Conventional Final Covers for Landfills 101

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EREF
Environmental Research
& Education Foundation
Lighting a path to sustainable waste management practices

Office of Sustainability
UNIVERSITY OF WISCONSIN-MADISON

Functions of Covers

- Control percolation into waste

- Control gas movement

    oxygen ingress

    radon egress

    methane and carbon dioxide egress

- Isolate waste from surrounding environment

Types of Covers

- Simple soil cover	(cheap)
- Compacted clay cover	(modest)
- Geosynthetic clay liner cover	(modest)
- Composite cover	(expensive)
- Monolithic soil cover	(cheap to modest)
- Capillary barrier (soil) cover	(modest)

Categories of Engineered Covers

Conventional covers – cover designs where a barrier layer (clay, geomembrane, etc.) having low saturated hydraulic conductivity is the primary impediment to leakage and gas flow.

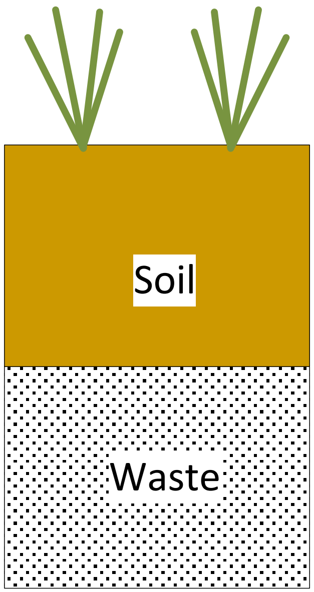
clay covers, GCL covers, composite covers

Water balance covers – cover designs where leakage is controlled by balancing the water storage capacity of unsaturated finer-textured soils and the ability of plants and the atmosphere to extract water stored in the soil. Also known as *water balance* covers, *evapotranspiration* (ET) covers, *store-and-release* covers.

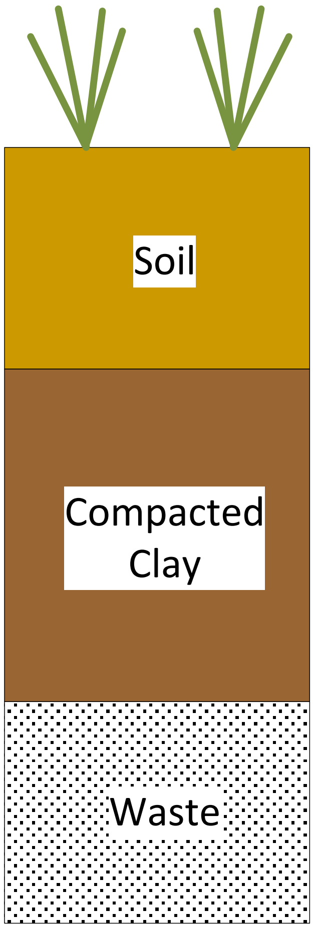
monolithic covers, capillary barriers

Conventional Resistive Covers with a Soil Barrier

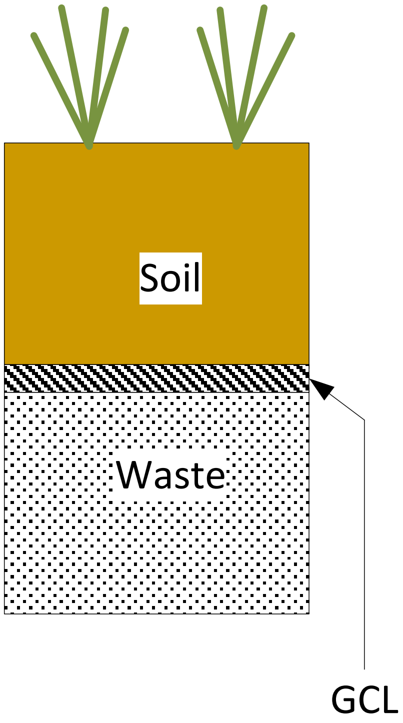
Simple
Soil Cover



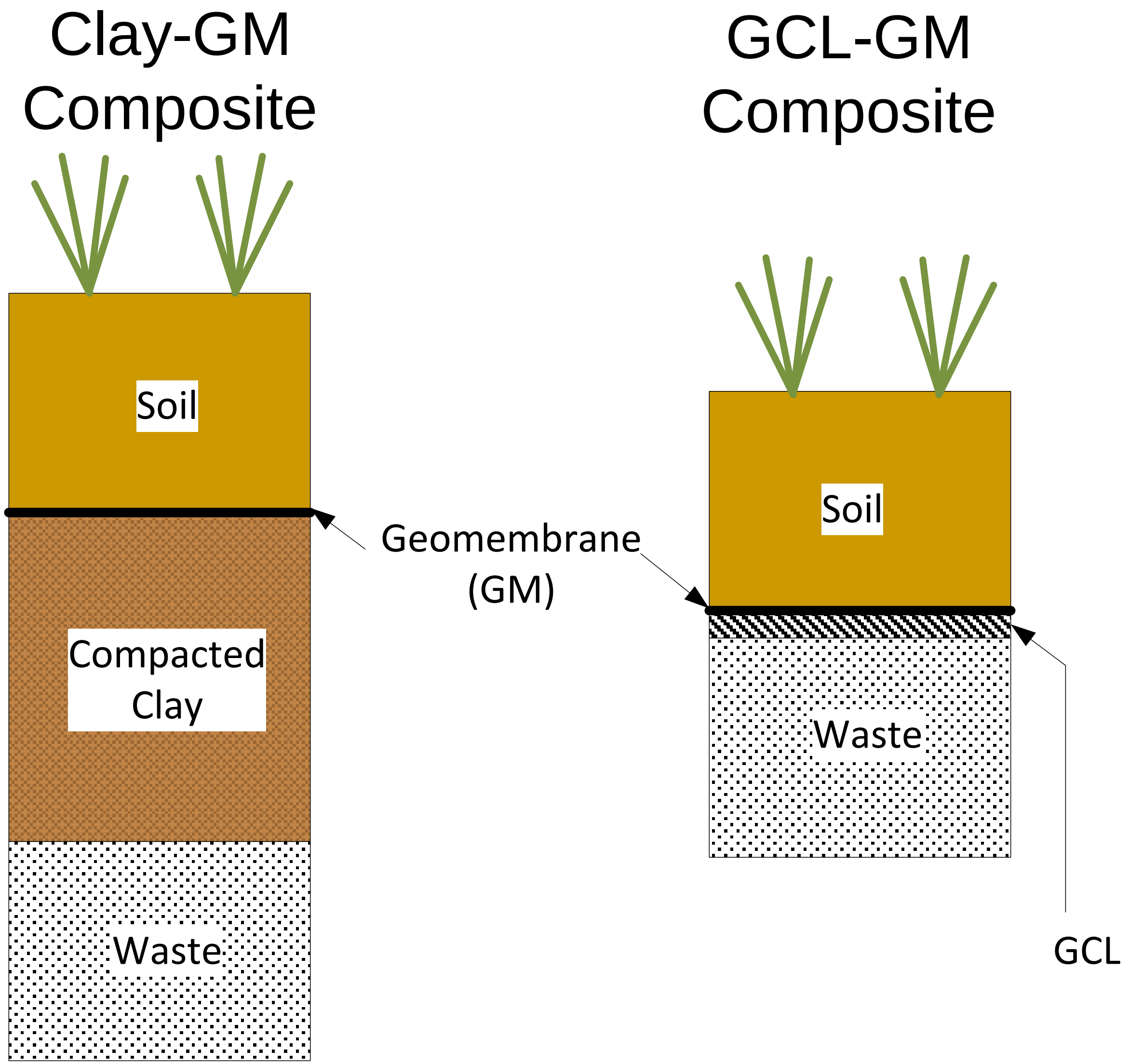
Compacted
Clay Cover



Geosynthetic
Clay Liner
(GCL) Cover



Conventional Resistive Covers with a Composite Barrier



Alternative Water Balance Covers

Monolithic Barrier

Capillary Barrier

Cover Selection Criteria

- Acceptable percolation
    - regulatory driven (e.g., 1-3 mm/yr in USEPA's ACAP)
    - risk driven (acceptable flux into waste)

- Bathtub principle – cover shall not leak more than the base liner. Not realized in practice when profiles are matched.

- Acceptable oxygen flux or LFG emission rate

- Regulatory acceptance – will the agency accept the design?

- Expected lifetime or maintenance period – life cycle cost

- Acceptable capital cost

Cover Type	Percolation Rate	Gas Flux	Cost ($/ac)
Simple Soil	Highest	Highest	25,000
Clay	Modest	Modest	75,000
GCL	Modest	Modest	75,000
Composite	Very low	Very Low	125,000
Monolithic	Very low - low	Modest	50,000
Capillary Barrier	Very low - low	Modest	50,000

What I Will Be Covering

- Issues for barrier design (clay barriers, composite barriers)
- Drainage layer design
- Stability issues
- Field performance data

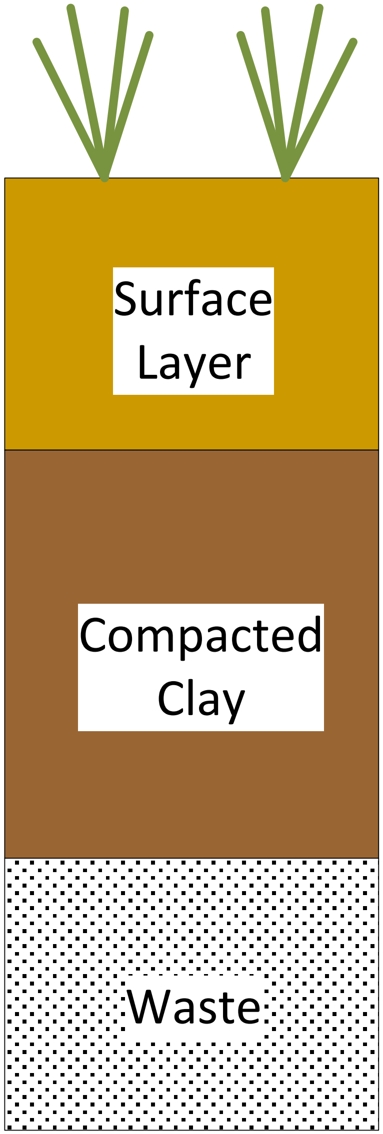
What I Won’t Be Covering

- Design and construction of compacted clay liners (see liner webinar)
- Storm water control & management
- Erosion
- Maintenance

I Will Be Assuming that You …

- Know basic principles of geotechnical engineering and hydraulics
- Know the basic principles behind designing and constructing compacted clay barriers.
- Have a working knowledge of general solid waste principles and practices.

Compacted Clay Covers



150-1000 mm thick
(6 – 40 inches)

450-900 mm thick
(18 – 36 inches)

Objectives:

(1) Construct a soil barrier (compacted clay) with low saturated hydraulic conductivity.

(2) Protect the clay barrier from damage that may increase hydraulic conductivity

Types of Damage:

- Frost
- Desiccation
- Differential settlement (normally a problem with municipal solid waste, but not mining wastes, coal ash, etc.)
- Erosion

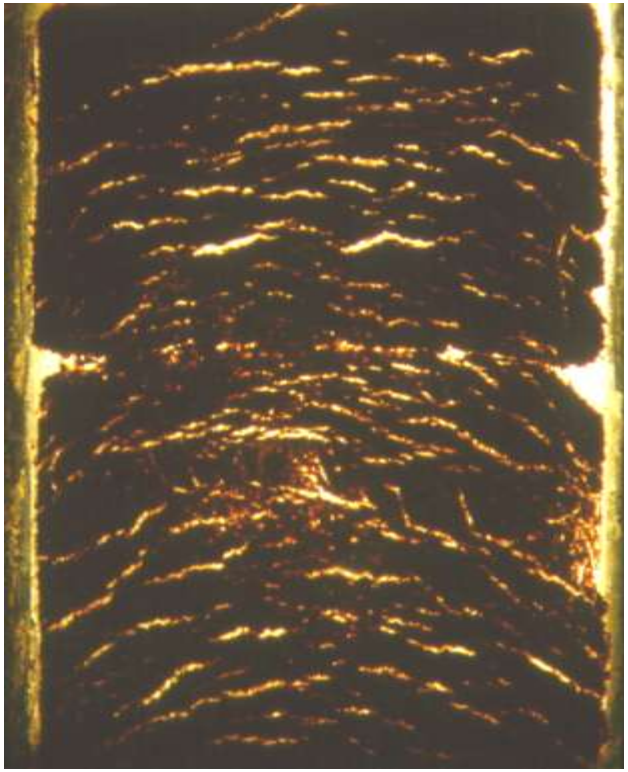
Sensitivity to Frost Damage:

Freezing of compacted clay barriers causes:

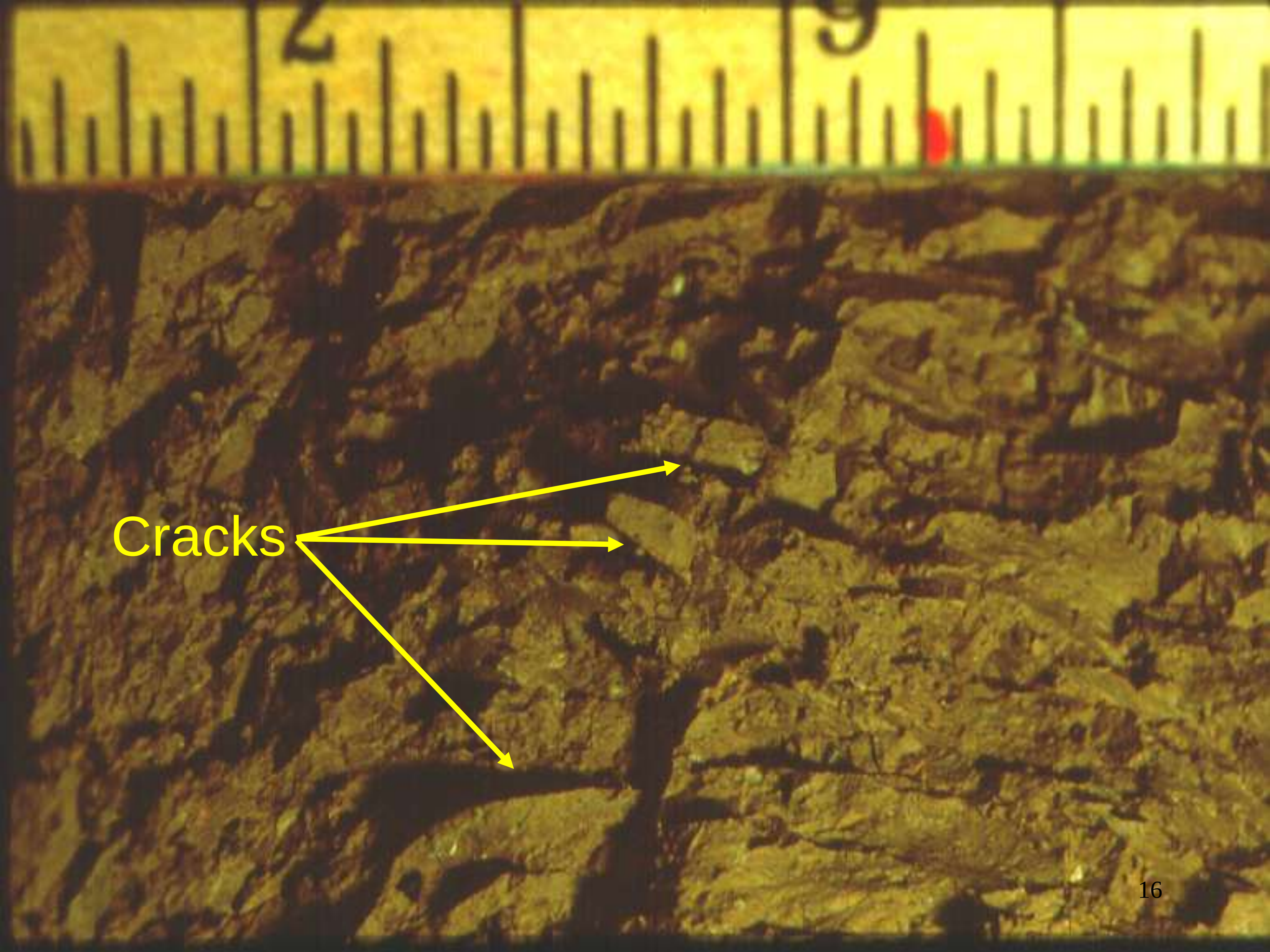
- formation of ice lenses: cracking

- formation of desiccation cracks as water moves to freezing front

- cracking that causes increases in hydraulic conductivity



Protect clay barrier with insulation (synthetic or burial).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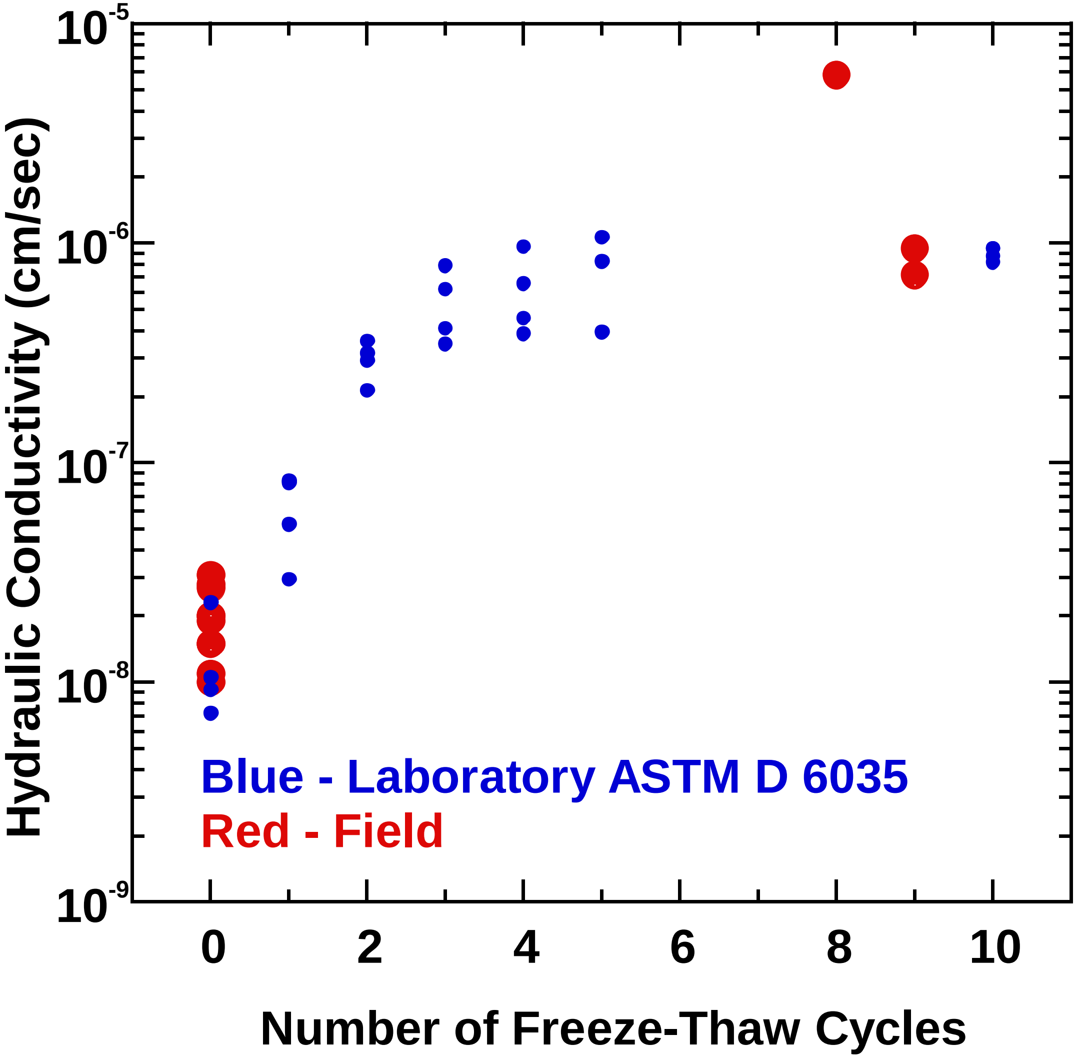
9
Cracks

How much does the hydraulic conductivity increase?

At least 10 X

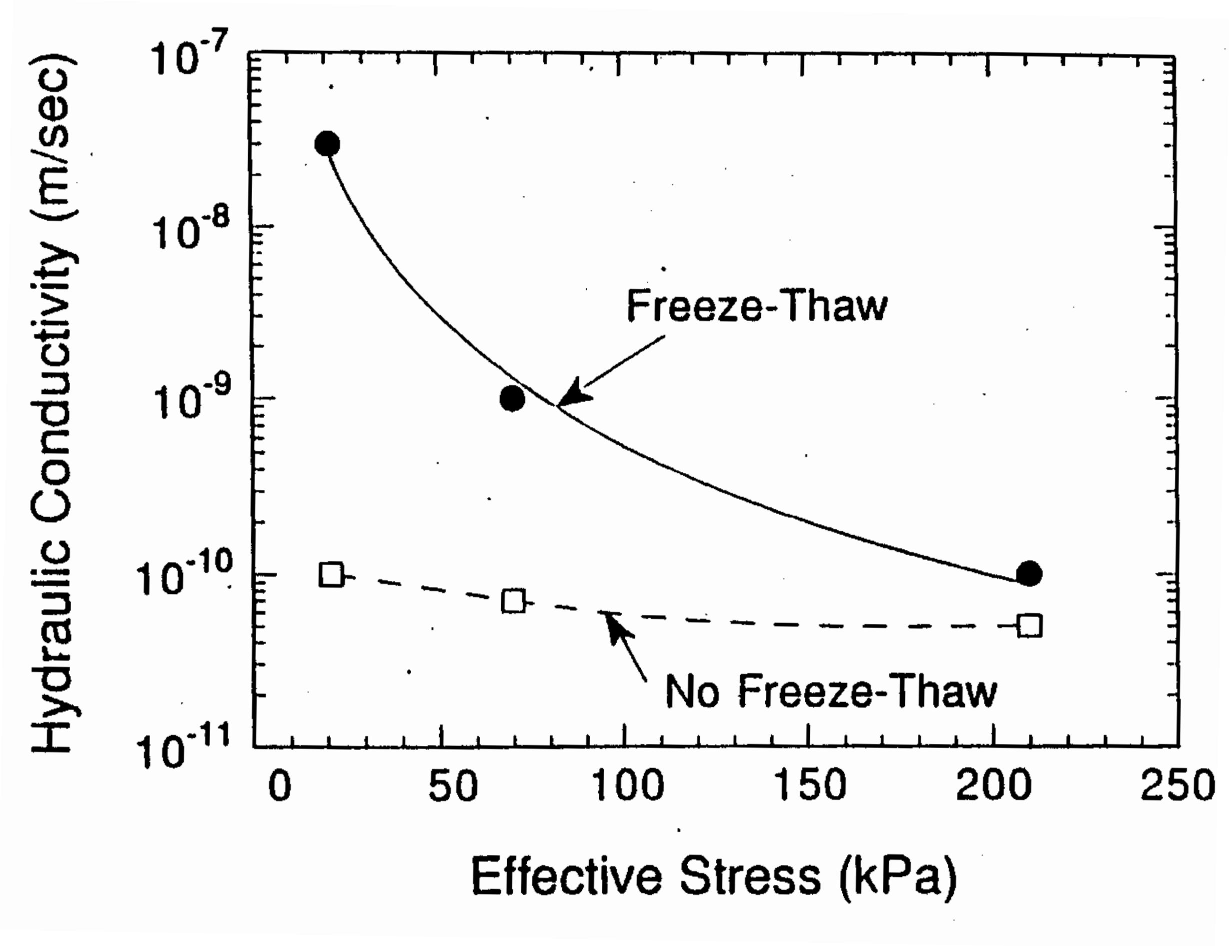
Typically 100 to 1000 X

Occasionally 10,000 X



Benson, C., Abichou, T., Olson, M., and Bosscher, P. (1995), Winter Effects on the Hydraulic Conductivity of Compacted Clay, *J. of Geotech. Eng.,* ASCE, 121(1), 69-79.

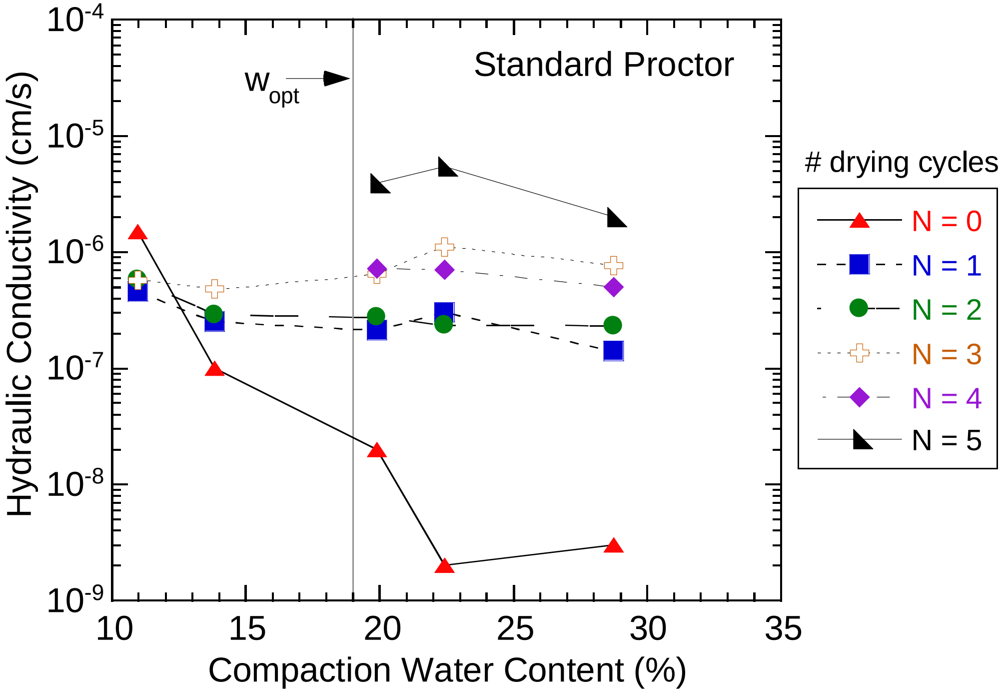
Is the increase permanent?



