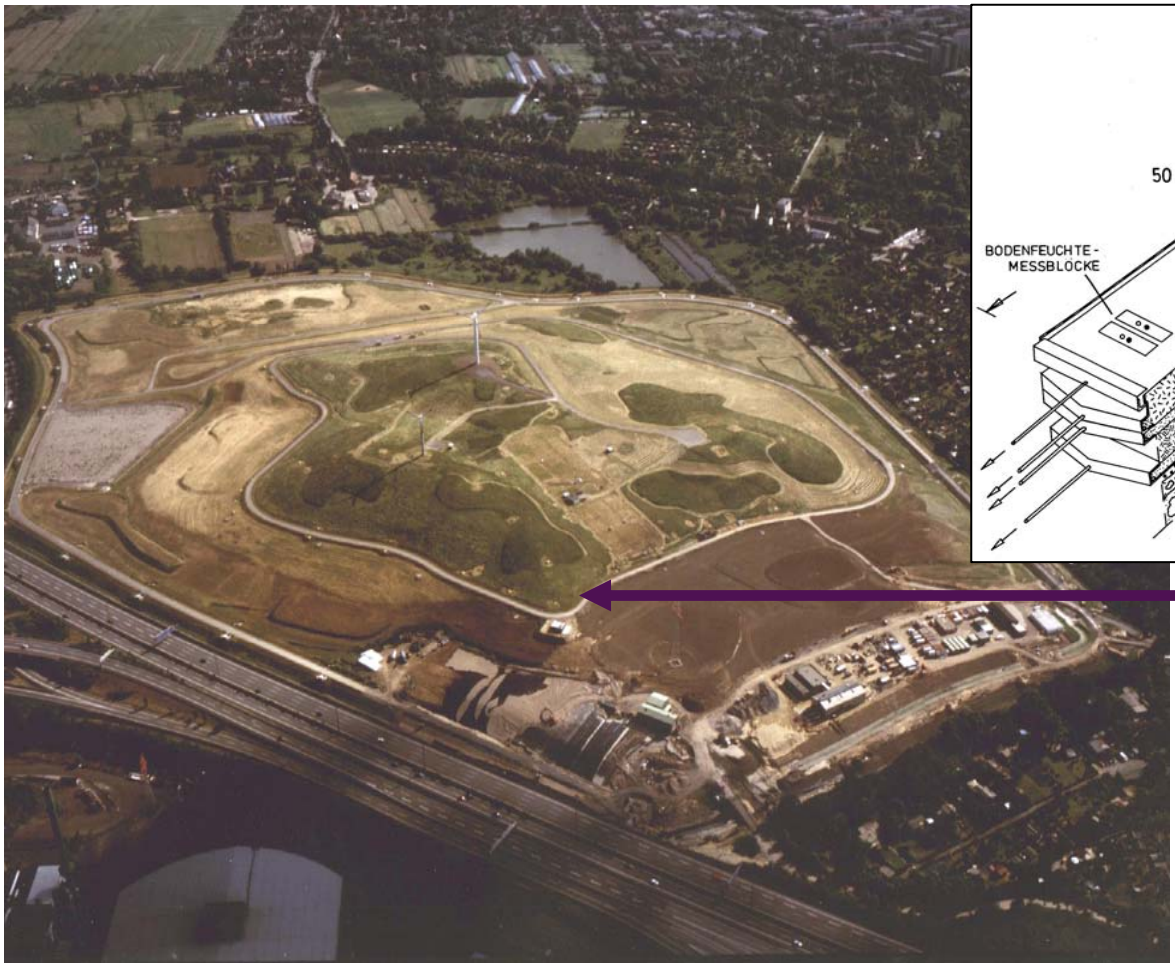
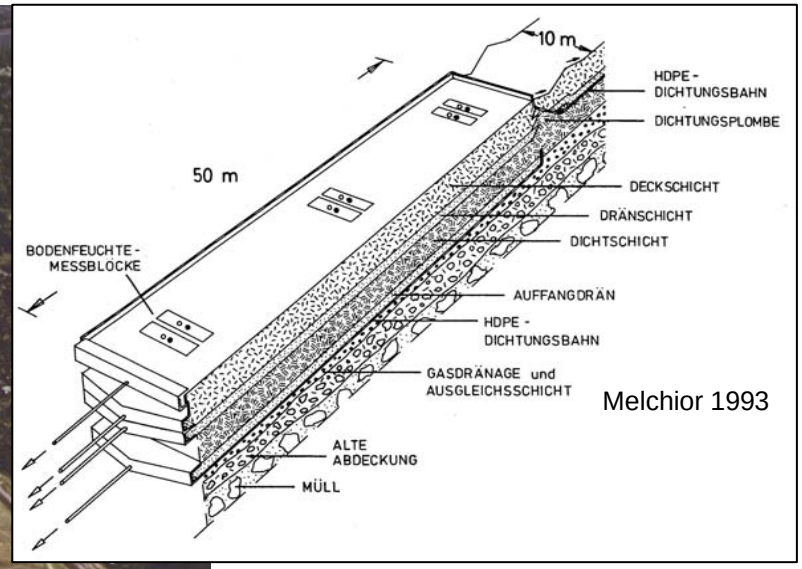
Damage by tools, larger particles or whilst installing the cover materials(Bonaparte and Gross 1990)



- Average (studie 1990): 14 holes /ha
- Good QA/QC: 2 to 3 holes /ha
- Typical area leak: 1 cm2
- Leakage “best practice” liners 200 litres per hectare per day (73 m^3/ha/year)

Landfill Hamburg-Georgswerder





Melchior 1993

Field Trials

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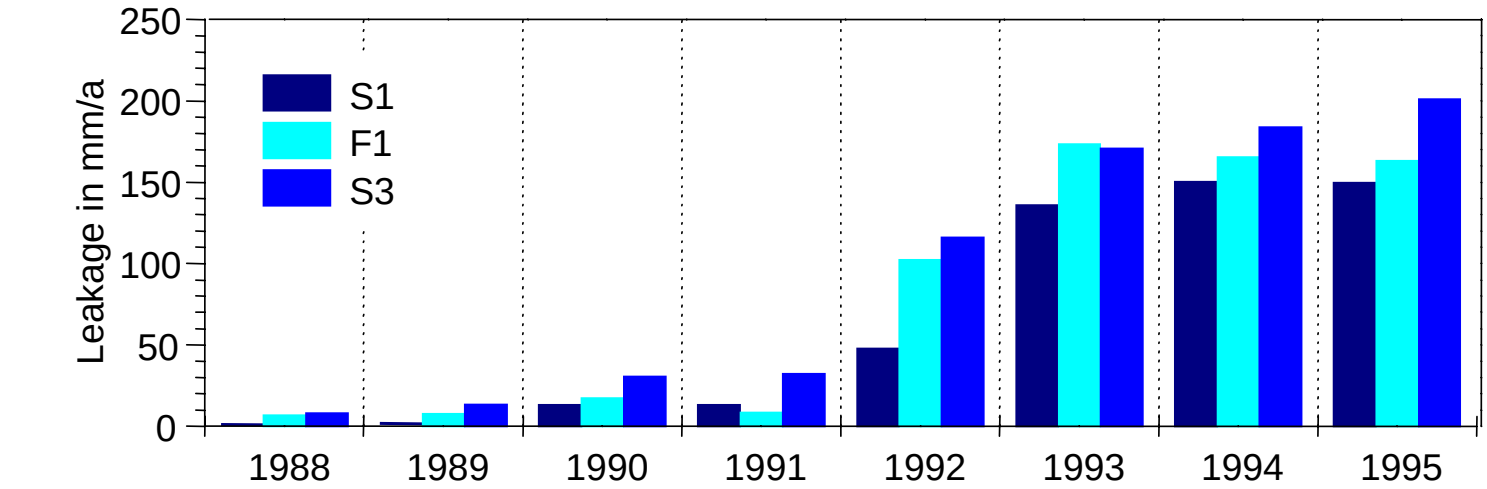
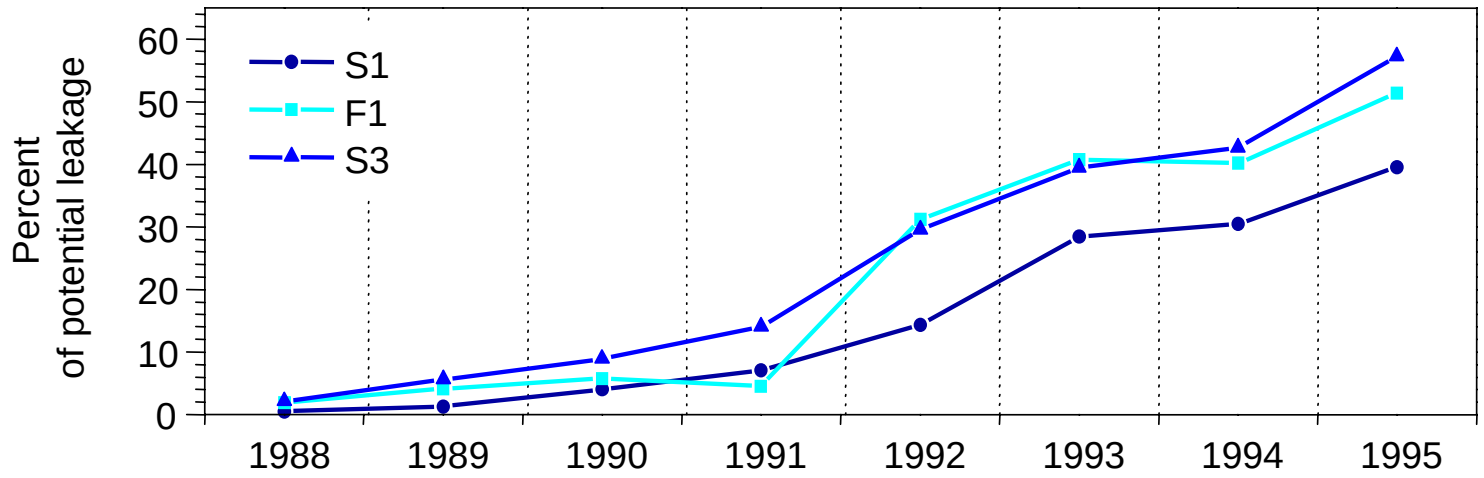
Annual leakage trhough compacted cohesive soll barriers





