4.0 System Considerations

- 4.1 Composite Barriers
- 4.2 Response Action Plans (RAP's)
- 4.3 Geosynthetic Clay Liners (GCL's)
- 4.4 Liquid Management Schemes
- 4.5 Multilined Side Slope Stability
- 4.6 Access Ramps
- 4.7 Solid Waste Stability
- 4.8 Cover System Considerations
Erosion
Control Systems

4.1 Composite Barriers

(a) Types

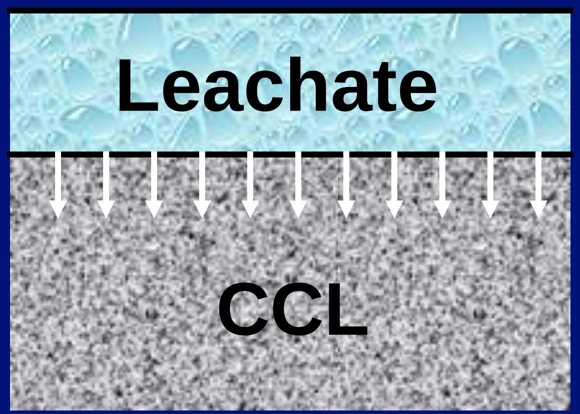
GM/CCL

GM/GCL

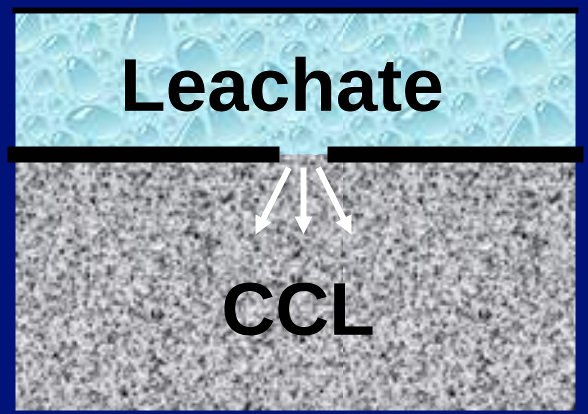
GM/GCL-CCL

Calculations show greatly reduced composite leakage over GM by itself or CCL by itself or GCL by itself, provided that intimate contact is attained

(b) Intimate Contact Issue



Clay Liner
(by itself)



Composite Liner
(with intimate contact)

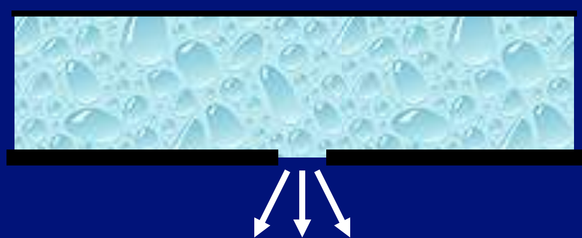
Composite Liner
(GM + GCL)

Does the GT compromise the composite liner concept?

Ans: Generally no...

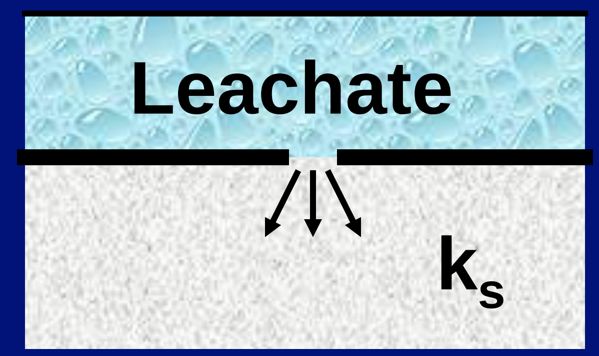
(c) Theoretical Leakage

GM alone (hole area "a")



$$Q = C_B \, a \sqrt{2gh}$$

Composite liner (GM/CCL)



$$Q = 0.21 \, a^{0.1} \, h^{0.9} \, k_s^{0.74}$$

(for good contact)

$$Q = 1.15 \, a^{0.1} \, h^{0.9} \, k_s^{0.74}$$

(for poor contact)

Ref. Bonaparte, Giroud & Gross, GS '89)

Generalized Leakage Rates Through Liners

(ref. Giroud and Bonaparte, Jour. G & G, 1989)

Type of Liner	Leakage Mechanism	Liquid height on top of the geomembrane			
		0.03 m	0.3 m	3 m	30 m
Geomembrane alone (between two sand layers)	Diffusion Small holes* Large holes*	0.01 300 10,000	1 1,000 30,000	10 3,000 100,000	300 10,000 300,000
Composite liner (poor field conditions, i.e., waves)	Diffusion Small holes* Large holes*	0.01 0.8 1	1 6 7	100 50 60	300 400 500
Composite liner (good field conditions, i.e., flat)	Diffusion Small holes* Large holes*	0.01 0.15 0.2	1 1 1.5	100 9 11	300 75 85
		Values of leakage rate in lphd (figures to be divided by approximately 10 to obtain values expressed in gpad)			

*assumes 3 holes/ha (i.e., 1.0 hole/acre)

4.2 Response Action Plans (RAP's)

- Only applicable with double liner systems
- Worldwide, 58% HSW (incl. USA) and 14% of MSW require double liner systems
- Requires measurement of liquid quantity in leak detection system
- If above the preset action leakage rate (ALR), different requirements are set in motion, e.g.,
  - continuous monitoring
  - characterize liquid
  - stop receiving waste
  - remove waste to locate leak(s)
- Obviously, a very sensitive issue for all parties involved

Some Comments onResponse Action Plans (RAP's)

(a) "de minimum" leakage ~ 10 lphd (~ 1.0 gpad)

- vapor diffusion through perfect geomembrane with no flaws = 0.2 to 20 lphd

(b) typ. action leakage rate (ALR) ~ 50 to 200

- continuous monitoring
- assess liquid characteristics
- compare to primary leachate

(c) typ. intermediate leakage rate (ILR) ~ 200 to 1000

- stop adding waste
- continue monitoring and testing

(d) typ. rapid and large leak (RLL) > 1000 lphd

- remove waste
- repair leak(s)

Note: all of the above RAP values are for illustration only -- they must be site specifically determined -- note that EPA only requires the establishment of an ALR value

Leakage Rates from Leak Detection Systems of Double-Lined Landfills

Ref. EPA Study CR-821448 by R. Bonaparte

All Flow Rates in Liters/Hectare-Day (lphd)

