GMB and GCL covers: what practitioners should know about cover durability

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Geosynthetics in Covers

There have been a very large number of successful applications in covers.

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

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 (poor design/construction can lead to failures)

Cover Design Considerations

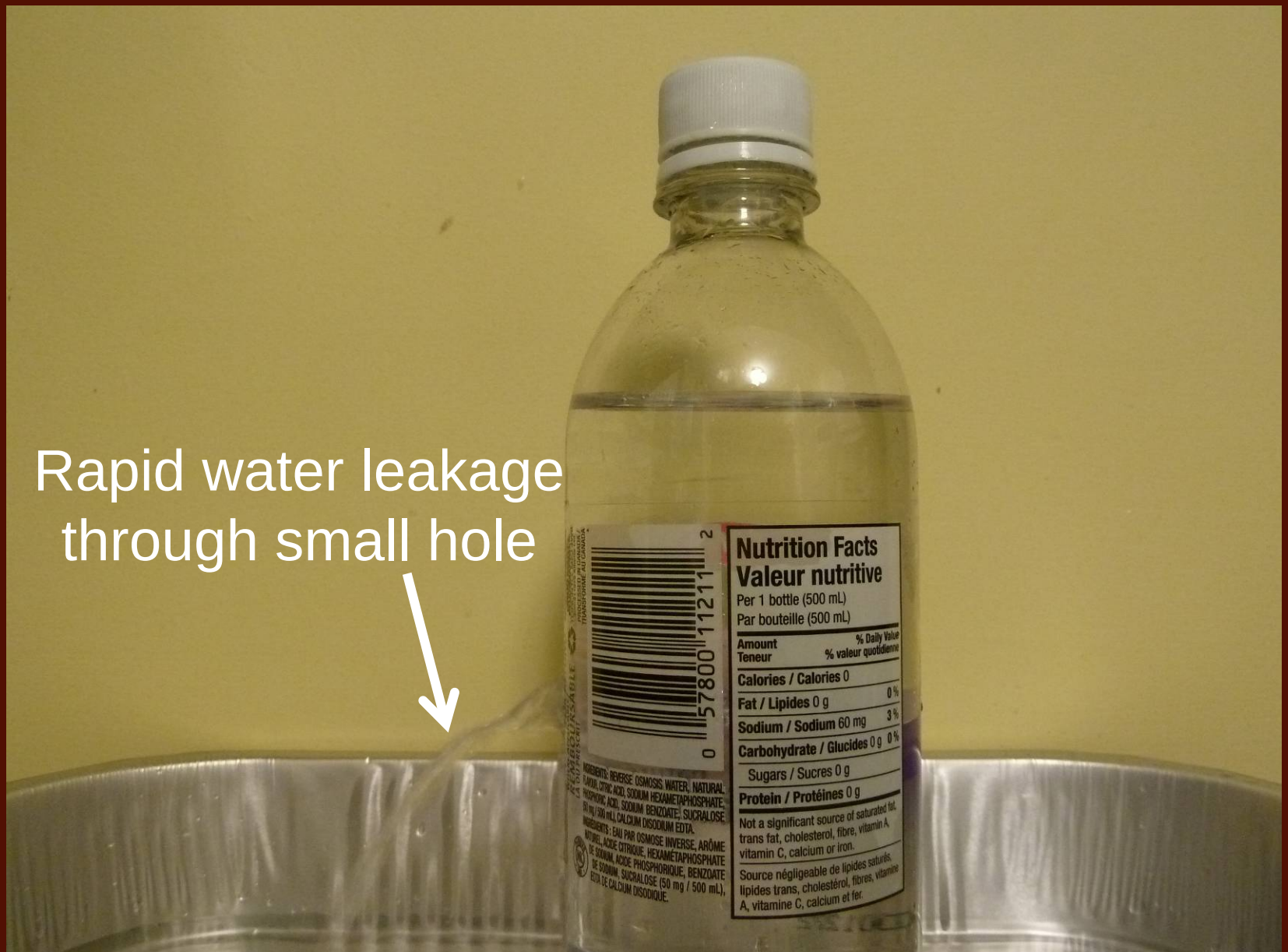
- Effectiveness as a hydraulic barrier
- Effectiveness as (O_2) diffusive barrier
- Stability
  - global
  - cover (including consideration of shear strength and provision of adequate drainage)
- Long-term performance
- Maintenance

Geomembranes

- Are excellent barriers to water and air (oxygen) if there are no holes

Plastics hold water well

Plastics hold water well - if no hole



Geomembranes

- Are excellent barriers to water and air (oxygen) if there are no holes
- Holes in geomembranes occur
  - during construction
  - with placement of cover soil
  - due to post-construction damage
  - with stress cracking (e.g., at end of service life)

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- Holes in geomembranes occur
  - during construction
  - with placement of cover soil
  - due to post-construction damage
  - with stress cracking (e.g., at end of service life)
- Holes in geomembranes can be minimized by
  - good design and construction quality assurance
  - leak detection surveys
  - a suitable soil cover
  - appropriate cover maintenance

Long-term leakage through GMBs

Depends on

- Number and size of holes in GMB

Holes in GMB

- 2.5 – 10 holes/ha typical design value
- 3 holes/ha after installation*
- 12 holes/ha after placement of drainage layer*
- These numbers can be reduced substantially with a leak survey

* Nosko & Touze-Foltz (2000)

Long-term leakage through GMBs

Depends on

- Number and size of holes in GMB
- Exposure of GMB

Exposed GMBs

- Avoid construction holes due to placement of overlying soils
- Are readily subject to damage by humans and animals

- Campers (pitching tents on warm GMB; lighting fires)
- ATVs
- Hunters
- Bushfires
- Deer, bears, rodents, kangaroos, etc.

Exposed GMBs

- Avoid construction holes due to placement of overlying soils
- Are readily subject to damage by humans and animals
- Experience
  - expansion on heating which causes increases wrinkling, and
  - contraction on cooling (potentially introducing tension when temperature drops below installed temperature)

Exposed GMBs

- Are subject to
  - UV exposure, and
  - heating (> 70^{o}C for black; > 40^{o}C for white)

  which eventually degrade the polymer

  but
- Service life may exceed 40 years (and possibly longer) with good stabilizers
- Beware of colours other than black and white

Covered GMBs

- Require considerable care during covering,

BUT, when appropriately covered:

- are largely protected from:
  - human and animal damage
  - the significant thermal cycles experience by exposed GMBs
- have a potentially (with a suitable polymer and additive/stabilizer package) much longer service life than exposed GMBs (discussed more later)

Long-term leakage through GMBs

Depends on

- Number and size of holes in GMB
- Exposure of GMB
- Nature of material
  - above, and
  - below

