Lessons learned from landfills about liner performance and leakage

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Geosynthetics in Covers and Bottom Liners

There have been a very large number of successful applications.

Geosynthetics:

- work extremely well!!!, BUT
- they are engineered materials and need to be treated with the same respect as other engineered materials

Geosynthetics in Covers and Bottom Liners

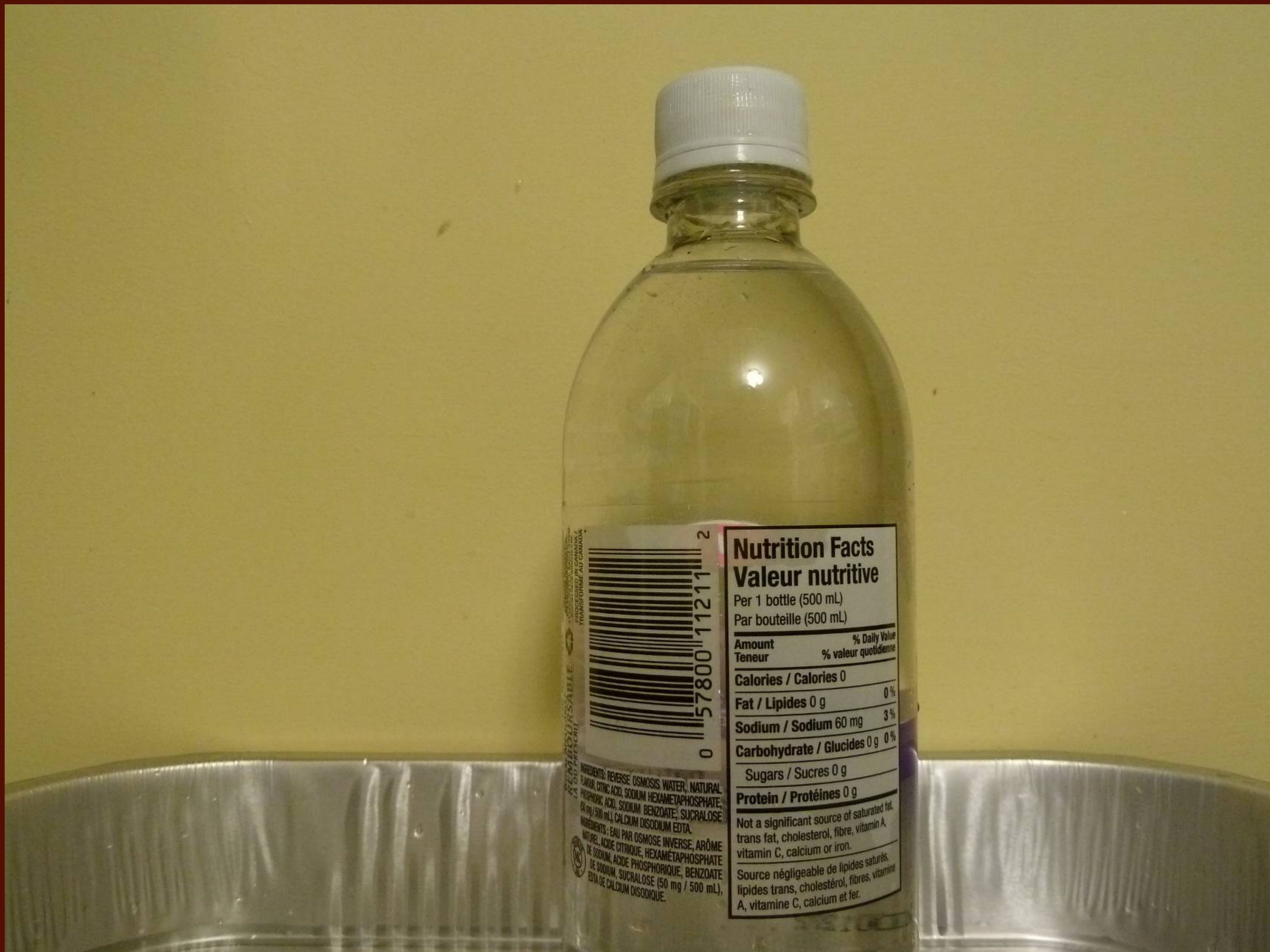
Manufacturers provide many options:

- Different products are intended for different applications
- It is the engineers responsibility to select the right materials for their application
- You might get what you ask (and pay) for
- Good engineering can be relied on
- Luck is fickle

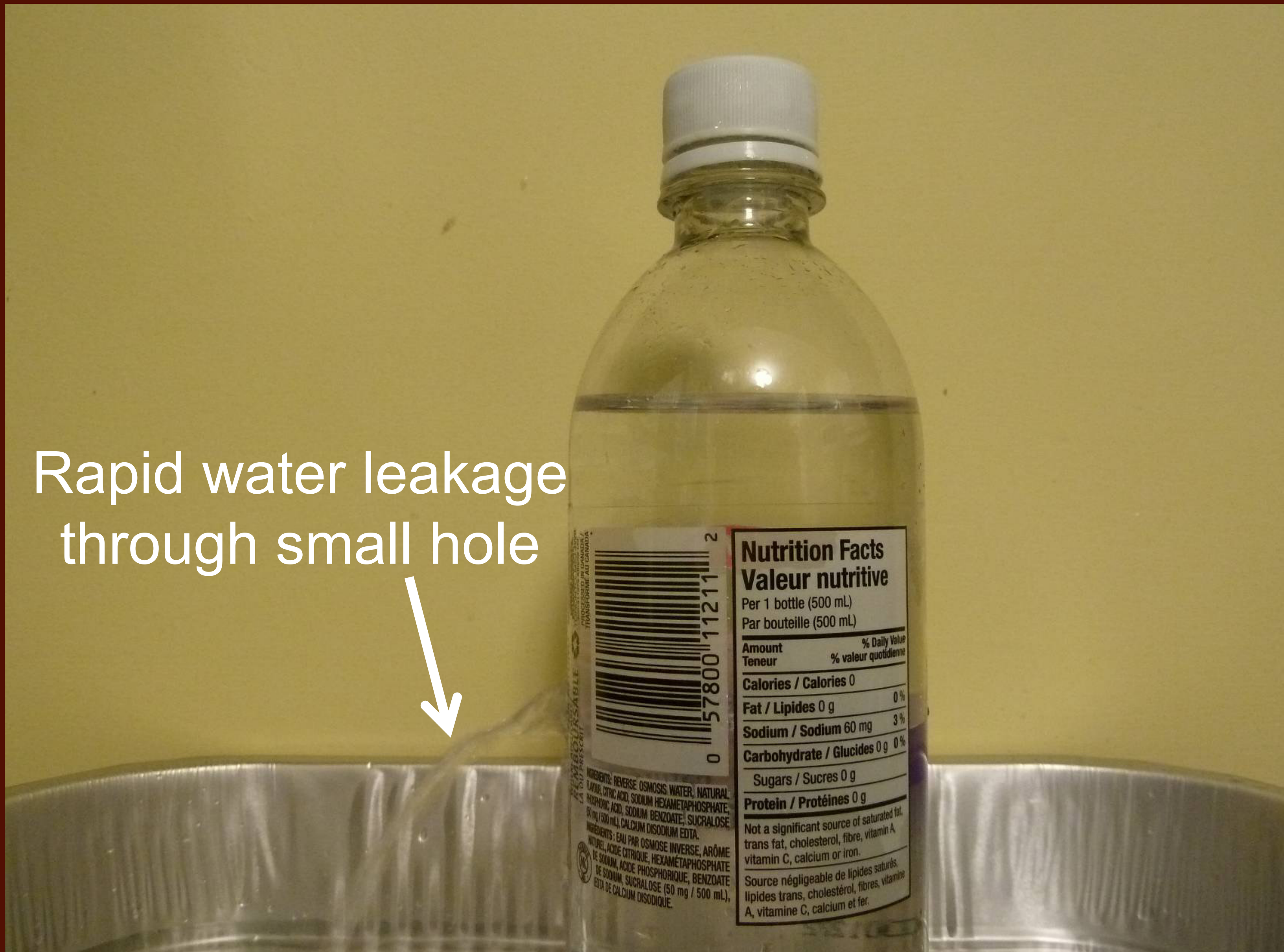
Topics

- Holes in geomembranes
- Leakage through geomembrane liners
- Leakage through clay liners
- Leakage through composite liners
  - Direct contact
  - Observed leakage
  - Wrinkles/waves
  - GCL overlaps/ panel shrinkage
  - GM/GCL interface and desiccation of compacted clay liners (CCL)

Plastics hold water well



Plastics hold water well - if no hole



Holes in GM

- 2.5 – 10 holes/ha typical design value
- 3 holes/ha after installation*
- 12 holes/ha after placement of drainage layer*
- 5 holes/ha assumed in presentation
- Median equivalent radius – 5.6mm (typical)

* Nosko & Touze-Foltz (2000)

Topics

- Holes in geomembranes
- **Leakage through geomembrane liners**
- Leakage through clay liners
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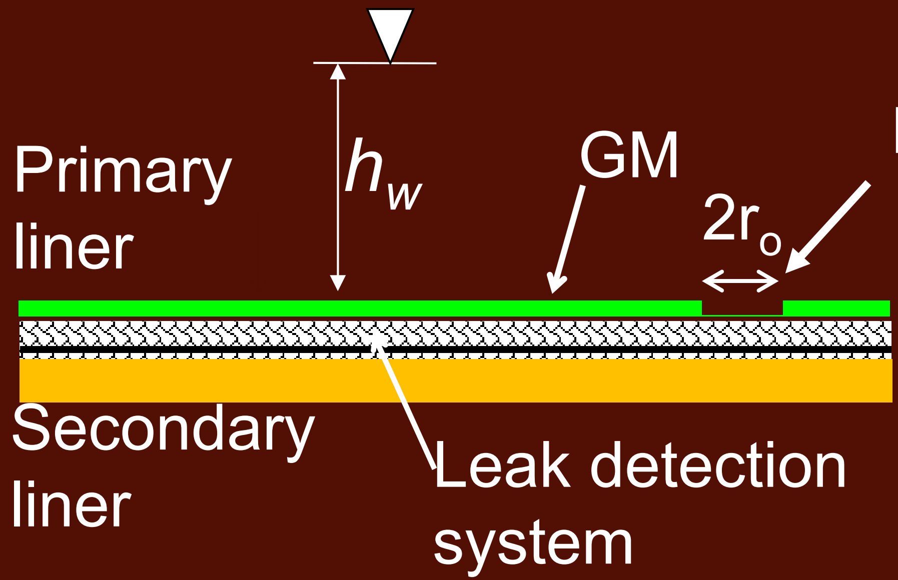
Leakage through single GM liner



h_w (m)	r_o (mm)	Q (litres per hectare per day)
0.3	0.5	500
0.3	1	2,000
0.3	5.6	63,000

GM 5 holes/ha

Rowe (2012)

Topics

- Holes in geomembranes
- Leakage through geomembrane liners
- **Leakage through clay liners (CCL and GCL)**
- Leakage through composite liners
  - Direct contact
  - Observed leakage
  - Wrinkles/waves
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  - GM/CCL interface and desiccation of compacted clay liners (CCL)

Cation Exchange and GCLs

- When hydrating or when hydrated, sodium bentonite may experience cation exchange (replacement of sodium ions by other cations such as calcium and magnesium)

- This cation exchange may be caused by cations:
  - in the bentonite
  - in the pore water of adjacent soil

Cation Exchange and GCLs

- A number of publications* examining GCLs after 3-10 years use in landfill covers have indicated cation exchange and:
  - a decrease in swelling capacity (SI)
  - an increase in hydraulic conductivity of SOME GCLs by as much as 5 orders of magnitude (to 10^{-6} m/s) – others had no significant change in k
  - high hydraulic conductivity associated with low moisture content of GCL (≤ 50%)
  - effect depends on local conditions (especially thickness of soil above GCL and presence of cations in adjacent soil) AND type of GCL
- Design wisely!