Liner/leak det. Type	Type I (GM-Sand)			Type II (GM-GN)			Type III (GM/CCL-Sand)		
Life Cycle Stage	1	2	3	1	2	3	1	2	3
Average Flow	380	170	64	90	100	ND	210	140	64
Minimum Flow	7.6	0.0	0.2	4.8	1.4	ND	1.2	22	0.0
Maximum Flow	2140	1480	240	370	360	ND	1180	660	270
No. of ì pointsî	30	32	8	7	11	ND	31	41	15
No. of landfills	11	11	4	4	6	ND	11	11	4
Liner/leak det. Type	Type IV (GM/CCL-GN)			Type V (GM/GCL-Sand)			Type VI (GM/GCL-GN)		
Life Cycle Stage	1	2	3	1	2	3	1	2	3
Average Flow	170	83	65	130	22	0.3	6.5	2.6	ND
Minimum Flow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ND
Maximum Flow	690	500	130	970	280	0.9	34	9.0	ND
No. of ì pointsî	21	27	12	19	19	4	6	4	ND
No. of landfills	6	9	3	3	3	1	2	2	ND

Life Cycle Stages:

Stage 1 – Initial Life

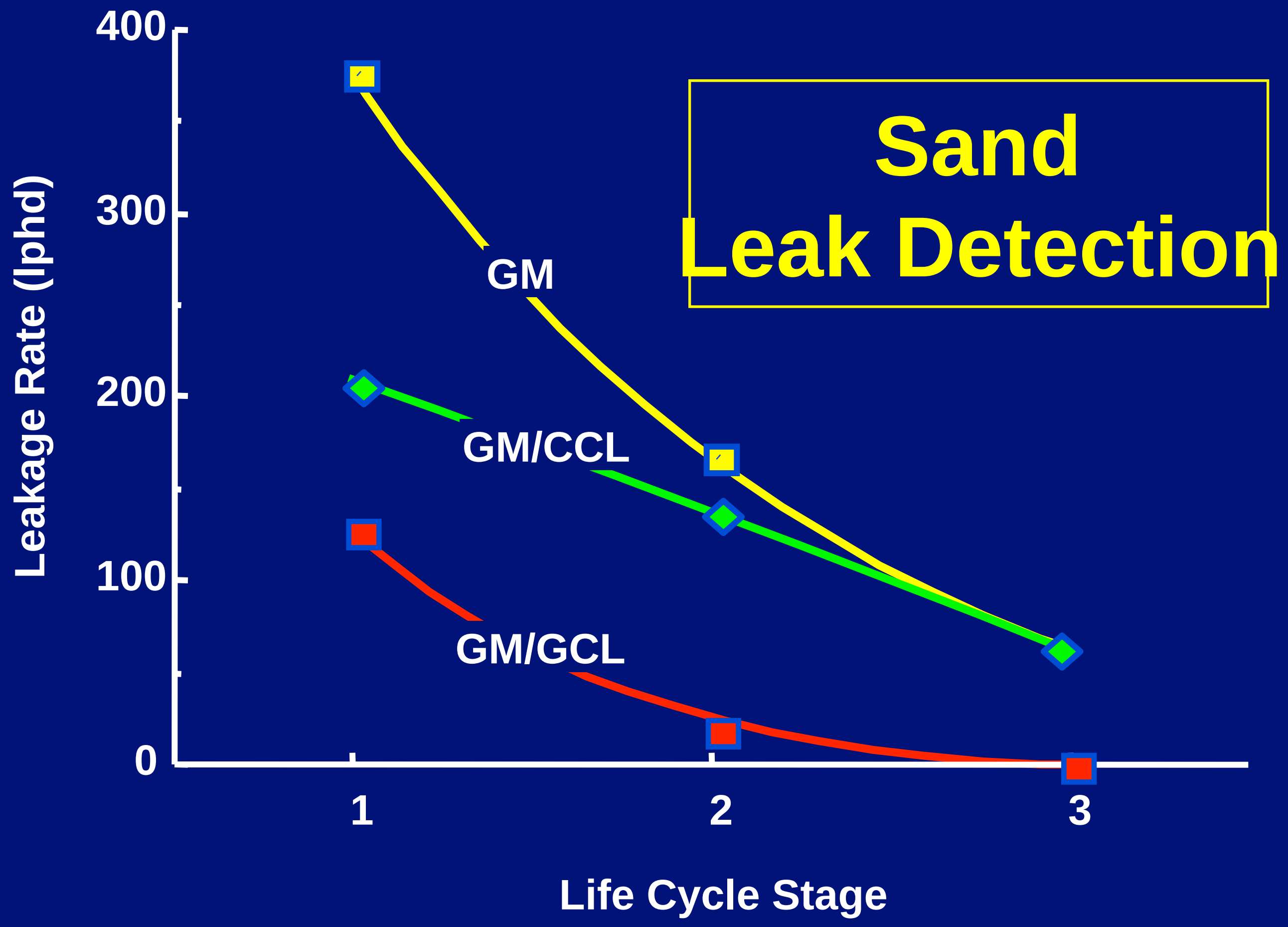
Stage 2 – Active Life

Stage 3 – Post Closure

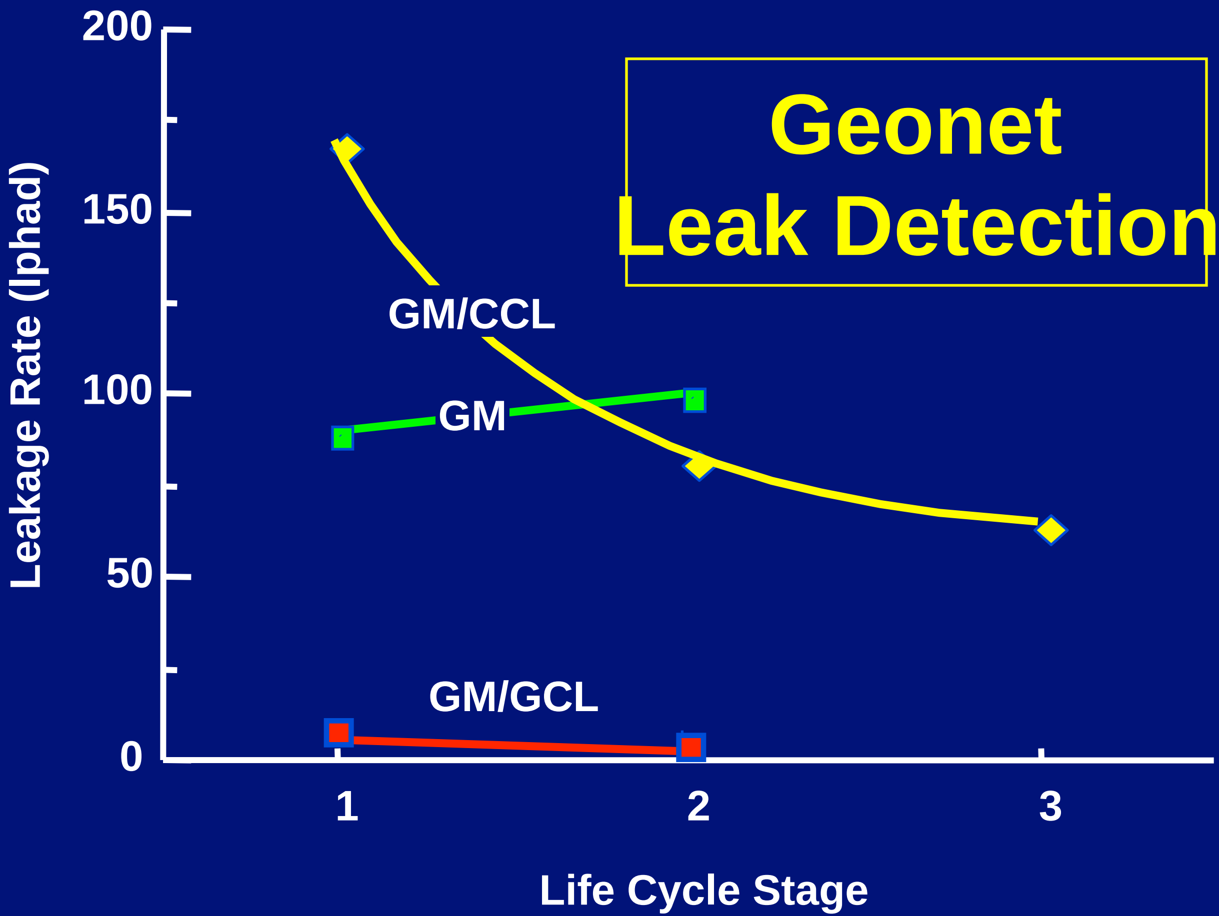
"points" = Number of measuring points (i.e., outlets of single or multiple cells)

