ESTIMATING LEAKAGE RATES THROUGH BARRIER SYSTEMS

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Keep in Mind…

There are known knowns. These are things we know that we know.

There are known unknowns. That is to say, there are things that we know we don't know.

But there are also unknown unknowns. There are things we don't know we don't know.

Donald Rumsfeld

What is liner leakage?

- Flow that occurs through a lining system.
- No leakage is a great objective, but is not usually realistically achievable.

Why are leakage rates important?

Leakage rates are:

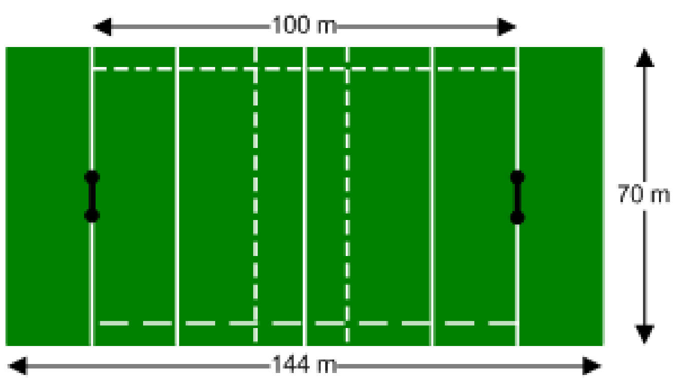
- Used in groundwater models undertaken for risk assessments/ analyses to determine possible and likely impacts from new facilities.
- Used in groundwater models to determine likely impact of possible mitigation measures for existing and for new facilities.
- Used to design drainage elements.

Monitoring and interpreting leakage rates can indicate when a problem has occurred and this can be mitigated before it impacts the environment significantly.

Grasping Leakage Rates

How big is a hectare?

Rugby (International size: 1.008 ha)



How much does a bucket hold?

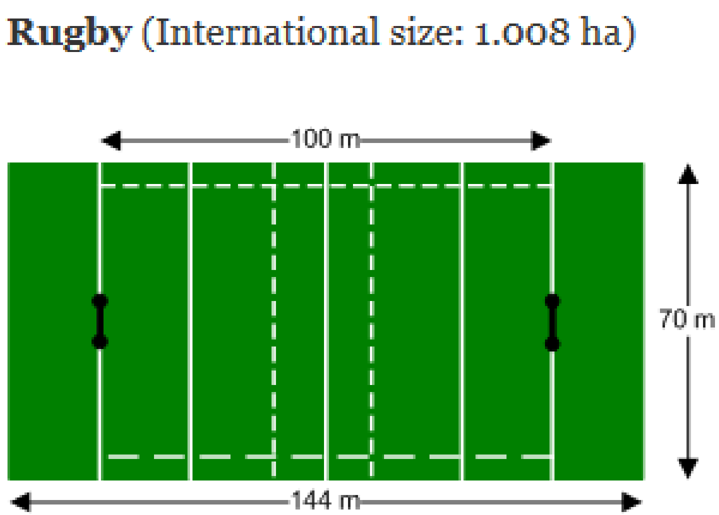
10 litres

Leakage rate of 10 litres per hectare per day is equivalent to emptying a bucket of ~~water~~ contaminated liquids over a rugby field every 24 hours.

Grasping Leakage Rates

How big is a hectare?

How many litres does a bath hold?

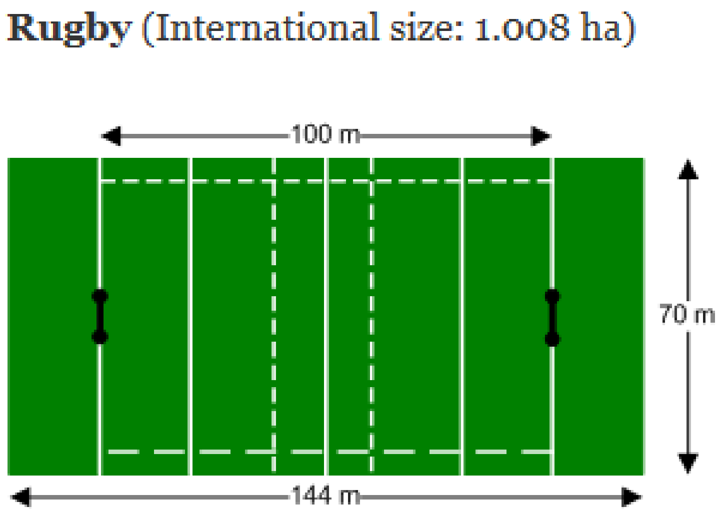


Leakage rate of 150 litres per hectare per day is equivalent to emptying a bath full of ~~water~~ contaminated liquids over a rugby field every 24 hours.