Frost damage is permanent.
Frost damage does not “heal” over time.

Sensitivity to Desiccation Damage:

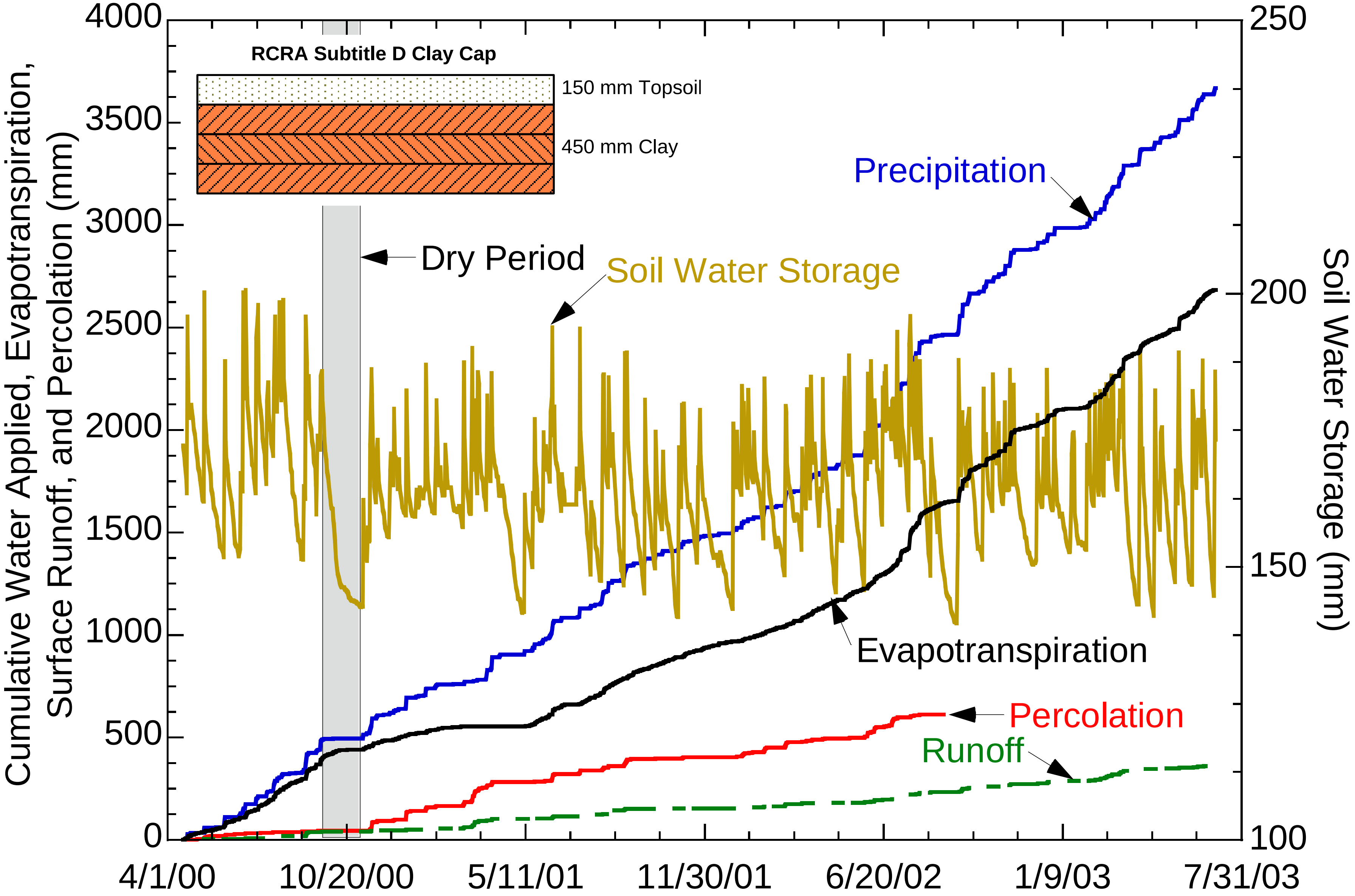
Drying of compacted clay barriers causes desiccation cracks to form, increasing the hydraulic conductivity.



Large-scale cracks may form, as in this clay barrier in southern Wisconsin five years after construction.

Albrecht, B. and Benson, C. (2001), Effect of Desiccation on Compacted Natural Clays, *J. of Geotech. and Geoenvironmental Eng.*, 127(1), 67-76.

Field Site in Albany, GA

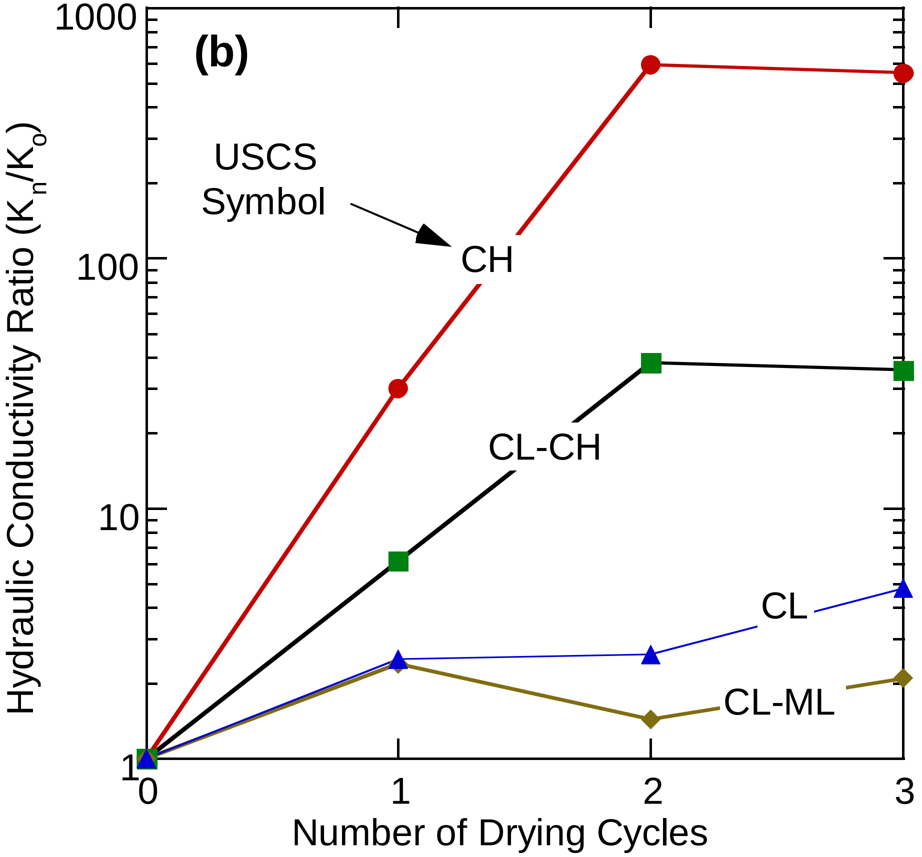


Percolation constituted 8.6% of precipitation before drought, 29.3% afterwards.

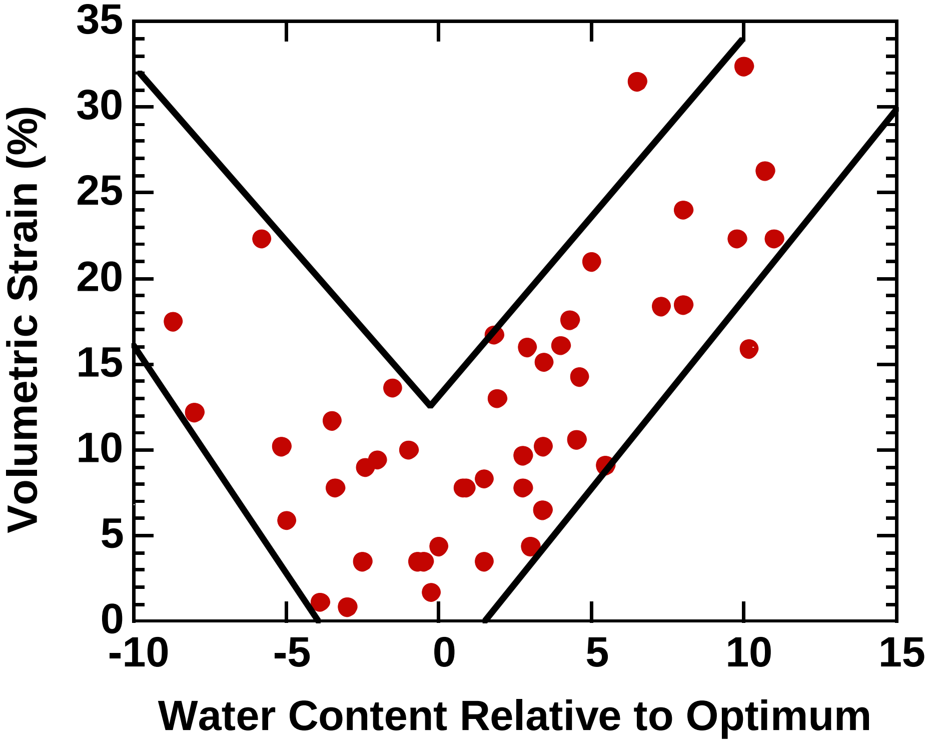
Field Hydraulic Conductivity Measurements on Clay Barrier - February 2004

Test	Hydraulic Conductivity (cm/s)	K_f/K_o
As-Built	$4.0\text{x}10^{-8}$	1.0
SDRI	$2.0\text{x}10^{-4}$	5000
TSB - 1	$5.2\text{x}10^{-5}$	1300
TSB - 2	$3.2\text{x}10^{-5}$	800
TSB - 3	$3.1\text{x}10^{-3}$	77,500

Influence of Plasticity



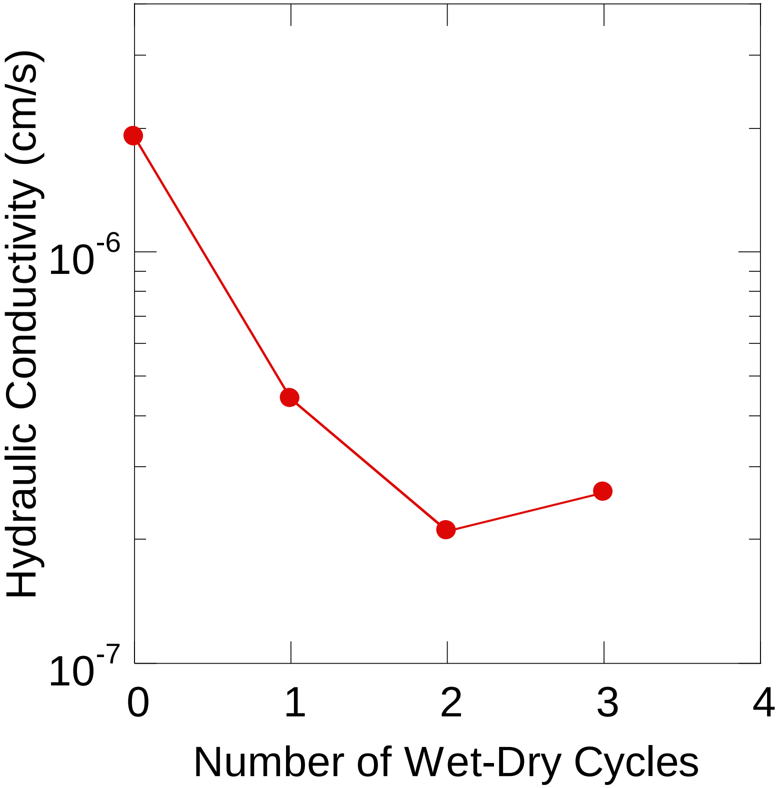
Influence of Water Content

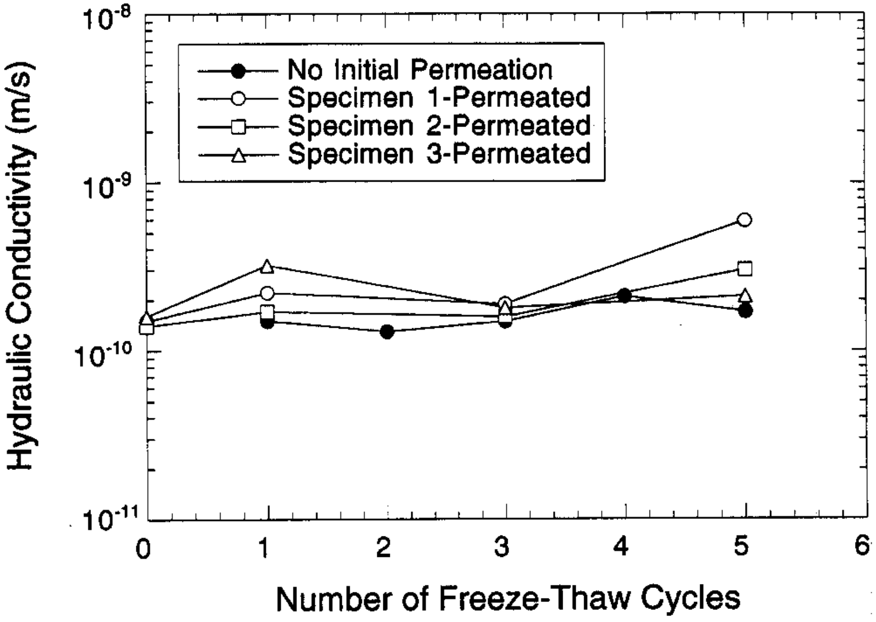


No definitive means to prevent desiccation cracking without a geomembrane. Reduce impacts by using less plastic clay and compacting as close to optimum water content as possible.