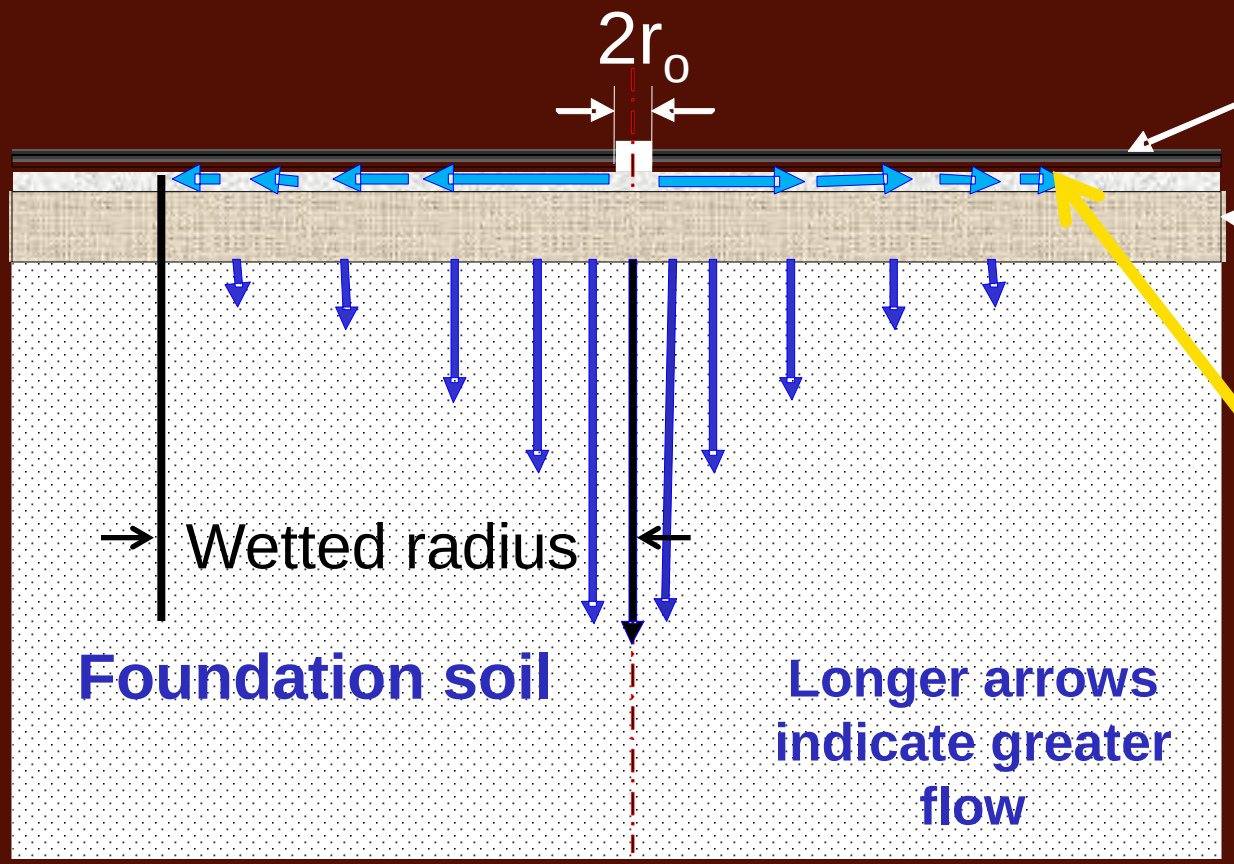
  the GMB

Findings from field monitoring

- Leakage with composite liners much less than with a single geomembrane
- Composite liners with a GCL perform 10 to 100 times better than a composite with a CCL

– **why?**

Leakage through GMB in Direct Contact with Clay Liner



GMB

GCL or CCL

Interface between GMB and clay liner (Transmissivity, **θ**)

GMB/GCL Interface Transmissivity, θ

Typically for water as permeant, needle-punched GCLs (no coating) have

- GMB/GCL $\theta \sim 2 \times 10^{-11}$ m^2/s

Compared to

- GMB/CCL $\theta > 2 \times 10^{-8}$ m^2/s

GMB/CCL interface is about 1000 times more transmissive than GMB/CCL

Rowe (2012)

Long-term leakage through GMBs

Depends on

- Number and size of holes in GMB
- Exposure of GMB
- Nature of material
  - above, and
  - below

  GMB
- How the GMB is placed (wrinkles)

Findings from field monitoring

- Leakage with composite liners much less than with a single geomembrane
- Composite liners with a GCL perform 10 to 100 times 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?**

GMB in Direct Contact with GCL

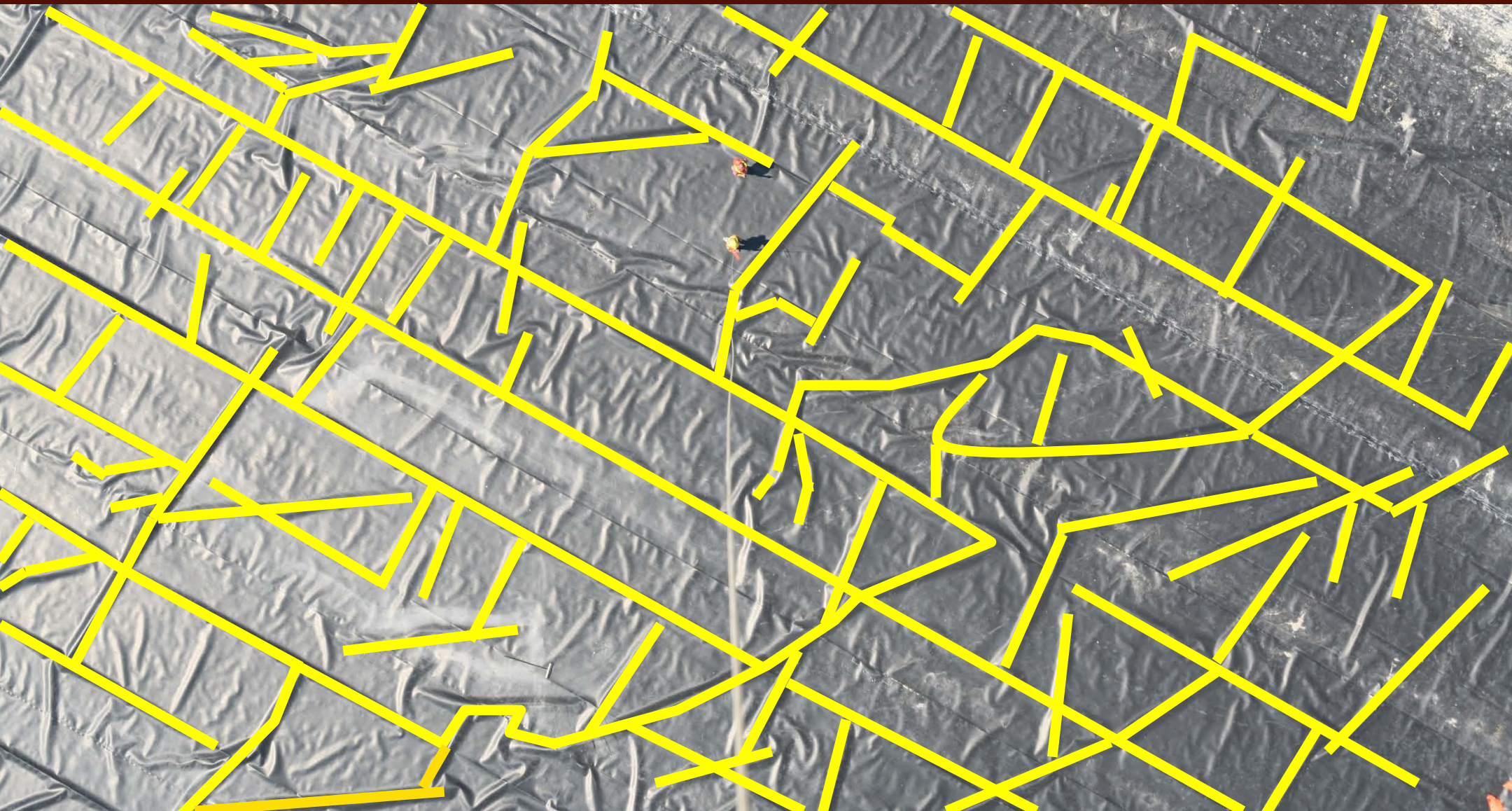
GMB with no wrinkles; cloudy November morning when ambient T = 3 ^{o}C