Grasping Leakage Rates

How big is a hectare?

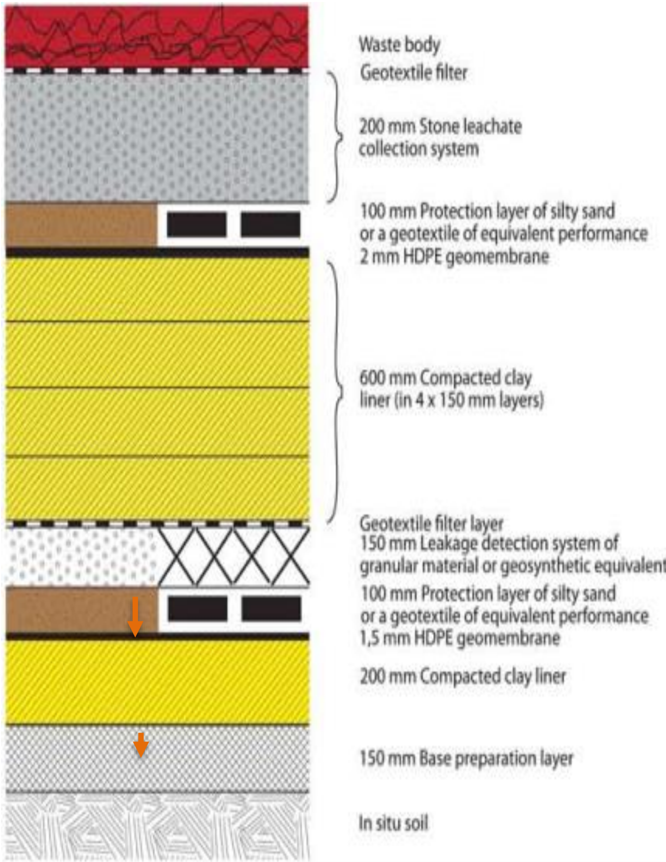
How many litres does a big pool hold?



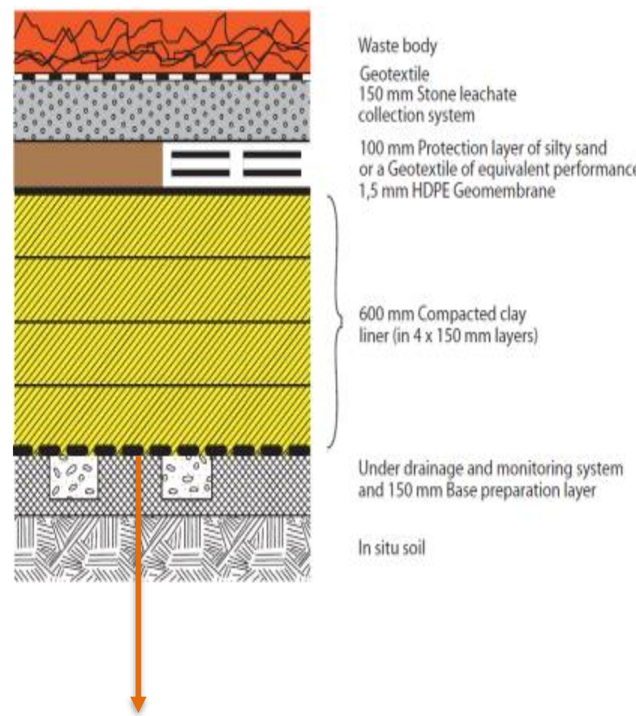
Leakage rate of 100 000 litres per hectare per day is equivalent to emptying a big pool full of ~~water~~ contaminated liquids over a rugby field every 24 hours.