* e.g. Meer and Benson (2007)
Benson et al. (2010)
Scalia and Benson (2011).

Degree of saturation of GCLs

Why is it important?

Because it influences:

- the effect of cation exchange from surrounding soil on GCL hydraulic performance
- the ability of the GCL to limit oxygen movement
- GCL panel shrinkage, etc.

and so we need to understand what influences the uptake of moisture by different GCLs

What influences Degree of Saturation

- How the GCL is manufactured (they are not all the same - even if they use the same bentonite)
- Grain size distribution of the soil on which it rests
- Water content of the soil on which it rests
- Cation exchange
- Drying cycles
- Normal stress on GCL

Calculated leakage through a single primary liner

	h_w =	0.3 m
Liner	Q (lphd)	Q (lphd)
GM	63,000	63,000
CCL	1,300	

CCL: H_L = 0.6 m, k_L = 1x10^{-9} m/s,

GM: 5 holes/ha, r_o = 5.6mm

Rowe (2012)

Calculated leakage through a single primary liner

	h_w =	0.3 m
Liner	Q (lphd)	Q (lphd)
GM	63,000	63,000
CCL	1,300	13,000

CCL: H_L = 0.6 m, $k_L = 1 \times 10^{-9}$ m/s, $k_L = 1 \times 10^{-8}$ m/s

GM: 5 holes/ha, r_o = 5.6mm

Rowe (2012)

Calculated leakage through a single primary liner

Liner	h_w =	0.3 m
	Q (lphd)	Q (lphd)
GM	63,000	63,000
CCL	1,300	13,000
GCL	1,300	

CCL: H_L = 0.6 m, $k_L = 1 \times 10^{-9}$ m/s, $k_L = 1 \times 10^{-8}$ m/s
GCL: H_L = 0.01 m, $k_L = 5 \times 10^{-11}$ m/s,
GM: 5 holes/ha, r_o = 5.6mm

Rowe (2012)

Calculated leakage through a single primary liner

Liner	h_w = Q (lphd)	0.3 m Q (lphd)
GM	63,000	63,000
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CCL: H_L = 0.6 m, $k_L = 1 \times 10^{-9}$ m/s, $k_L = 1 \times 10^{-8}$ m/s

GCL: H_L = 0.01 m, $k_L = 5 \times 10^{-11}$ m/s, $k_L = 5 \times 10^{-10}$ m/s

GM: 5 holes/ha, r_o = 5.6mm

Rowe (2012)