Melchior 1998, 2001

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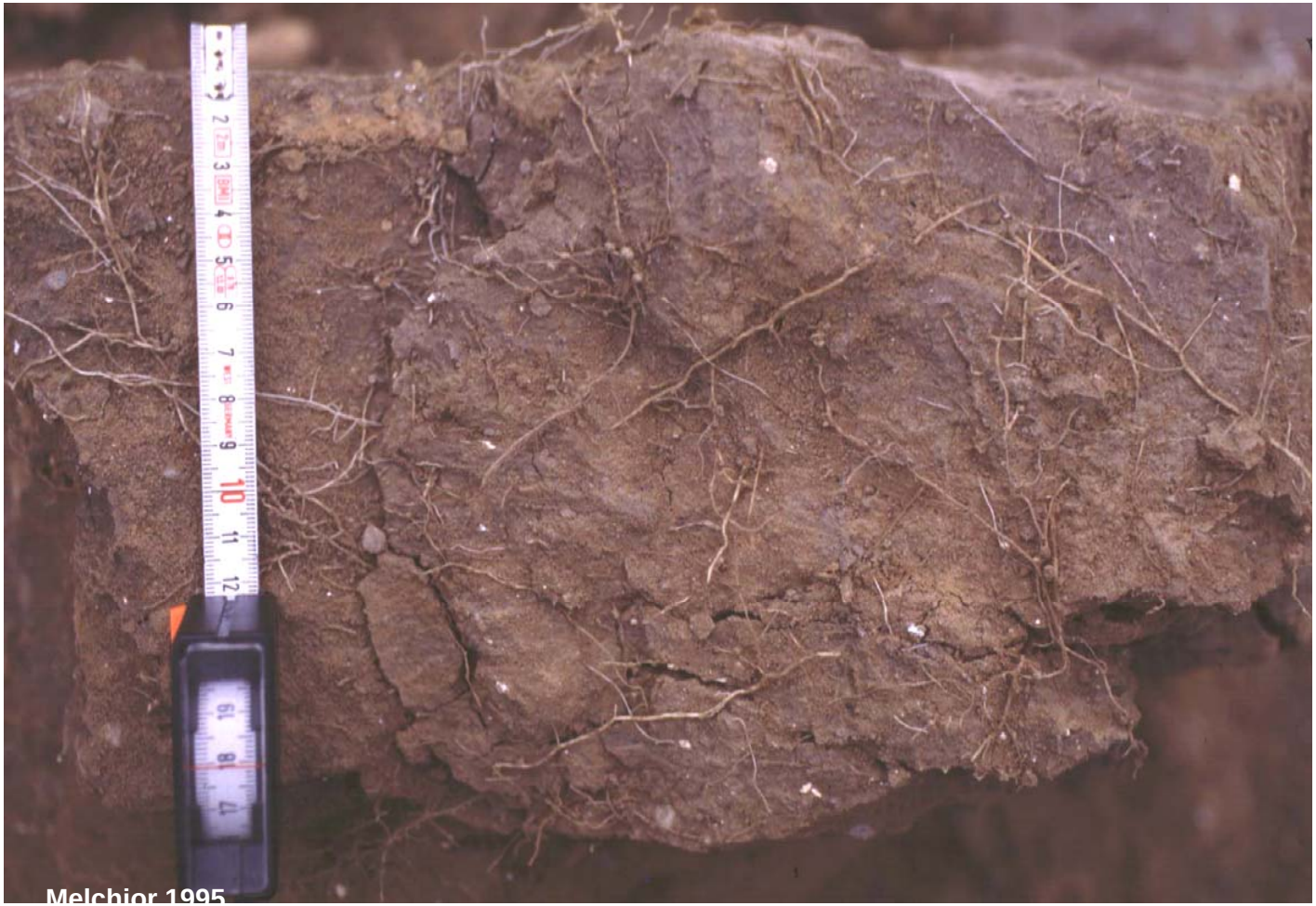
Field Trial Georgswerder in October 1995



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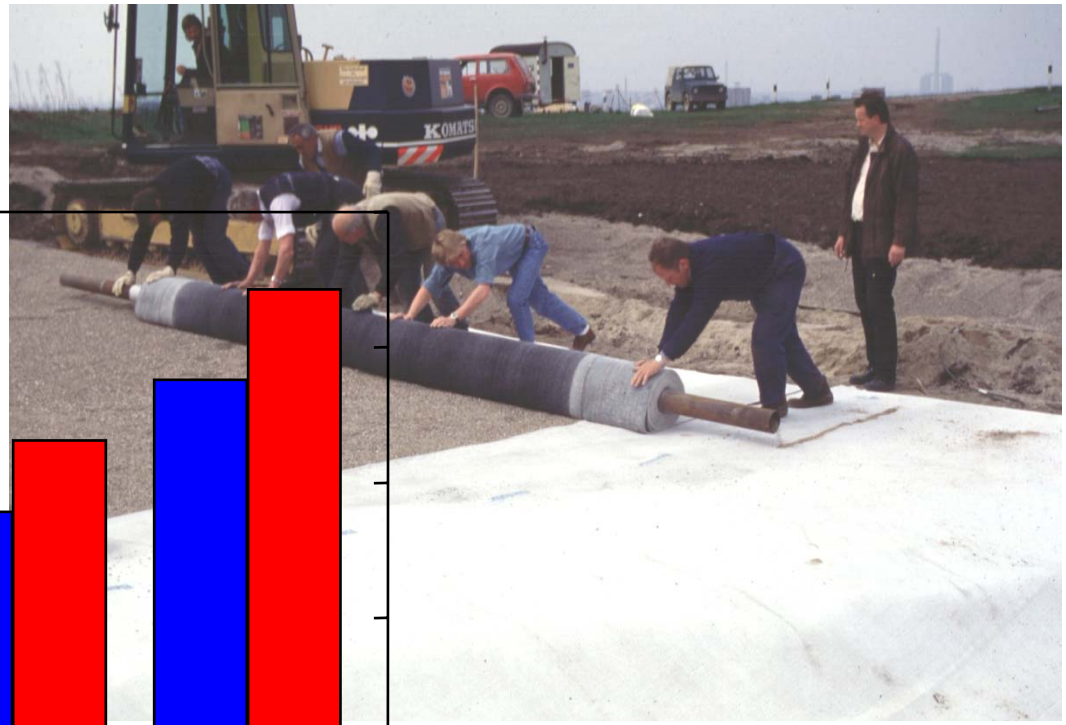
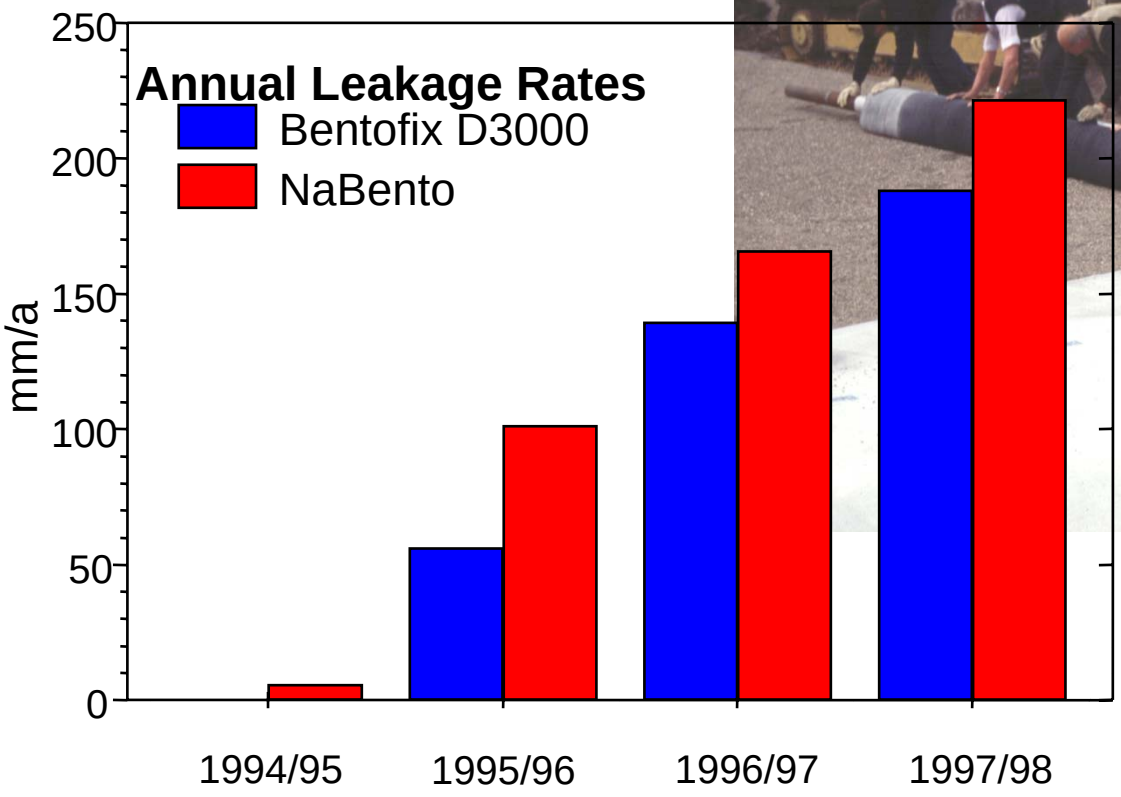
Geosynthetic clay liner (GCL): Field Trial Georgswerder