Barrier Systems: Norms and Standards (2013)

Class A landfill for disposal of Type 1 Wastes



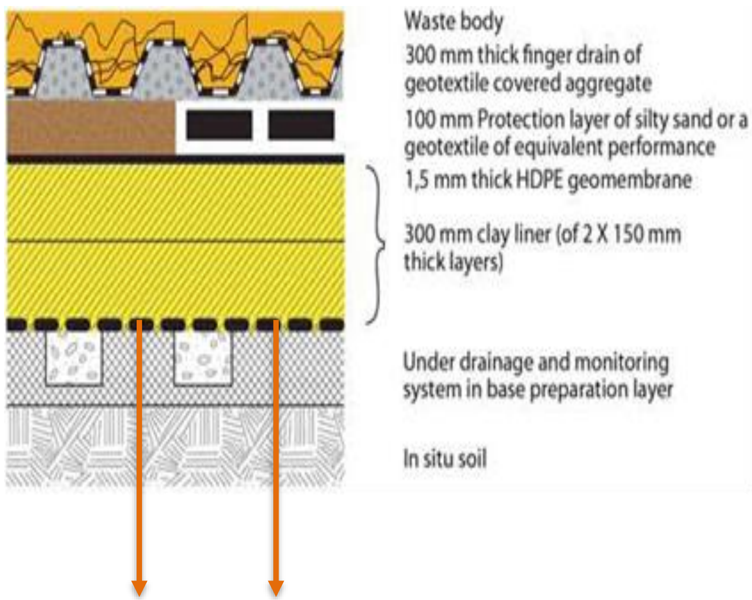
Class B landfill for disposal of Type 2 Wastes



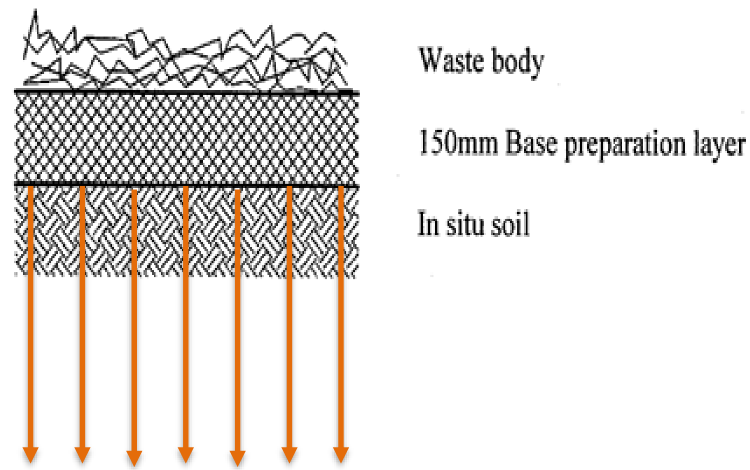
Department of Environmental Affairs, 2013. National Norms and Standards for Disposal of Waste to Landfill, No. R. 636, Government Gazette No. 36784.

Barrier Systems: Norms and Standards (2013)

Class C landfill for disposal of Type 3 Wastes



Class D landfill for disposal of Type 4 Wastes



Department of Environmental Affairs, 2013. National Norms and Standards for Disposal of Waste to Landfill, No. R. 636, Government Gazette No. 36784.

HOW NOT TO ESTIMATE LEAKAGE RATES

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1. Obtain facility information

2. Undertake minimal liner design

3A. Calculate likely range of leakage for minimum liner design from old literature, don't consider chemical compatibility, assume materials, construction etc will be ideal etc

3B. OR Pull out some composite liner leakage rates from overseas literature, where design and CQA requirements are strict

4. Use the low leakage rates chosen in the *RISK ANALYSIS* without stating assumptions

5. Get approval and file it

6. Don't include assumptions made regarding materials, construction, protection, operation and rehabilitation into subsequent documentation (design, tenders, construction quality plans, operating manuals etc)