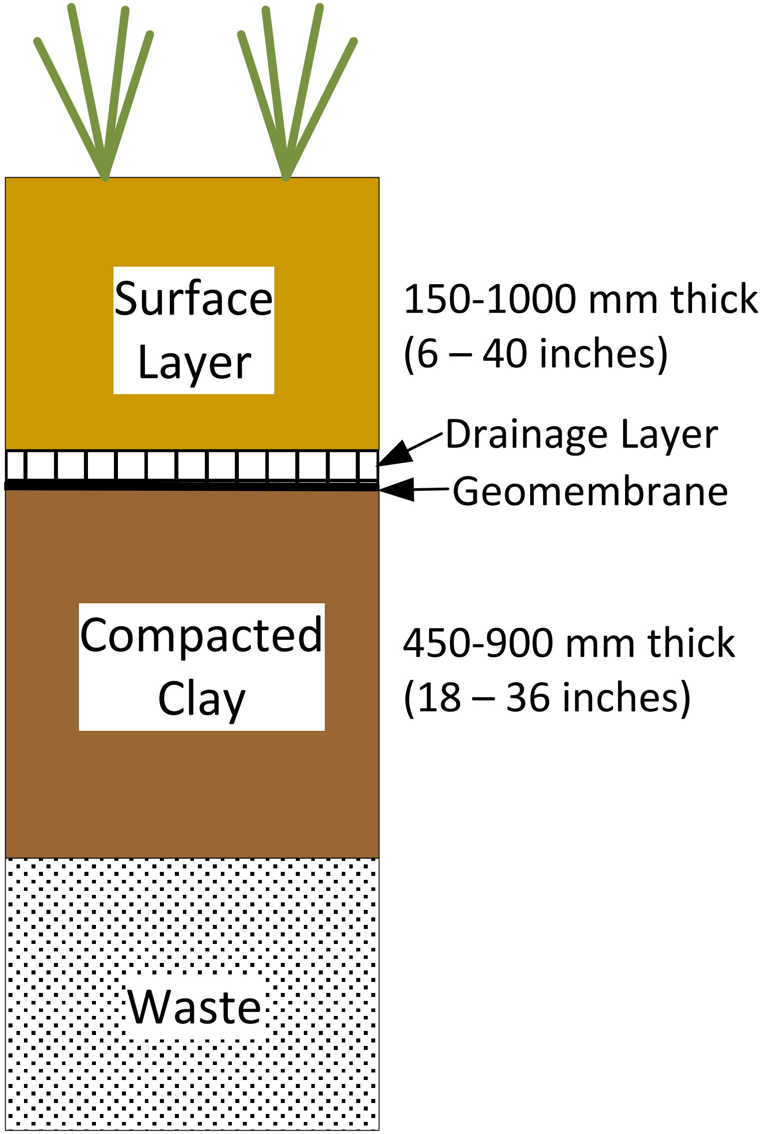
Are Soil-Bentonite Barriers Prone to Similar Damage?

Frost and desiccation have little effect on soil-bentonite barriers. Consider data from mixture of crushed waste rock and bentonite (left) and from a sand-bentonite mixture (right).

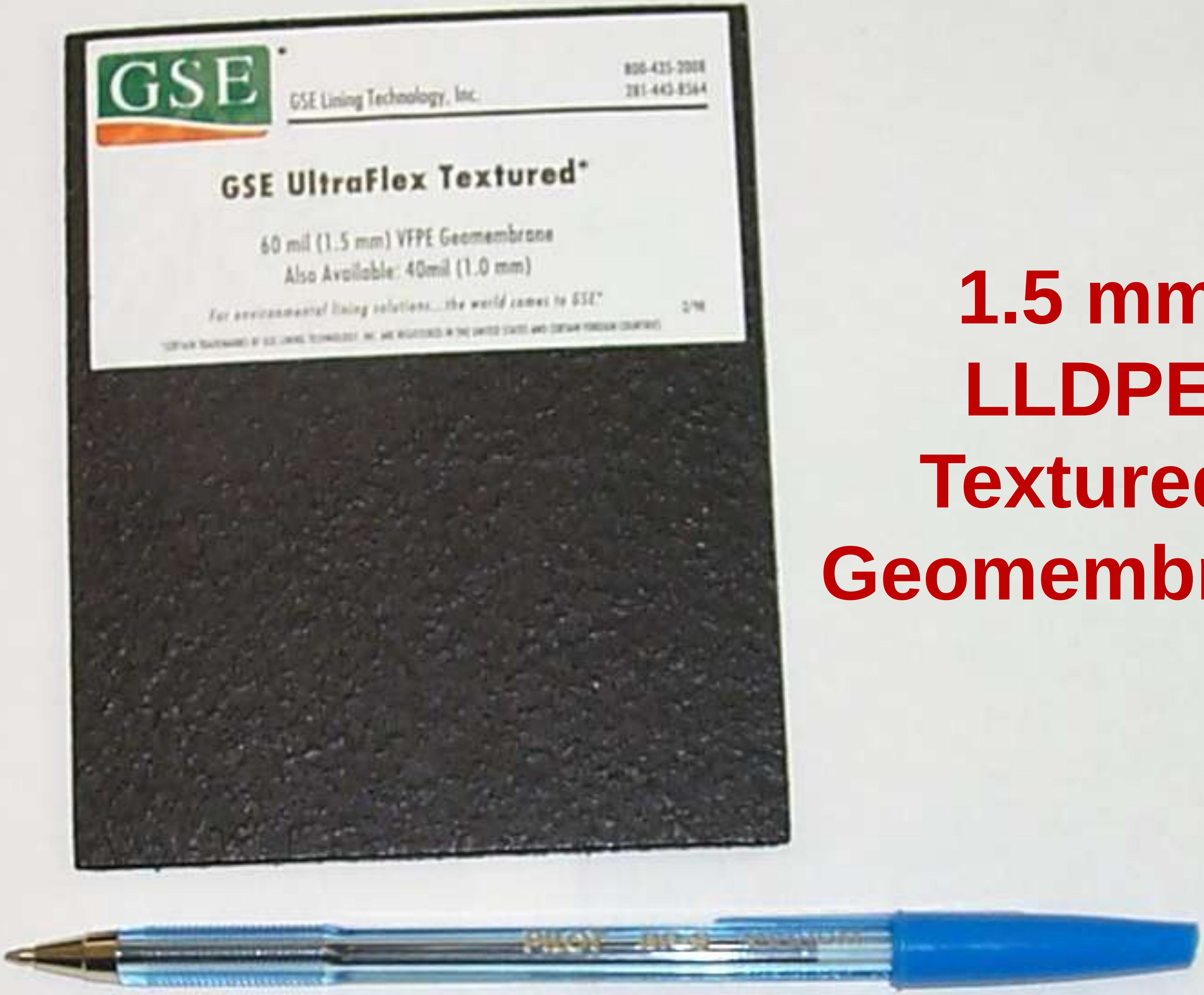




Typical Composite Cover



- Geomembrane added directly on top of clay barrier or GCL
- Drainage layer frequently added on top of geomembrane to enhance stability by limiting pore water pressures.



1.5 mm
LLDPE
Textured
Geomembrane

Extrusion welding sump boot.

For covers, chemical compatibility normally is not a concern when selecting geomembrane polymer. Key issues are:

- constructibility
- durability
- cost
- availability with texturing

All of the cited geomembranes can be welded in the field using wedge or extrusion techniques to obtain welds with higher strength than parent material.

LLDPE and HDPE geomembranes are most commonly used for covers

Drainage Layers

Functions:

Reduce Head on Barrier Layer

-Reduce Pore Pressure Build Up

Materials:

- Coarse-Grained Soil (clean sand, crushed rock)
- Geocomposite Drain

Design Approach:

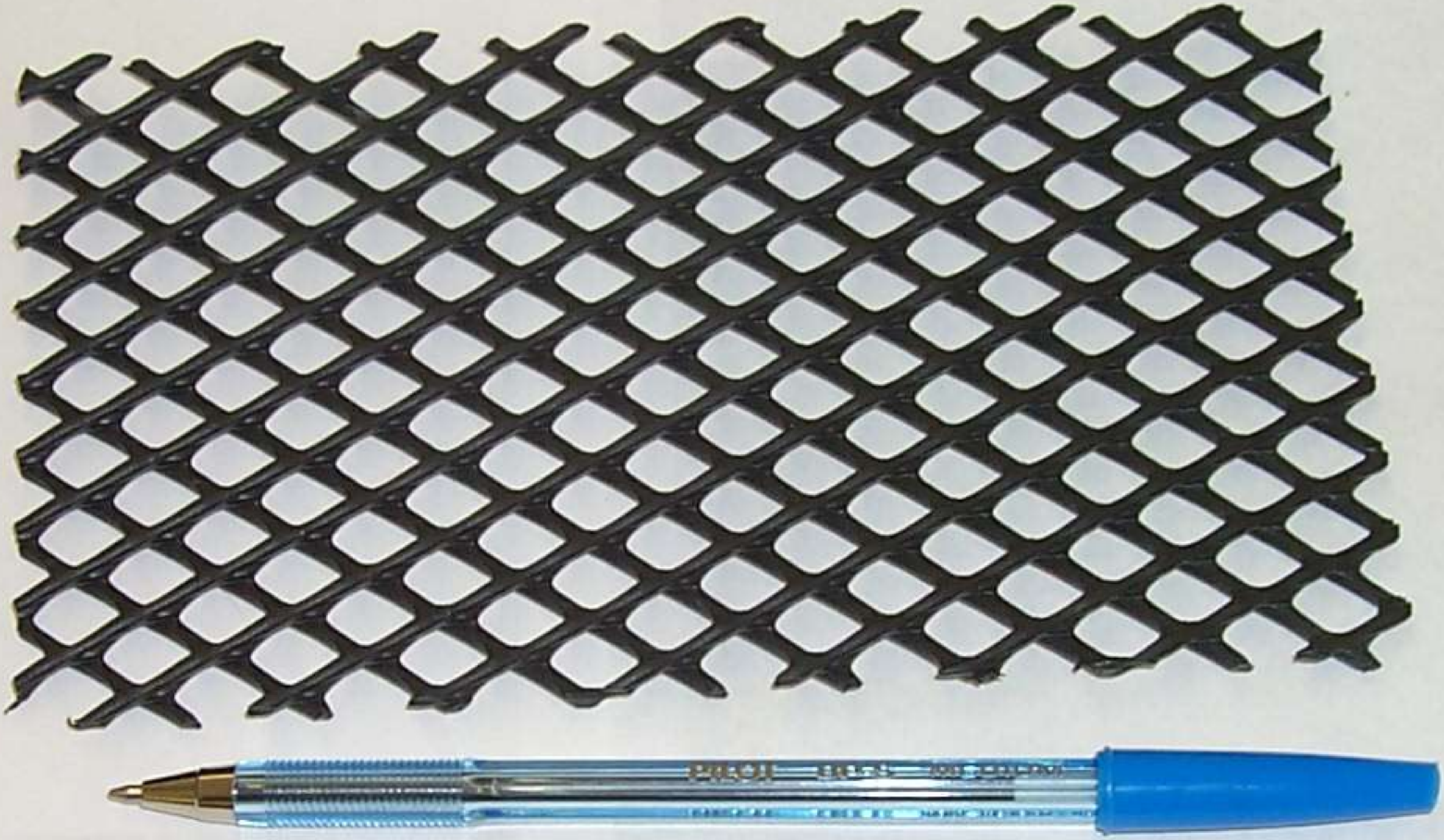
-Select drain that provides acceptable head

-Adequate hydraulic conductivity

-HELP, conservative (over-predicts lateral drainage)