GMB Wrinkles

GMB with wrinkles; midmorning when ambient T = 17 ^{o}C (same location, QUELTS, as shown in earlier slide)

Rowe et al. (2012)

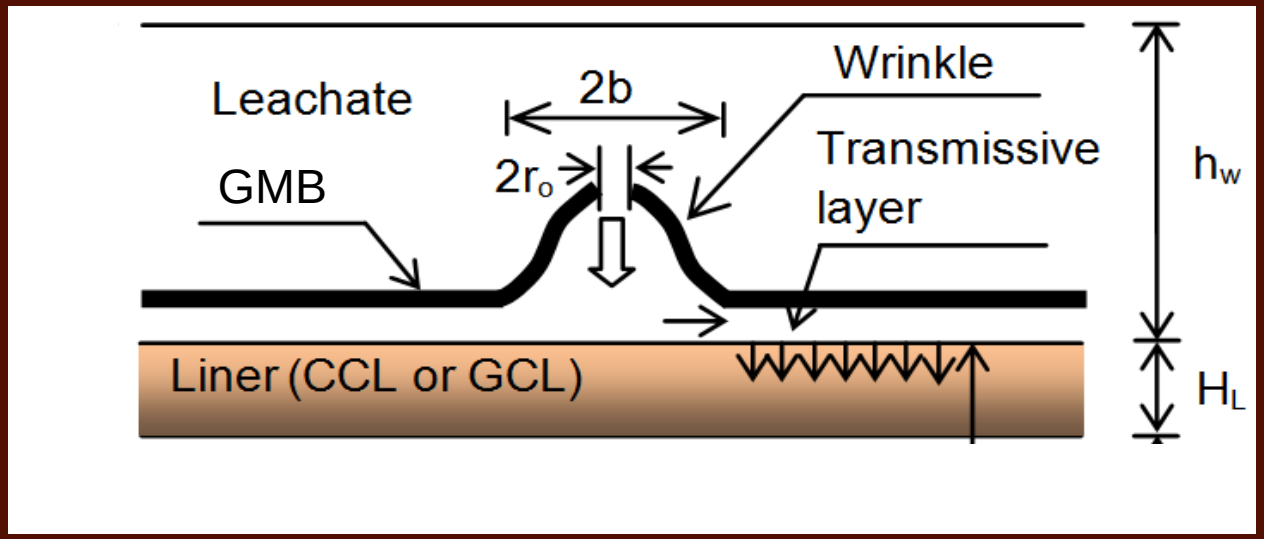
Note Extent and Interconnectedness of Wrinkles



Leakage Calculations

Rowe (1998) equation:

$$Q = L\,[k_s\,2b + 2(k_s\,H_L\,\theta)^{0.5}]\,h_d / H_L$$



Q: flow through GMB

L: wrinkle length

k_s: hydraulic conductivity of liner

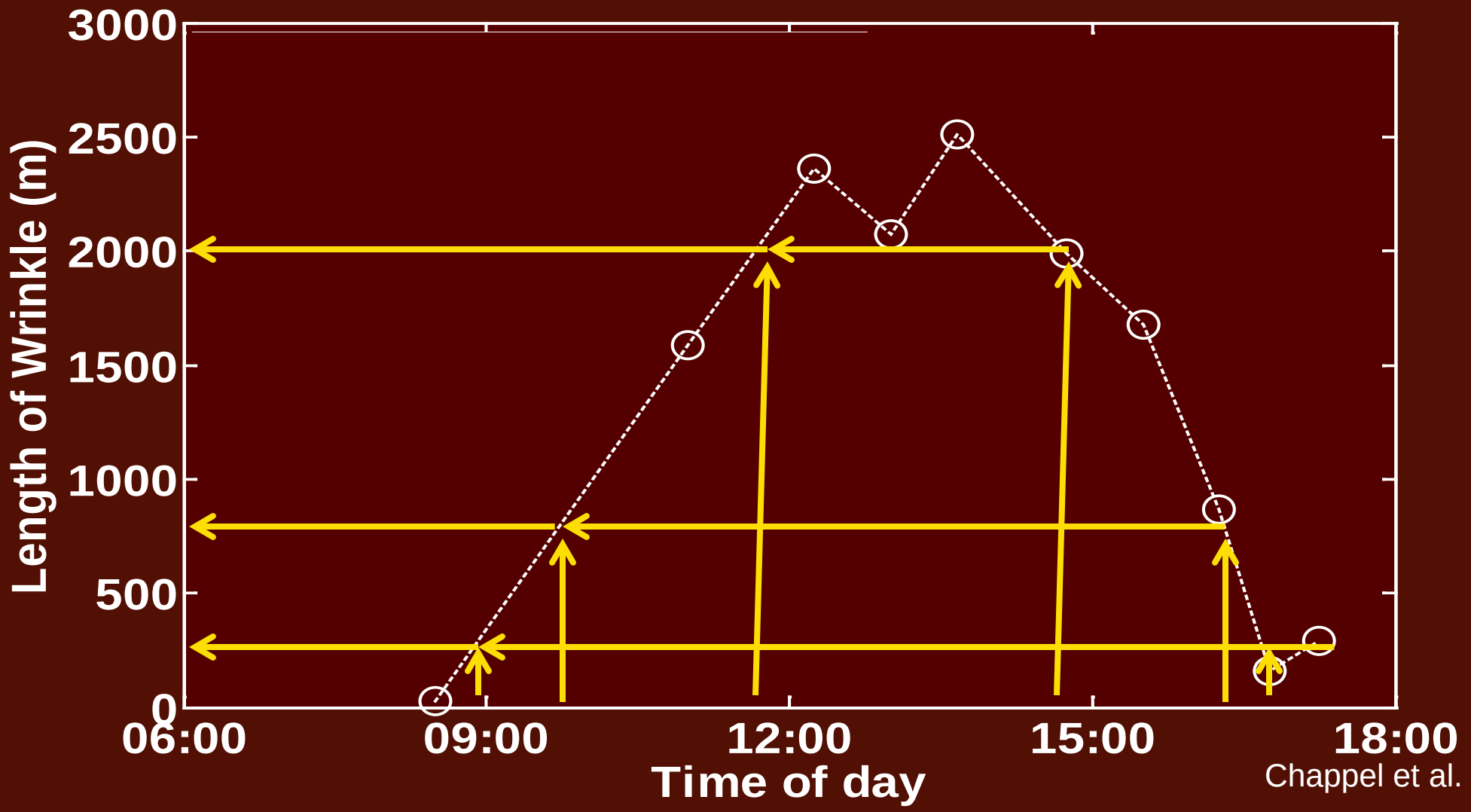
2b: width of wrinkle

H_L: Liner thickness

θ: transmissivity between GMB and clay liner

h_d: Head loss ($h_d = h_w + H_L$)

Change in connected wrinkle length with time



Chappel et al. (2012)

Black HDPE Wrinkle Summary

- Wrinkling related to solar radiation and GMB temperature (may be 20-40^{o}C > ambient)
- Typical wrinkle width about 0.2 - 0.3 m
- Typical wrinkle height about 0.06m (but some may exceed 0.2m)
- Wrinkles could range from a few % to more than 30% depending on time GMB is covered

White HDPE Wrinkle Summary

- White GMBs may 20^{o}C cooler than black on a sunny day
- Wrinkles do develop in a white GMB but much more slowly than on black
- At any given time on a sunny day there will be fewer/smaller wrinkles for white than black
- White gives a wider range of times when GMB can be covered with an acceptably small number of wrinkles

Long-term leakage through GMBs

Depends on

- Number and size of holes in GMB
- Exposure of GMB
- Nature of material
  - above, and
  - below

  GMB
- How the GMB is placed (wrinkles)
- Type of GMB used (e.g., polymer and antioxidant/stabilizer package)

Geomembranes: not all the same

- Different polymers (e.g., PVC, Polyethylene)
- Even polyethylene can vary:
  - High density (HDPE), and
  - Linear low density polyethylene (LLDPE)
  - Blends of polyolefin (e.g., HDPE & LLDPE)

  are most common in civil engineering applications

Geomembranes: not all the same

	LLDPE	HDPE
Polymer Structure	• **significant numbers of short chain branches** • **94-96% PE resin** • **2-3% carbon black** • **0.25-3% antioxidants**	• **fewer chain branches than LLDPE** • **96-98% PE resin** • **2-3% carbon black** • **0.25-1% antioxidants**

- Carbon black is help provide protection against UV
- Antioxidants/stabilizers protect against oxidation and UV (discussed later)

Geomembranes: not all the same

	LLDPE	HDPE
Polymer Structure	• significant numbers of short chain branches • 94-96% PE resin • 2-3% carbon black • 0.25-3% antioxidants	• fewer chain branches than LLDPE • 96-98% PE resin • 2-3% carbon black • 0.25-1% antioxidants
Density	**0.915-0.939 g/cm^3**	**0.941-0.959 g/cm^3**

- Despite “HDPE” name, since mid 1990’s most GMBs used in civil engineering are actually made with MDPE resin to increase stress crack resistance (can be a problem with real HDPE resin) and GMB density (resin + carbon black) is at low end of “HDPE” range.
- The wide range of densities for LLDPE means that there could be a wide range of performance depending on specific resin used

Geomembranes: not all the same

- LLDPE:
  - higher flexibility (than HDPE) is better suited to handling significant settlement;
  - may have better large scale puncture resistance;
  - less prone to stress cracking than HDPE;
  - may be more prone to chemical attack than HDPE (but depends on resin and antioxidant package);
  - mechanical properties may be degraded by texturing;
  - can be welded like HDPE but may be more difficult to repair.

Properties of some HDPE GMBs

	Thick-ness (mm)	Depends on: Antioxidant package Std-OIT (min)	HP-OIT (min)	Resin Stress crack resistance (hrs)
MyA	2	135	380	5200
MyB	1.5	135	660	3700
MyC	1.5	175	900	1000
MxA	1.5	135	245	720
MxC	1.5	160	960	800

OIT values rounded to nearest 5 mins., SCR to nearest 2 significant digits

Service Life of Covered GMBs

when appropriately designed, covered 1.5-mm-thick HDPE

- has a potentially much longer service life than exposed GMBs (> 300 years with a suitable polymer and additive/ stabilizer package)

- Most data and research is for HDPE (although with a very good antioxidant/stabilizer package LLDPE and blended PE polymers may also perform very well).

