Naue

Geosynthetic Clay liners – Sustainable and resilient barrier applications in hydraulic engineering

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Chairman: CEN TC 189 WG6 Barriers and WG7;
Board: The IGS Foundation, Technical Advisory Committee Geosynthetics
Lecturer : University of Applied Sciences Bielefeld, University of Applied Sciences Ostwestfalen-Lippe

Content of the presentation

Topics

- CEN TC189/WG7
- ISO/TR 18228-9 Design using geosynthetics — Part 9: Barriers
- Water stress and rainfall
- Failure in past designs
- Dykes/levees
- Underwater installation canals
- Hydropower dams
- GCLs - sustainable, ecological, economical, resilient
- Summary

Content of the presentation

CEN TC189 WG7 proposed scope

Requirements related to the revised Construction Products Regulation (CPR) common to Geosynthetics, including sustainability and environmental topics, such as:

- Release of dangerous substances;
- Environmental performance;
- Circular Economy;
- Potential release of microplastics during the different stages of the life cycle of the product.

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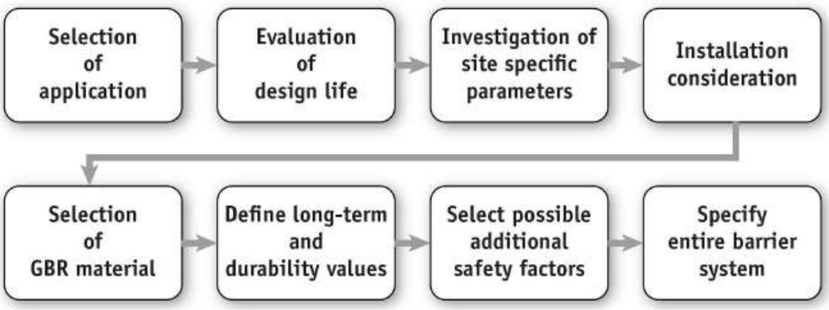
Geosynthetic barrier design guide

ISO/TR 18228-9 Design using geosynthetics - Barriers

The reason Introduction to geosynthetic newcomers.

The Result: Show new technologies rather than using conservatism and past approaches.

The Solution: Educating and removing the fears or concerns about geosynthetic solutions



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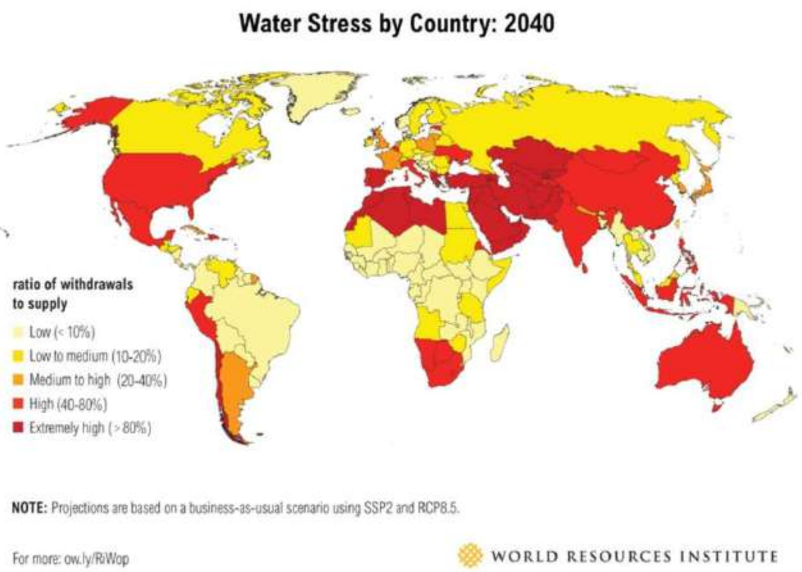
Water is very valuable – today and tommorow



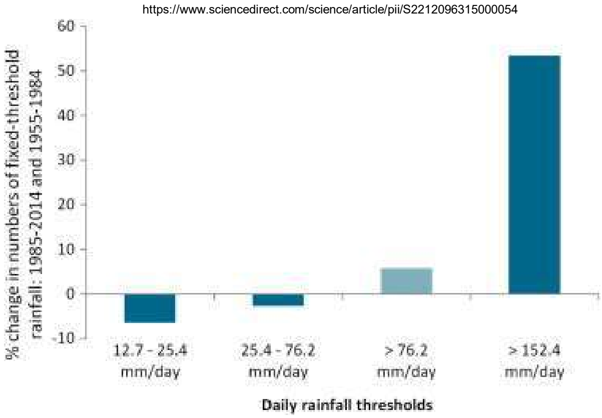
https://www.climatechangenews.com/2015/08/27/middle-east-faces-extreme-water-shortages-by-2040/

Rainfall change 1955 – 1984 compared to 1985 - 2014

Change of rain intensity is the unpredictable.

https://www.mei.edu/publications/addressing-worldwide-flood-concerns-empowering-local-communities

https://www.sciencedirect.com/science/article/pii/S2212096315000054



Unsecure levees

Flood Event in Germany

More than 100 dykes bursted and caused floods around River Mulde Aug. 2002

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Life-saving levees

Goondiwindi's levee, Australia, saves the town from flooding, but surrounding areas are under water (2022)

As flood risks increase, it’s time to recognize the importance but also the limits of levees

https://www.abc.net.au/news/2021-12-04/qld-goondiwindi-levee-saves-town-from-flooding/100674936/

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Unsecure levees

Flood Event in Germany

Main causes of the levees bursting

- **Many levees > 50 years old**
- **Animals forming burrows**
- **Longer, drier summers**
- **Cracking of levee**
- **Root formation**
- **Designed to withstand water pressure for a shorter period**
- **Heavier rainfalls**
- **Longer exposure to water pressure**
- **Built too close to river**

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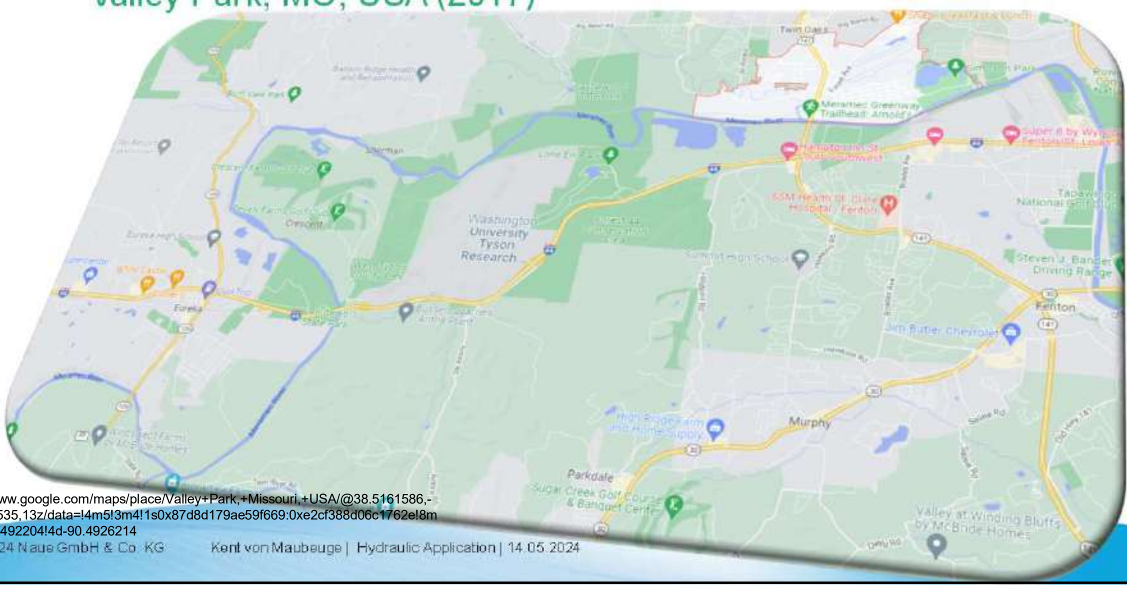
Secure new and higher levees

Meramec River flood event in in Valley Park, MO, USA (2017)



https://www.google.com/maps/place/Valley+Park,+Missouri,+USA/@38.5161586,-90.5769535,13z/data=!4m5!3m4!1s0x87d8d179ae59f669:0xe2cf388d06c1762e!8m2!3d38.5492204!4d-90.4926214

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Secure new and higher levees

Meramec River flood event in in Valley Park, MO, USA (2017)

https://youtu.be/LTv6RkFnelM

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No or too low levees and more flood water due to higher levees upstream