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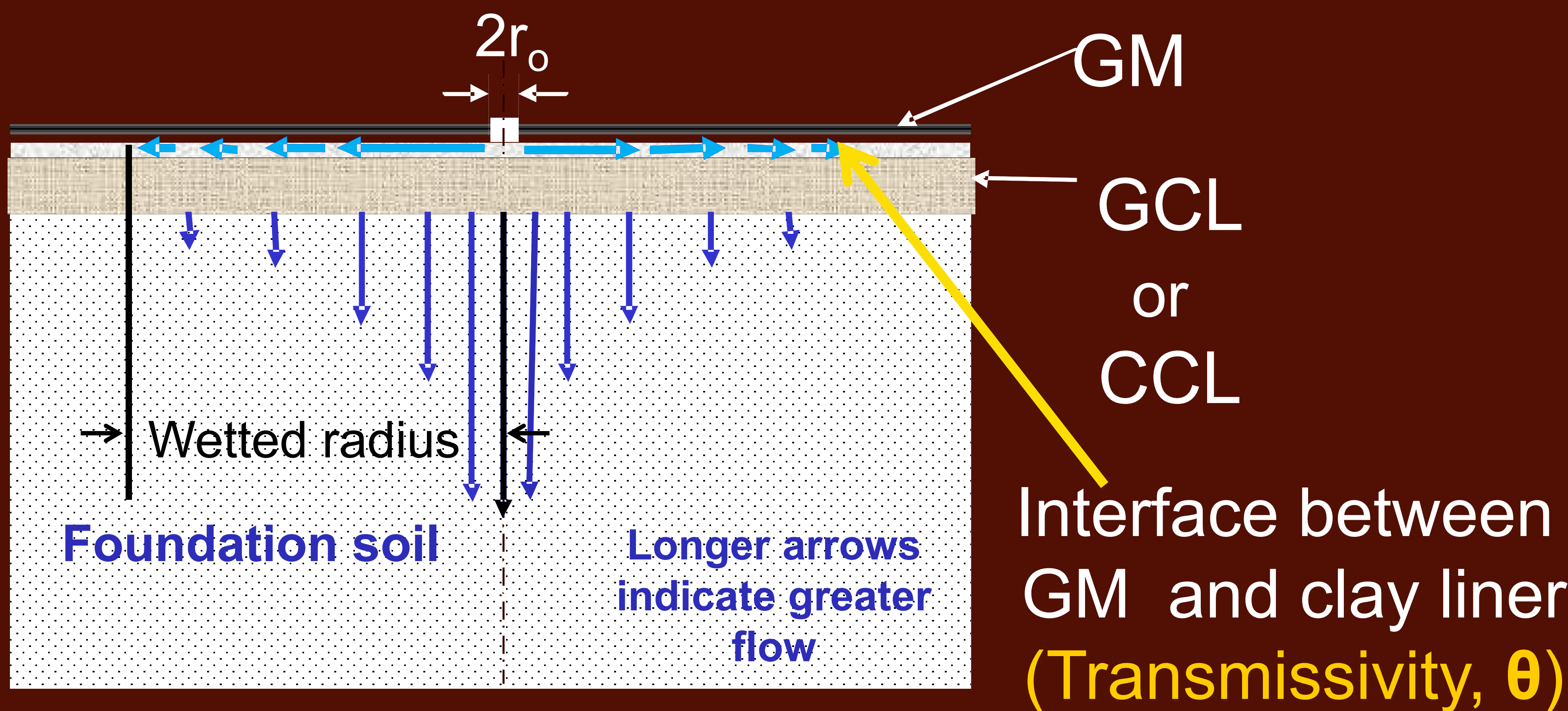
Leakage through GM in Direct Contact with Clay Liner



GM/GCL Interface Transmissivity, θ

- Harpur et al. (1993)

  $2x10^{-10}$ m^2/s (at 7 kPa)

  $2x10^{-12}$ m^2/s (at 70 kPa)

- Barroso et al. (2008, 2010)

  $1\text{-}4x10^{-11}$ m^2/s (at 50 kPa) both smooth and textured GM

All for sodium bentonite – water as permeant

GM/GCL Interface Transmissivity, θ

- Mendes et al. (2010)

  $2\text{-}3\text{x}10^{-11}$ m^2/s (at 50 kPa) Na-Bentonite with

  $k_L = 3\times10^{-11}$ m/s (water)

  $3\text{x}10^{-11}$ m^2/s (at 50 kPa) Ca-Bentonite with

  $k_L = 7\times10^{-10}$ m/s to 6×10^{-8} m/s (water)

- Rowe and Abdelatty (2012)

  $2\text{x}10^{-11}$ m^2/s (at 100 kPa) before clay-leachate interaction (water)