Melchior 1995

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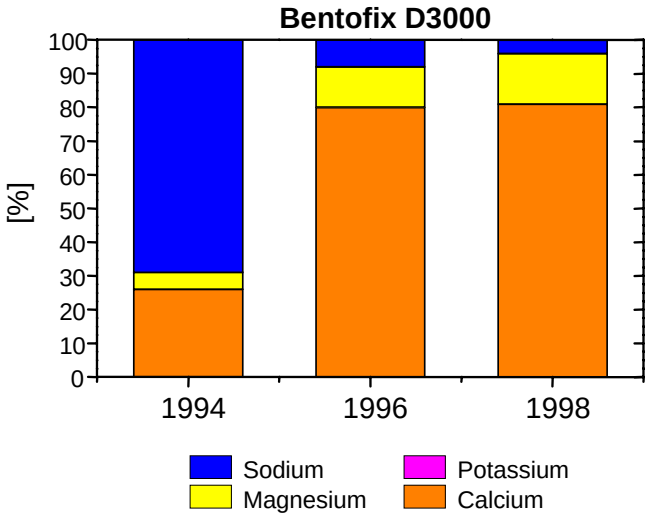
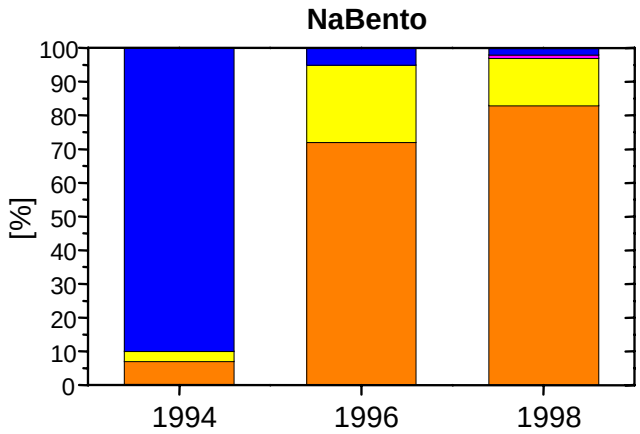
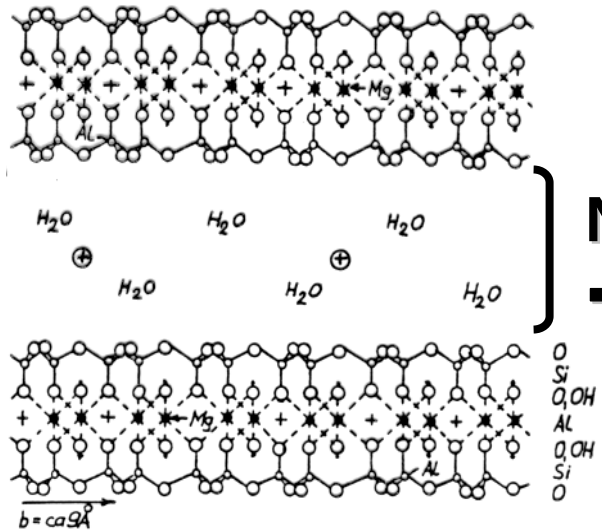
Cation Exchange in Geosynthetic Clay Liners: Field Test Georgswerder





Melchior 1998, 2002



Montmorillonite structure

Na^+ / Ca^{++} ➔ Swell

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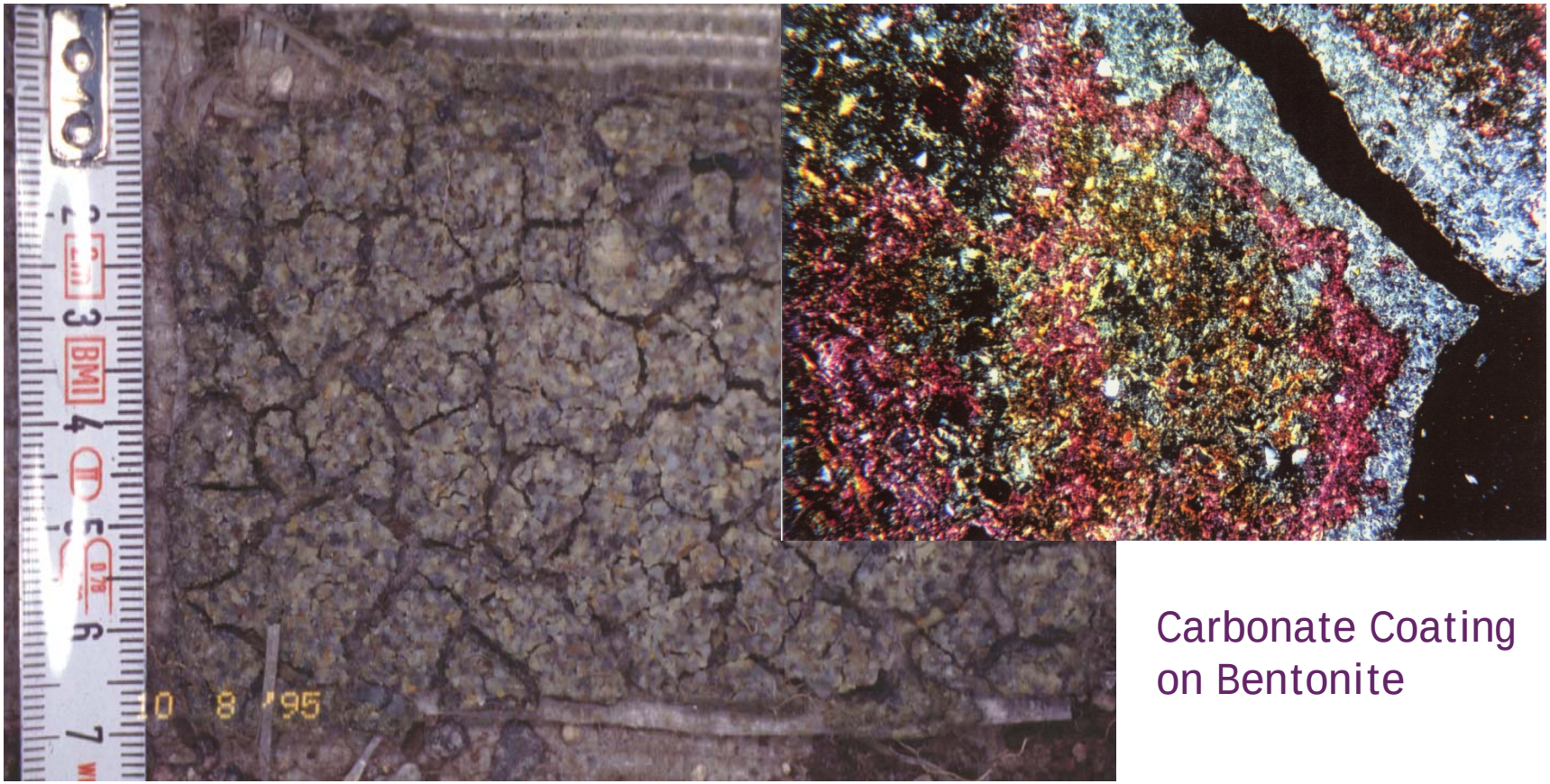
Carbonate Coating on Bentonite aggregates
Geosynthetic clay liner (GCL): Field Trial Georgswerder



Carbonate Coating
on Bentonite

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Annual percolation rates through four different mineral liners used in a cap

	TRISOPLAST®	GCL	CCL	BES
Barrier thickness d [m]	0.07	0.01	1.00	0.50
Hydraulic conductivity k [m/s] as installed	3×10^{-11}	3×10^{-11}	1×10^{-9}	5×10^{-10}
likely increase factor after 10 to 100 years	1-2	10-100,000	2-10,000	2-100
Percolation rate q [mm/a] fresh / after 10 years	8 / 8-16	52/ >400	35/ 70->400	26/ 52->400

(calculation using Darcy´s equation assuming a total hydraulic head of 1 m (0.5 m suction tension, 0.5 m hydraulic head above the mineral liner) over a period of 200 days directly after installation and after 10 – 100 years (based on experiences and independent research results)

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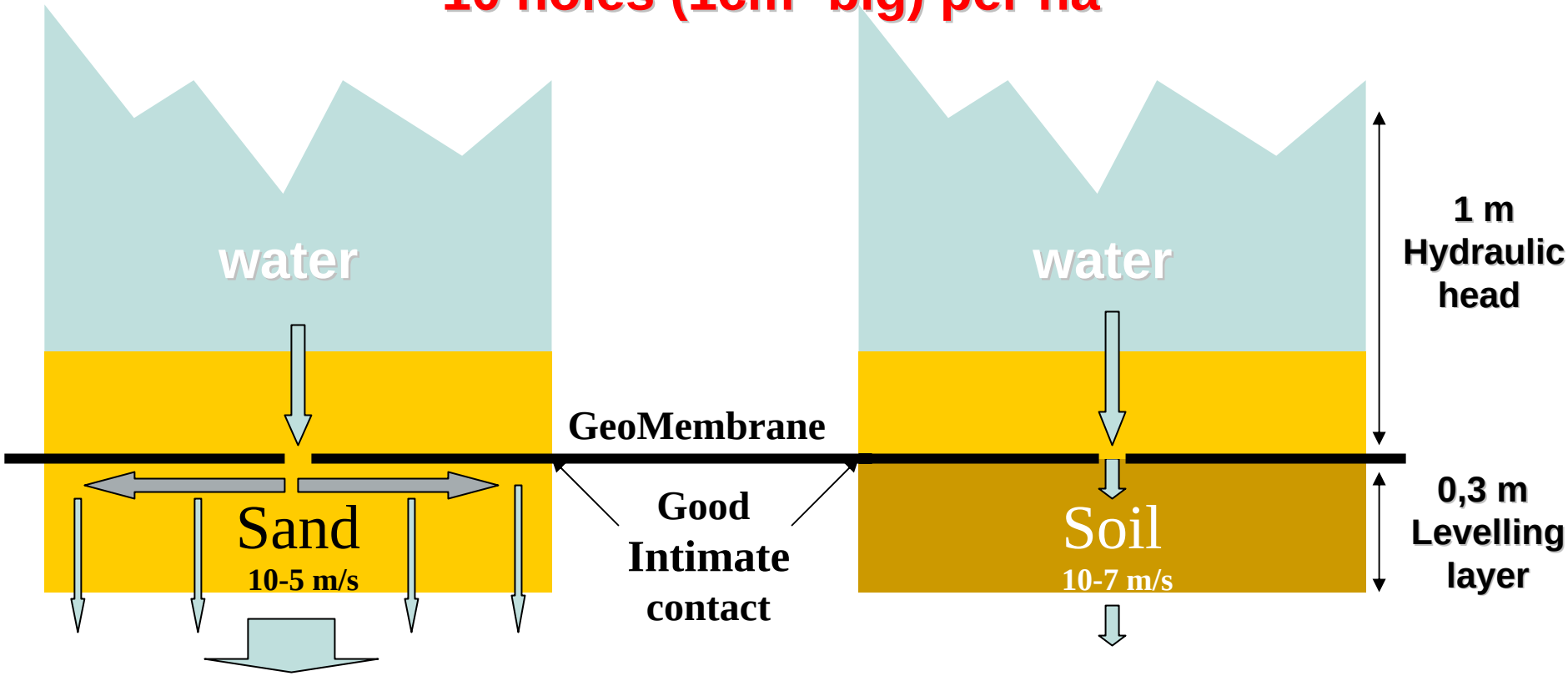
Percolation rates Geomembrane