Meramec River flood event in Eureka, MO, USA and the consequences (2017)

https://youtu.be/LTv6RkFnelM

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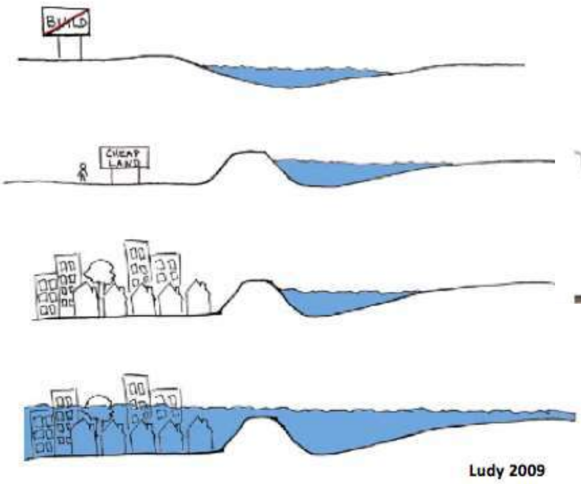
It is not only the fault of climate change



https://thewateraway.wordpress.com/2012/02/06/two-types-of-levees-and-that-other-kind-of-risk/

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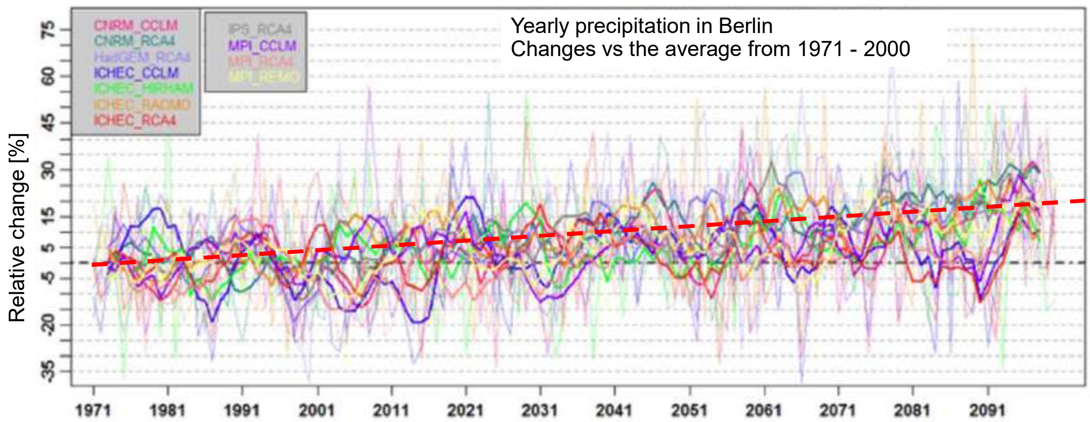
Climate change

Yearly precipitation in Berlin, GER 1971 -2000 and future prediction



Yearly precipitation in Berlin (Changes vs the average from 1971 - 2000 (Bild: SenUVK)

https://www.berlin.de/sen/uvk/klimaschutz/anpassung-an-den-klimawandel/auswirkungen-des-klimawandels/

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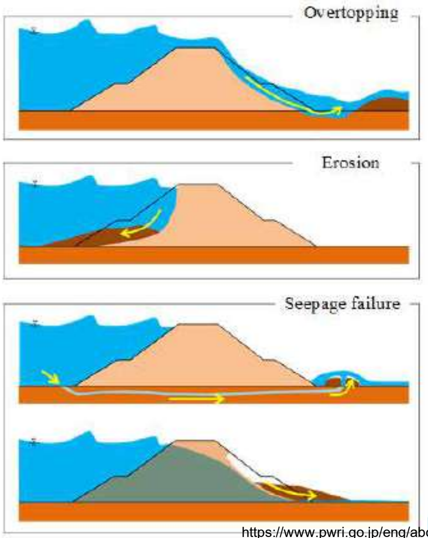
Damage to levees

Mechanisms of damage to levee



If levees are not high enough

If flow is higher and lasts longer

If flood lasts longers and permeation is high

https://www.pwri.go.jp/eng/about/pr/webmag/wm048/kenkyu.html

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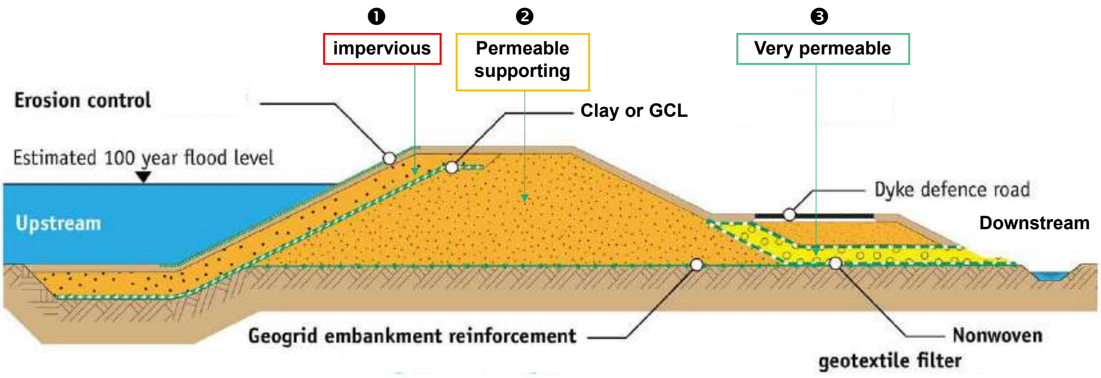
Fundamentals in designing river levees

The 3 Zone Levee Concept

(DVWK-Guideline „River dykes“ 210/1986 or DIN 19712)



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Fundamentals in designing river levees

Permeation of Dykes

Soil	k_x [L/T]	k_y [L/T]	n_{eff} [-]	
	$1.000 \cdot 10^{-5}$	$1.000 \cdot 10^{-5}$	0.20	Clayey cover
	$1.000 \cdot 10^{-4}$	$1.000 \cdot 10^{-4}$	0.20	Dyke core
	$1.000 \cdot 10^{-6}$	$1.000 \cdot 10^{-6}$	0.20	Subsoil

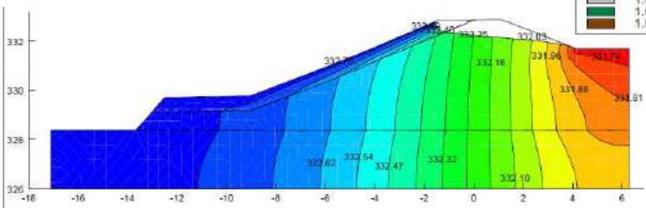
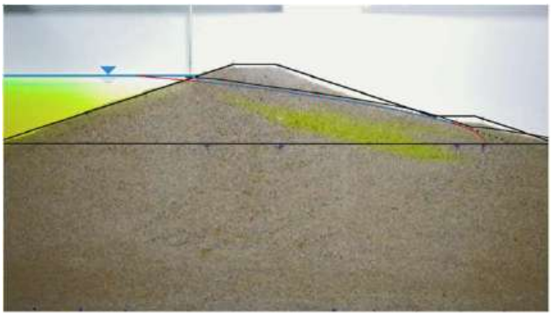


Abb. 2: Stationärer Zustand
(Wasserseite: WSP links = 332,8 mNN, Luftseite = 331,75 mNN)



https://www.researchgate.net/profile/Benedikt-Haumer/publication/309231006_Vergleichende_Darstellung_der_Durchsickerungsprozesse_an_Deichen_und_Dammen_Comparison_of_seepage_processes_in_dikes_and_dams/links/5806329e08ae5ad1881625e8/Vergleichende-Darstellung-der-Durchsickerungsprozesse-an-Deichen-und-Daemmen-Comparison-of-seepage-processes-in-dikes-and-dams.pdf

Abb. 2: Stationärer Zustand
(Wasserseite: WSP links = 332,8 mNN, Luftseite = 331,75 mNN)

Soil	k_x [L/T]	k_y [L/T]	n_{eff} [-]	
	$1.000 \cdot 10^{-5}$	$1.000 \cdot 10^{-5}$	0.20	Clayey cover
	$5.000 \cdot 10^{-10}$	$5.000 \cdot 10^{-10}$	0.05	GCL
	$1.000 \cdot 10^{-4}$	$1.000 \cdot 10^{-4}$	0.20	Dyke core
	$1.000 \cdot 10^{-6}$	$1.000 \cdot 10^{-6}$	0.20	Subsoil

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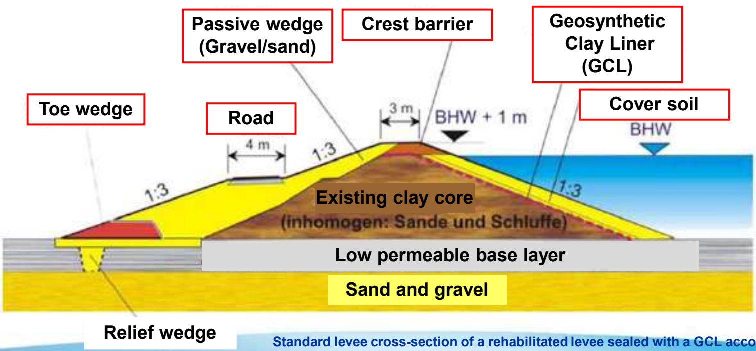
Fundamentals in designing river levees

The BRAD 16 Guideline

- GCLs in levee construction (rehabilitation and new construction) in the state of Brandenburg, Germany but adapted in other German states and in the Netherlands.
- Applies to design, tender, awarding as well as construction and quality assurance.