ND = No Data

Average Values of Leakage Quantities



Average Values of Leakage Quantities *(cont'd)*



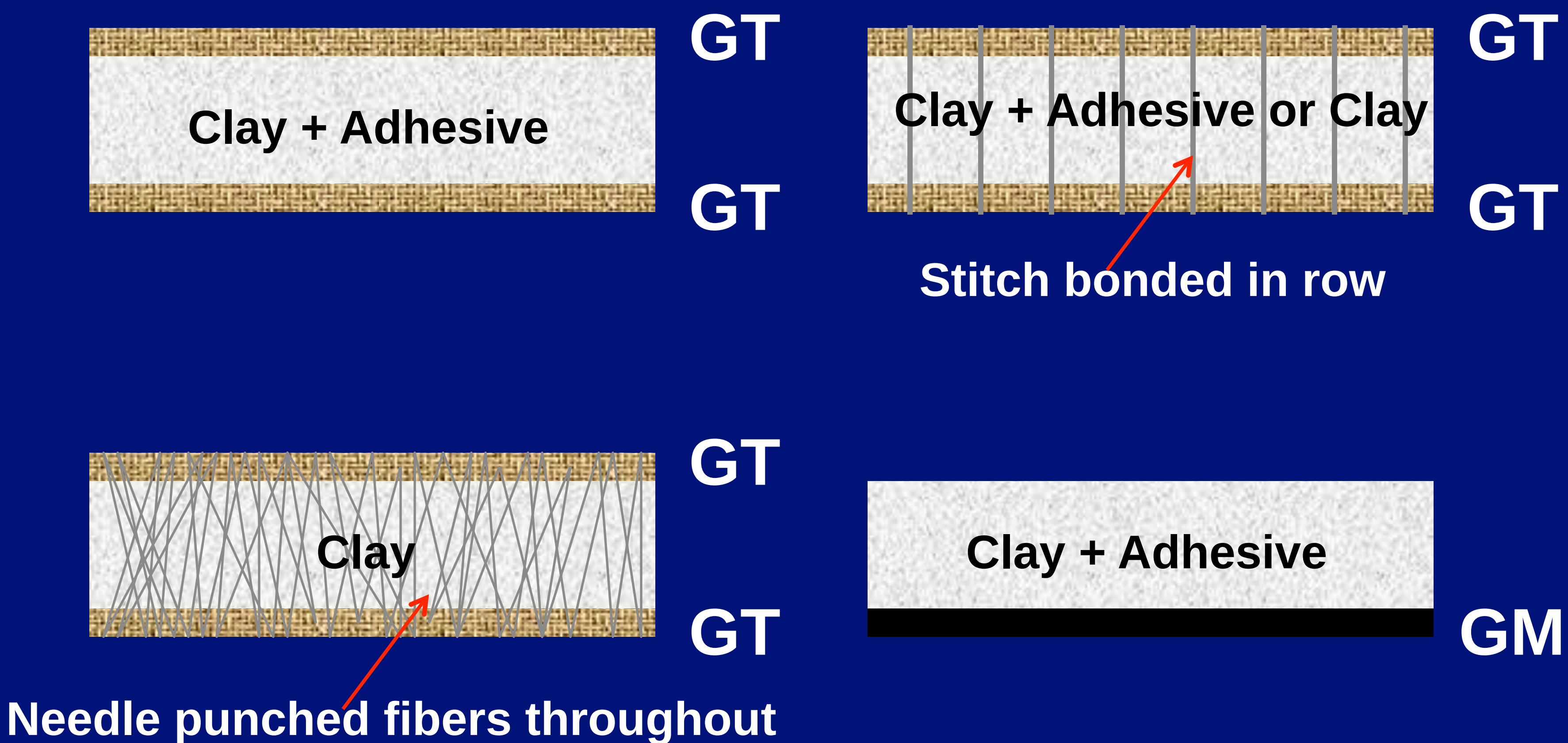
4.3 Geosynthetic Clay Liners

- factory fabricated liners using dry bentonite (powder or granules)
- Na-bentonite in No. America, Ca-bentonite elsewhere
- usually sandwiched between GTs
- bonded by adhesives, needling or stitching
- two products are GM-associated
- many products are available
- various styles of each product
- potential replacement of (or augmentation to) CCLs