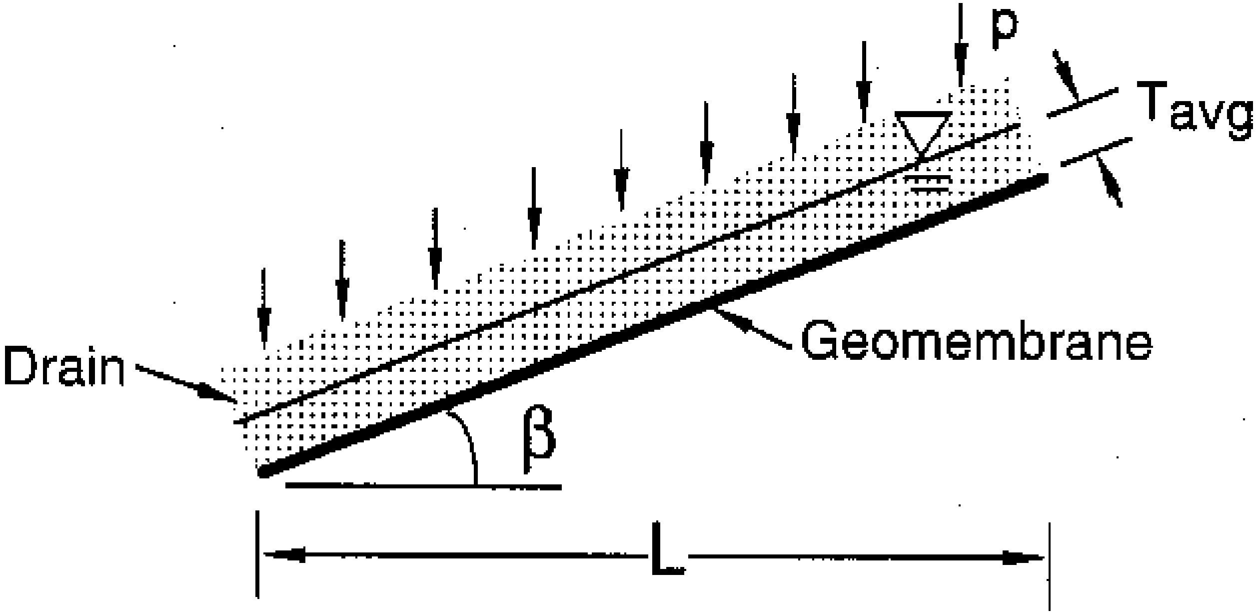
-Giroud & Houlihan's Method

Geocomposite Drain



Geonet

Limit depth of liquid in drainage layer to thickness of layer



$$T_{avg} = \frac{pL}{K \sin b}$$

$$\frac{p}{K} < 0.25 \tan^2 b$$

P = impingement rate = hydraulic conductivity of surface layer.

K = hydraulic conductivity of drainage layer.

Other Drain Design Details:

- Provide Clogging Protection: Geotextile
- Ensure Effluent End is Freely Draining
- Ensure Effluent Drains Away from Liner & Anchor Trenches

Geotextile Separator:

0_{95} is particle diameter (glass beads) where 95% of particles having this diameter pass through the geotextile

Select a moderate weight (> 4 oz/yd^2 or 150 g/m^2) non-woven needle-punched geotextile meeting the following 0_{95} criteria.

Percent Fines (No.200 Sieve) in Upper Layer < 50%:

$$0_{95} < 0.6 \text{ mm}$$

Percent Fines (No.200 Sieve) in Upper Layer > 50%:

$$0_{95} < 0.3 \text{ mm}$$

Stability Checks in Composite Cover Design

- Assess interface shear strength and potential for sliding along interfaces

- Measure interface strength using ASTM D 5321. Obtain peak and large-displacement strength

- Conservative check on stability by infinite slope

without seepage: $$F_s = \frac{\tan d}{\tan b}$$

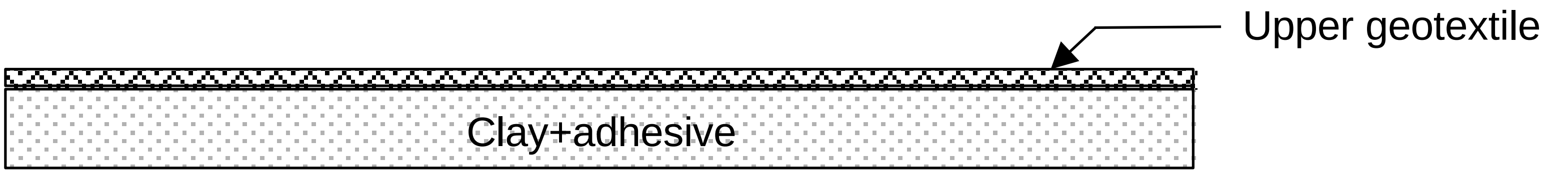
with full seepage: $$F_s = \frac{g'\tan d}{g_{sat}\tan b}$$

where δ is interface friction angle from D 5321. Require $F_s > 1.5$ when using δ for peak strength and $F_s > 1.3$ when using δ for large-displacement strength.

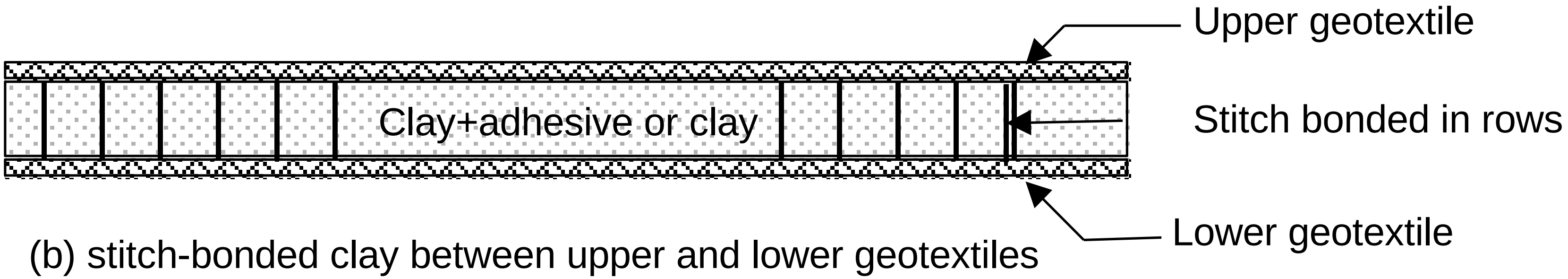
- If infinite slope shows instability, check using more sophisticated analysis including toe buttress. See solutions by Fox in appendix.

- Provide adequate drainage above geomembrane to eliminate condition of full seepage.

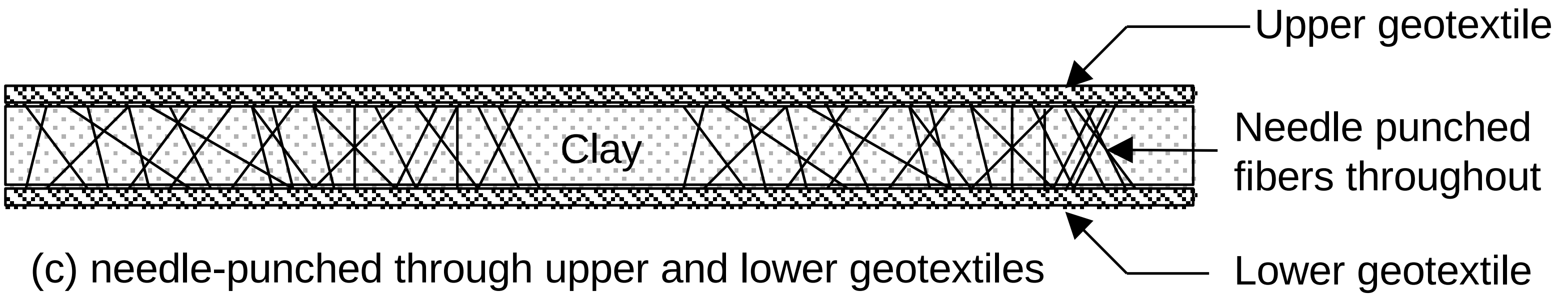
Using Geosynthetic Clay Liners in Covers



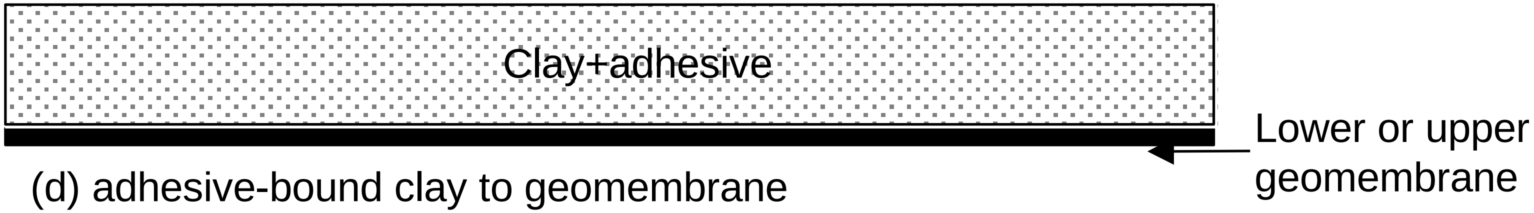
(a) adhesive bound clay to upper and lower geotextiles



(b) stitch-bonded clay between upper and lower geotextiles



(c) needle-punched through upper and lower geotextiles



(d) adhesive-bound clay to geomembrane

GCLs and Frost Damage

UW Frost Damage Study: COLDICE Project*

Laboratory Tests

- Tests on Specimens Frozen in Lab

- Tests on Large-Specimens Frozen in Field

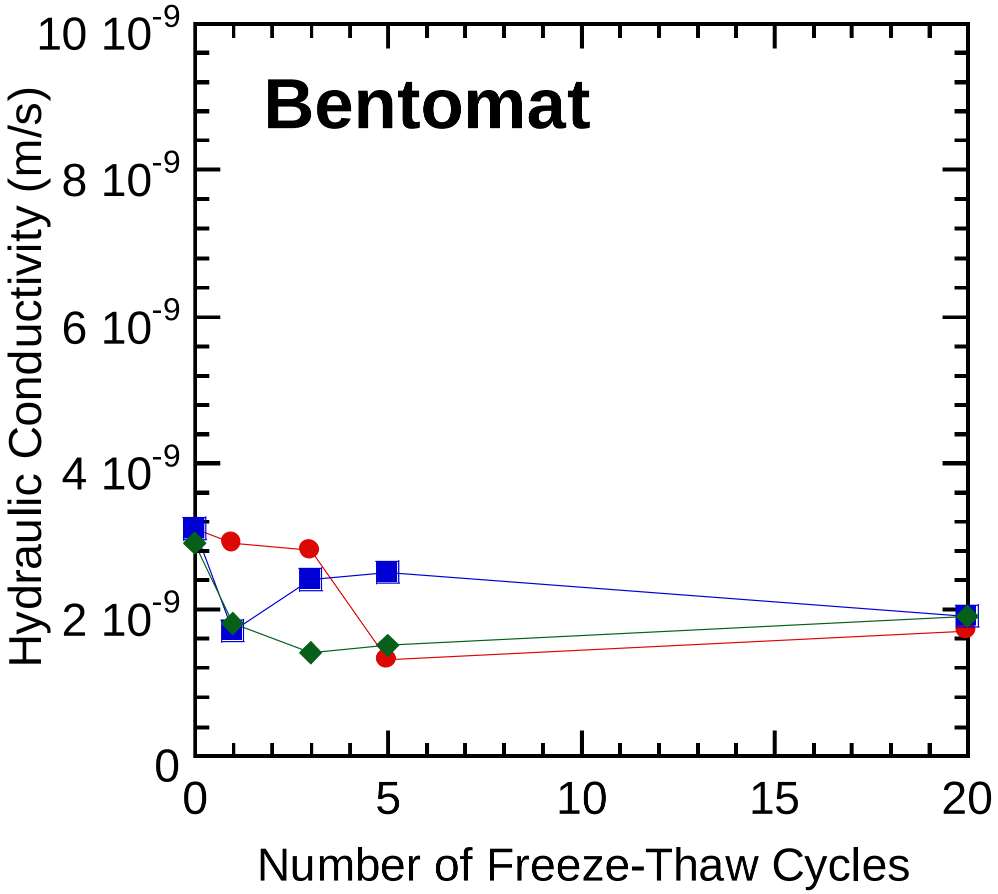
Field Tests

- Test Pans

- Ponds

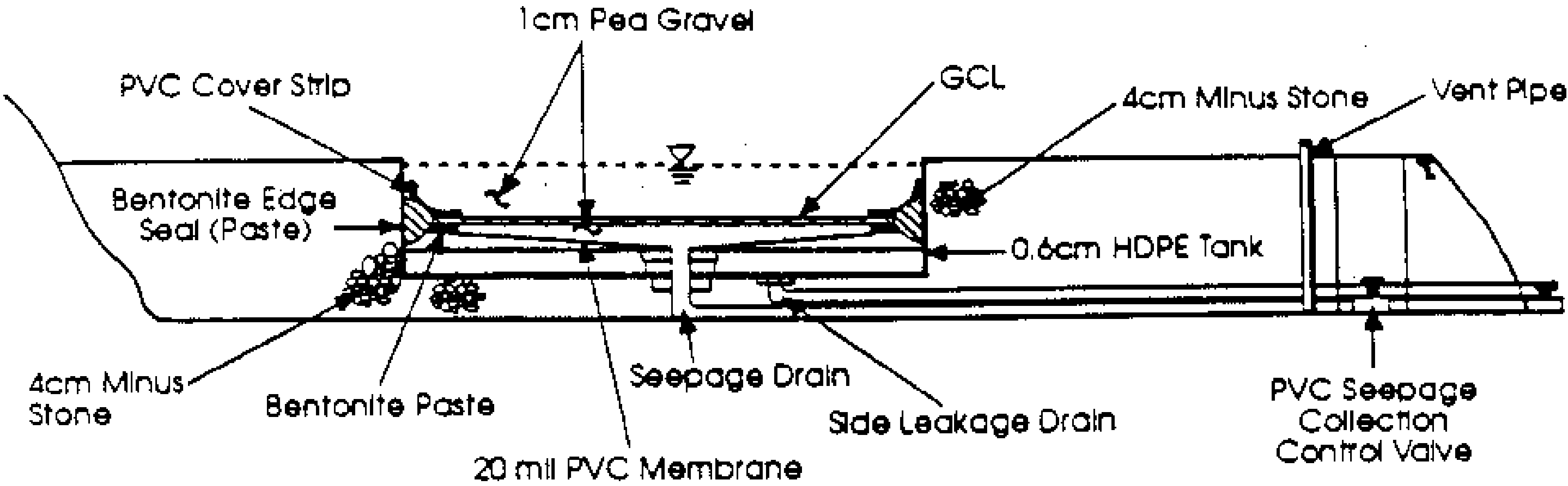
*Kraus, Benson, Erickson, and Chamberlain. (1997), Freeze-Thaw and Hydraulic Conductivity of Bentonitic Barriers, *J. of Geotech. and Geoenvironmental Eng.*, 123(3), 229-238.