Standard levee cross-section of a rehabilitated levee sealed with a GCL according to BRAD 16 (LfU, Potsdam)

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Requirements for levee classes

The BRAD 16

Typen: A (needle-punched) B (needle-punched) C (stitch-bonded)

≥ 3m

Anlage 1: Anforderungskatalog

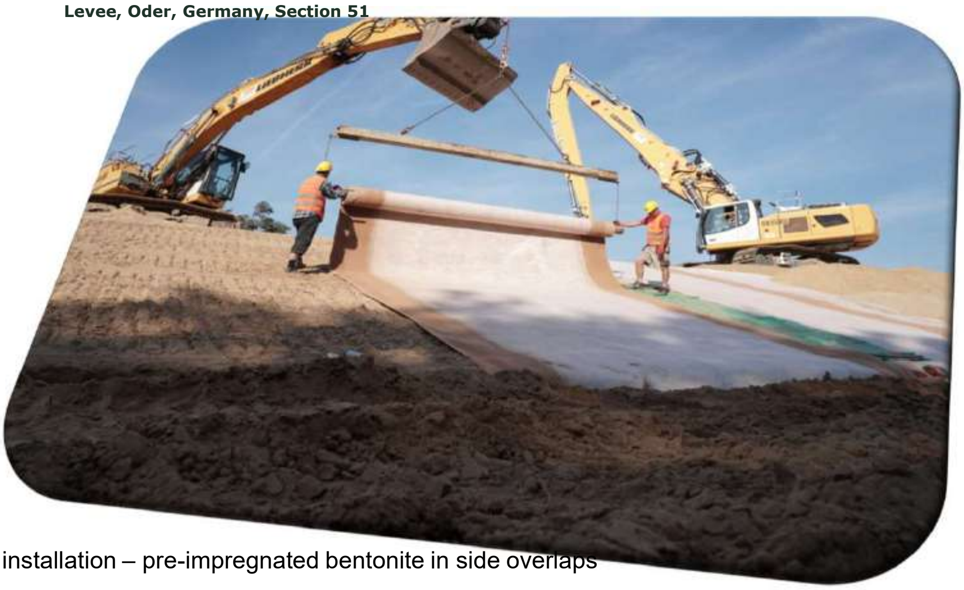
Zeile	Kennwert der GTD	Norm	Deichklasse [1] II und III	Deichklasse I [2]
1	Flächenbezogene Masse des Tonbestandteils bei ≤ 15 % Wassergehalt	DIN EN 14196	natürliches oder aktiviertes Natriumbentonit ≥ 4.500 g/m² als Pulver oder Granulat	
	Montmorillonitgehalt	VDG P 69 [1]	Methylenblauwert ≥ 300 mg/g [15]	
2	Durchlässigkeitsbeiwert k_{20} [3]	DIN EN 16416	$< 5 \times 10^{-10}$ m/s	$< 1 \times 10^{-10}$ m/s
3	Deck- und Trägergeotextilien [4]	DIN EN ISO 9864 DIN EN ISO 10318	❷ Geogewebe (GTX-W): ≥ 180 g/m² ❸ Geoverbundstoff [5] (GCO): ≥ 250 g/m² ❶ Geovliesstoff (GTX-N) ≥ 150 g/m²	❷ Geogewebe (GTX-W): ≥ 250 g/m² ❸ Geoverbundstoff [5] (GCO): ≥ 350 g/m² ❶ Geovliesstoff (GTX-N): ≥ 300 g/m²
4	Durchdrückwiderstand [6]	DIN EN 12236	≥ 1,5 kN	≥ 3,5 kN
5	Höchstzugkraft bei Geovliesstoffen in MC/CMD [6) 7) 9)]	DIN EN ISO 10319	≥ 12 kN/m	≥ 15 kN/m
6	Höchstzugkraft bei Geogeweben und Mischprodukten in MC /CMD [6) 8) 9)]	DIN EN ISO 10319	≥ 35 kN/m	≥ 50 kN/m
7	Dehnung bei Bruch der GTD in MC /CMD	DIN EN ISO 10319	≥ 10 %	≥ 30 %
8	Verbundfestigkeit im Schälversuch (MD)	DIN EN ISO 13426-2 [13] ASTM D 6496 [14]	≥ 60N/10cm	≥ 100N/10cm
9	Langzeitscherfestigkeit [10) 11)]	LAGA [8]	Böschungsneigung 1:3 : ≥ 15 kN/m²	
10			Böschungsneigung 1:2,5: ≥ 18 kN/m²	
11	äußere Standsicherheit	DIN EN 1054 DIN 4084	Nachweis der Sicherheit gegen Abgleiten in den Scherfugen GTD- Böden (für Träger- und Deckgeotextil) mit den lokalen bodenbezogenen Reibungswinkeln	
12	Erosionsbeständigkeit [12]	RPW [3]	Bentonitverluste ≤ 5% (nach DIN EN 13361:2013, B.4.4) bei einer Versuchslaufzeit von 96 Std.	
13	Nachweis der Langzeitbeständigkeit für GTD	DIN EN 13361, Anhang Dauerhaftigkeit, aktuelle Ausgabe	≥ 25 Jahre in natürlichen Böden mit einem ph_Wert von 4 bis 9 und einer Bodentemperatur ≤ 25°. Leistungserklärung DoP nach CPR	
14	Nachweis der Langzeitbeständigkeit für Deck- und Trägergeotextilien	DIN EN 13255: 2016-12, Anhang B Dauerhaftigkeit	≥ 100 Jahre in natürlichen Böden mit einem ph-Wert von 4 bis 9 und einer Bodentemperatur ≤ 25°. Als Zusatzerklärung auf der Leistungserklärung DoP oder als gesonderte Deklaration des Herstellers	
15	Umweltunbedenklichkeit der GTD	MGeokE 2016 [1] Kapitel 6.29 und 7.7	Nachweis der Unbedenklichkeit	

1) Deichklasse nach DIN 19712, Tab. 1, Bauwerkshöhe < 3 m über landseitigem Gelände
2) Deichklasse nach DIN 19712, Tab. 1, Bauwerkshöhe ≥ 3 m über landseitigem Gelände. Diese Spalte gilt auch für Deiche der Klasse II und III mit zu erwartenden Setzungen > 0,5 m
3) bei 30 kPa Auflast, ΔH = 150 cm und 20°C. Die Durchlässigkeit ist auch für den Überlappungsbereich nachzuweisen
4) nachzuweisen an den Ausgangsprodukten, da im Endzustand eine Trennung der Komponenten nicht möglich ist.
5) Gilt für mehrlagige Vliesstoff- Gewebe-Kombinationen und für Geovliesstoffe mit stabilisierender Gewebeeinlage. Das Mindestgewicht für die leichtere Komponente beträgt 100 g/m².
6) nachzuweisen am Endprodukt
7) gilt auch, wenn eine stabilisierende Geweseeinlage im Vliesstoff vorhanden ist oder eine Gewebe- und Vlieslage direkt miteinander verbunden sind
8) Maßgeblich auch wenn nur eines der Träger- oder Deckgeotextilien aus Geogewebe besteht.
9) Die Anforderungen an die Zugfestigkeit müssen auch von allen Einzellagen der GTD erfüllt werden, d.h. der erste Peak der Kraft-Dehnungskurve und damit das Versagen der ersten Geotextilkomponente ist das Bewertungskriterium für die Zugfestigkeit
10) Analog LAGA Eignungsverfahren für GTD. Ergebnis eines Langzeitscherfestigkeitsversuches mit ≥ 10.000 h. Nachweis gemäß Bundeseinheitlicher Qualitätsstandard 5-5 Oberflächenabdichtungskomponenten aus [illegible] Tondichtungsbahnen vom 02.12.2015, Abschnitt 3.2" der LAGA
11) können bei neu entwickelten Produkten noch keine Untersuchungen der Langzeitscherfestigkeit vorliegen, wird für einen Übergangszeitraum bis Ende 2017 der Nachweis der Verbundfestigkeit von > 100N/10 cm nach Zeile 8 akzeptiert.
12) Das Prüfkriterium wurde abweichend von der RPW festgelegt. Nach RPW wird nach dem Turbulenztest die Durchlässigkeit bestimmt.
13) bevorzugt für vernähte Produkte
14) bevorzugt für vernadelte Produkte
15) entspricht ca. 70 % Montmorillonit

Levee, Oder, Germany, Section 51

Bird´s view

Levee, Oder, Germany, Section 51



GCL installation – pre-impregnated bentonite in side overlaps

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Levee, Oder, Germany, Section 51

GCL anchor trench

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Reason for relying on a GCL (in GCL they trust)

GCL advantages

- **Thinner equivalent sealing system**
- **Less excavation on site required**
- **Faster to install than clay**
- **Manufacturing quality controlled**
- **Higher resilience to settlement, desiccation, frost/thaw cycles**
- **High resilience and erosion stable**
- **Slope stability**
- **Long-term durable (confirmed by excavations)**
- **Cost effective**

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Levee in the Netherlands

following basics of BRAD 16

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GCL underwater installation

How can a GCL be installed underwater?