10 holes (1cm² big) per ha



>4000 m3/ha /year

(Calculation using Giroud, Badu-Tweneboah & Bonaparte ´s equations)

230 m3/ha /year

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Annual Percolation rates through a geomembrane

Intimate contact to subgrade and permeability subgrade of high influence on percolation rates:

GM= Geomembrane	GM over 0.3 m soil @ 10^{-7} m/s	GM over 0.3 m soil @ 10^{-6} m/s	GM over 0.3 m soil @ 10^{-5} m/s
good intimate contact (not likely)	23	127	>400
poor intimate contact	121	>400	>400

Percolation rates through 10 round holes (1cm² big) per ha in a geomembrane (calculation using Giroud, Badu-Tweneboah & Bonaparte ´s equations and a total hydraulic head of 1m (0.5 m suction tension, 0.5 m hydraulic head above membrane) overlying a 0.3 m thick levelling layer of different permeability

Leachate Treatment Cost

	TRISOPLAST		GCL	
Formula T = I*(1+R)^a				
Total Nett Value (T)				
Inflation	3,0%		3,0%	
Installation Cost per m²	10	€	5	€
Instalation costs (I)	200.000,00	€	100.000,00	€
Interest Rate (R)	4,50%		4,50%	
Surface Area	20.000,00	m²	20.000,00	m²
Lechate in mm	10	mm	200	mm
Lechate Treatment Cost	10,00	€/m³	10,00	€/m³
Yearly Lechate	200	m³	4.000	m³
Yearly Lechate Treatment Cost	2.000	€	40.000	€

Year	Direct Cost Trisoplast	Interest gain Trioplast	Direct Cost GCL	Morecosts GCL	Morecoast GCL / m²
0	200.000,00	0	100.000,00	-100.000 €	-5,00 €
1	202.060,00	-4.500,00	141.200,00	-65.360 €	-3,27 €
2	204.181,80	-7.441,20	183.636,00	-27.987 €	-1,40 €
3	206.367,25	-8.700,62	227.345,08	12.277 €	0,61 €
5	210.936,82	-5.646,18	318.736,40	102.153 €	5,11 €
10	223.615,59	41.495,89	572.311,83	390.192 €	19,51 €
30	298.005,36	1.302.612,99	2.060.107,13	3.064.715 €	153,24 €
50	**432.361,55**	**6.911.953,80**	**4.747.230,93**	**11.226.823 €**	**561,34 €**

(simplified fictive Prices!)

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Aftercare Costs (if allowed for right from the start- excluding the reoccurring earthworks/excavation!!!)

	TRISOPLAST	GCL
Formula T = I*(1+R)^a		
Total Nett Value (T)		
Average Replacement Periods (a)	100 Years	15 Years
Inflation	3,0%	3,0%
Installation Cost per m²	10 €	5 €
Instalation costs (I)	200.000,00 €	100.000,00 €
Interest Rate (R)	4,50%	4,50%
Surface Area	20.000,00 m2	20.000,00 m2

Trisoplast

Time (year)	Lifetime of Barrier (year)	Real Installation Costs (€)	Required Individual Investment today (€)	Required Total Investment today (€)	System Cost (€/m²)
0	100	200.000	200.000	200.000	10,00
105	200	3.843.726	47.111	247.111	12,36
Maximum Cost Eternity				261.628	13,08

GCL

Replacement Period (year)	Lifetime of Barrier (year)	Real Installation Costs (€)	Required Individual Investment today (€)	Required Total Investment today (€)	System Cost (€/m²)
0	15	100.000	100000	100000	5,00
15	30	155.797	80503	180503	9,03
30	45	242.726	64808	245311	12,27
45	60	378.160	52173	297484	14,87
60	75	589.160	42001	339484	16,97
75	90	917.893	33812	373296	18,66
90	105	1.430.047	27220	400516	20,03
105	120	2.227.966	21913	422429	21,12
Maximum Cost Eternity				512.741	25,64

Total Cost Saving Trisoplast 251.113 € Saving per m² 12,56 €

(simplified fictive Prices!)

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Gain of Void Space

Price of Waste:	100	€
Size of Project	20.000,00	m²
Denisty of Waste	1	t/m³

	Trisoplast	Trisoplast +Attenuation Layer	Clay
Thickness	0,09 m	0,50 m (0,09 m+0,41 m.)	1 m
gained Voidspace in m³	0,91	0,50	0,00
cost savings in € per m²	91,00	50,00	0,00
Total cost saving in €	**1.820.000 €**	**1.000.000 €**	0,00

(simplified fictive Prices!)

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Root Penetration Experiments with Barley on Trisoplast and the Georgswerder Cohesive Soil Barrier Melchior et al. 2001

Trisoplast® - Barrier

Glacial Marl

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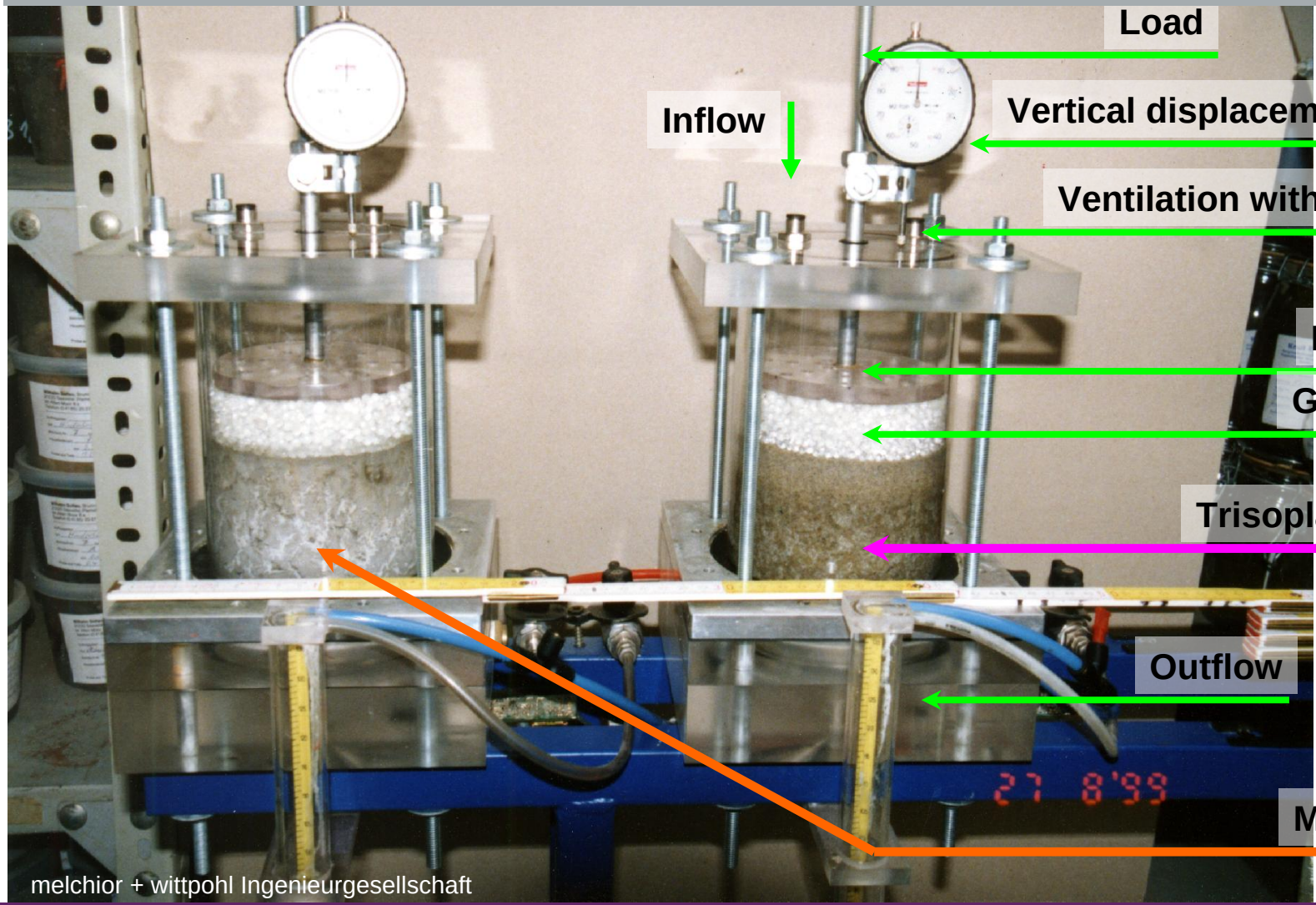
Percolation Test Cells