  $k_L = 3\times10^{-11}$ m/s

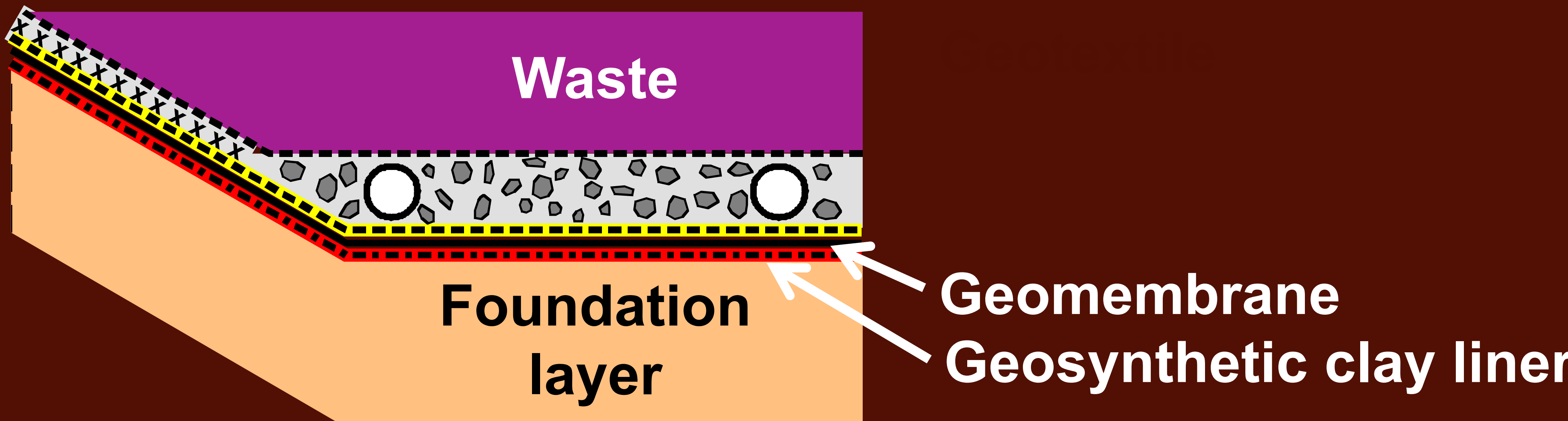
  $1\text{x}10^{-11}$ m^2/s (at 100 kPa) after clay-leachate interaction (leachate)

  $k_L = 4\times10^{-10}$ m/s

Compared to > $2\text{x}10^{-8}$ m^2/s for GM/CCL

Rowe (2012)

Single Composite Liner Systems



GM in Direct Contact with GCL

GM with no wrinkles; cloudy November morning when ambient T = 3 ^{o}C

Calculated Leakage for Direct contact

	GM/GCL	GM
h_w (m)	Q (lphd)	Q (lphd)
0.3	0.2	63,000

GM: 5 holes (r_o = 5.64 mm)/ha

GCL: H_L = 0.01 m, k_L = 2×10^{-8} m/s, θ = 1×10^{-10} m^2/s

Rowe (2012)

Calculated Leakage for Direct contact

	GM/GCL	GM/CCL	GM
h_w (m)	Q (lphd)	Q (lphd)	Q (lphd)
0.3	0.2	3	63,000

GM: 5 holes (r_o = 5.64 mm)/ha

GCL: H_L = 0.01 m, k_L = 2x10^{-8} m/s, θ = 1x10^{-10} m^2/s

CCL: H_L = 0.6 m, k_L = 1x10^{-9} m/s, θ = 2 x10^{-8} m^2/s

Rowe (2012)