- Installation of canal liners – without lowering existing water levels
- Enormous challenging - Low to no visibility, uplift-forces, flow velocities

GCL requirements:

- Low hydraulic conductivity
- Easiness of installation and QA
- Safe and reliable (in the area and for connections, overlaps)
- Robustness
- Economic and environmental friendly

Empfehlungen zur Anwendung von Oberflächendichtungen an Sohle und Böschung von Wasserstraßen

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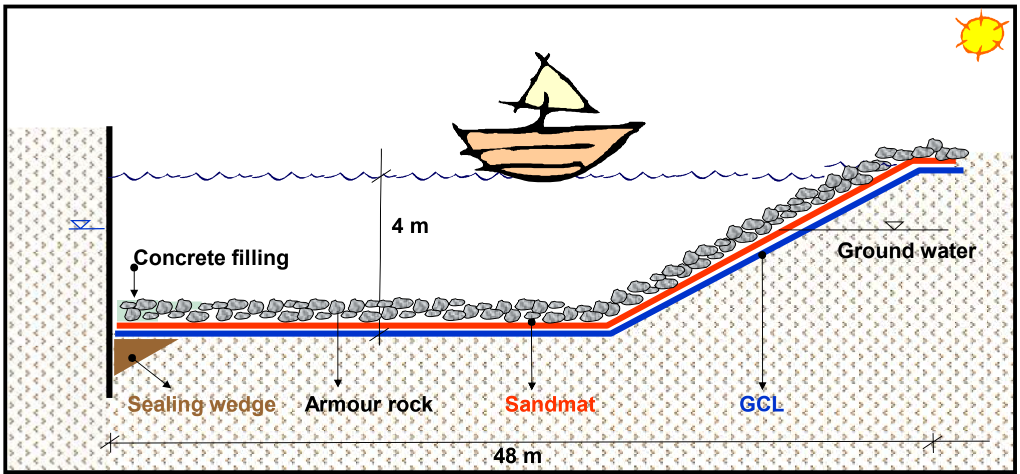
GCL underwater installation

Specific requirements (Overlaps, connections, protection)



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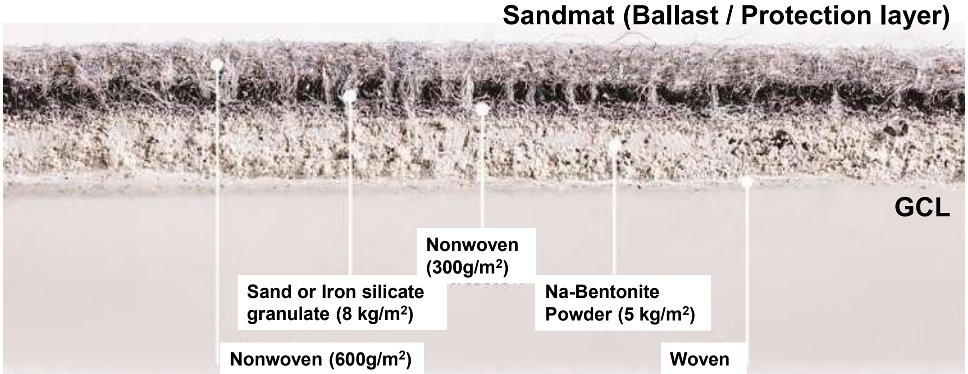
GCL underwater installation

GCL specific requirements

Sandmat (Ballast / Protection layer)



- The sand layer acts as a ballast for sinking,
- is a confining pressure against swelling of the bentonite and
- acts as a protection layer against dropping armour rock

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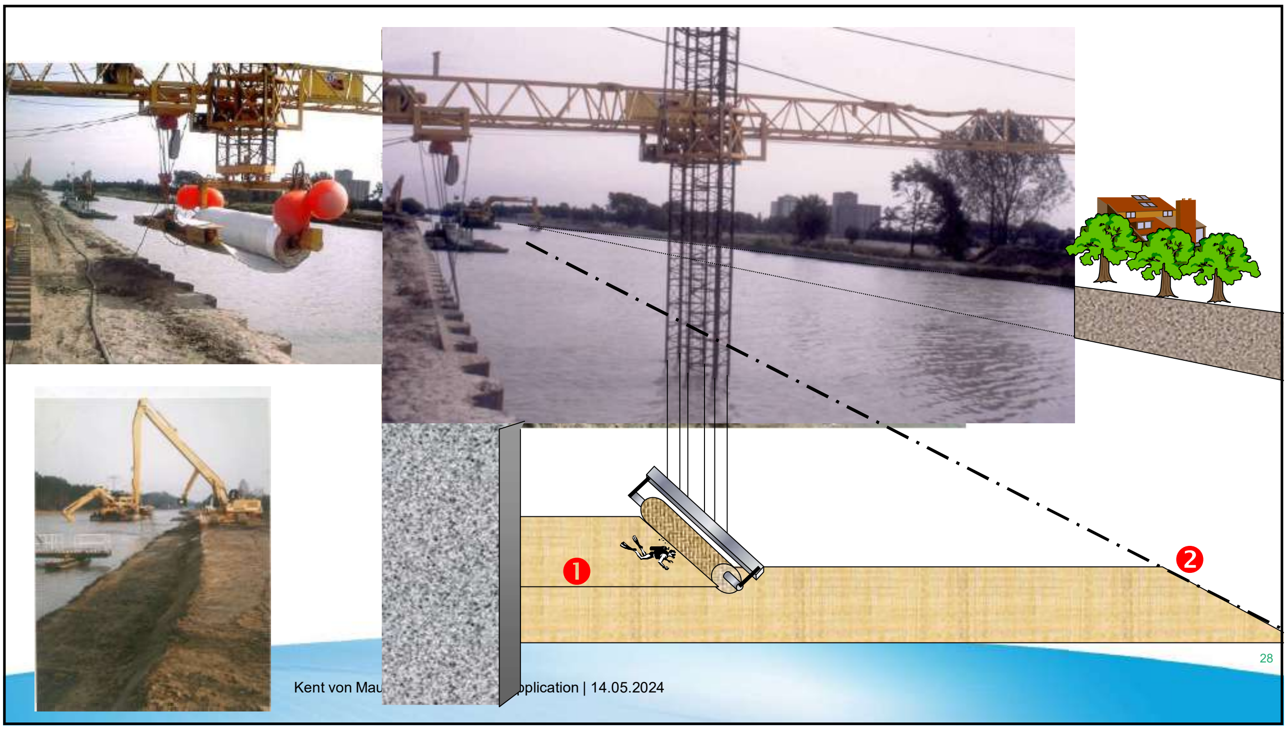

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GCL underwater installation

Danube river concrete rehabilitation, Ellgau, Bavaria






With improved GPS installation the location can be mapped.

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Huge stormwater retention dam

Repair of a clay liner sealed dam, Glashütte, Germany

Project

- Old dam destroyed during flood event in 2002 (overflowing)
- First immediate repair with a smaller dam, to be increased in height later
- Height: 28 m, Length: ca. 180 m,
- Slopes: upstream (V:H) 1:2,5
downstream (V:H) 1:2 to 1:2,8
- Lower dam approx. 16 m high with clay core
Top dam approx. 12 m with GCL
- Water storage capacity >1 mio m³


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Huge stormwater retention dam

Repair of a clay liner sealed dam, Glashütte, Germany

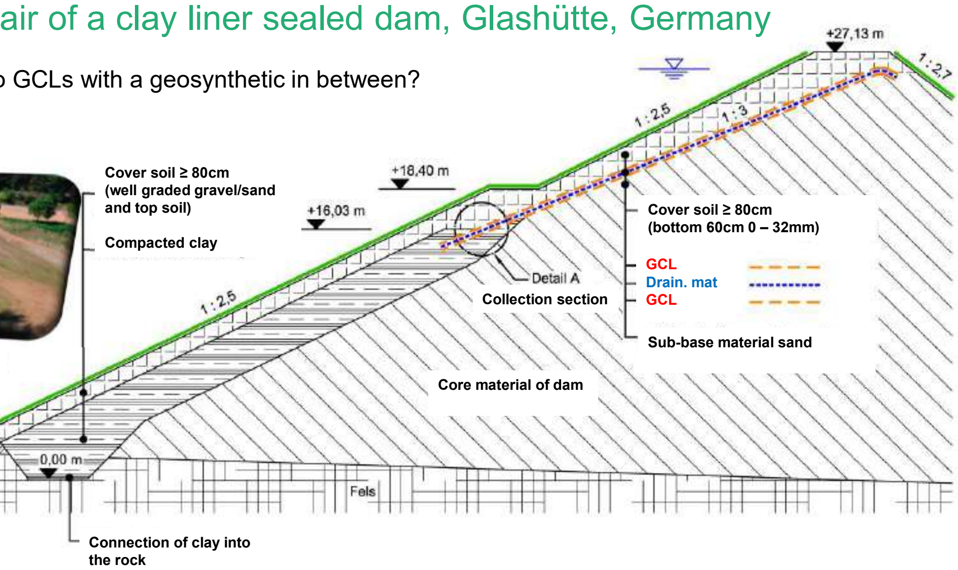
GCL Requirements

Property	Value	Unit
❶ Cover PP or PE nonwoven mass per unit area (MPUA)	300	g/m²
❷ Carrier PP or PE woven MPUA	110	g/m²
❸ Sodium bentonite powder MPUA	> 9,000	g/m²
❸ Sodium bentonite moisture content at delivery	approx. 10	%
GCL total MPUA	10,400	g/m²
GCL thickness	9	mm
GCL tensile strength (machine and cross-machine direction)	12	kN/m
GCL CBR (plunger puncture) strength	2,000	N
Permittivity	$< 5 \cdot 10^{-9}$	1/s
Permeability	$2 \cdot 10^{-11}$	m/s
Bentonite impregnated length overlaps for self-sealing	0.5	m
Roll weight	< 1	t