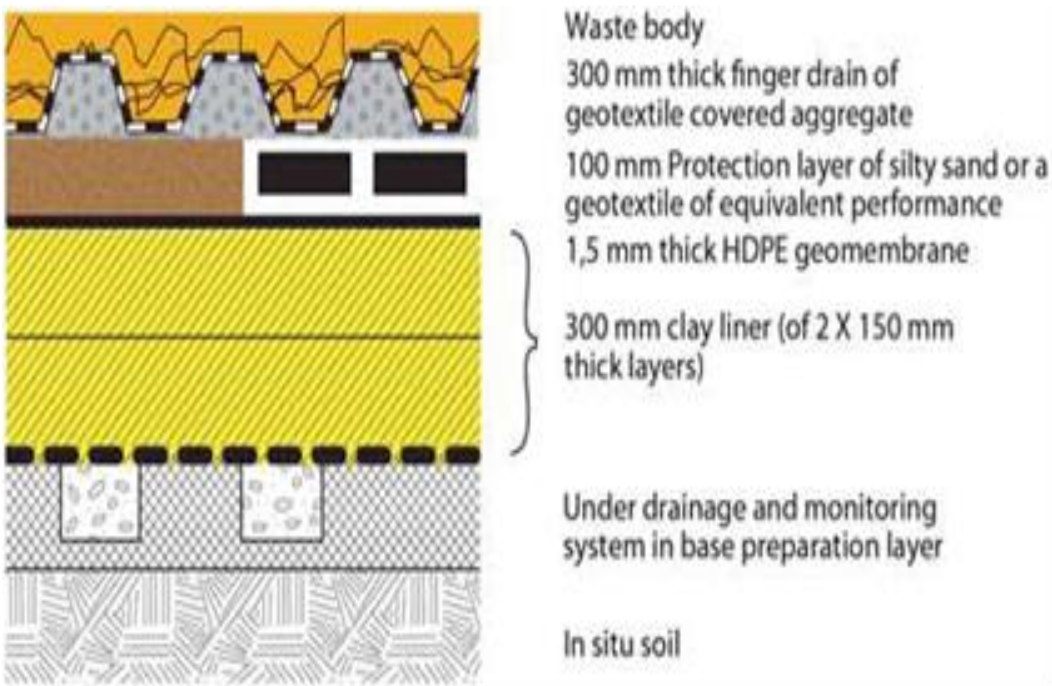
7. Don't appoint specialists to construct liners

8. Don't undertake construction quality assurance

9. Don't monitor leakage rates nor compare with assumptions used in *RISK ANALYSIS*

Theoretical Example 1

- Large, wet tailings facility proposed.
- Assume a Class C liner from the National Norms and Standards:



Theoretical Example 1

- That's a composite liner, and we'll get good contact between the geomembrane and the clay, with maybe only a few small holes, and our finger drains will keep the liquid height on top of the liner at not more than 300mm, right?
- Pull leakage rates from Giroud (1989):

Table 1 - 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	0.01	1	10	300
	Small Holes*	300	1,000	3,000	10,000
	Large Holes*	10,000	30,000	100,000	300,000
Composite liner (poor field conditions, i.e., waves)	Diffusion	0.01	1	100	300
	Small Holes*	0.8	6	50	400
	Large Holes*	1	7	60	500
Composite liner (good field conditions, i.e., flat)	Diffusion	0.01	1	100	300
	Small Holes*	0.15	1	9	75
	Large Holes*	0.2	1.5	11	85
		Values of leakage rate are in lphd (values can be divided by approximately 10 to obtain values expressed in gpad)			

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

Theoretical Example 1 continued

- Use a leakage rate of 2 l/ha/day into your risk analysis for the whole facility, pollution control dam included.
- Risk analysis shows no significant impacts.
- Great! Recommend Class C liner.

BUT:

- The literature you've used is from 1989, and parts have been superceded.
- You haven't checked the assumptions made in the 1989 paper. (USA typically requires clay liners of 1m thick, constructed in layers with permeability of minimum 1 x 10^{-7}cm/s, and construction quality assurance (CQA) on site, and chemical compatibility testing, etc etc).