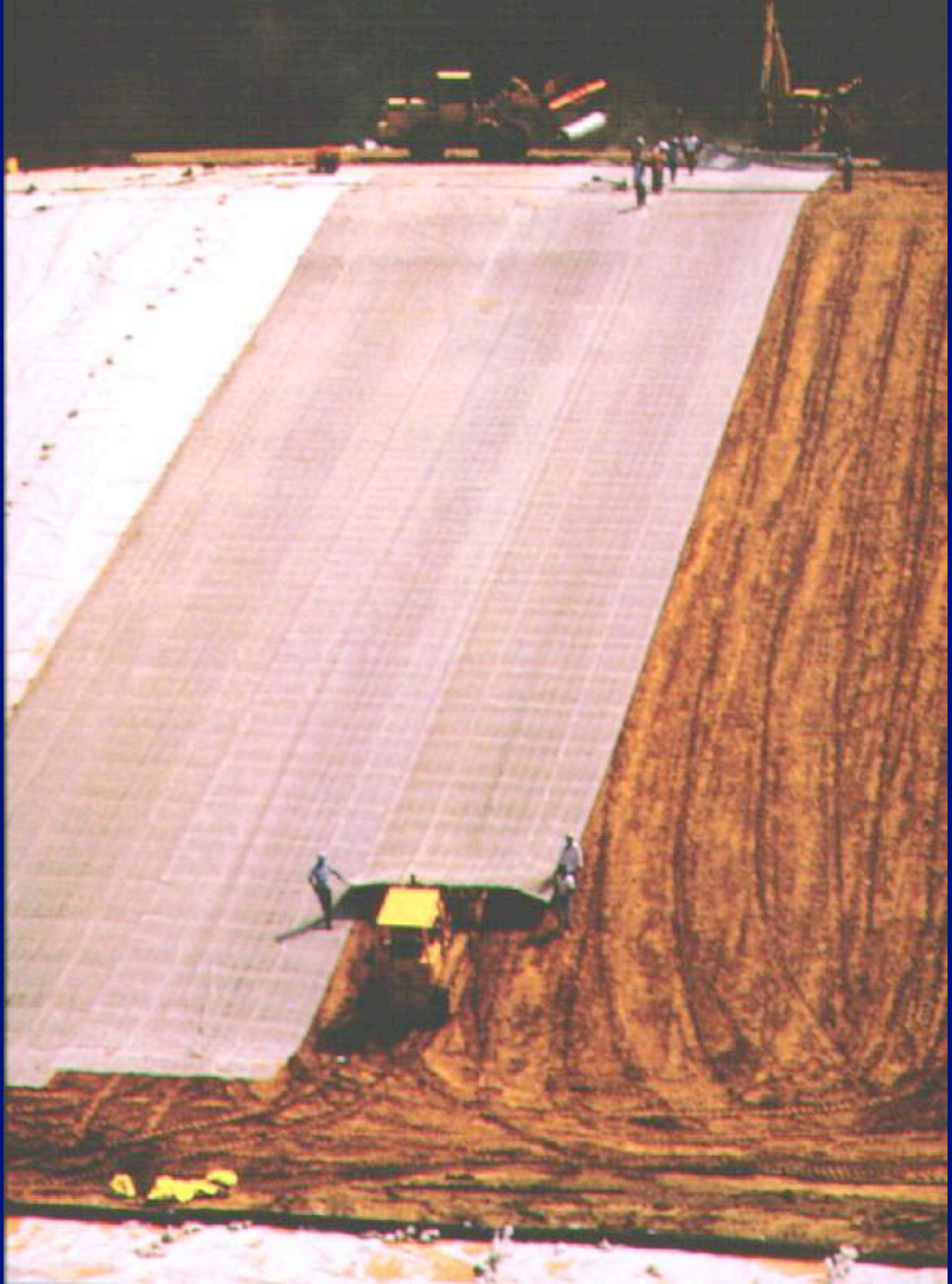
Currently Available GCLs (1999)

Manufacturer	Trademark	Substrate	Infill	Superstrate	Bonding Method
CETCO	Claymax	geotextile	bentonite	geotextile	adhesive and stitch bonded
CETCO	Claymax	geotextile	bentonite	thin GM-film laminated	adhesive and stitch bonded
CETCO	Bentomat	geotextile	bentonite	geotextile	needle punched
Naue Fasertechnik and BTI	Bentofix	geotextile	bentonite	geotextile	needle punched
Naue Fasertechnik	Bentofix	geotextile	bentonite/geotextile/ bentonite	geotextile	needle punched
GSE	Gundseal	geomembrane	bentonite	none	adhesive bonded
Huesker	NaBento	geotextile	bentonite	geotextile	stitch bonded
Rawell	unknown	geotextile	bentonite (polymer modified)	none	moisture
Geosynthetics	Equiva-Seal	geotextile	bentonite within a geonet	geotextile	thermal
Laviosa	Modulo-Geobent	geotextile	bentonite	geotextile	adhesive
Aashi	unknown	geotextile	bentonite	geotextile	Unknown
GID	Trisoplast	soil subgrade	bentonite (polymer modified and sand filler)	none	in-situ fabrication

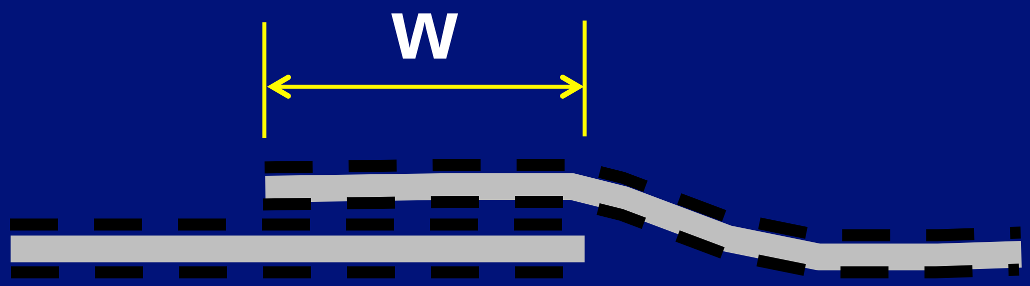
Cross-sections of Currently Available GCLs