Upper Geotextile

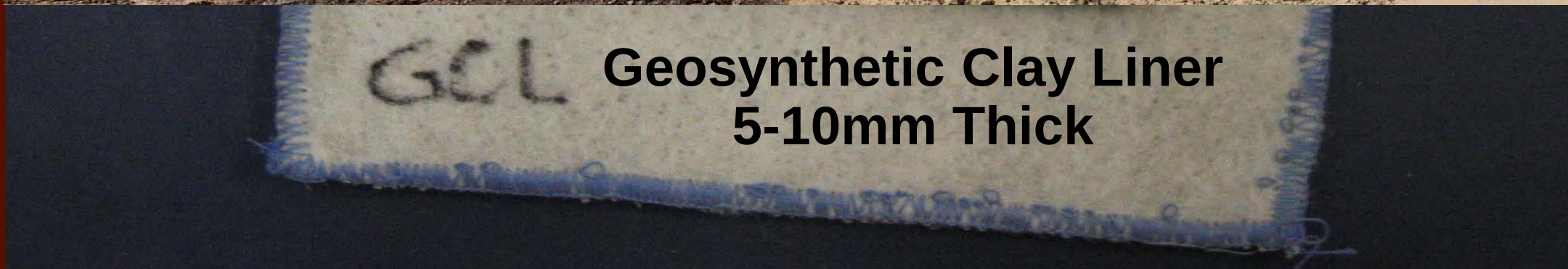
Needle Punched Fibres Throughout

Lower Geotextile

Needle Punched Clay Through Upper and Lower Geotextiles

Geosynthetic Clay Liner
5-10mm Thick


GCL used alone (with cover soil)
Photo: B. Herlin
GCL


GCL
Geosynthetic Clay Liner
5-10mm Thick

or
as part of a
Composite Liner
GMB+GCL

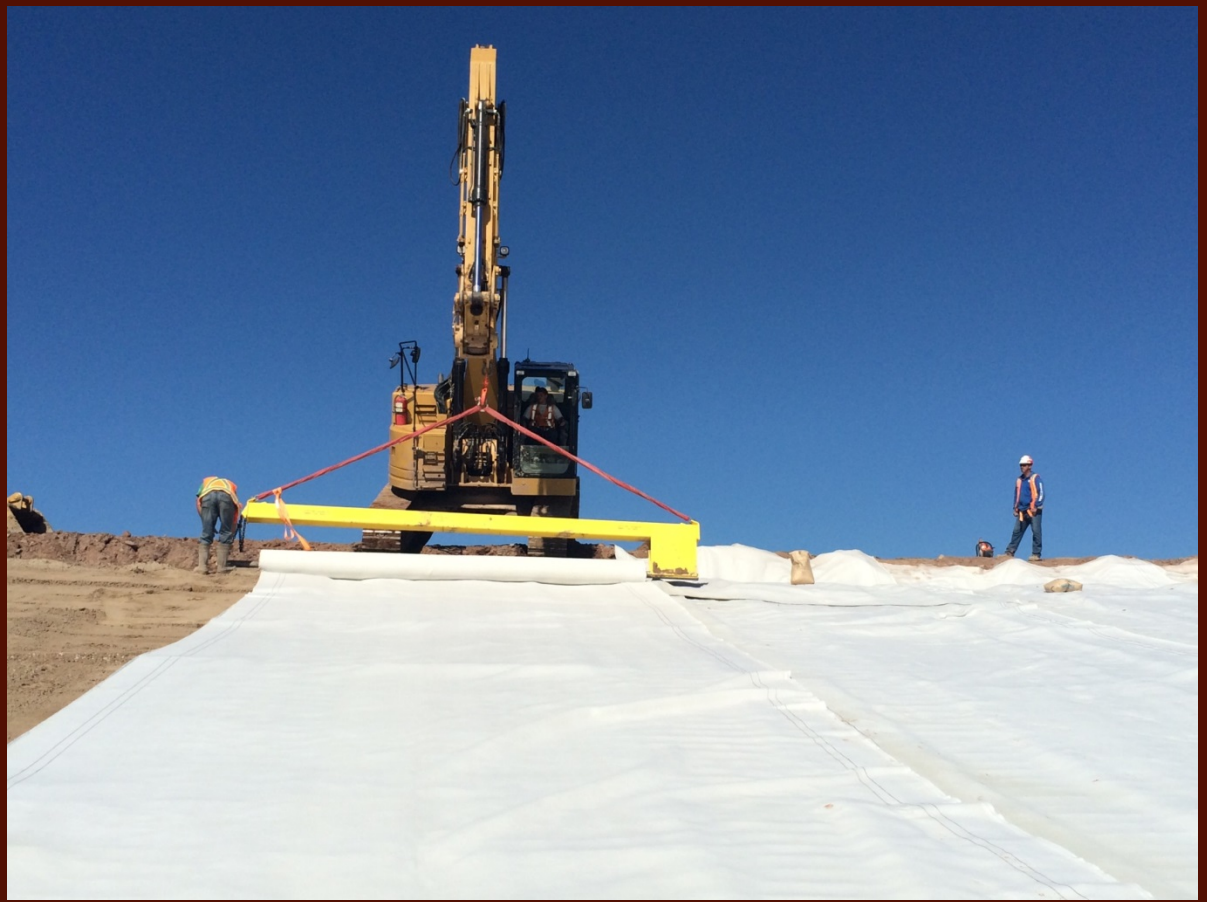
GMB **Geomembrane Liner**

GCL

Geosynthetic Clay Liner
5-10mm Thick

Geosynthetic Clay liners (GCLs)

- With proper design, GCL selection (they are not all the same), and installation GCLs can be very good hydraulic and oxygen diffusion barriers



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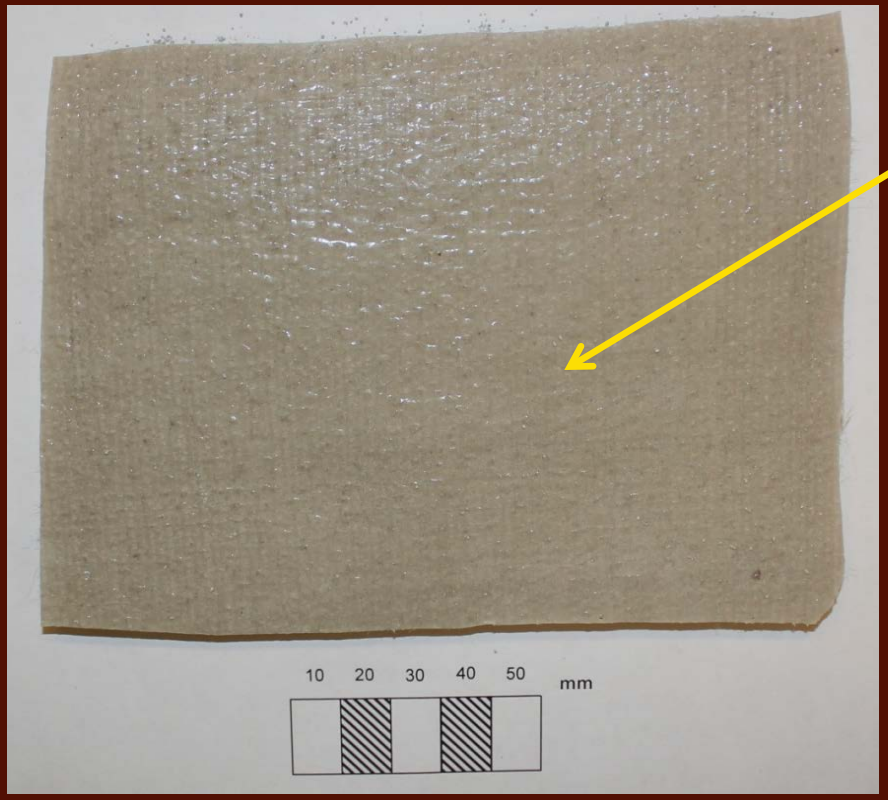
- In critical situations they are best used as part of a composite liner
- Some GCLs come with a polymer coating which substantially enhances performance but is not a full composite liner