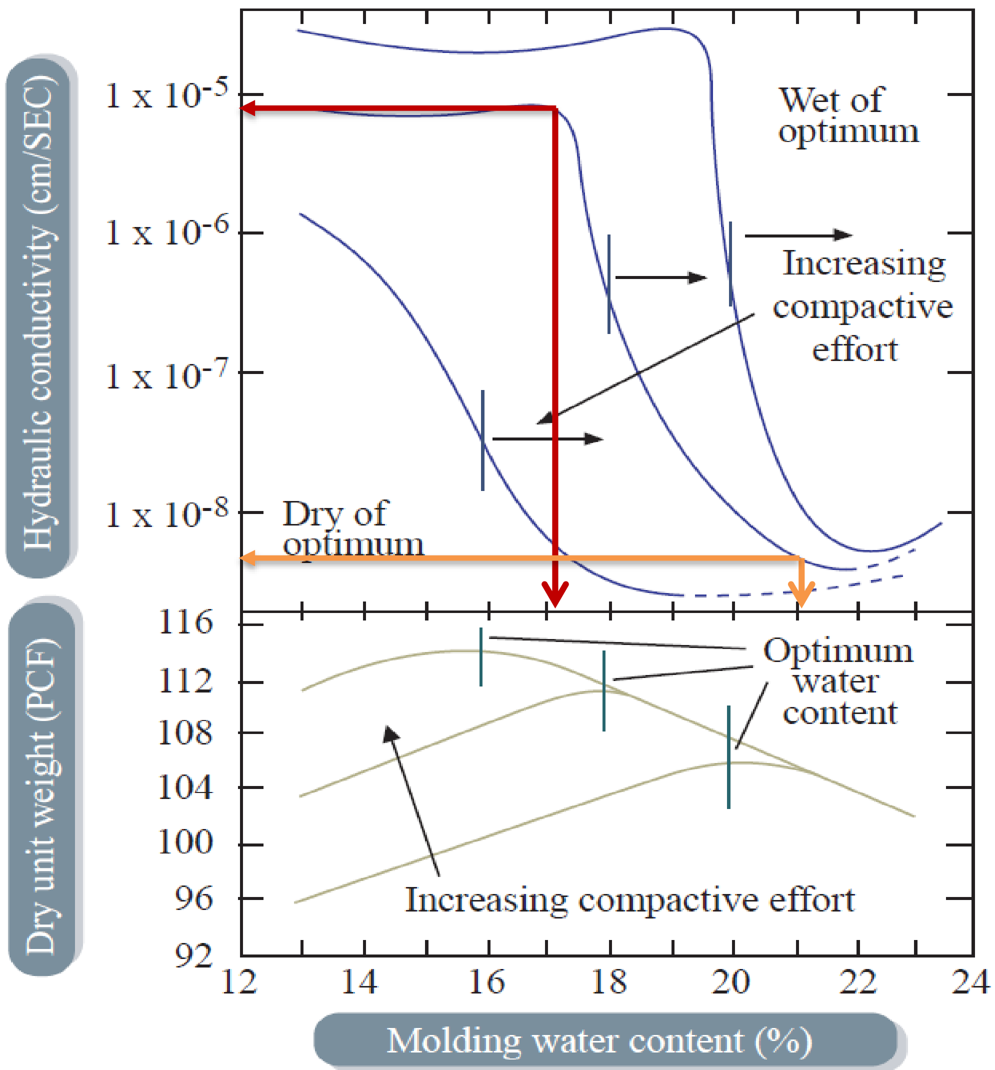
Theoretical Example 1 continued

AND:

You haven't taken into account that the Class C liner design is for a waste site generally with limited liquid input and output, and finger drains are not likely to drain wet tailings sufficiently, plus you have a pollution control dam with a much higher liquid head.

THEN:

The Contractor doesn't really understand the objectives. He messes up the selection from borrow, doesn't control moisture content of the clay liner, builds 1 x 300mm layer instead of 2 x 150mm layers, and only uses a smooth roller for compaction. The "clay liner" contains large particles that can damage the overlying geomembrane.



Effect of molding water content and compactive energy on hydraulic conductivity.

Adapted from: Daniel, D. E. "Clay Liners." *Geotechnical Practice for Waste Disposal*. Edited by D. E. Daniel. New York: Chapman & Hall, 1993, pp. 137-163.

A difference of <8% moisture content of this soil at the time of compaction makes a difference of 1000 times to its permeability/ hydraulic conductivity using standard Proctor compaction.

<u>So if compacted too dry, the soil liner could let 1000 times more seepage through than if its minimum permeability was achieved</u>.

Theoretical Example 1 continued

AND:

- There isn't quality control or assurance on placement of the geomembrane, it's from a dodgy supplier, and is full of tiny pinholes and sub-standard welds.
- There is no wrinkle control on site, and the geomembrane is really wrinkled when it's time to cover it. Black plastic in Africa?
- It's really hard putting a 100mm sand layer over a geomembrane! No-one is checking that the sand doesn't contain large particles that could damage the geomembrane, big trucks and plant are used, and these nick the top of the geomembrane wrinkles.