Laboratory Study:
GCLs Not Damaged by Freeze-Thaw Cycling



- Openings from ice lenses close under most stress in soft hydrated bentonite during thawing
- Small but statistically significant decrease in hydraulic conductivity.
- DOE studies over many more cycles show same result.

Test Pans



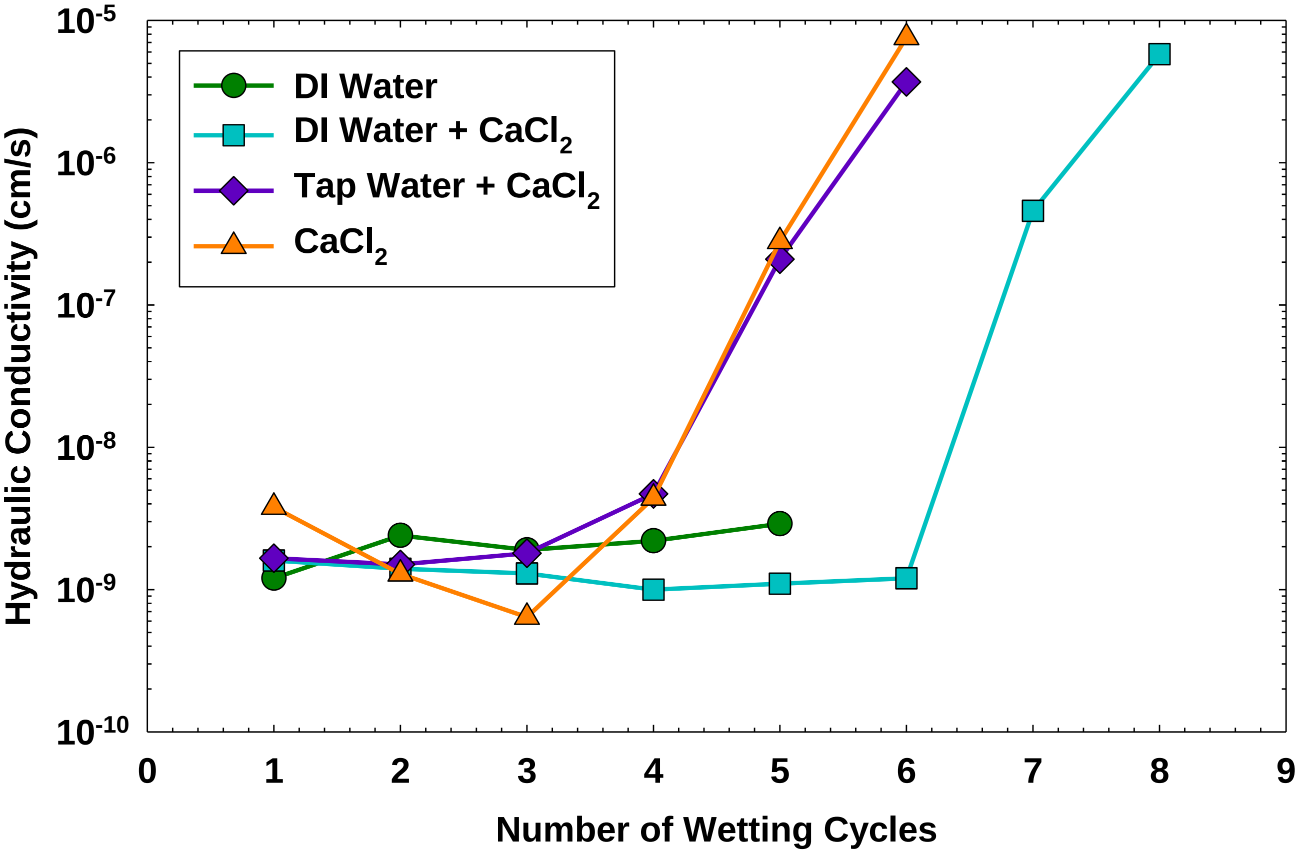
- Double ring design to check for side-wall flow

- Exposed for two winters

Results from Test Pans

GCL	Seam?	Hydraulic Conductivity (cm/s)		K_{after}/ K_{before}
		Before Freezing	After Freezing	
Bentomat	Yes	1.5×10^{-8}	1.9×10^{-8}	1.3
Bentomat	Yes	1.0×10^{-8}	1.4×10^{-8}	1.4
Bentomat	No	no flow	1.0×10^{-8}	-
Claymax	Yes	2.8×10^{-8}	7.0×10^{-7}	25
Claymax	Yes	2.0×10^{-8}	3.0×10^{-8}	1.5
Claymax	No	2.4×10^{-8}	2.8×10^{-8}	1.2

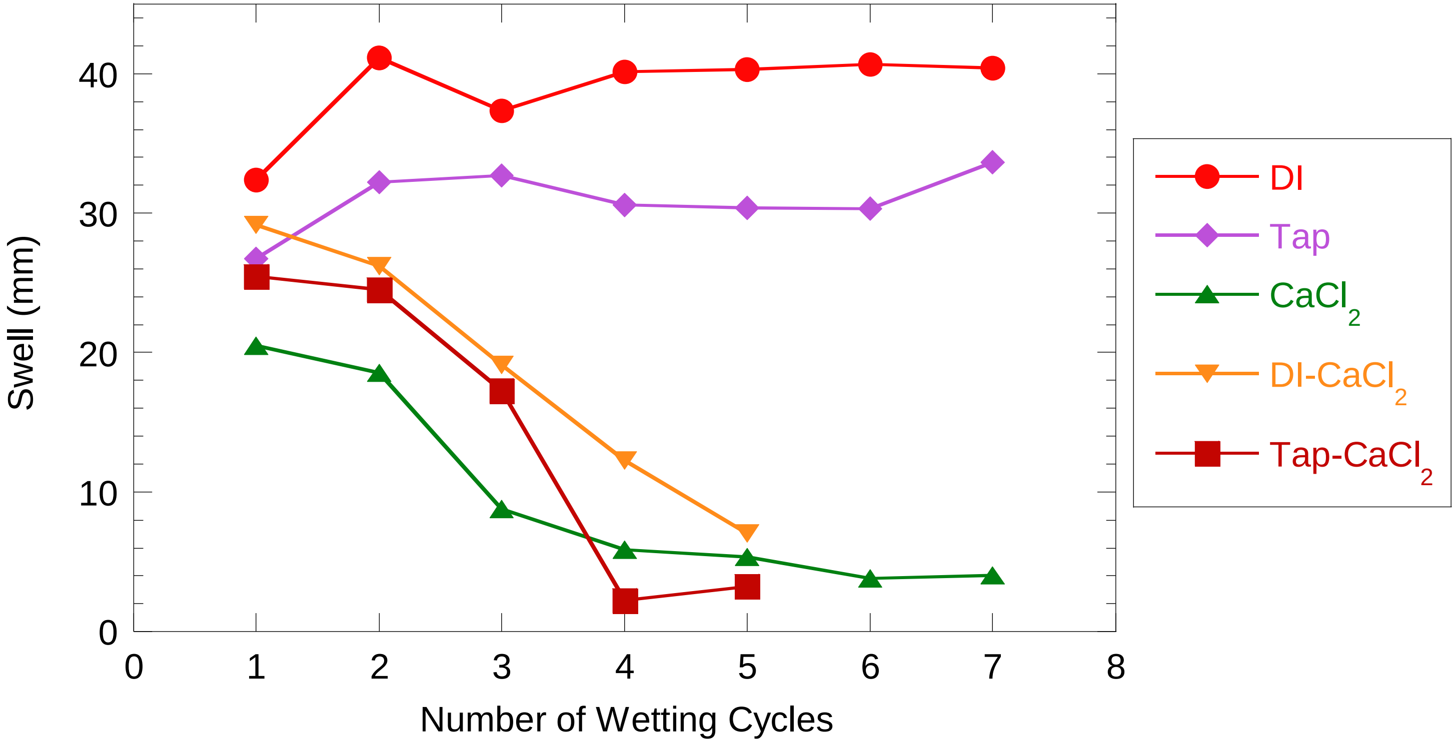
UW Desiccation Study: Effect on Hydraulic Conductivity



Divalent for monovalent cation exchange results in inability to close desiccation cracks, resulting in large increase in K.

*Lin, L. and Benson, C. (2000), Effect of Wet-Dry Cycling on Swelling and Hydraulic Conductivity of Geosynthetic Clay Liners, *J. of Geotech. and Geoenvironmental Eng.,* 126(1), 40-49.

UW Desiccation Study: Effect on Swelling*



Divalent for monovalent exchange results in loss of swelling capability … and potentially healing capability

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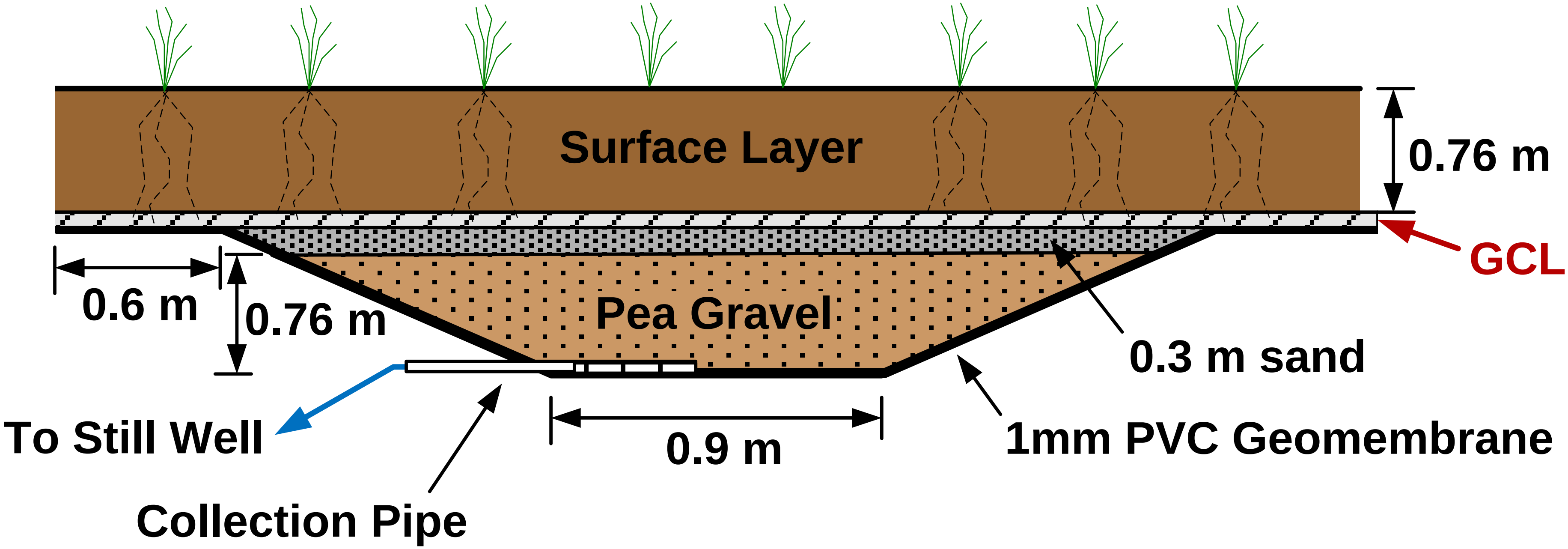
*Lin, L. and Benson, C. (2000), Effect of Wet-Dry Cycling on Swelling and Hydraulic Conductivity of Geosynthetic Clay Liners, *J. of Geotech. and Geoenvironmental Eng.,* 126(1), 40-49.