Huge stormwater retention dam

Repair of a clay liner sealed dam, Glashütte, Germany

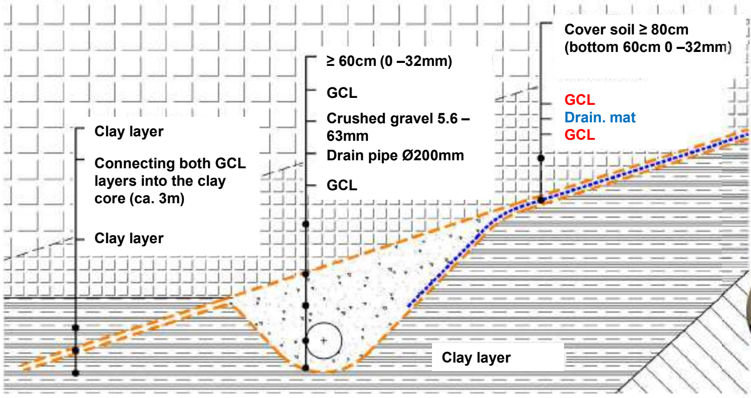
But why two GCLs with a geosynthetic in between?



Huge stormwater retention dam

Repair of a clay liner sealed dam, Glashütte, Germany

Detail A – Collection and control section



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Huge stormwater retention dam

Repair of a clay liner sealed dam, Glashütte, Germany

Bird´s view of construction site

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Huge stormwater retention dam

Repair of a clay liner sealed dam, Glashütte, Germany

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Hohenwarte II pump storage station

Geosynthetic Clay Liner as Primary Lining System

Permeation starting on the downstream toe

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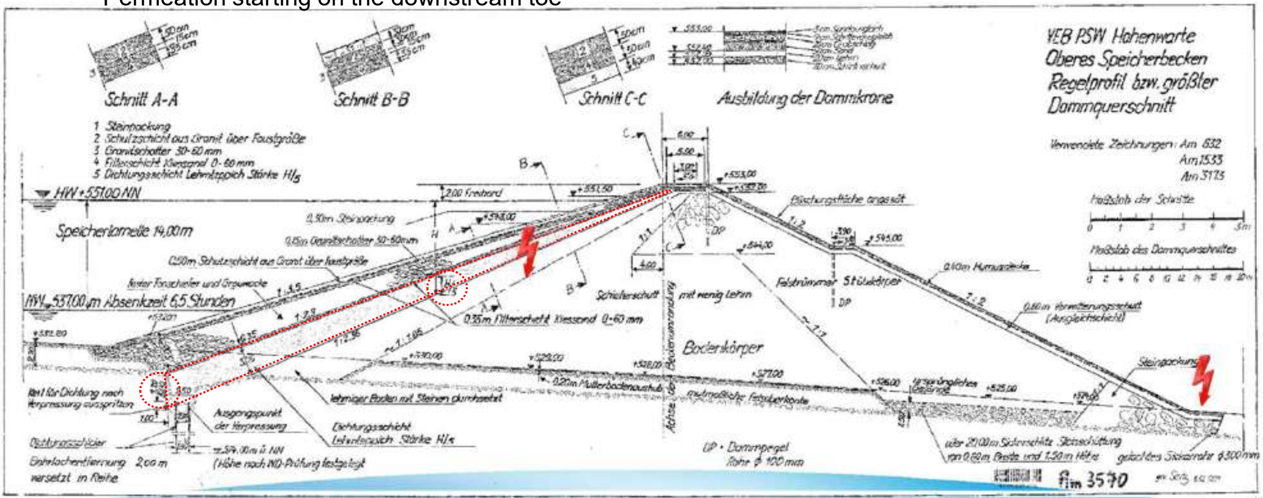
Hohenwarte II pump storage station

Dam in operation from 1965 (construction begin 1956)

Permeation starting on the downstream toe



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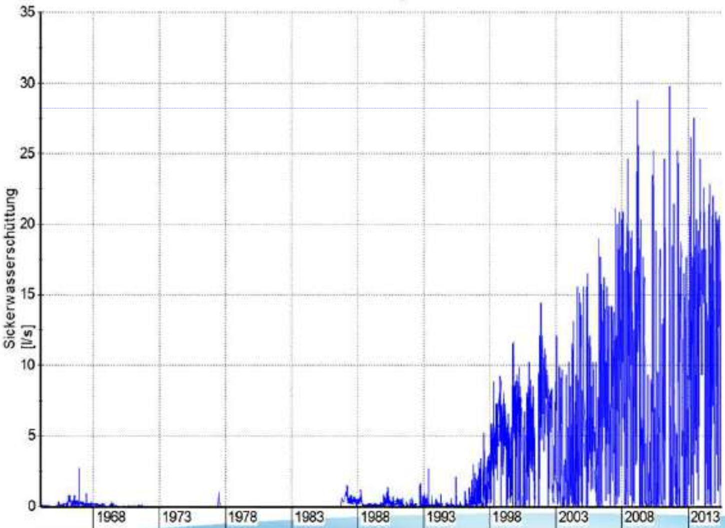
Hohenwarte II pump storage station

Dam in operation from 1965 (construction begin 1956)



Critical value

- Increase of permeation in the dam downstream area
- constant increase since 1998
- Annual permeation increase of about 3l/s

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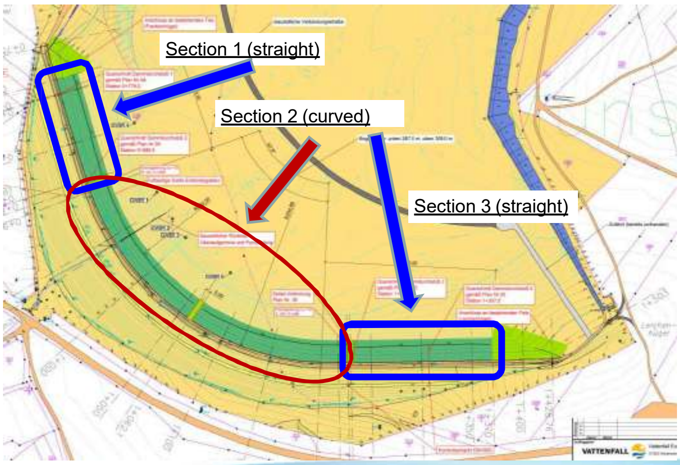
Hohenwarte II pump storage station

Selected possible repair solutions

Sections of repair



- Local repair was not an option
- New clay liner – time intense, costs
- Asphalt concrete – connections, technology
- Briposan – not enough experience
- Geomembrane – connections, stiffness
- Geosynthetic clay liner – cost efficient, positive experience in Glashütte, self-sealing potential

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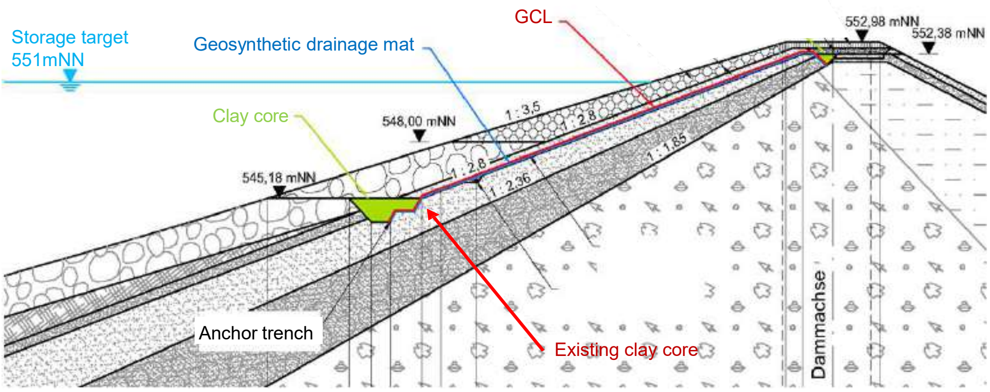
Hohenwarte II pump storage station

Proposed design solution

Sections of repair



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Hohenwarte II pump storage station