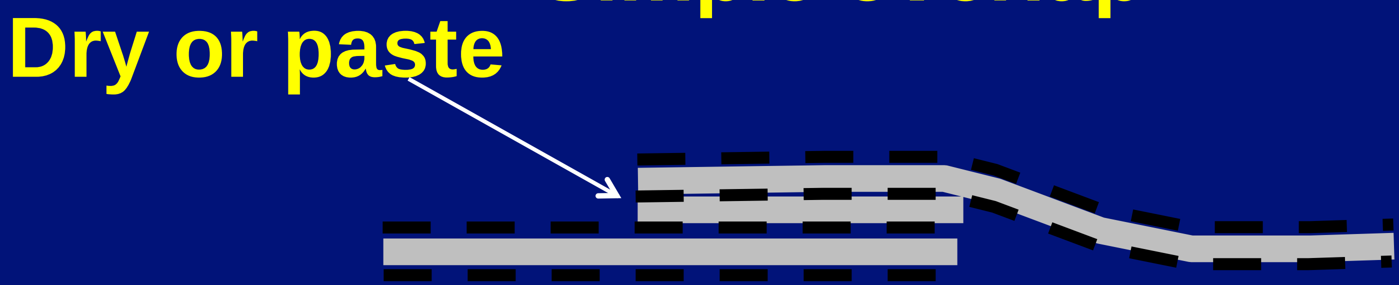

Bentomat®
Bentofix®
Gundseal®
Na Bento®
Claymax®



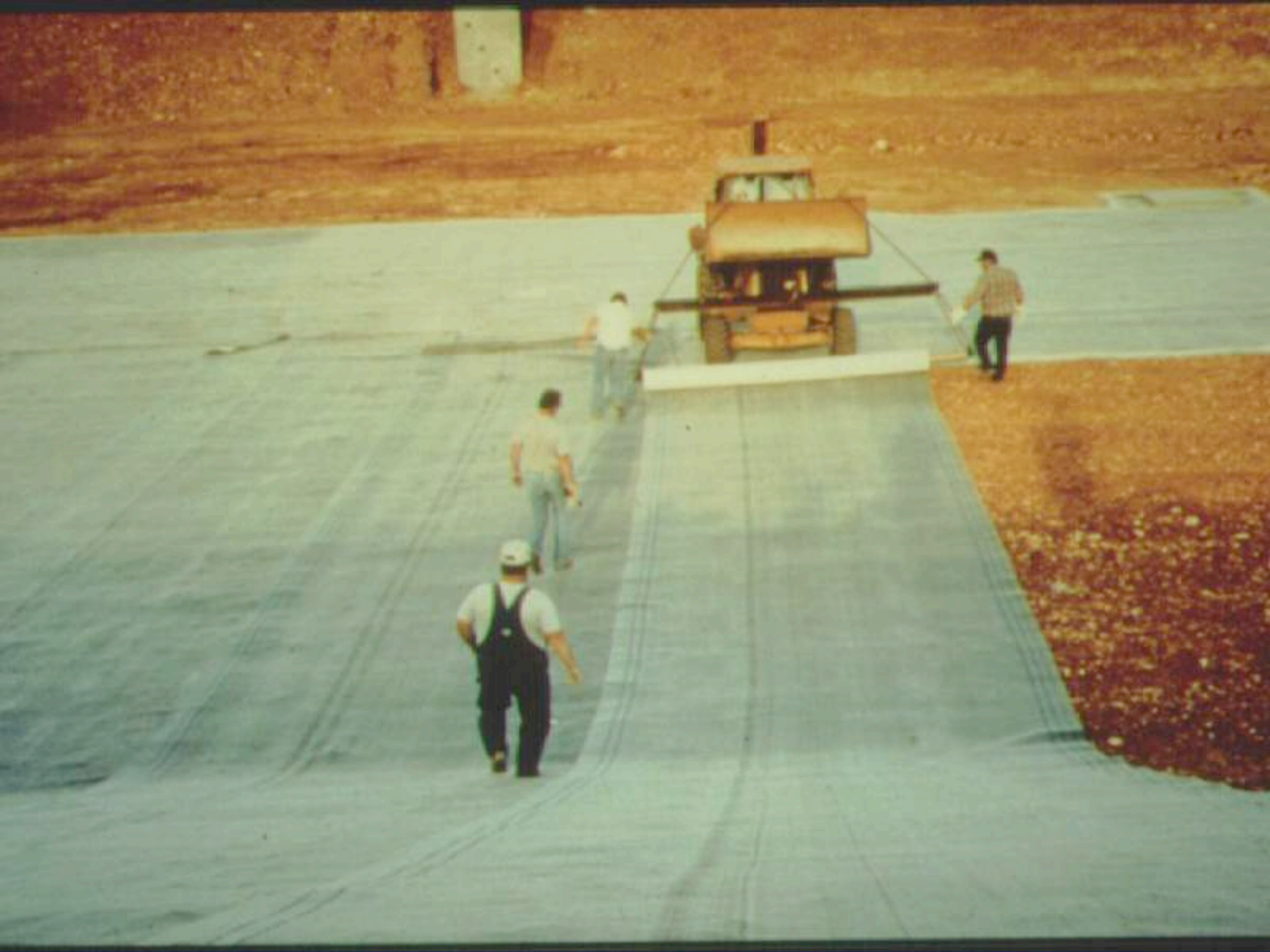
Overlap Seaming Alternatives



Simple overlap



Overlap with bentonite



Manufacturing Quality Control (MQC) guide modified and expanded from ASTM D5889.

Property	Test Method	Limiting Value	Frequency of Testing
Bentonite:			
Moisture content (max.)	ASTM D4643	10%	Based on specific shipment unit of 50 tonnes
Swell index[1] (min.)	ASTM D5890	25 ml	
Moisture adsorp. (min.)	Enslin-Neff[2,4]	600%	
Geotextile:[3]			
Mass/unit area[1]	ASTM D5261	product specific	Typically 20,000 m^2 (200,000 ft^2)
Thickness	ASTM D5199	" "	
Grab Tensile Strength[1]	ASTM D4632	" "	
Trap. Tear Strength	ASTM D4533	" "	
Burst Strength	ASTM D3786	" "	
Puncture	ASTM D4833	" "	
Geomembrane:[3]			
Thickness (smooth)[1]	ASTM D5199	product specific	Typically 20,000 m^2 (200,000 ft^2)
Thickness (textured)[1]	ASTM D5994	" "	
Tensile Strength	ASTM D638	" "	
Tear Resistance	ASTM D1004C	" "	
Puncture	ASTM D4833	" "	
As Manufactured-GCL:			
Mass/unit area[1] (min.)	ASTM D5993	5.0 kg/m^2 (1.0 lb/ft^2)	Frequency varies greatly (currently being balloted in ASTM D35.04)
Thickness	ASTM D5199	product specific	
Grab Tensile Strength	ASTM D4632	" "	
Puncture Resistance	ASTM D4833	" "	
Peel Strength[5]	ASTM D4632	" "	
Moisture Content[1] (max.)	ASTM D4643	25%	
Flux (max.)[1]	ASTM D5886	product specific	

[1] Currently under consideration for a ASTM MQC Guide Standard

[2] Using distilled, deionized water

[3] Properties are evaluated on the material before manufacturing into the GCL product. All of the tests listed are routinely performed on the respective manufactured geotextiles or geomembranes.

[4] See Koerner (1998) for the test method description

[5] Applicable only for needle punched GCLs

Selected Design (Performance) Tests for GCLs

Property	Test Method	General Comments
Flux	ASTM D5887	• always important • should use site-specific permeant • should use site-specific stress and pressure conditions • should have thickness measured at end of the test so as to calculate hydraulic conductivity (permeability)
Direct Shear	ASTM D5321	• necessary for side slope designs • generally the upper interface is of main concern • sometimes internal strength is of concern • sometimes the lower interface is of concern
Creep Shear	ASTM D5321-mod.	• difficult and costly test • sometimes necessary with low factor-of-safety designs • generally the upper interface is of concern • sometimes internal strength is of concern • rarely is the lower interface required

Selected Design (Performance) Tests for GCLs *(cont'd)*

Property	Test Method	General Comments
Wide Width Tensile Strength and Elongation	ASTM D4595	• only necessary when tensile stresses are to be resisted • possibly when shear stresses are to be resisted
Wide Width Tensile Strength for Overlaps	ASTM D4595-mod.	• only necessary when tensile stresses are to be resisted which include GCL overlaps
Multi-Axial Tension	ASTM D5617-mod.	• only for anticipated yielding subgrade situations
Soil Compatibility, or Indentation	ASTM D5818-mod.	• for subgrades with soil particles ≥ 12 mm (0.5 in.) • for cover soils with particle sizes ≥ 12 mm (0.5 in.)
Chemical Resistance	ASTM D6141	• for aggressive or reactive liquid permeants