Composite Liner Topics

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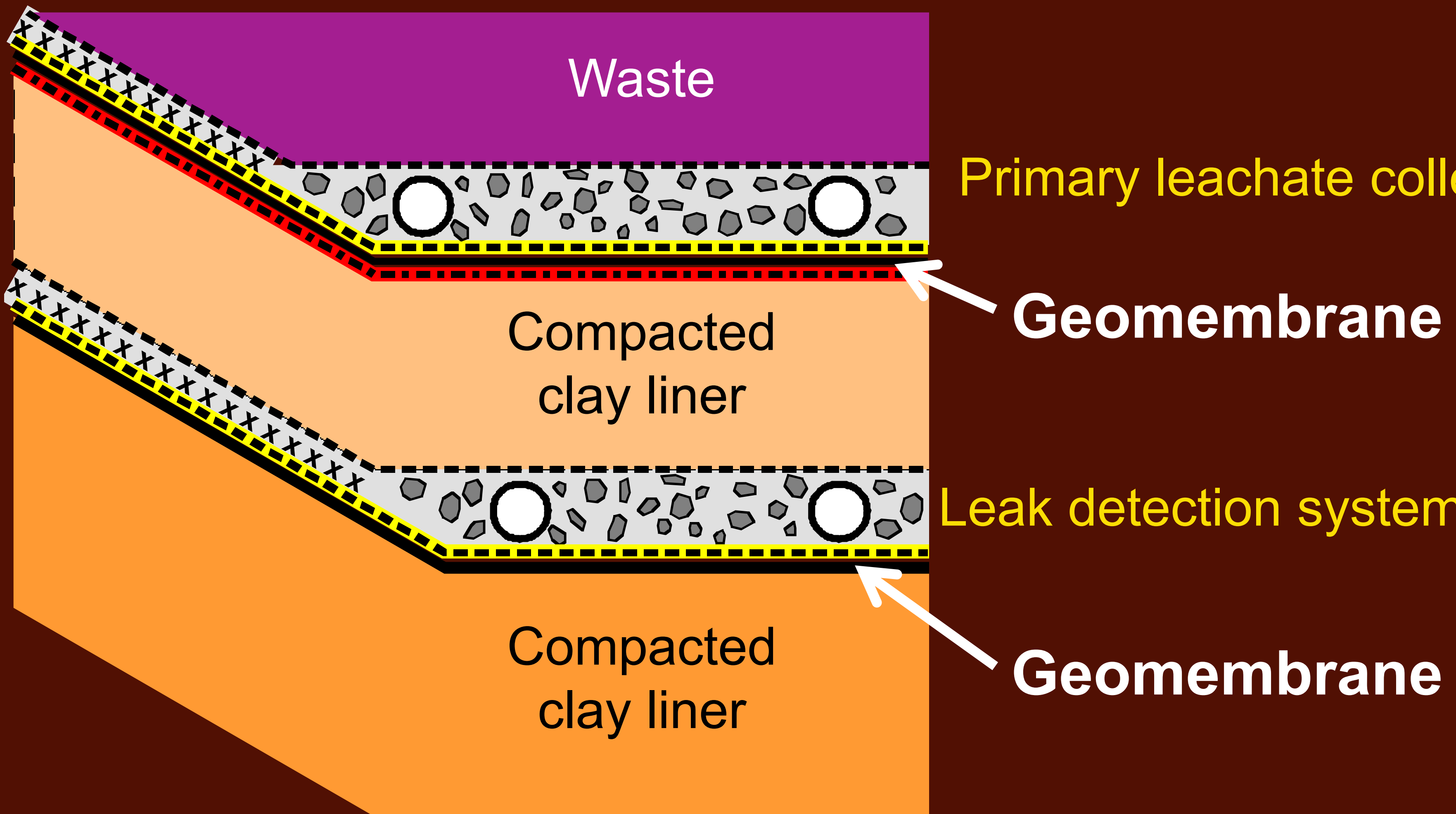
Double Composite Liner System



Observed leakage

		Avg. Monthly flow (lphd)		Peak monthly flow (lphd)	
		Mean (Typical)	Max.	Mean	Max
GM/CCL	Active	90	260	250	1240

Based on data from Bonaparte et al. (2002)

Rowe (2005)

Observed leakage

		Avg. Monthly flow (lphd)		Peak monthly flow (lphd)	
		Mean (Typical)	Max.	Mean	Max
GM/CCL	Active	90	260	250	1240
GM/GCL	Active	1.5	11	9	54

Based on data from Bonaparte et al. (2002)

Rowe (2005)

Observed leakage

		Avg. Monthly flow (lphd)		Peak monthly flow (lphd)	
		Mean (Typical)	Max.	Mean	Max
GM/CCL	Active	90	260	250	1240
	Closure	50	220	60	250
GM/GCL	Active	1.5	11	9	54
	Closure	0.6	2	4	10

Based on data from Bonaparte et al. (2002)

Rowe (2005)

Observed leakage

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Observations

- To minimize leakage you need a composite liner
- Data shows that composite liners with a GCL perform **much** better than a composite with a CCL

BUT

- Observed leakages 10 to 10,000 times larger than calculated using traditional equations assuming direct contact and a reasonable number of holes/ha – **why?**

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Questions?

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