Specified GCL properties and requirements

Property	Value	Unit
❶ Cover PP or PE nonwoven mass per unit area (MPUA)	300	g/m²
❷ Carrier PP or PE woven MPUA	110	g/m²
❸ Sodium bentonite powder MPUA	> 9,000	g/m²
❸ Sodium bentonite moisture content at delivery	approx. 10	%
GCL total MPUA	10,300	g/m²
GCL thickness	12	mm
GCL tensile strength (machine and cross-machine direction)	12	kN/m
Permeability	$< 1 \cdot 10^{-11}$	m/s
Bentonite impregnated length overlaps for self-sealing	0.5	m
Roll length	27	m
System friction angle (EC7, section 2.4.5	26	°
Acceptable mean flow rate per unit area through the GCL	0.25	ml/s per m²

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Hohenwarte II pump storage station

Repair and GCL installation phase

GCL installation wit 0.5m overlaps

GCL anchoring in the clay core

Placement of geosynthetic drainage mat

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Hohenwarte II pump storage station

Bird´s view of construction site

Sequence of construction

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Hohenwarte II pump storage station

Entire view of construction site

Bird´s view

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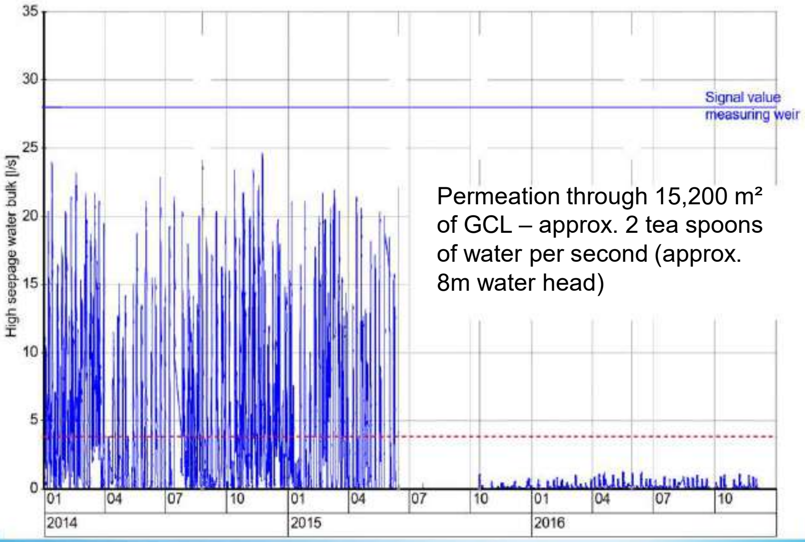
Hohenwarte II pump storage station

Post installation permeation measurements



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Geosynthetic clay liners

Sustainable, ecological, economical, resilient

Less transportation vehicles

Less noise emission

Less impact to roads

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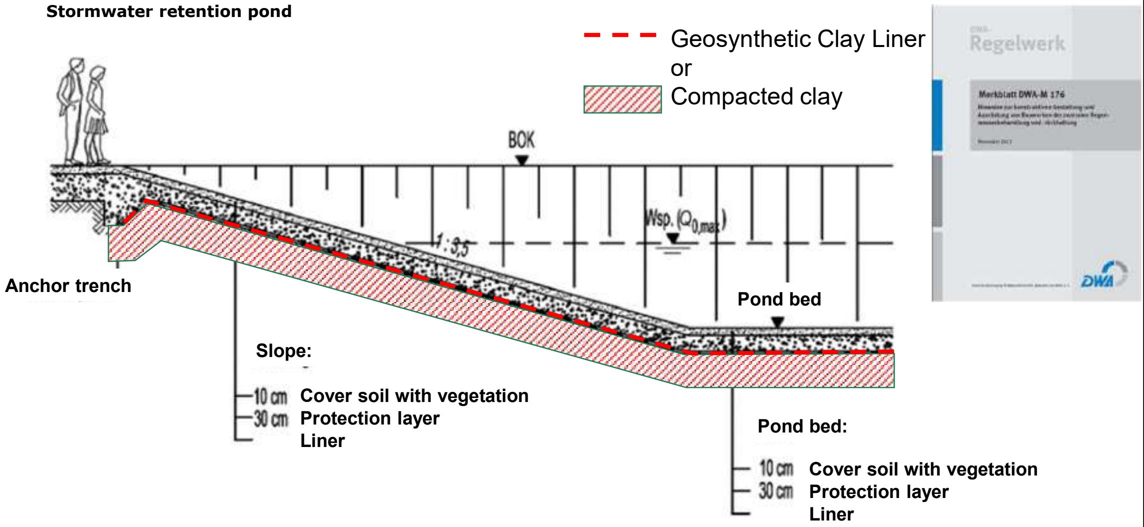
Stormwater retention pond



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Soil classificationin waste groups and approx. Deposit pricing

Market prices for landfill storage [Bauindustrieverband Niedersachsen / Bremen, 2014]

			Ca. 1,75 to/cbm
	Boden bis LAGA Z0	5,00 – 6,00 Euro/cbm	5,00 – 6,00 Euro/cbm
April 2020	Boden bis LAGA Z1.1	9,00 – 11,00 Euro/cbm	9,00 – 11,00 Euro/cbm
ca. 40 €/to	Boden bis LAGA Z1.2, DK0	19,00 – 22,00 Euro/to	33,25 – 38,50 Euro/cbm
ca. 50 €/to	Boden bis LAGA Z2, DK0	22,00 – 26,00 Euro/to	38,50 – 45,50 Euro/cbm
ca. 65 €/to	Boden bis LAGA > Z2	28,00 – 32,00 Euro/to	49,00 – 56,00 Euro/cbm
	Boden LAGA Z3, DK1	38,00 – 50,00 Euro/to	66,50 – 84,50 Euro/cbm

For the following example 35 €/m³ were estimated (likely now 75 – 80 €/m³)