Technical Equivalency Issues of GCLs vis-à-vis CCLs

ACharacteristic	GCLs	CCLs
Materials	Bentonite, adhesives, GTs and GMs	Native soils, bentonite admixes
Thickness	Approximately 10 mm	Typically 300 to 900 mm
Hydraulic conductivity	$\leq$ (1 to 5) $\times 10^{-9}$ cm/sec	$\leq 1 \times 10^{-7}$ cm/sec
Construction deployment	Rapid and simple installation	Slow complicated construction
Regarding manufacturing quality control (MQC)	Factory manufacturing requires constant MQC	Naturally found materials or mineral layers
Regarding construction quality assurance (CQA)	Relatively simple, straightforward, common-sense procedures	Complex CQA procedures requiring detailed knowledge of clay soils and moisture/ compaction details

Technical Equivalency Issues of GCLs vis-à-vis CCLs *(cont'd)*

Characteristic	GCLs	CCLs
Vulnerability to damage due to desiccation	When dry no concern; when wet desiccation can occur but upon rewetting bentonite self-heals	CCLs are nearly saturated and can desiccate during construction; upon rewetting little self-healing occurs
Available of materials	Materials easily shipped to any site	Suitable materials not available; may require long transportation
Typical Cost	Approx. \$3.00 to \$5.00 per square meter for a large site	Highly variable -- estimated range: \$5.00 to \$50.00 per square meter
Experience	Limited due to newness	Used successfully and unsuccessfully for many years

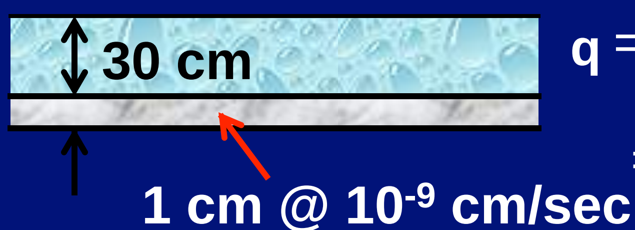
Equivalency Issue*

CCL

$$q = kiA$$

$$= 1 \times 10^{-7} \left(\frac{120}{90}\right) 1.0$$

$$= 1.33 \times 10^{-7}\ cc/sec$$



GCL

$$q = kiA$$

$$= 1 \times 10^{-9} \left(\frac{31}{1}\right) 1.0$$

$$= 31 \times 10^{-9}\ cc/sec$$

Ratio of q_{CCL}/q_{GCL}

$$= \frac{1.33 \times 10^{-7}}{31 \times 10^{-9}} = 4.3$$

Thus, the CCL = 4.3 times greater in flow rate than the GCL!

---

*Assumes that the GCL does not become thinner from storage, transportation, handling, installation, trafficking by vehicles, etc.

Generalized technical equivalency assessment for "liners" beneath landfills and surface impoundments, after Daniel & Koerner.

Criteria for evaluation	GCL is probably superior	GCL is probably equivalent	GCL is probably not equivalent	Equivalency depends on site or product
Hydraulic Issues				
Steady flux of water		X		
Steady solute flux		X		
Chemical adsorption capacity			X	
Breakout time				
Water				X
Solute				X
Horiz. flow in seams or lifts		X		
Horiz. flow beneath geomembrane	X			
Generation of consolidation water	X			
Physical/Mechanical Issues				
Freeze-thaw behavior	X			
Total settlement		X		
Differential settlement	X			
Slope stability				X
Bearing capacity			X	
Construction Issues				
Puncture resistance			X	
Subgrade condition			X	
Ease of placement	X			
Speed of construction	X			
Availability of materials	X			
Requirements for water	X			
Air pollution concerns	X			
Weather constraints				X
Quality assurance considerations		X		

Generalized technical equivalency assessment for ”cover" above landfills, after Daniel & Koerner.

Criteria for evaluation	GCL is probably superior	GCL is probably equivalent	GCL is probably not equivalent	Equivalency depends on site or product
Hydraulic Issues				
Steady flux of water		X		
Breakout time of water				X
Horiz. flow in seams or lifts		X		
Horiz. flow beneath geomembrane	X			
Generation of consolidation water	X			
Permeability to gases		X		
Physical/Mechanical Issues				
Freeze-thaw behavior	X			
Wet-dry behavior	X			
Total settlement		X		
Differential settlement	X			
Slope stability				X
Vulnerability to erosion				X
Bearing capacity			X	
Construction Issues				
Puncture resistance			X	
Subgrade condition			X	
Ease of placement	X			
Speed of construction	X			
Availability of materials	X			
Requirements for water	X			
Air pollution concerns	X			
Weather constraints				X
Quality assurance considerations		X		

Important CQC/CQA Issues

- must be covered before hydration
- min. cover soil thickness = 300 mm (Corps of Engineers requires 450 mm)
- work downgradient when possible
- overlap edges from 150-300 mm
- double nonwoven GTs require bentonite powder or paste in overlap area

4.4 Liquid Management Schemes

- maximum cell drainage required immediately after construction (i.e., dewatering)
- waste greatly attenuates the precipitation
- after closure, flow rate decreases considerably
- scheme “a” - remove leachate continuously
- scheme “b” - recycle leachate above (and through) waste
- scheme “c” – add liquids up to field capacity
- potential problem with clogging (more later)
- potential problem with daily cover (alternatives to soil follow)