Liner wrinkling

Fig. 11. Photograph of wrinkles at QUELTS (same bottom liner as shown in Fig. 8) on 23 March 2007 when ambient temperature was 9 °C. Note longitudinal wrinkles at 3.3 m spacing are beginning to form. White patches are what remain of a sprinkling of snow on liner from the previous night. Water puddles from melting snow are constrained from flowing off the base (slope 3% from left to right — north to south) by the wrinkles.

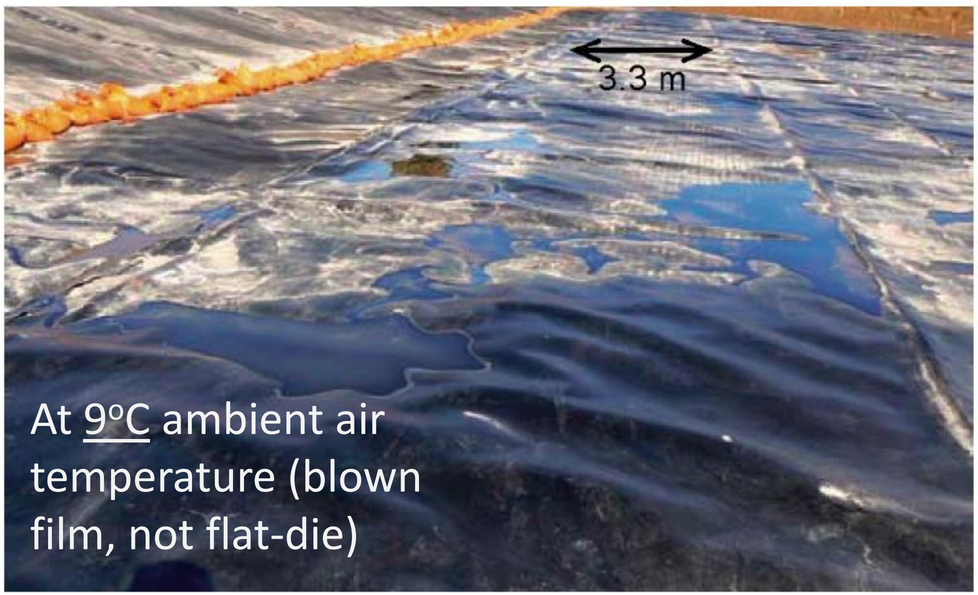
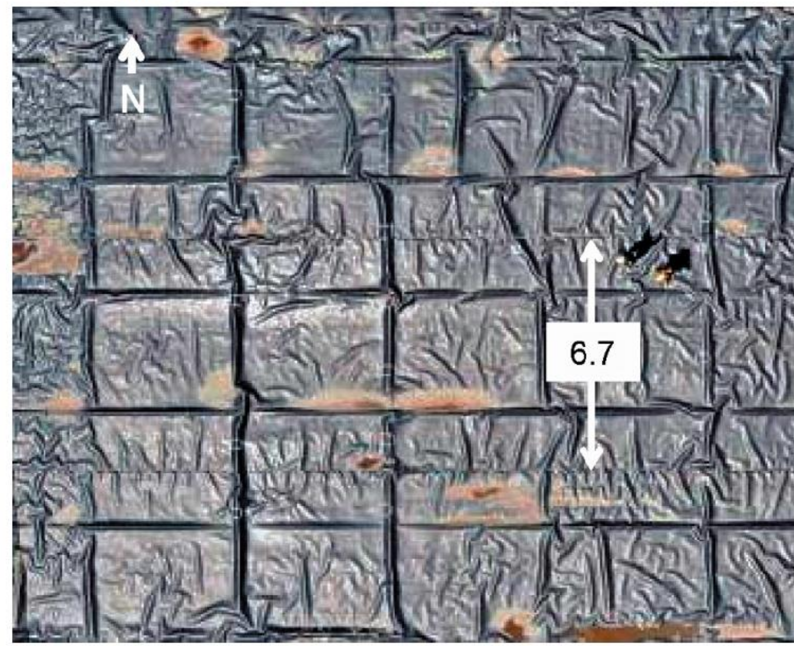


Fig. 12. Aerial photo showing a small portion of connected wrinkle network on the base liner at QUELTS (same bottom liner as shown in Figs. 8 and 11) (modified from Rowe et al.[2]). Photo taken on 28 May 2008 at 1300; air temperature of 11 °C; GM temperature on the base of 53 °C. Distance between GM seams is approximately 6.7 m as shown.