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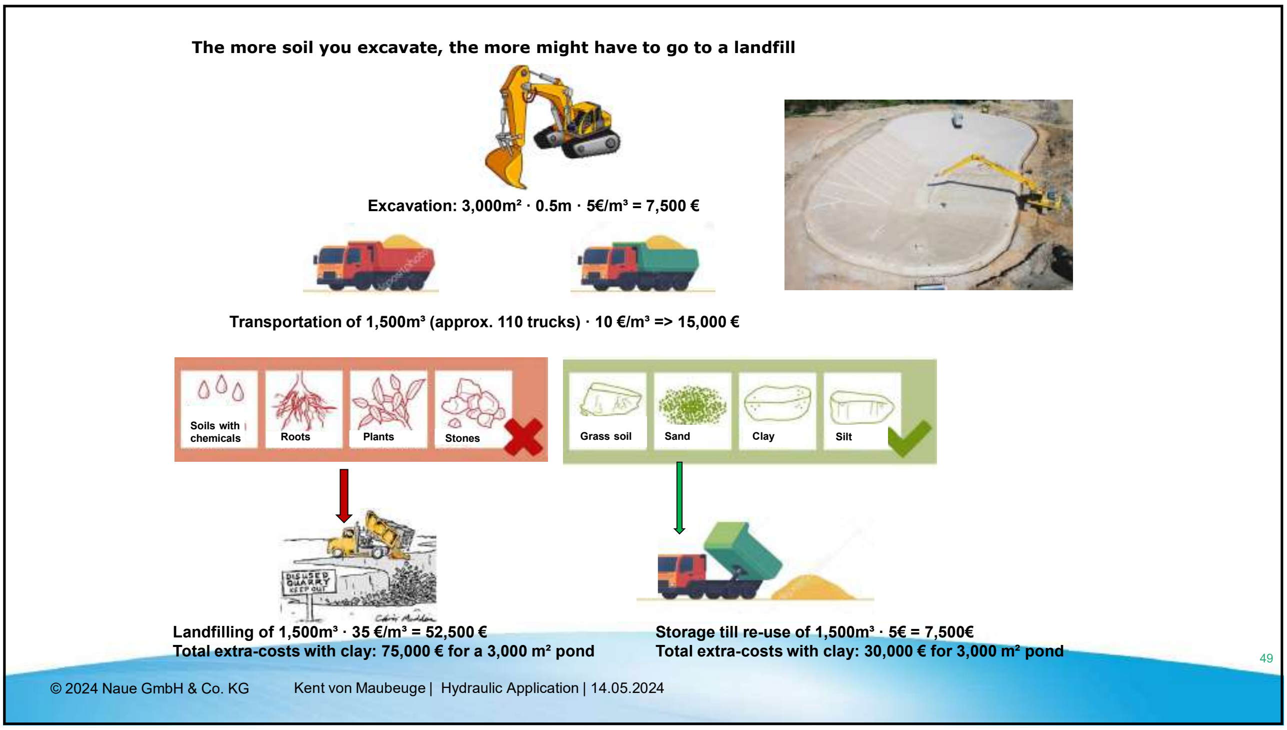
The more soil you excavate, the more might have to go to a landfill
Excavation: 3,000m² · 0.5m · 5€/m³ = 7,500 €
Transportation of 1,500m³ (approx. 110 trucks) · 10 €/m³ => 15,000 €
Soils with chemicals
Roots
Plants
Stones
Grass soil
Sand
Clay
Silt
Landfilling of 1,500m³ · 35 €/m³ = 52,500 €
Total extra-costs with clay: 75,000 € for a 3,000 m² pond
Storage till re-use of 1,500m³ · 5€ = 7,500€
Total extra-costs with clay: 30,000 € for 3,000 m² pond
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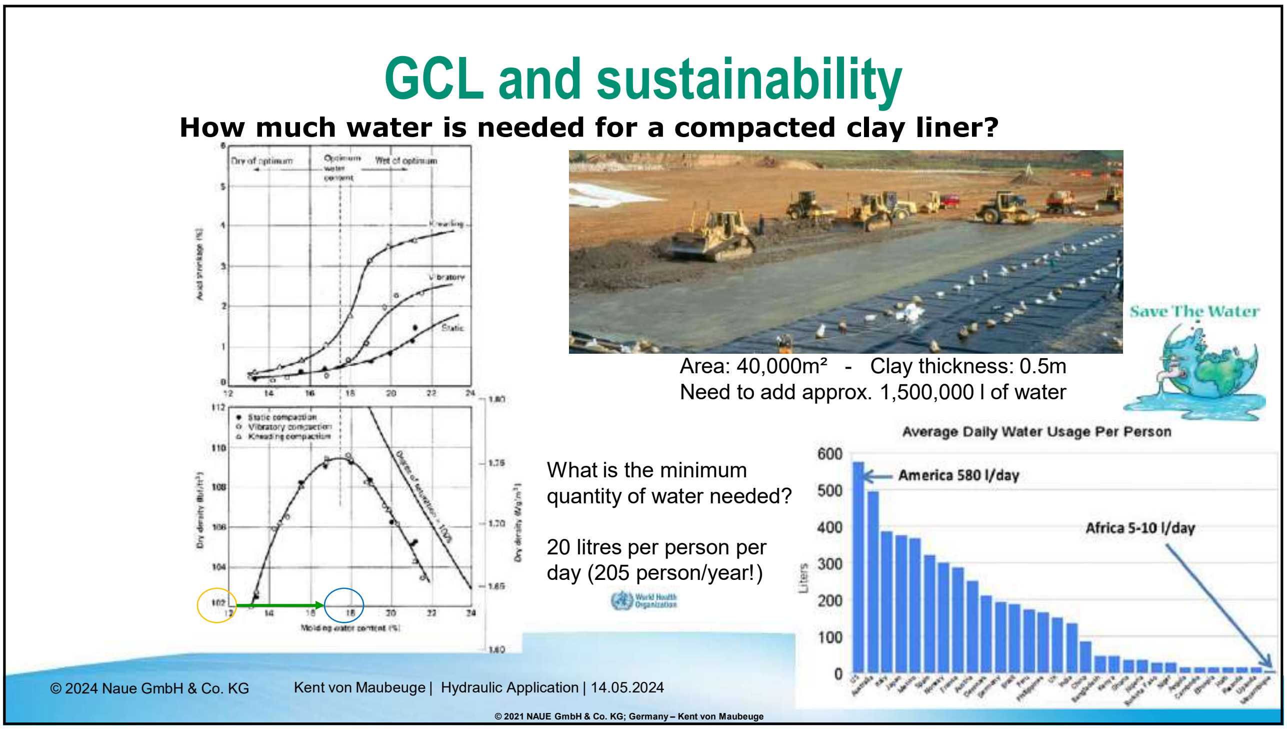
GCL and sustainability
How much water is needed for a compacted clay liner?
Area: 40,000m² - Clay thickness: 0.5m
Need to add approx. 1,500,000 l of water
Save The Water
Average Daily Water Usage Per Person
America 580 l/day
Africa 5-10 l/day
What is the minimum quantity of water needed?
20 litres per person per day (205 person/year!)
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Fact 17: Transportation benefits GCLs

Example:

4,500m² sealing with Bentofix® GCL

Equals:

1 truck

4,500m² sealing with compacted clay (500mm thick)

Equals:

187 trucks

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Installation of a compacted clay liner


❶ Project size 4.500m²


❷ 187 truck loads


❸ Stress on the access roads


❹ Large storage area


❺ in situ mixing


❻ Transportation on site


❼ 1st clay layer


❽ Watering


❾ Compaction of 1st layer


❿ Vibration compaction


11 2nd clay layer


12 Watering


13 Compaction 2nd layer


14 Vibration compaction


15 Desiccation


16 Cover soil placement


17 Cover soil movement

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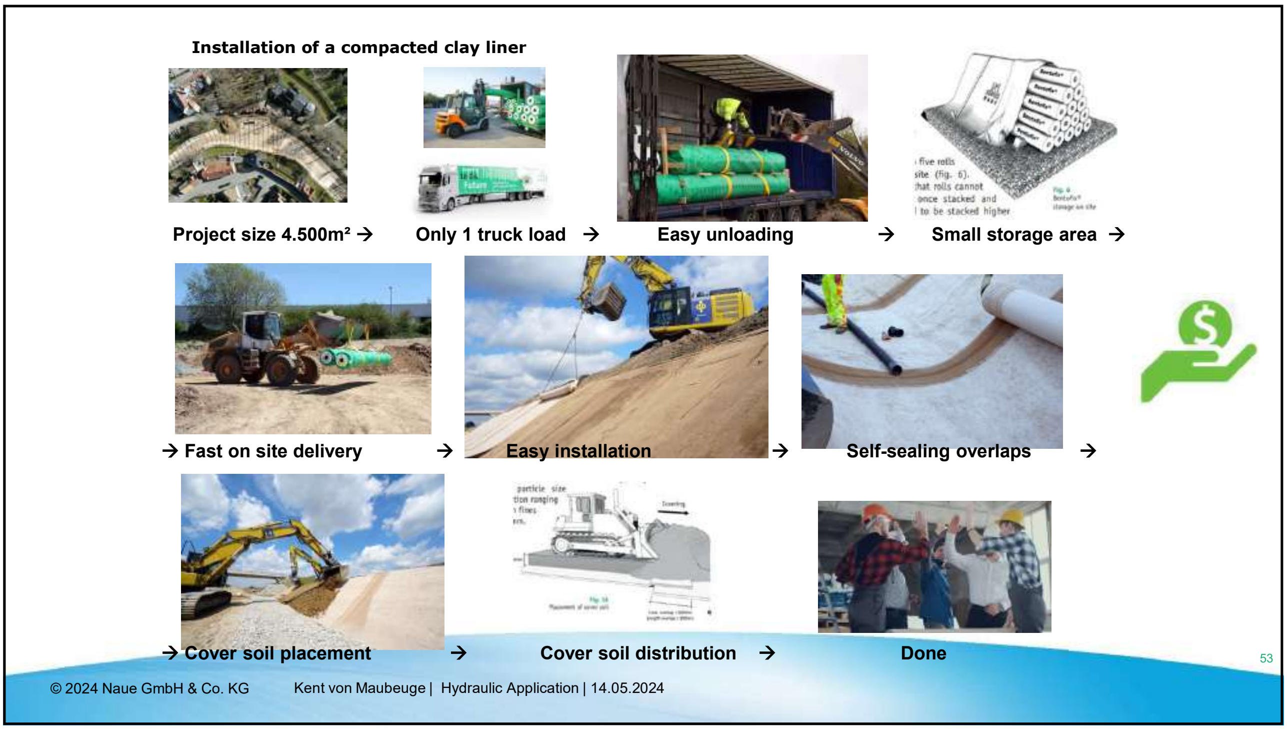
Installation of a compacted clay liner
Project size 4.500m² →
Only 1 truck load →
Easy unloading →
Small storage area →
→ Fast on site delivery →
Easy installation →
Self-sealing overlaps →
→ Cover soil placement →
Cover soil distribution →
Done
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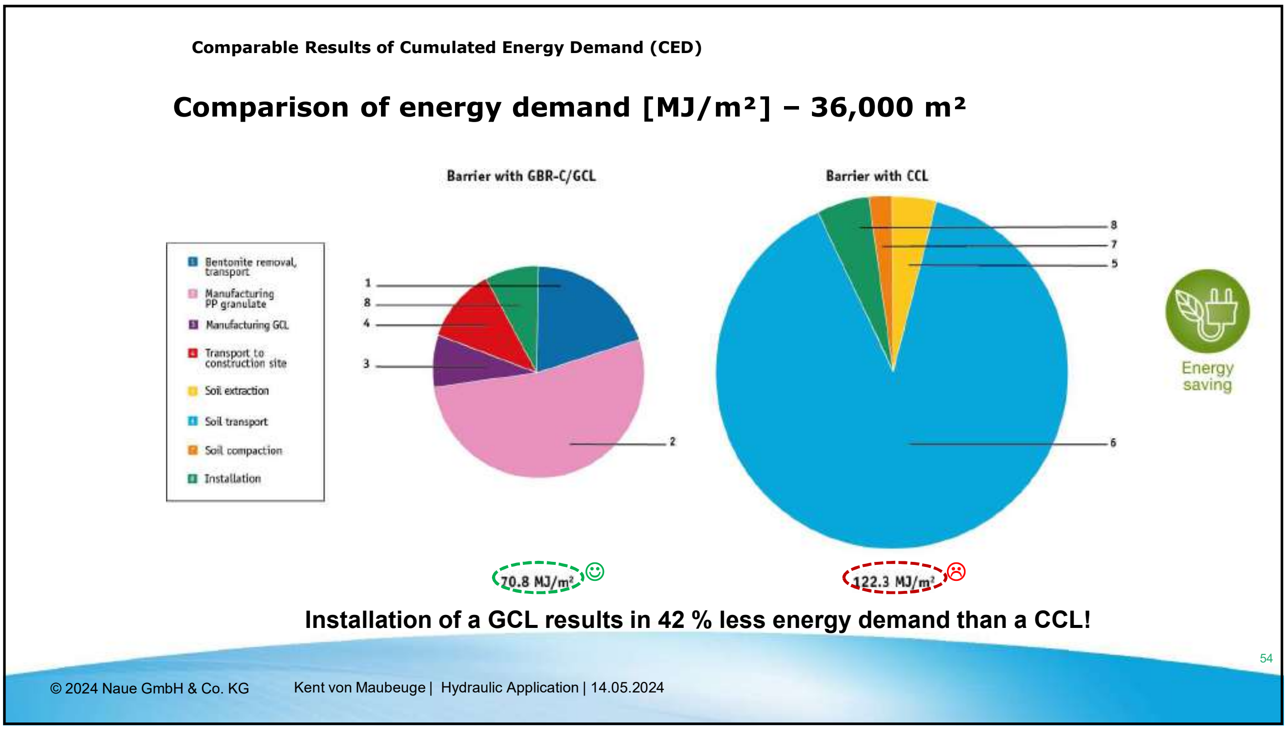
Comparable Results of Cumulated Energy Demand (CED)
Comparison of energy demand [MJ/m²] – 36,000 m²
Barrier with GBR-C/GCL
Barrier with CCL
1 Bentonite removal, transport
2 Manufacturing PP granulate
3 Manufacturing GCL
4 Transport to construction site
5 Soil extraction
6 Soil transport
7 Soil compaction
8 Installation
70.8 MJ/m²
122.3 MJ/m²
Energy saving
Installation of a GCL results in 42 % less energy demand than a CCL!
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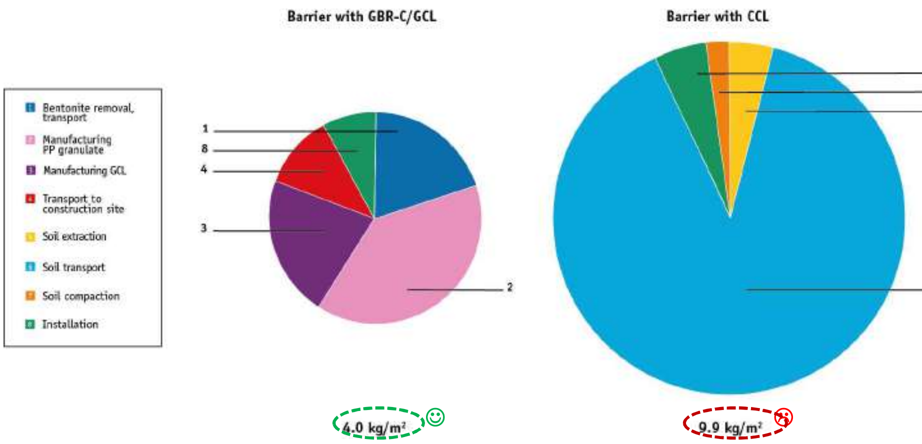
Comparable Results of Emissions based on the CED