Wet Landfills

Concept/Goals

- accelerate degradation
- strip pollutants from waste

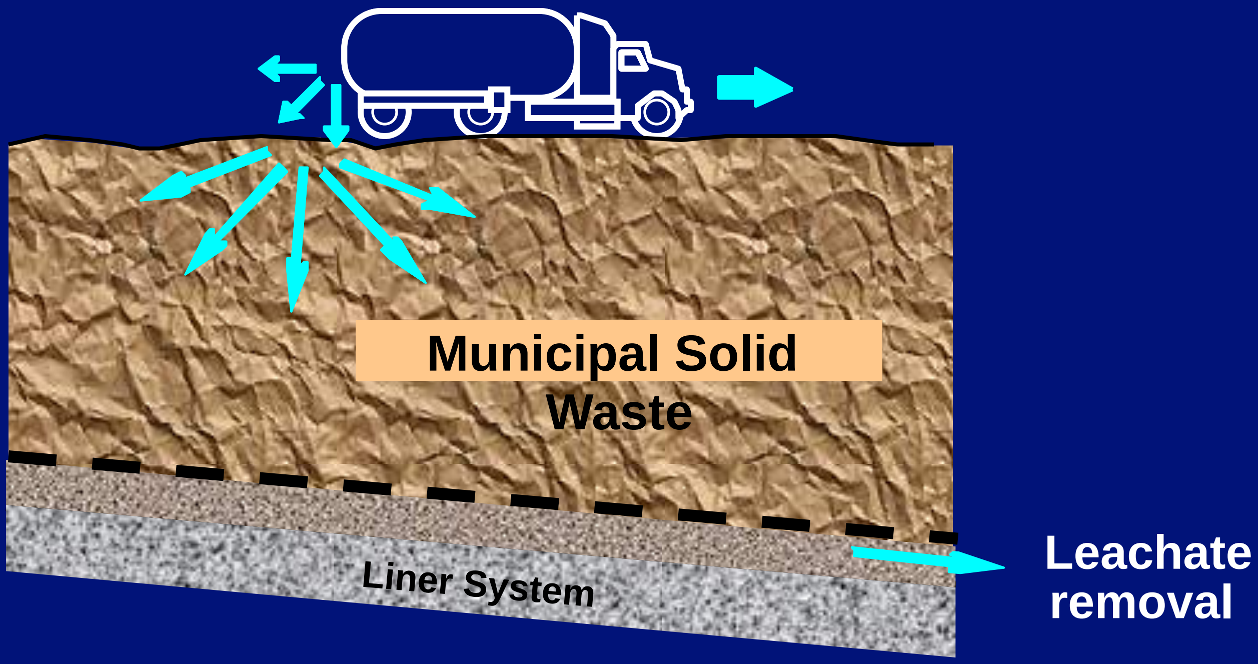
Methods

- surface application using tank trucks
- perforated pipe manifold system under the landfill cover
- injection wells through cover (but don't be too deep or aggressive)!

Current Efforts

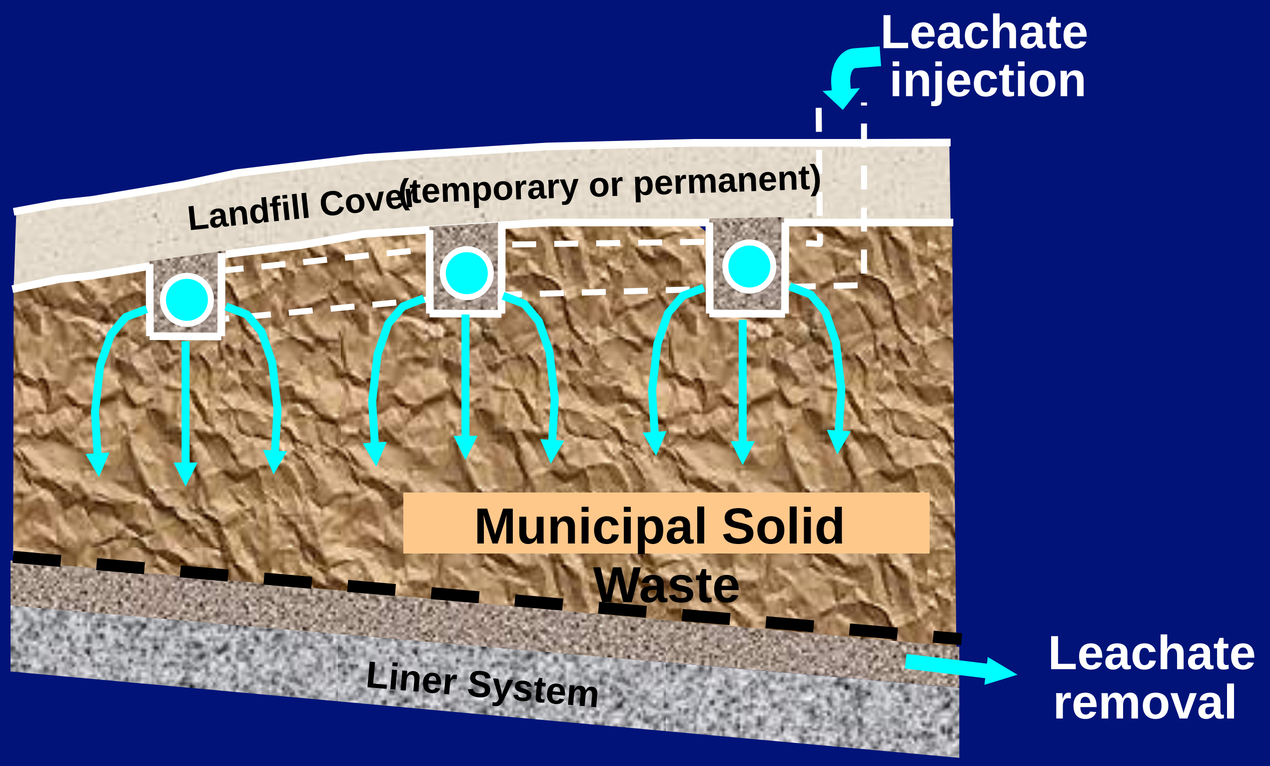
EPA project via Dave Carson (513) 569-7527 through Dr. D. Reinhart at Univ. of Central Florida

Different Injection Systems to Recirculate Leachate in Municipal Solid Waste Landfills



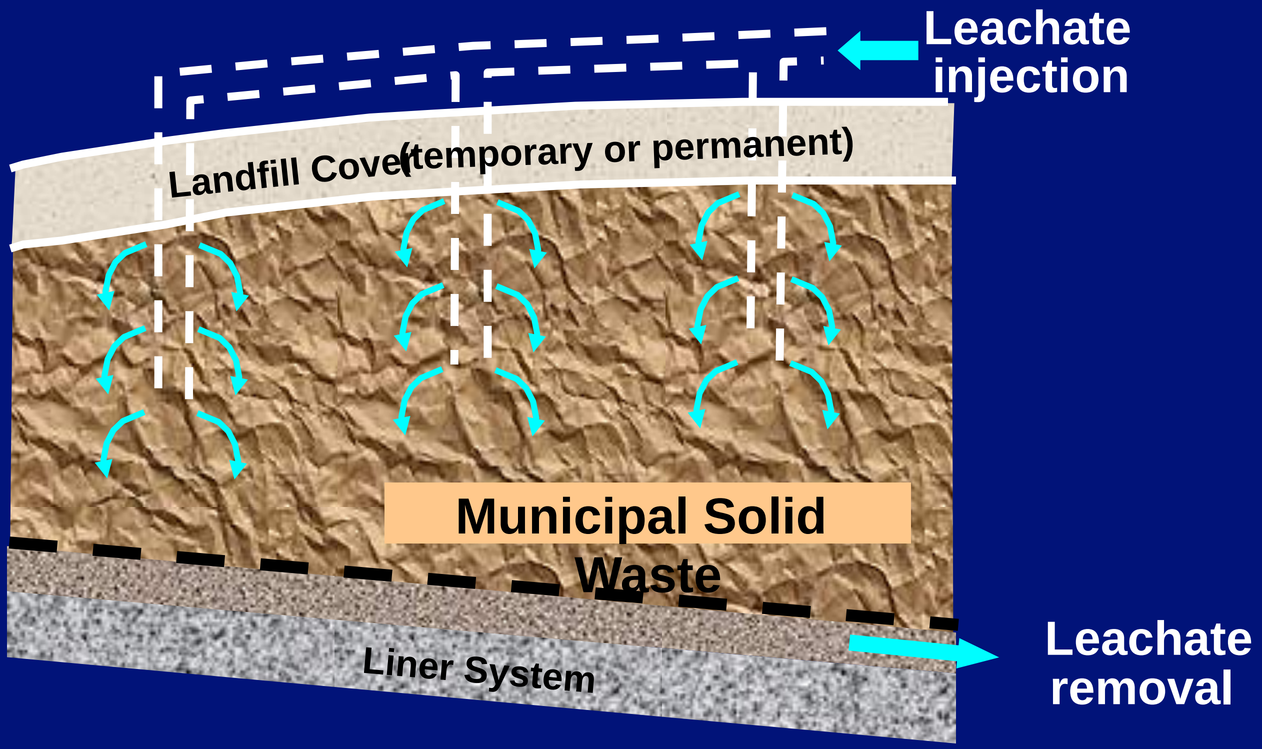
(a) Surface distribution directly on waste