GCL with polyolefin coating



Polyolefin coated carrier GTX

Coating thickness may vary from 0.1 to 1mm

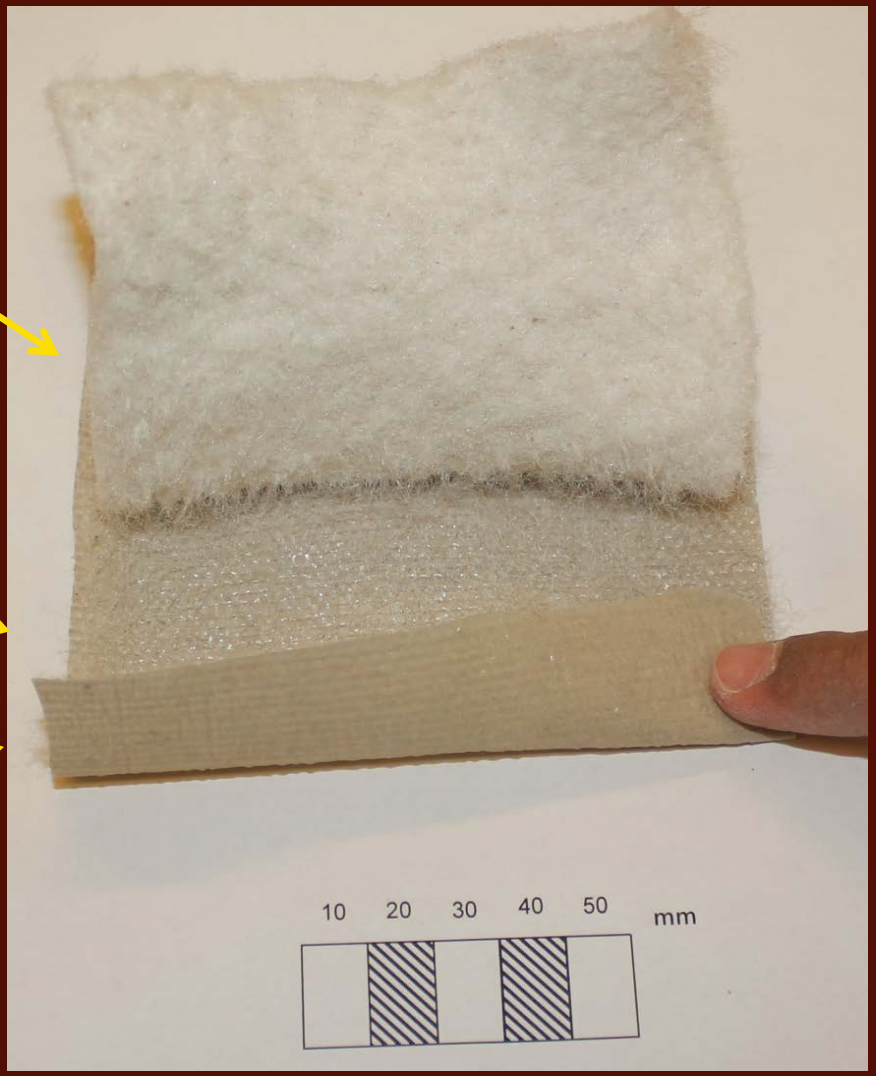
GCL – PLAN VIEW – carrier GTX

GCL with polyolefin coating

Nonwoven cover GTX

Woven carrier GTX

Polyolefin coating



GTX of GCL - Bentonite removed

GCL with polyolefin coating

Other polyolefin coated **GCLs include those with scrim reinforced nonwoven**

Some GCL Characteristics

- GCLs can be a very cost-effective and technically superior alternative to compacted clay
- GCL's uptake of water from an adjacent soil can be significant and is needed for best performance
- New GCLs:
  - have low hydraulic conductivity to water and low O_2 diffusion coefficient at degree of saturation, $S_r > 80\%$
  - self-healing for small holes

BUT what affects the long-term performance?

Degree of saturation of GCLs

Is 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.

Thus, to perform well in a cover, GCLs need

- to be able to hydrate to S_r > 80% from adjacent soil
- remain hydrated (especially to be a good O_2 barrier); i.e., avoid wet-dry cycles

GCLs in covers

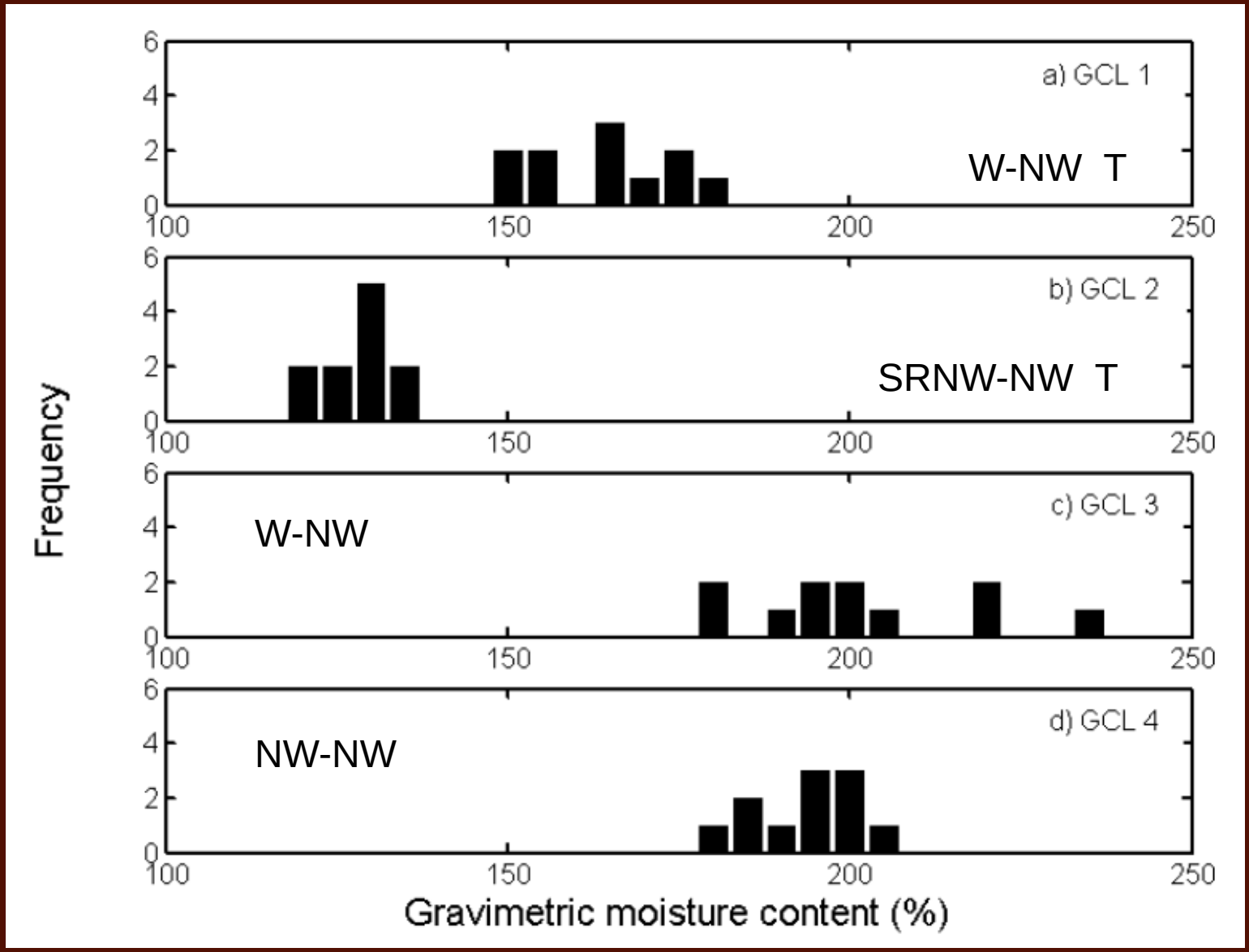
- A number of publications* examining GCLs after 3-10 years use in landfill covers have indicated:
  - a decrease in swelling capacity (SI)
  - an increase in hydraulic conductivity of SOME GCLs by as much as 5 orders of magnitude (to 10^{-6} m/s) – others had no significant change in k
  - high hydraulic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