Wisconsin GCL Case History

Leakage monitored with lysimeter (collection pan) directly beneath GCL



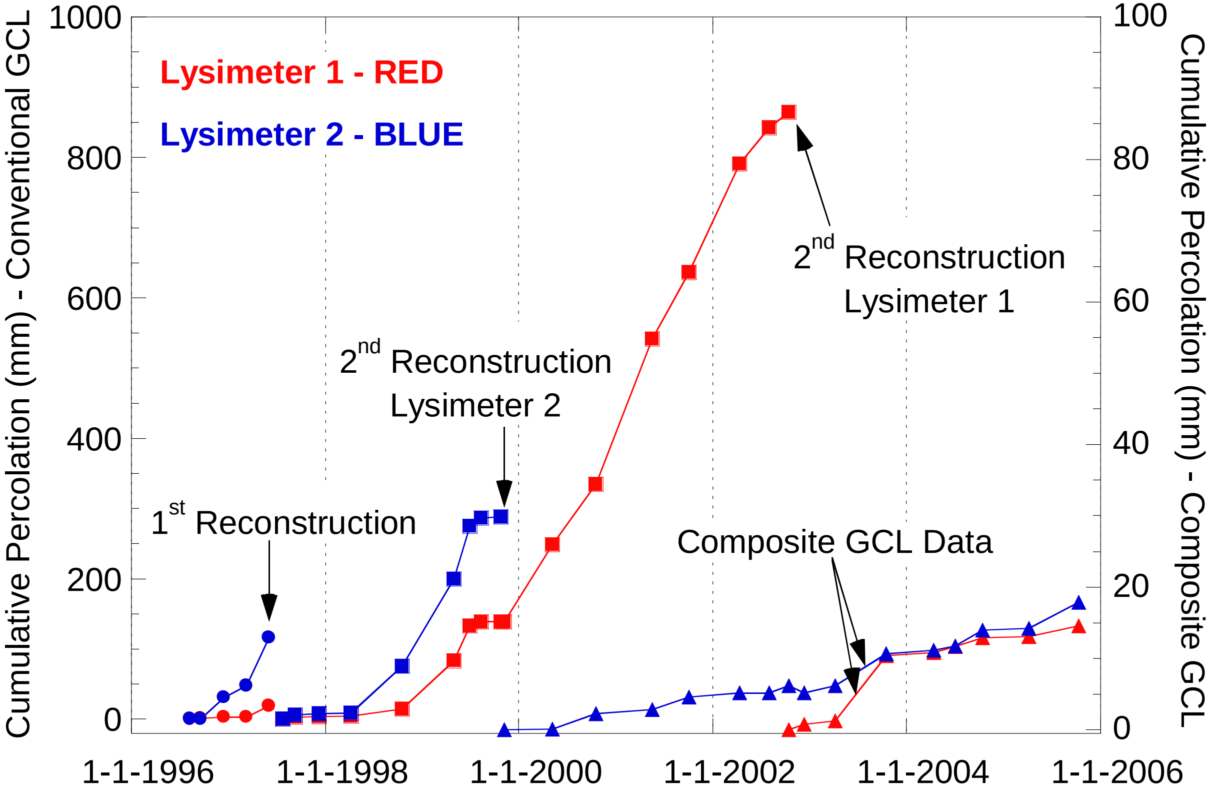
- Not to Scale -

Leakage Rates

1997 - Lysimeters reconstructed. Thinning of GCL caused by pressure exerted by underlying gravel believed to be failure mechanism. Placed sand overlain by a geotextile on top of gravel.

1999 - Lysimeter 2 reconstructed again. Dry and cracked GCL exhumed. Replaced with laminated GCL in November 1999. Low leakage rate since.

2002 - Lysimeter 1 reconstructed again with laminated GCL.



Conventional GCL: 203-262 mm/yr

Laminated GCL: 2.6-4.1 mm/yr

Hydraulic Data – Conventional GCL:

Leakage Rate: 110 - 220 mm/yr

As-Built Lab Hydraulic Conductivity: 2 x 10^{-9} cm/s

Exhumed Lab Hydraulic Conductivity: 2 x 10^{-7} cm/s

“Field” Hydraulic Conductivity: 3 x10^{-7} to 7 x 10^{-7} cm/s

Exchange Complex:

As-Built: Na:Ca/Mg = 1.4:1

Exhumed: Na:Ca/Mg = 1:13.5

Hydraulic Data – Conventional GCL:

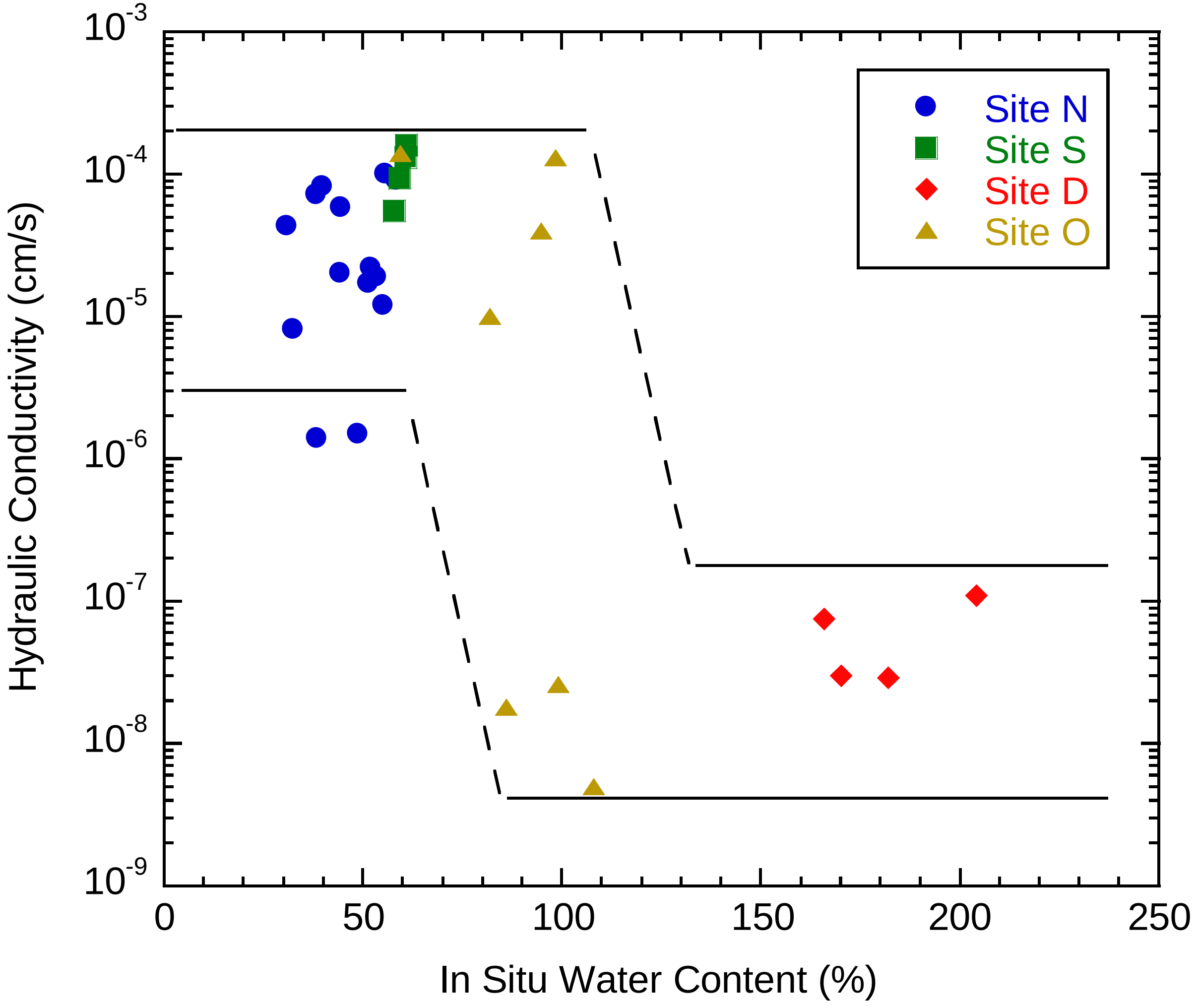
Long-term leakage rate: 2.6-4.1 mm/yr

GCLs Exhumed from In-Service Caps

All specimens underwent Ca/Mg for Na exchange

Only those with w > 120% maintained low K

Need to protect GCL from drying and/or cation exchange.

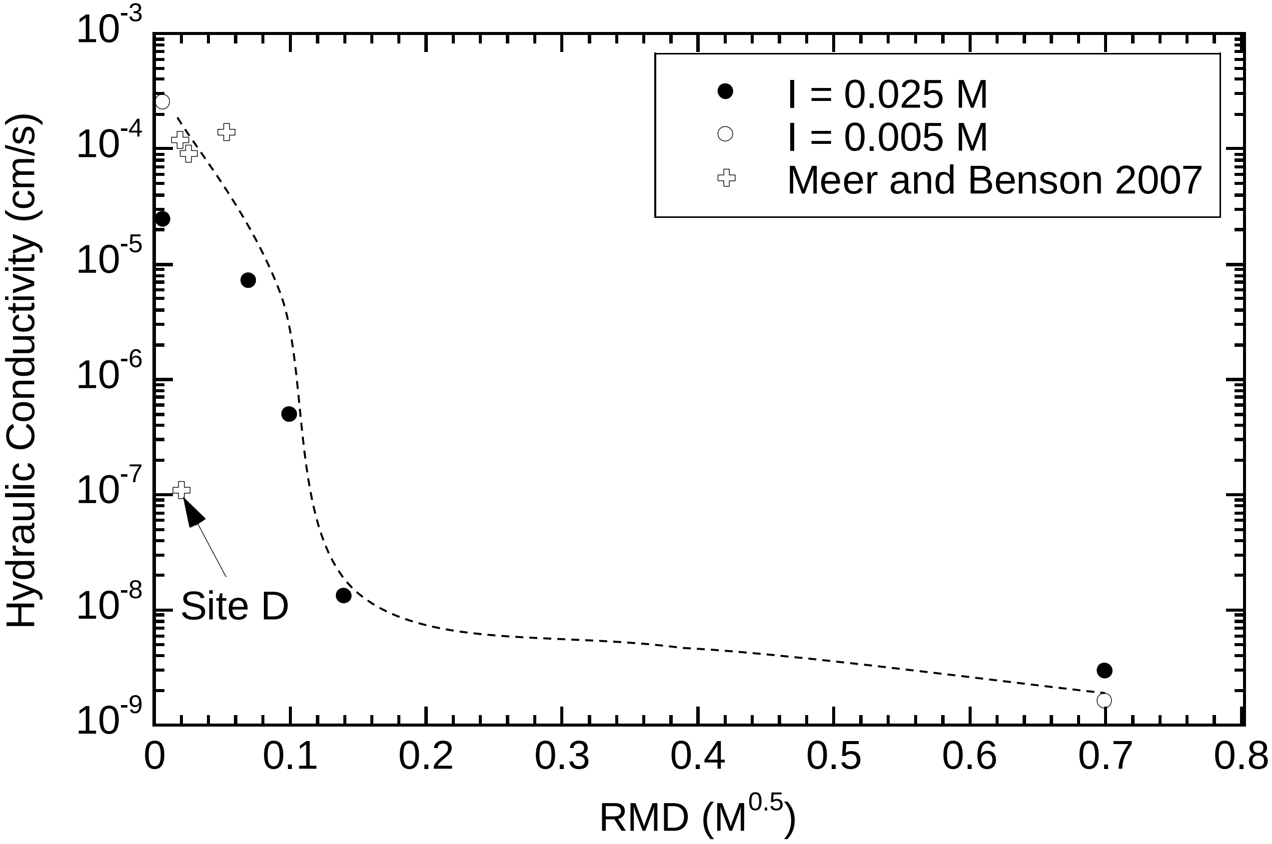


Laboratory Tests on Solutions with Monovalent and Divalent Cations

Simulated range of conditions for natural pore waters

RMD > 0.14 $M^{1/2}$ … little effect on hydraulic conductivity

Evaluate RMD using ASTM D 6141.



$$\mathrm{RMD} = \frac{M_M}{\sqrt{M_D}} = \frac{\text{total molarity monovalent cations}}{\sqrt{\text{total molarity polyvalent cations}}}$$

Field Data from the
Alternative Cover Assessment Program (ACAP)