Different Injection Systems to Recirculate Leachate in Municipal Solid Waste Landfills *(cont'd)*



(b) Distribution beneath cover using manifold system

Different Injection Systems to Recirculate Leachate in Municipal Solid Waste Landfills *(cont'd)*



(c) Injection from within vertical wells

Regulatory Purposes of Daily Cover

- eliminate disease carrying vectors (birds, flies, insects, rodents)
- eliminate fires
- control odors
- eliminate blowing litter
- discourage scavenging

Problems with Soil as Daily Cover

- loss of landfill volume (i.e., air space)
- costs in obtaining proper soil material
- placement of soil at crowded working face
- excavation of soil following day
- creates de-facto barriers at every lift
- side wall seepage occurs frequently
- discontinuity of vertical flow occurs at each lift (leachate recycle problems)

Alternate Daily Cover Materials*

Polymer Foams

- Rusmar
- Saniform
- Terrafoam
- Topcoat

Slurry Sprays

- Con Cover (paper)
- Land-Cover (clay/polymer)
- Posishell (paper)

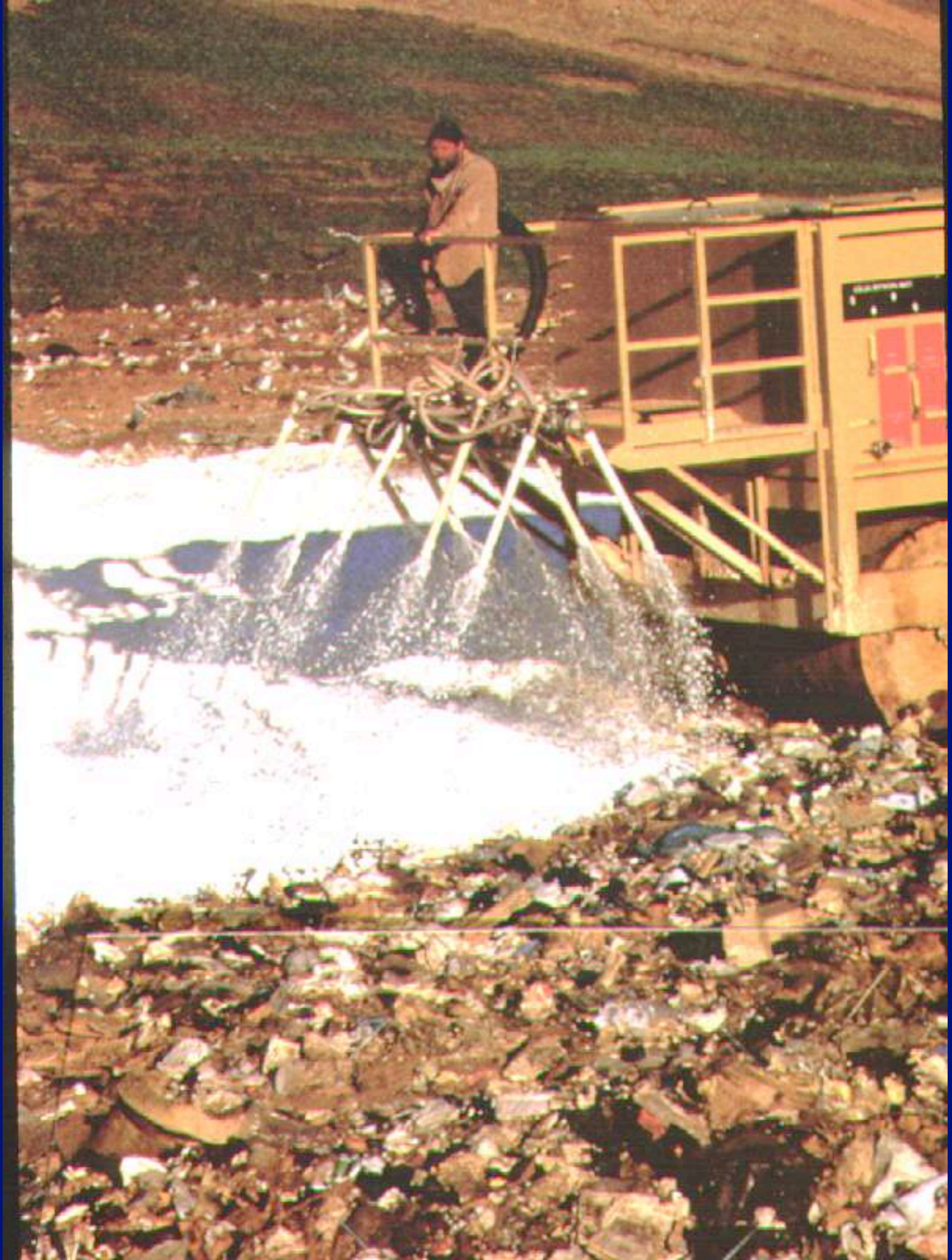
Sludges & Indigenous Materials

- Naturite/Naturefill
- N-Viro Soil
- Chemfix
- Green waste/compost
- Ash-based
- Auto fluff
- Foundry sand
- Shredded Tires

Reusable Geosynthetics

- Air Space Saver
- Griffolyn
- Cormier
- FabriSoil
- Covertech
- Sanicover
- Aqua-Shed
- Polyfelt
- Tarpmatic
- Typar

*see Pohland & Graven Report to EPA, EPA/600/R-93/172 (NTIS PB 3-227197)




ConCover

Values Added to O/O

- Airspace is saved
- Soil is not required
- Soil can impede liquid flow
- Soil can impede gas flow
- Generally is cost effective

Suggested Method to Assess Technical Equivalency of ADCMs*

Regulatory Concerns w/r to Daily Cover	150 mm Soil Rating	ADCM Product "x"	Relative Equivalency
• control of vectors (birds, animals, flies)	25	20	slightly less**
• air-borne controls (blowing litter, odors)	25	20	slightly less**
• control of fires (waste at surface and at depth)	20	15	slightly less**
• control of water infiltration	15	25	better
• control of gas movement	15	25	better
Total Score	100	105	better

*Table considers Regulations only; not the value added to the owner/operator.
**Issue must be judged as being noncritical or permit adjusted accordingly in order to approve the ADCM.

End of File