6 year without damage

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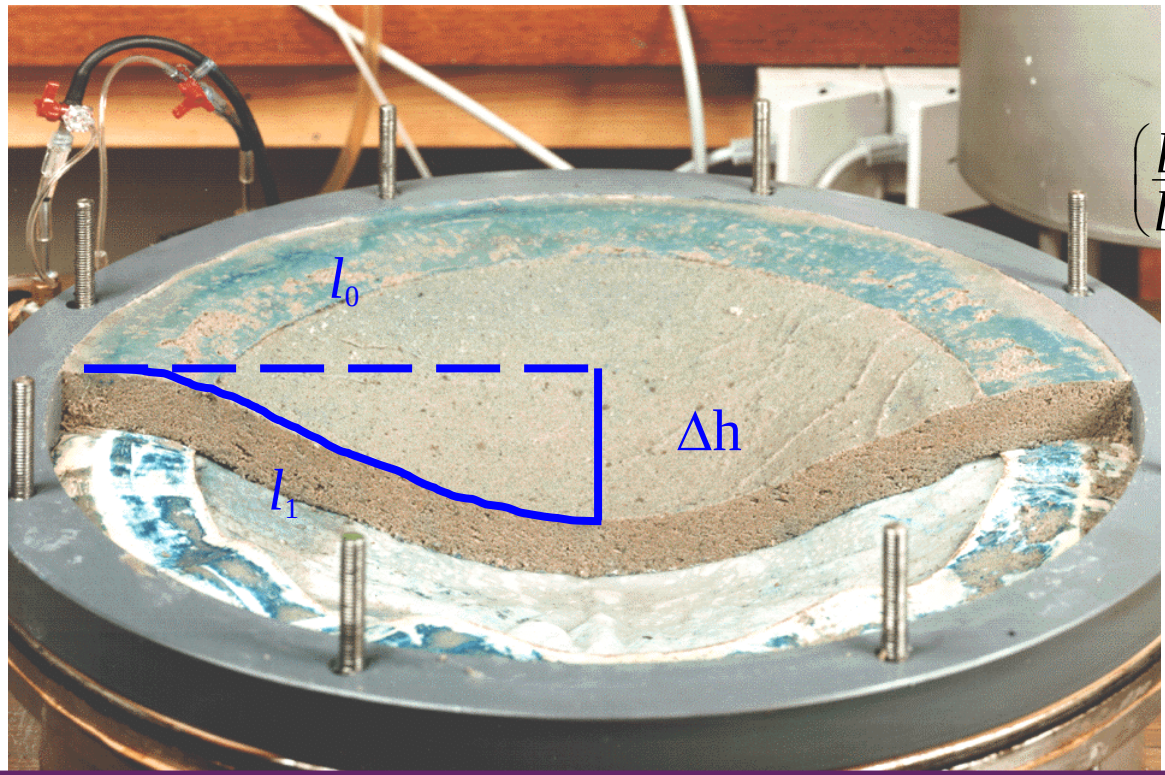
Results of wet/dry cycles

- **Clays and GCLs:** Strong influence of drying cycles
  - Glacial Marl (18% clay) fails completely after one drying cycle, visual cracks.
  - Schlieper Ton (36% clay): extremely high initial permeability after two cycles. Original permeability never reached again.
  - Both Calcium and 7kg Na-bentonite GCL have extremely high initial permeability after drying cycles. After saturation (4 – 10 weeks) factor remains 10 to 100 higher than initially. Na-bentonite mat shrinks 5 mm and loses swelling capacity.

- **Trisoplast:** Saturation and desiccation processes take place extraordinary slowly. Low permeability remains unaffected after several drying cycles (even after 5 years testing) with desiccation stresses of up to 1500 hPa.

TRISOPLAST® : PERMEABILITY AFTER DEFORMATION



Deformation (%) $\left(\frac{l_1}{l_0}-1\right)x100$	Permeability (x 10^{-10} m / s) Saturated	Unsaturated
0	0,06	
1	0,09	
2	0,11	
3	0,16	
5	0,23	
7,5	0,21	0,60
10	0,21	0,37

Deformation without damage

BOELS & VAN DER WAL (1999)

ALTERRA

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Shear characteristics of Trisoplast

Recommendation for slope stability calculations for preliminary design planning for landfill covers according to AK Trisoplast, 2002

CONSTRUCTION PHASE		LONG TERM SHEAR PARAMETERS	
State of failure	State of sliding	State of failure	State of sliding
$\varphi' = 35°$	$\varphi'r = 30°$	$\varphi' = 30°$	$\varphi'r = 30°$
$c' = 20\ kN/m^2$	$c' = 10\ kN/m^2$	$c' = 10\ kN/m^2$	$c' = 10\ kN/m^2$

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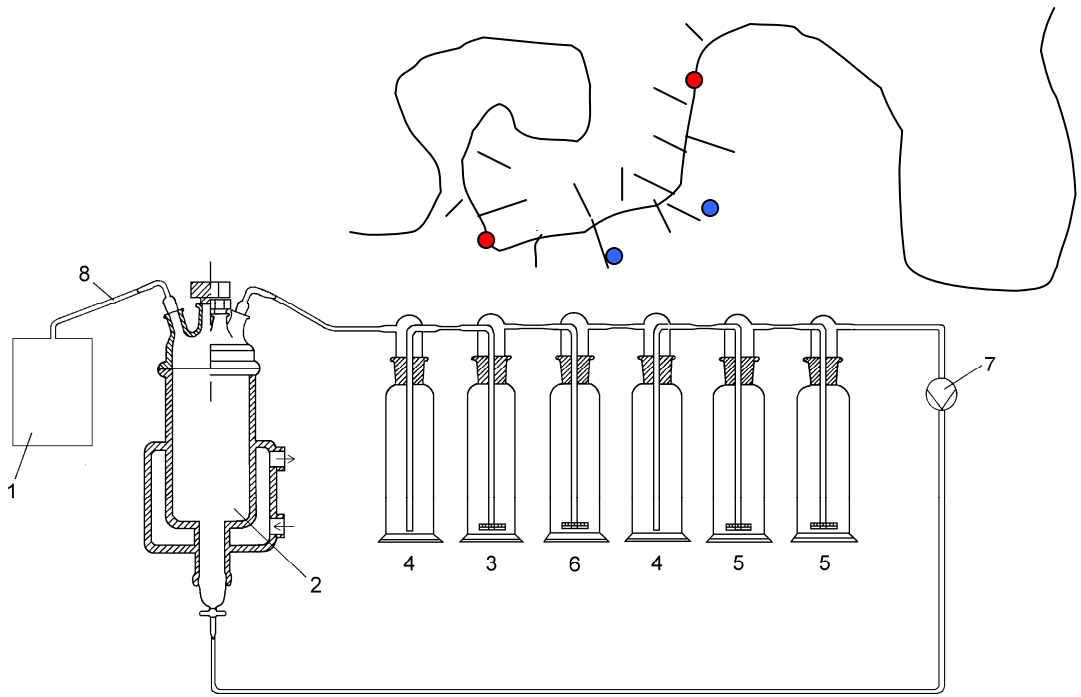
Biological and Chemical Stability by C14-Labelling Method r. Wienberg Umwelttechnisches Labor



- **Label** main chain
- Label **side** group

Main Conclusion: → These highly accurate tests confirmed that the actual polymer is marginally or totally non-degradable for a very long time even under very extreme conditions

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Excavations Trisoplast sites (build 1995 – 1996)

2001: Alterra (Uni Wageningen NL) and Melchior & Wittpohl (Hamburg)

- **Investigation of any negative influences caused by:**
  - Roots
  - Desiccation
  - Cation Exchange
  - Cracking
  - Aggregate Forming
  - k-value changes

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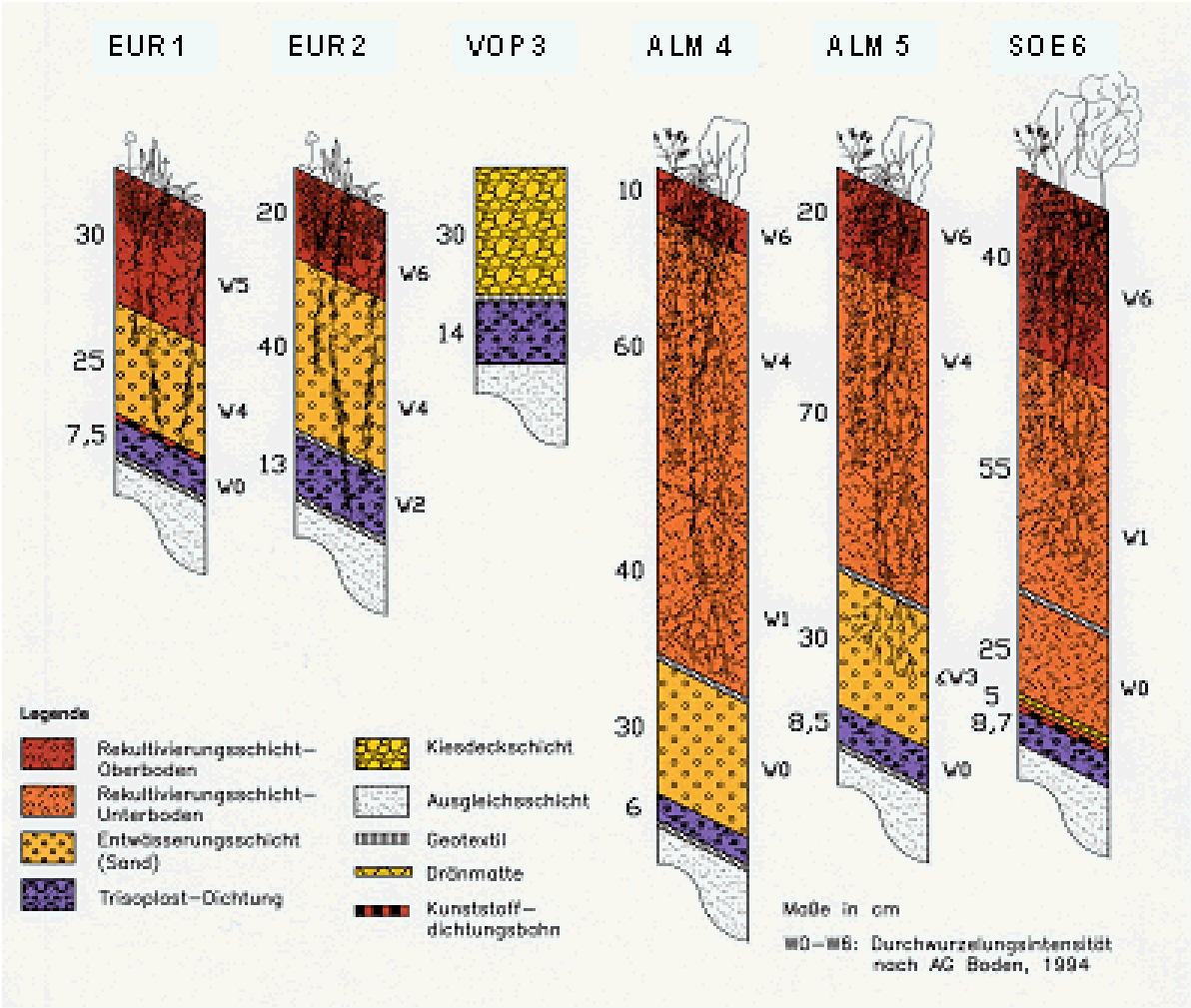
Excavations Trisoplast Seals in The Netherlands (September 2000)