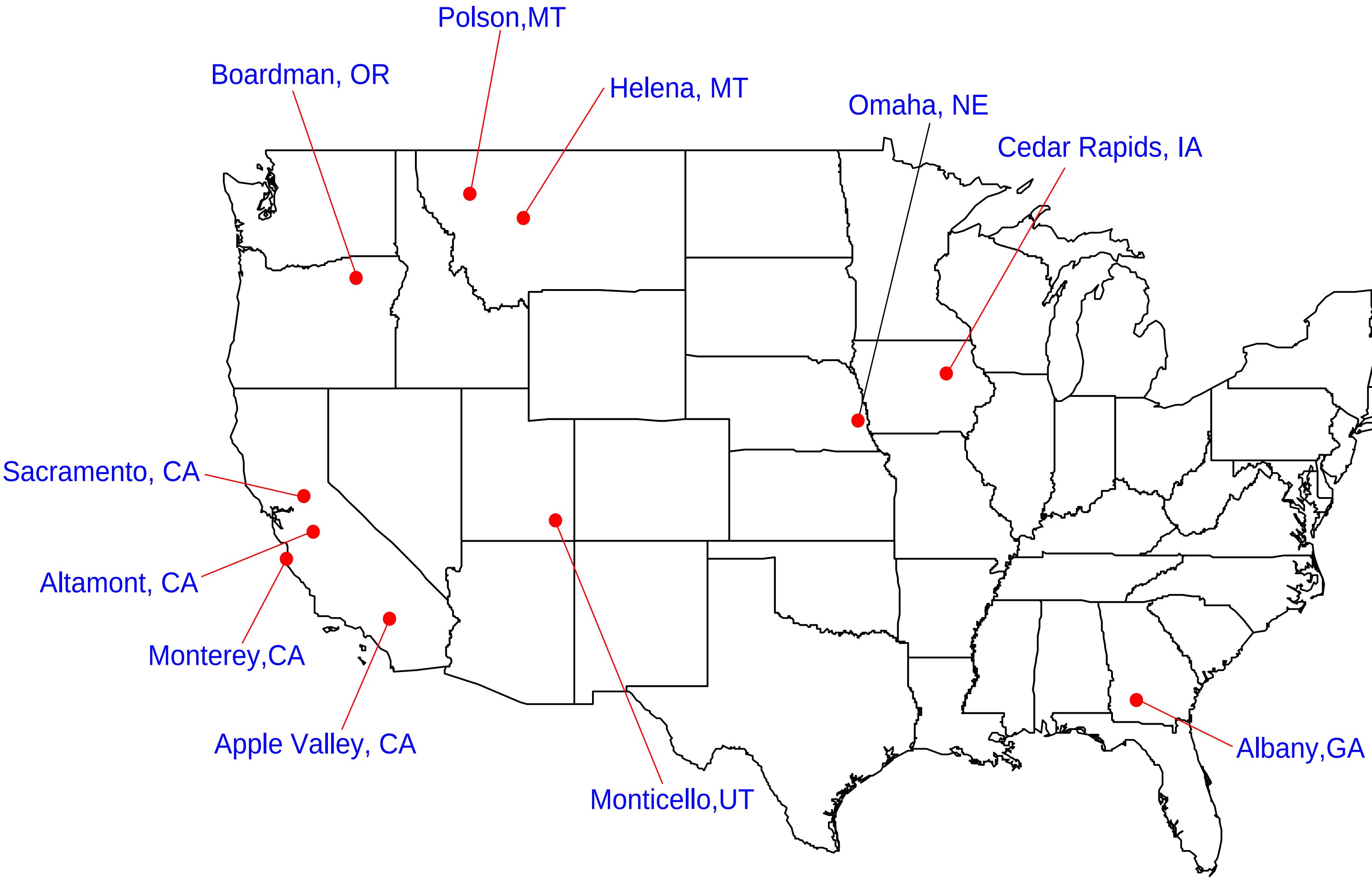
- Twenty-four test covers at eleven sites in seven states.

- Ten conventional covers (seven composite and three clay)

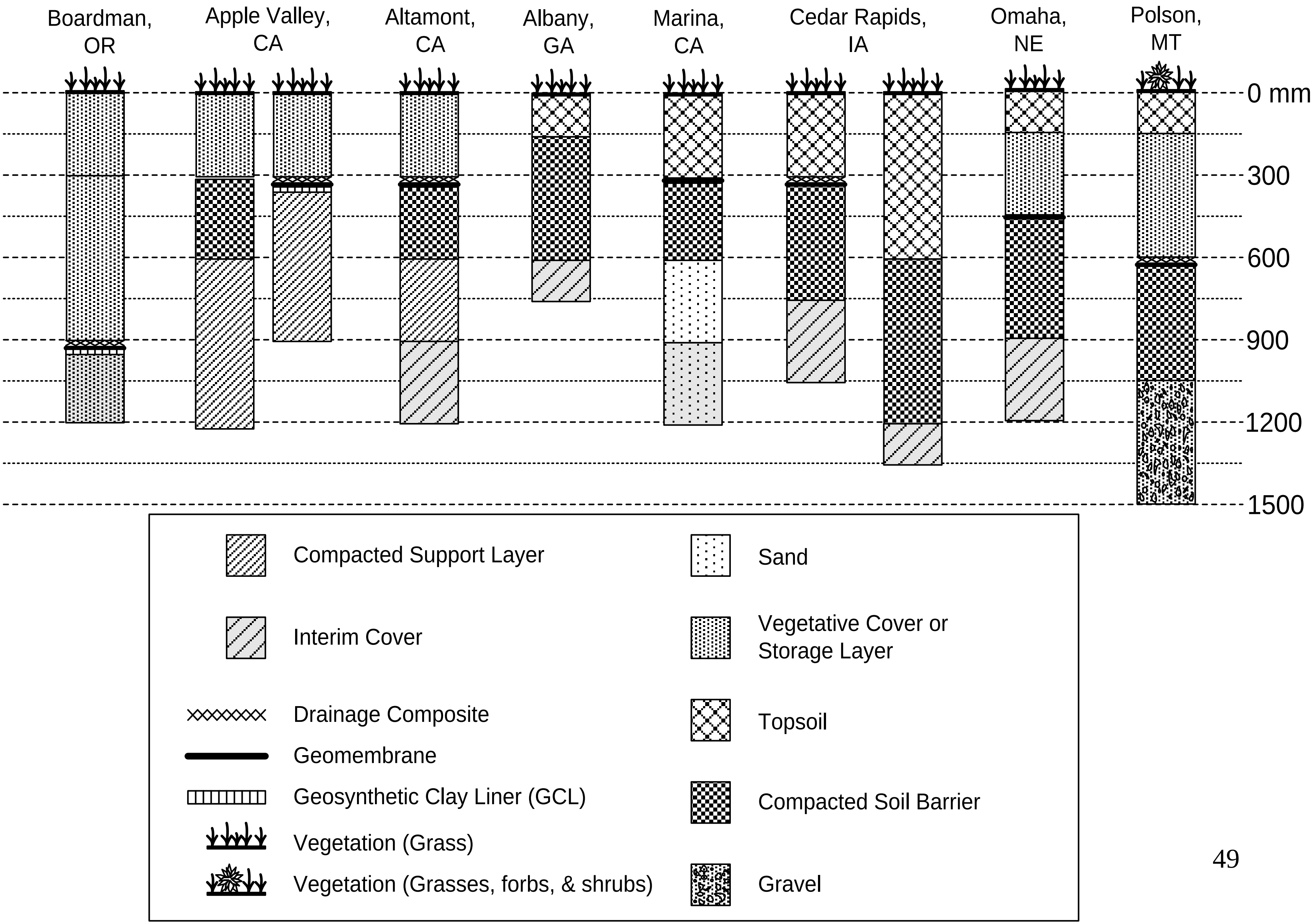
- Fourteen alternative covers (eight monolithic barriers and six capillary barriers)

- Eight sites with side-by-side comparison of conventional and alternative covers

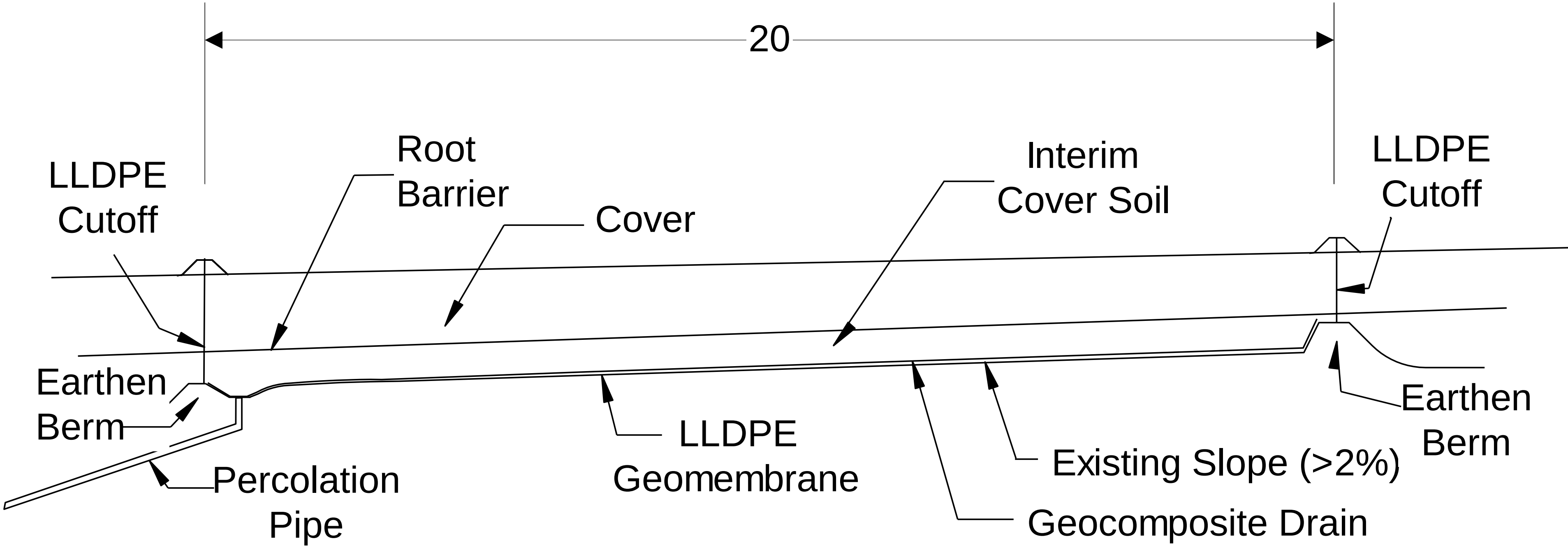
ACAP Field Sites



Conventional Covers Evaluated by ACAP



ACAP Lysimeter Cross-Section



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LLDPE Cutoff

Root Barrier

Cover

Interim Cover Soil

LLDPE Cutoff

Earthen Berm

Percolation Pipe

LLDPE Geomembrane

Existing Slope (>2%)

Geocomposite Drain

Earthen Berm

Construction Methods

Tow-behind tamping foot compactor for clay barrier layer at Cedar Rapids site.

Used full-scale construction methods to greatest extent possible

Included single design hole in geomembrane (11 mm diameter) of composite barriers

Leak tested all geomembrane seams with conventional QA methods (air pressure, vacuum box).

Aerial view of completed test sections at Kiefer Landfill, Sacramento County, California.

Kiefer Site:
Eight months after construction

Data for Conventional Covers

Cover Type	Site	Total Precipitation (July 1– June 30) (mm)			Surface Runoff (mm)	Lateral Flow (mm)	ET (mm)	Percolation	
		00-01	01-02	02-03				Total (mm)	Average (mm/yr)
Composite	Altamont	NF	291.1	394.2	59.0 (6.5%)	4.0 (0.4%)	1.5 (0.4%)	4.0 (0.4%)	1.5 (0.4%)
	Apple Valley	NA	NF	148.0	6.8 (4.6%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
	Boardman	NF	134.4	125.5	0.0 (0.0%)	0.2 (0.1%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
	Marina	288.0	335.0	343.7	98.7 (10.2%)	47.4 (4.9%)	23.1 (7.3%)	71.0 (7.3%)	23.1 (7.3%)
	Polson	350.0	292.1	290.6	17.7 (1.6%)	40.5 (3.6%)	0.4 (0.1%)	1.5 (0.1%)	0.4 (0.1%)
	Cedar Rapids	NF	NF	791.2	54.1 (2.8%)	96.2 (5.0%)	12.2 (1.4%)	26.9 (1.4%)	12.2 (1.4%)
	Omaha	NF	561.4	474.5	86.8 (5.8%)	43.3 (2.9%)	6.0 (1.1%)	16.5 (1.1%)	6.0 (1.1%)
Soil Barrier	Apple Valley	NA	NF	148.0	3.4 (2.3%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
	Albany	909.0	798.3	1447.8	359.4 (9.9%)	NA	195.2 (17.1%)	623.7 (17.1%)	195.2 (17.1%)
	Cedar Rapids	NF	NF	791.2	79.6 (4.2%)	29.5 (1.5%)	51.6 (6.0%)	113.6 (6.0%)	51.6 (6.0%)

NF = data not available for full year. 🟨 = semi-arid/sub-humid/arid. 🟩 = humid.

Summary:
Field Performance of Conventional Covers

- Percolation rates for composites are very low:
    < 1 mm/yr in semi-arid and arid climates
    < 5 mm/yr in humid climates

- Percolation rates for soil covers much higher than expected:
    - 195 mm/yr at Albany, GA
    - appears dominated by preferential flow

- Surface runoff is a small fraction of the water balance (<10%)

- Lateral drainage is a small fraction of the water balance (< 5%)

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