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

What influences Degree of Saturation

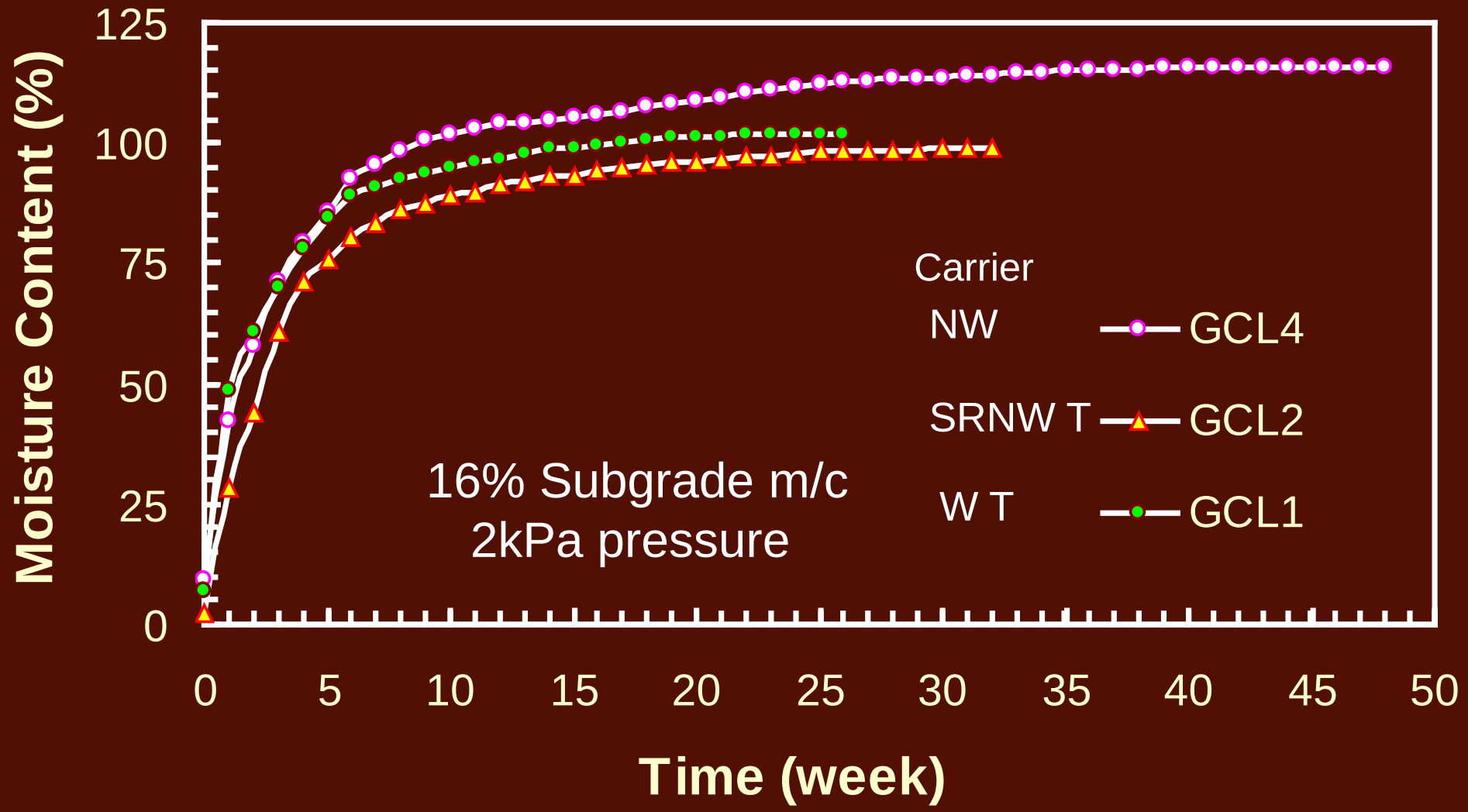
- How the GCL is manufactured (they are not all the same - even if they use the same bentonite)

Fully Hydrated GCLs (low stress)



Beddoe et al. (2011)

Effect of GCL Type



Rayhani et al. (2011)