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Braambergen, Almere (130.000 m2)

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VBM Rotterdam

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VBM Rotterdam

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Trisoplast Barrier (no Geomembrane)

Results of the Excavations:

- All the excavated Trisoplast seals were intact.
- The permeability remained unchanged at its low level (2,2 to 3,1 *10-11 m/s).
- No crack formations or other irregularities could be observed.
- The Trisoplast layers were homogeneous, moist and the plasticity was unchanged.
- Even the layers protected by only very thin cover soils and roots penetrating the layer showed no damage, a good placidity and had a low permeability.

Acceptance of Trisoplast/Compliance with the European Directive

- 0.07 m of Trisoplast can be regarded as equivalent to much thicker Clay (e.g. Germany: 0.5 m at 1 * 10-10 m/s)
- 0.09 m Trisoplast + 0.41 m of an existing Subsoil generally offer a better protection than the 0.5 m thick artificially reinforced Geological Barrier as specified in the European Directive
- Trisoplast has already been approved as Mineral Barrier for Landfill Capping and Basal Lining in a number of European & Non-European Countries

Landfills and Remediation

covering layer

drainage layer

waste

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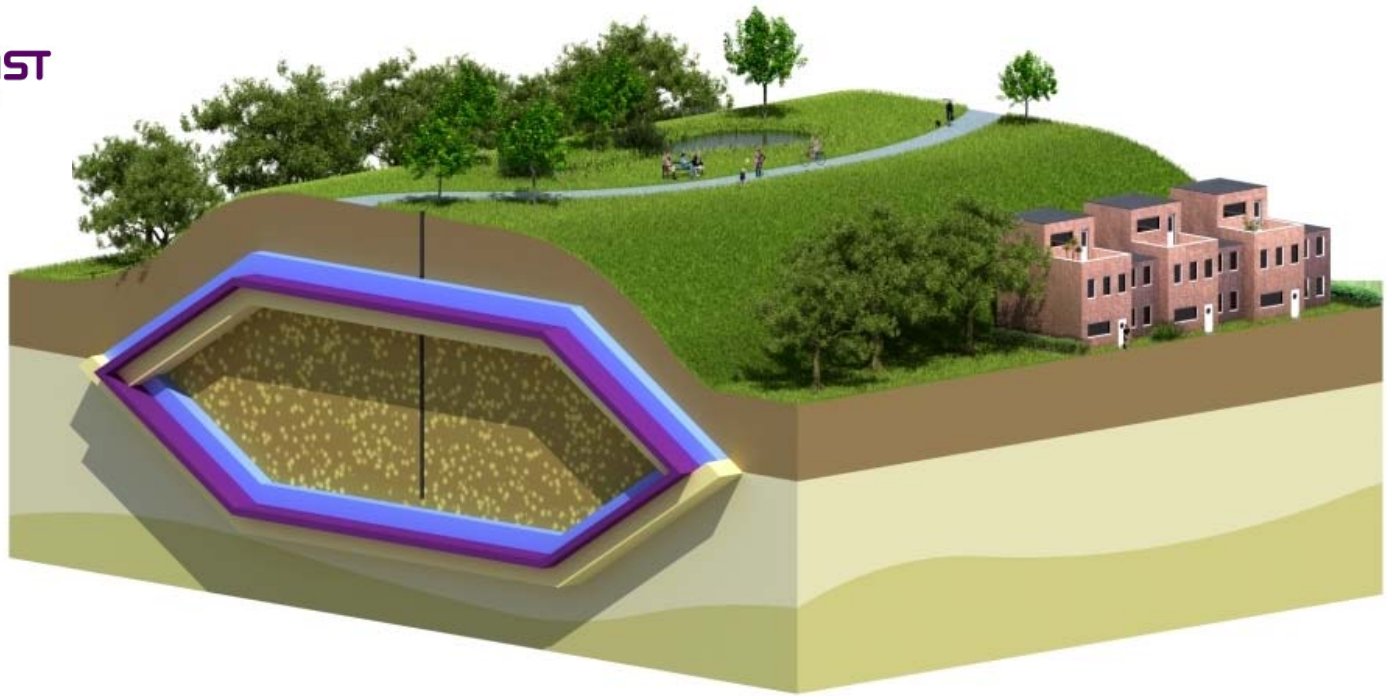
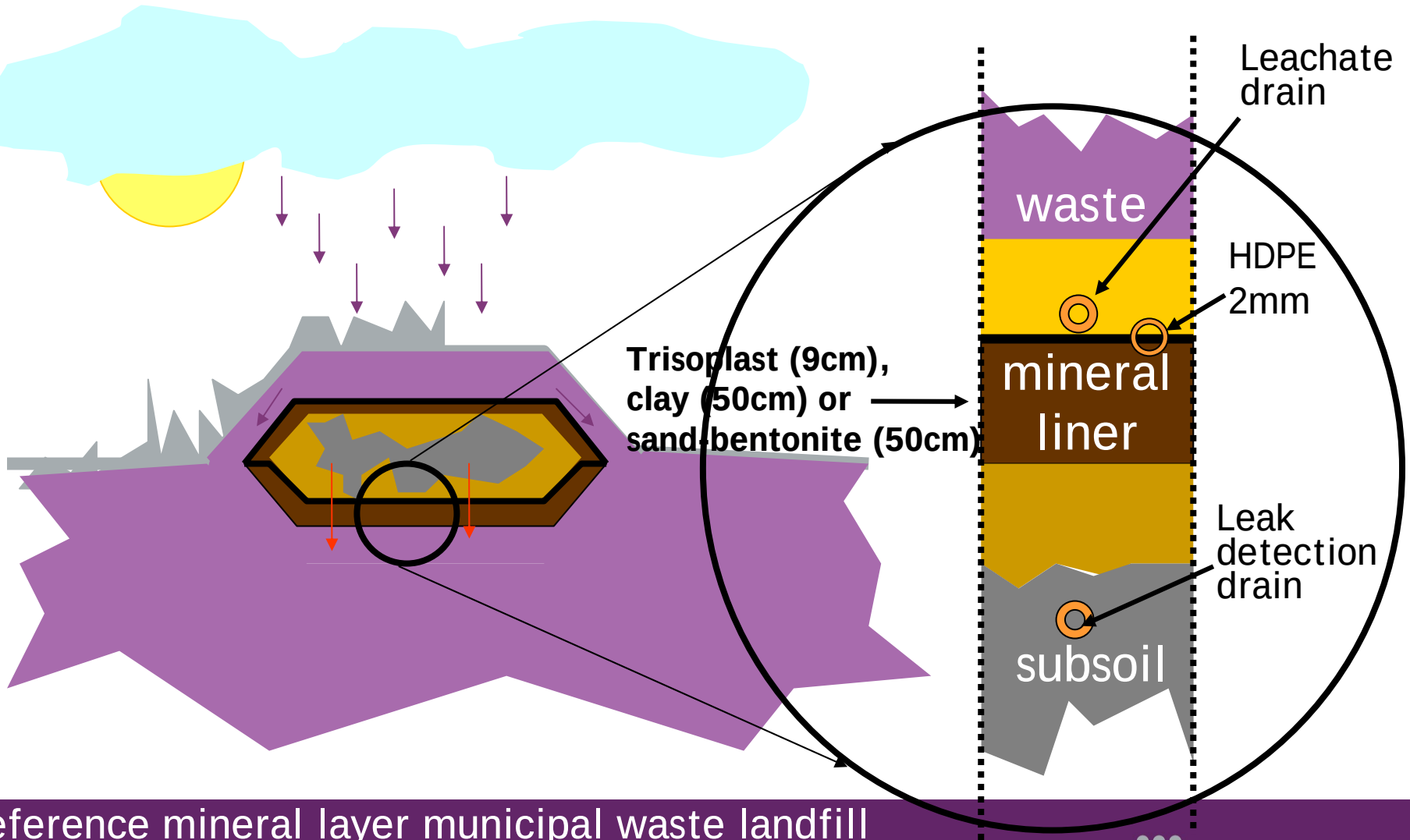
subgrade



Engineered barriers for Dutch landfills (e.g. basal liners)