Comparison of CO2 emissions in a 36,000 m² large landfill cap



Installation of a GCL results in 59 % less CO_2 emissions than a CCL!

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Infographic – GCL vs CCL

14 Important facts why a Bentofix® geosynthetic clay liner (GCL) outperforms a compacted clay liner (CCL)

01 Typically regulations or recommendations suggest 0.5m thick clay liners as a sealing element (with a permeability of e.g. $k \leq 5 \cdot 10^{-9}$ m/s). According to Darcy´s law the permeation rate at a 0.3m water head would 6.91 m³/ha/day. A Bentofix® GCL with $k \leq 5 \cdot 10^{-11}$ m/s would have - under same conditions - a permeation rate of only 1.34 m³/ha/day.

02 Will P. Gates et al. (2009) calculated the time in years it takes for 10cm of fluid to permeate through the system:

	CCL (100cm)	GCL (1 cm thick)
Deionised water	9.5 years	41 years
0.1 mol NaCL	2 years	10 years

03 While the permeation rate of a compacted clay liner (0.5m thick, $k \leq 1 \cdot 10^{-9}$ m/s, 0.3m water head) calculates theoretically to 1.38 m³/ha/day, a GCL (1cm thick, $k \leq 5 \cdot 10^{-11}$ m/s, 0.3m water head) calculates theoretically to 1.34 m³/ha/day). However, field excavations after installation on a clay liner (Rogowski, 1986)) show much higher values, e.g. 12.07 m³/ha/day, which were confirmed by Daniels (1994).

04 Data from excavations from several landfills indicate that the installation performance (poor, good or excellent) influences the performance of clay liners. To achieve the regulated permeability value $k = 1 \cdot 10^{-9}$ m/s the 0.5m thickness should be increased to approx. 0.8m to ensure the required regulated k value (assumption: good installation).

05 A perfectly installed clay liner (0.5m thick, $k \leq 1 \cdot 10^{-9}$ m/s) in a landfill cap in a research project worked very well for the first 4 years, with low permeation rates but in the following 4 years the permeation rates were always in the range 50 – 200mm per year (Melchior, 2010). A Bentofix® GCL in a 20 year period was always lower than 7mm per year and in a 5 year average less than 20mm/year (Müller-Kirchenbauer, 2016).

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Infographic – GCL vs CCL

14 Important facts why a Bentofix® geosynthetic clay liner (GCL) outperforms a compacted clay liner (CCL)

06 With enough confining stress (e.g. 1m cover soil) a CCL and a GCL can self-self once desiccated if enough water makes it to the lining system. However, a 0.5m thick clay liner would need 21 liters of water, while a GCL only needs 1.5 liters of water per m².

07 CCL has an average tensile strain at failure of 0.31%. Settlements in landfill caps can be much more. Heerten and Koerner (2008) have reported deformations varies from 1.8% to 27.4% in the CCL after seven years of monitoring of a 25-hectar landfill cap. This is far more than 0.31%. Needle-punched Bentofix® GCLs can have high tensile strain and withstand differential settlements (depending on product type 15% - 30%).

08 CCLs are placed and compacted in shifts on site, to achieve the required thickness. Due to the varying nature of clay and affecting parameters (e.g. compaction, moisture content, desiccation, etc.) it is difficult to achieve a uniform clay quality. Quality control on site requires to damage the CCL and the repair could cause leakage. GCLs are factory produced under controlled conditions and are installed without compaction or added water.

09 On earth we only have a limited amount of fresh water. Compacted clay liners need to be installed at an optimum moisture content and therefore need to be treated with fresh water on site. For a 40,000m² area approx. 2,340m³ fresh water is needed. Unnecessary wasted fresh water. A Bentofix® GCL is installed in dry state and needs no moistening with fresh water, as the bentonite hydrates with the surrounding soil moisture or rain water.

10 Transportation with trucks has an influence on the long-term performance of roads and generates environmental and noise pollution. With one truck load approx. 4.500m² GCL can be delivered on site. To deliver the same amount of compacted clay in 0.5m thickness 187 truck loads of clay are necessary.

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Infographic – GCL vs CCL

14 Important facts why a Bentofix® geosynthetic clay liner (GCL) outperforms a compacted clay liner (CCL)

11 It is known that sodium bentonite can undergo an ionic exchange and that under certain conditions (e.g. low confining stress) the permeability of the GCL can slightly increase. However, with a higher bentonite mass per unit area and confining stress the increase of the permeability can reduced.

12 Compacted clay liners are often 500mm thick. A geosynthetic clay liner (GCL) with approx. 10mm thickness offers economical and ecological advantages. It requires less excavation and therefore likely less material to deposit in a landfill, both saving enormous costs in excavation and transportation, with less impact for the environment. For a 3,000m² stormwater retention pond the savings where just on waste depost approx. 28,500€.

13 Transportation of clay (0.5m thick) to the construction site (35km) and the installation for a landfill cap (including cover soil placement) considering the whole life cycle of the clay (mining and processing of raw materials, production, distribution and transport, usage, consumption und disposal) has a energy demand of 122.3 MJ/m², while a GCL only consumes 70.8 MJ/m² (transportation 580km).

14 Transportation of clay (0.5m thick) to the construction site (35km) and the installation for a landfill cap(including cover soil placement) considering the whole life cycle of the clay (mining and processing of raw materials, production, distribution and transport, usage, consumption und disposal) has a CO_2 output of 9.9 kg/m², while a GCL only generates 4.0 kg/m² (transportation 580km).

15 There are other project-dependent advantages in favor of the bentonite mat, such as diffusion, freeze-thaw cycles, replastification, self-sealing overlaps, etc.

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Geosynthetic Clay Liners in hydraulic applications

Thank you very much for attending and listening

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