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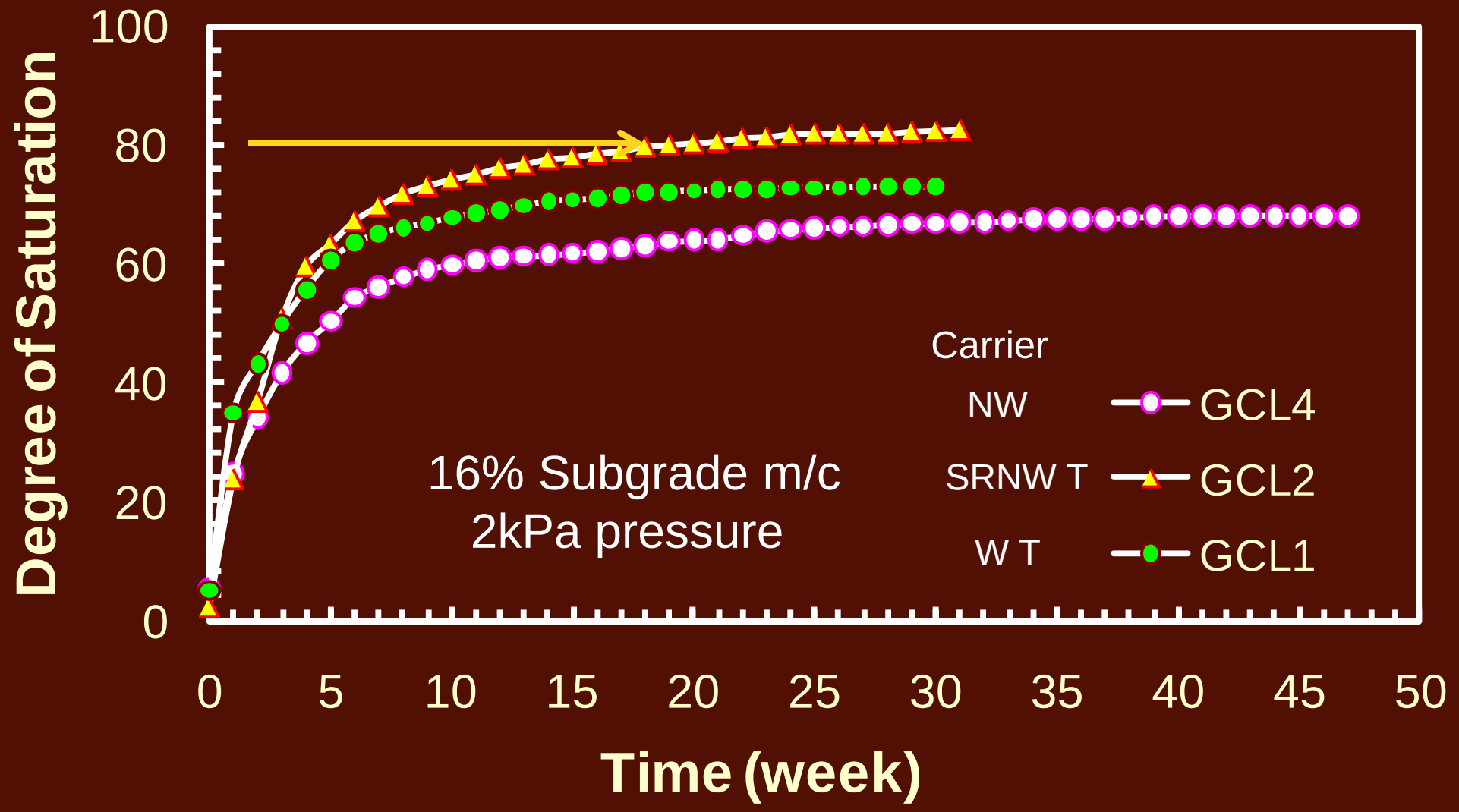

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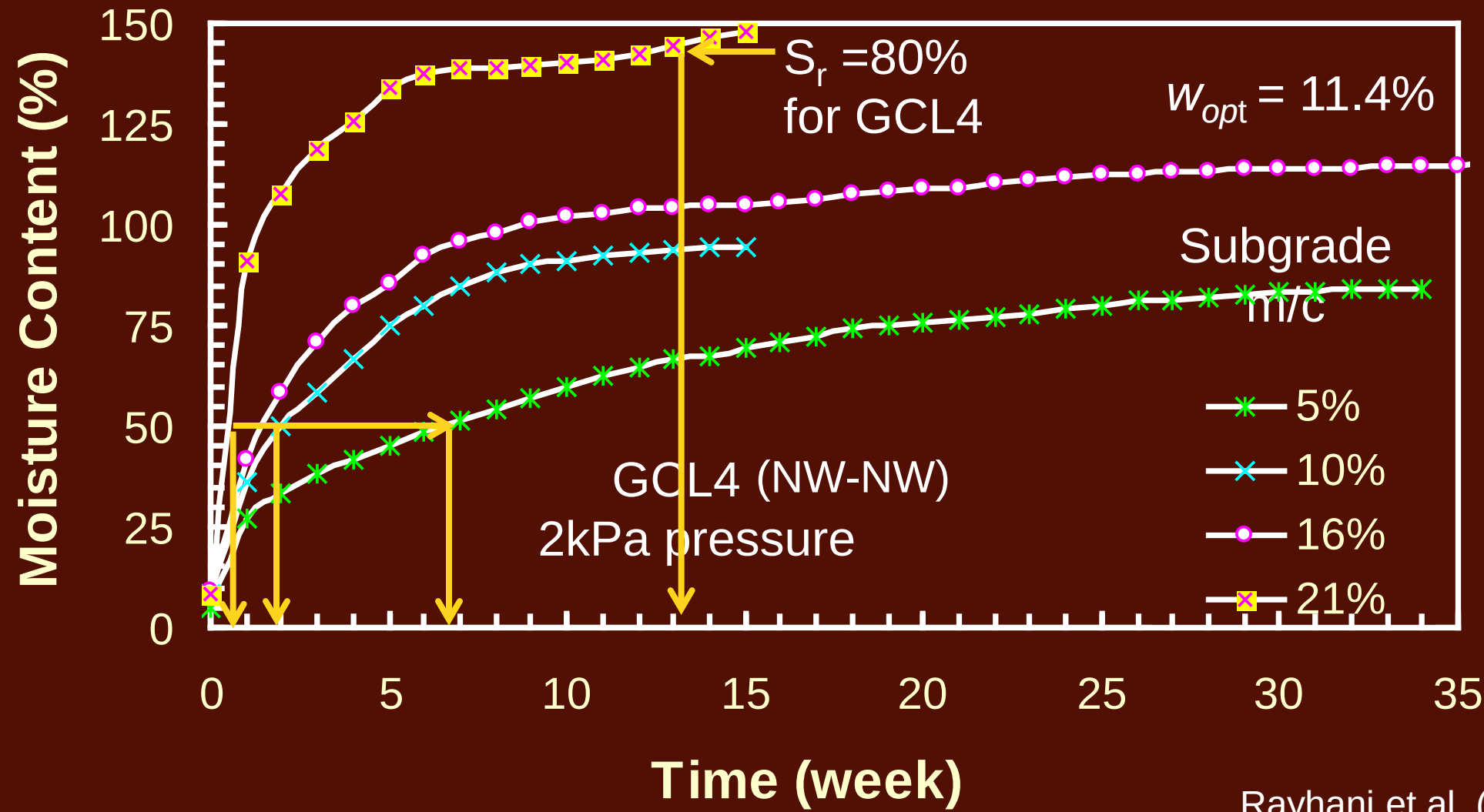
What influences Degree of Saturation

- 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

Effect of Subgrade Moisture Content



Rayhani et al. (2011)

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
- Drying cycles
- Normal stress on GCL

Both depend on the thickness of cover soil

Cover soil

- GMBs and GCLs will give best long term performance with adequate cover soil above them
- Adequate cover soil provides
  - protection from physical damage (human, animal, fires (within reason) etc.)
  - protection of GCL (or CCL) from wet-dry cycles
  - stress (which improves GCL performance)
- BUT, what is adequate depends on site location and conditions

Common causes of cover problems

include failure to:

- provided adequate thickness of cover soil above the low permeability liner
- consider interface strength at the various interfaces in the cover system
- evaluate which interface has lowest peak interface strength
- adequately consider effects of flow and pore pressures above the liner on stability

Geosynthetics in Covers

Can give excellent long-term performance,
BUT
the cover needs to be designed with

- appropriate geosynthetic materials, and
- an adequate overlying soil cover

To be continued ….

After the break – Episode II:

GMB and GCL covers: construction, maintenance, monitoring, repair and replacement

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