Reference mineral layer municipal waste landfill

NL: 0,5 m ; k-value < 2,3 x 10^{-10} m/s

EU: 1 m ; k-value < 1,0 x 10-9 m/s

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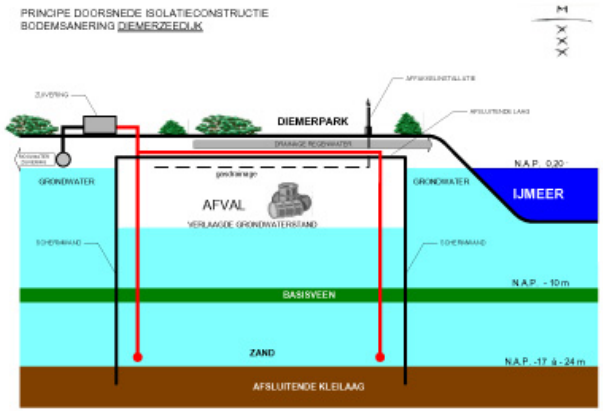
1998-2001

- Clean up and Isolation Constructions 155 Mio €
- Estimation of full modern liner and capping construction max 40 Mio €



Eternal aftercare for pumping system

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Landfill bottom liner
Hengelo, the Netherlands 2007

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Basal Lining Landgraaf 1/2 (60.000 m2)

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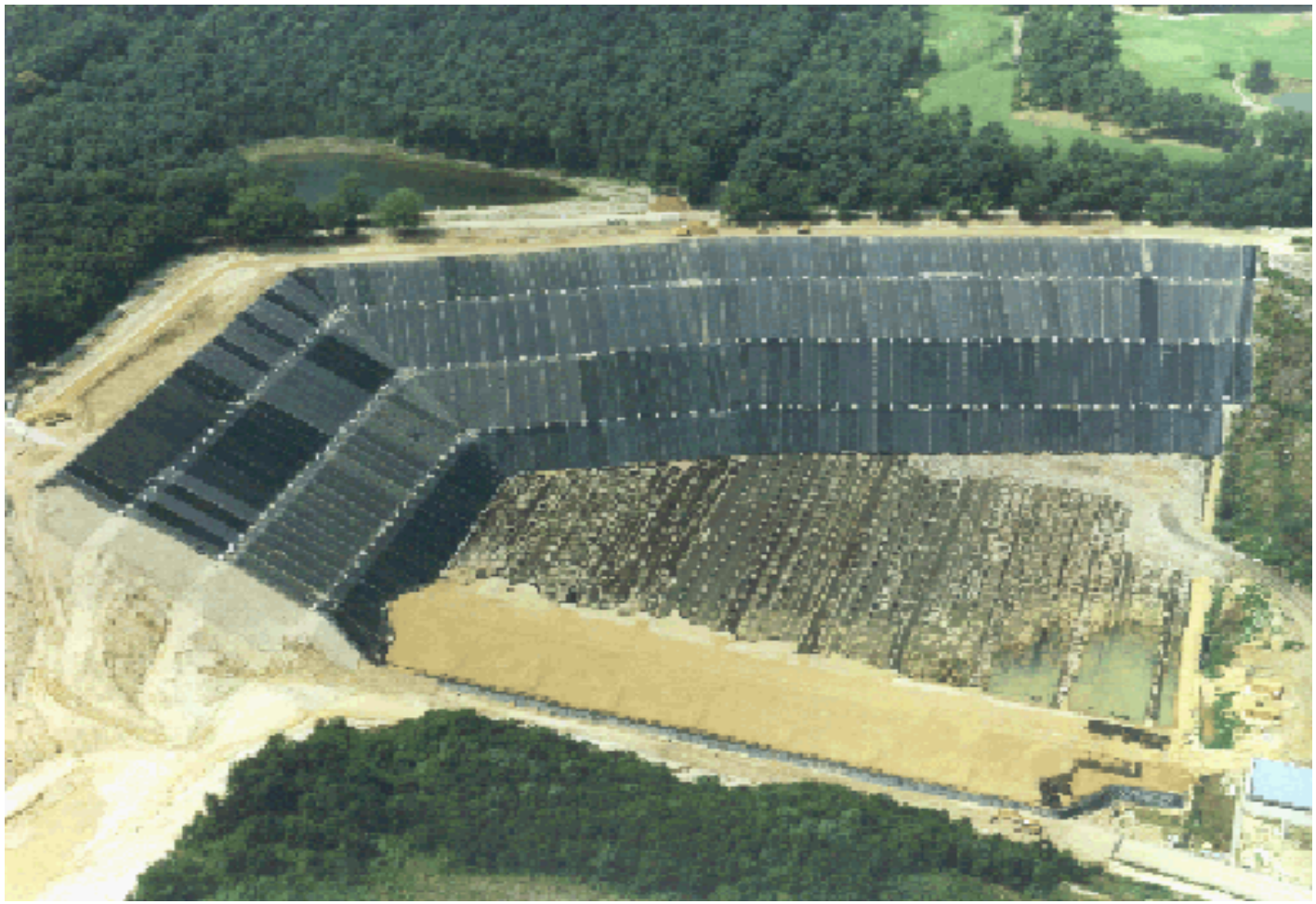
Basal Lining Landgraaf 2/2 (60.000 m2)



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Landfill Cap

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Trisoplast® handling by –10° Celsius

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Capping Zevenbergen (215.000 m2)

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Trisoplast® Landfill Capping Netherlands

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VBM Rotterdam: Re-capping 10 year old BES with Trisoplast

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Capping Frizzi-Au, Italy 12.500 m²

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Basal Lining Italy Steep Slope Application

Slope Angle:
1:1.5 = 34

Slope length:
65 mtr

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Basal Lining with Trisoplast, Landfill Frizzi Au 2005

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Steeper than you can walk!!!

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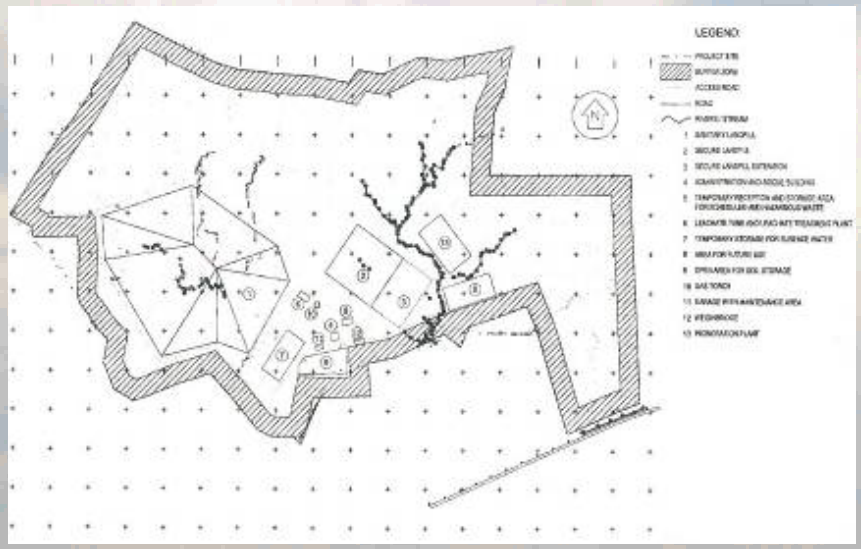

Landfill bottom liner
Kuching, Sarawak, Malaysia 2003

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Trisoplast® using Foundry Sand

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Trisoplast® Davor Landfill, Croatia

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Tailing ponds at Baia Mare project
Maramures, Romania 2004

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Tailing ponds at Baia Mare project
Maramures, Romania 2004

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Industry

concrete / gravel

drainage layer

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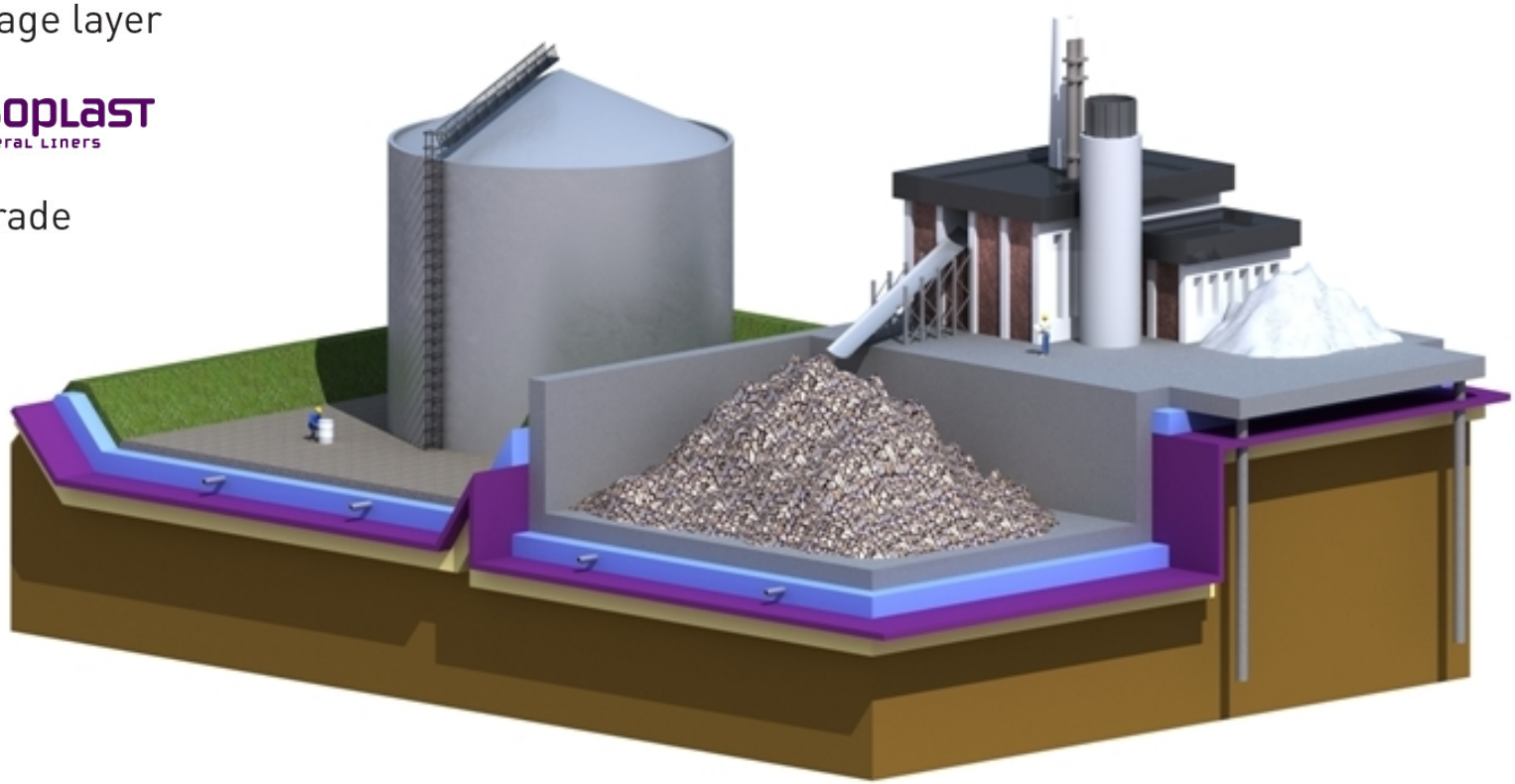
subgrade



Tank park

Liner for (benzene) tank park Shell
Singapore 2008

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Liner for (benzene) tank park Shell
Singapore 2008

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Remediation Buyskade, capping of polluted area
Amsterdam, Netherlands 1996

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Remediation former gas plant, capping polluted area + pond construction
Westergasfabriek Amsterdam, Netherlands 2004

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Trisoplast® for Industrial Sites

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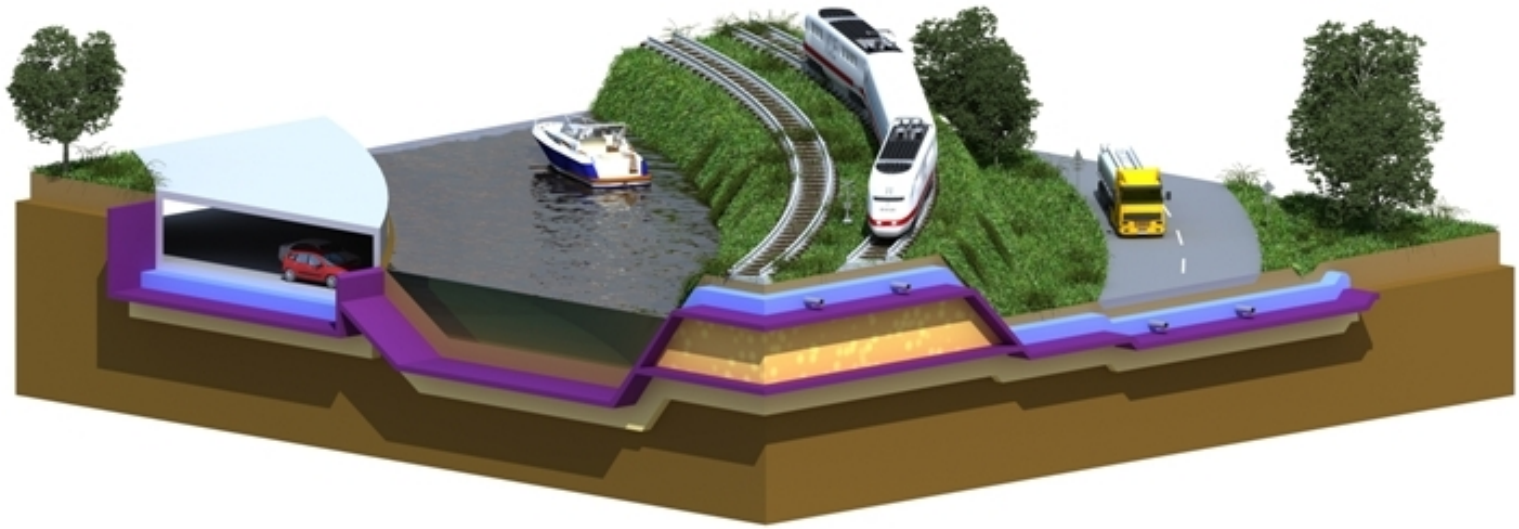
Trisoplast® for Industrial Sites

Infrastructure and Construction

- covering layer
- drainage layer
- waste
- TRISOPLAST Mineral Liners
- subgrade



Highway construction
Oss Paalgraven, Netherlands 2005-2006

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Highway construction
Oss Paalgraven, Netherlands 2005-2006

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Canal
Orléans, France 2007

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Canal
Orléans, France 2007

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Canal
Orléans, France 2007

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Landscaping

covering layer

drainage layer

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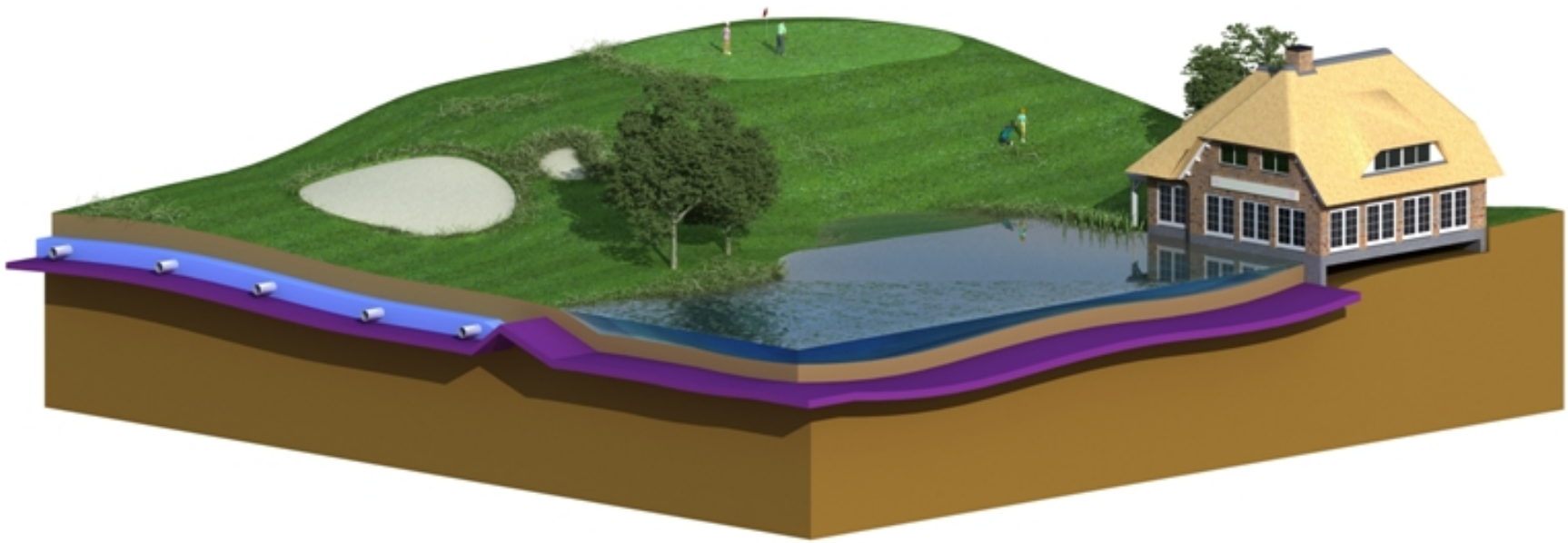

Private pond
Tanques, France 2006

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Ponds Golf course De Scherpenbergh
Lieren, Netherlands 2005

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Ponds Golf course De Scherpenbergh
Lieren, Netherlands 2005

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Ponds Golf course Prise d'eau
Tilburg, Netherlands 2007

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Ponds Golf course Prise d’eau
Tilburg, Netherlands 2007

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Ponds Golf course Prise d’eau
Tilburg, Netherlands 2007

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Ponds Spielberk Office Centre
Brno, Czech Republic 2006

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Ponds Spielberk Office Centre
Brno, Czech Republic 2006

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Ponds in public park
Thiais, France 2007

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Ponds for Recultivation at Former Mining Area
Drocourt, France 2007

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Ponds for Recultivation at Former Mining Area
Drocourt, France 2007

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Ponds for recultivation at former coal mining area
Drocourt, France 2007

TRISOPLAST
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Ponds for Recultivation at former Coal Mining Area
Drocourt, France 2007

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Ponds for Olympics 2012 Development
Swanscombe, London, UK 2008. 170.000 m2

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Private pond
Nuenen, Netherlands, 2006

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Private Pond
Nuenen, Netherlands, 2006

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Private Ponds Duysels Hof Estate
Duizel, Netherlands 2002-2003

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Private Ponds Duysels Hof Estate
Duizel, Netherlands 2002-2003

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Private ponds Duysels Hof Estate
Duizel, Netherlands 2002-2003

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Private Ponds Duysels Hof Estate
Duizel, Netherlands 2002-2003

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Private pond
Kaatsheuvel, Netherlands 2002

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Pond Crayenstein estate
Vught, Netherlands 2005

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Ponds at Fauna Overpass De Borkeld
Rijssen, Netherlands 2003

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Summarising Main Advantages Trisoplast:

- **Sealing** like the highest quality of clay, self-healing ability
- **Strength** like sand (durable slopes up to 1:1.5)
- **Flexibility** like chewing gum, no stress cracking
- **Durability** robust natural materials improved by modern polymer technique
- **Quality** simple installation of homogeneous mixtures, simple sealing to structures and penetrations, not damaged by sharp particles

Thank you

t o p q u a l i t y b e l o w

For more information, please contact us directly
or visit our website www.**trisoplast.com**

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