At 11°C ambient air temperature

Rowe, R.K. (2012). Short- and long-term leakage through composite liners. The 7th Arthur Casagrande lecture, Canadian Geotechnical Journal, Vol. 49 pp 141-169.

Theoretical Example 1 continued

PROBLEMS:

- The geomembrane line is riddled with pinholes, and has tears along the top of the wrinkles, and some gaps in the welds. This allows a lot of flow through to the "clay liner" below, especially as the wrinkles are linked.
- Because the clay liner wasn't constructed properly, the permeability is now 1 x 10^{-5}cm/s instead of 1 x 10^{-7}cm/s (i.e. 100 times more permeable).
- There isn't good contact between the "clay" and the geomembrane, so they don't work as a composite liner.
- The liquid head on the liner rapidly builds up on the liner as the above liner finger drains can't cope, and easily reaches 15m with time.
- The leakage value used in the Risk Analysis wasn't accurate to start with.

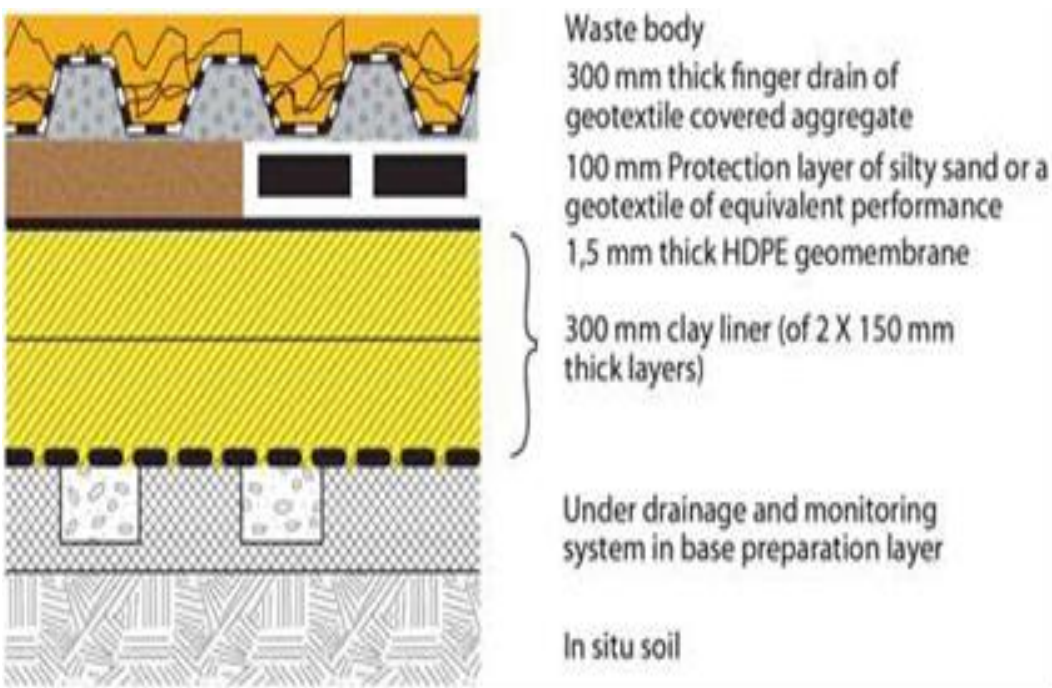
Theoretical Example 1 continued

RESULT:

- The actual leakage rate is more than 10 000 times the value used in the risk analysis, and major ground water pollution occurs as a result.
- The vast majority of the leakage from the tailings dam isn’t collected, because there are only finger drains below the “lining system”. (The finger drains weren't designed to handle such high flows anyway.)
- Because fairly low leakage rates were picked up in the underperforming underliner finger drains, no-one questioned if the liners were working until pollution of groundwater has occurred.
- The client has wasted the money they did spend on liners, as these have made very little difference.

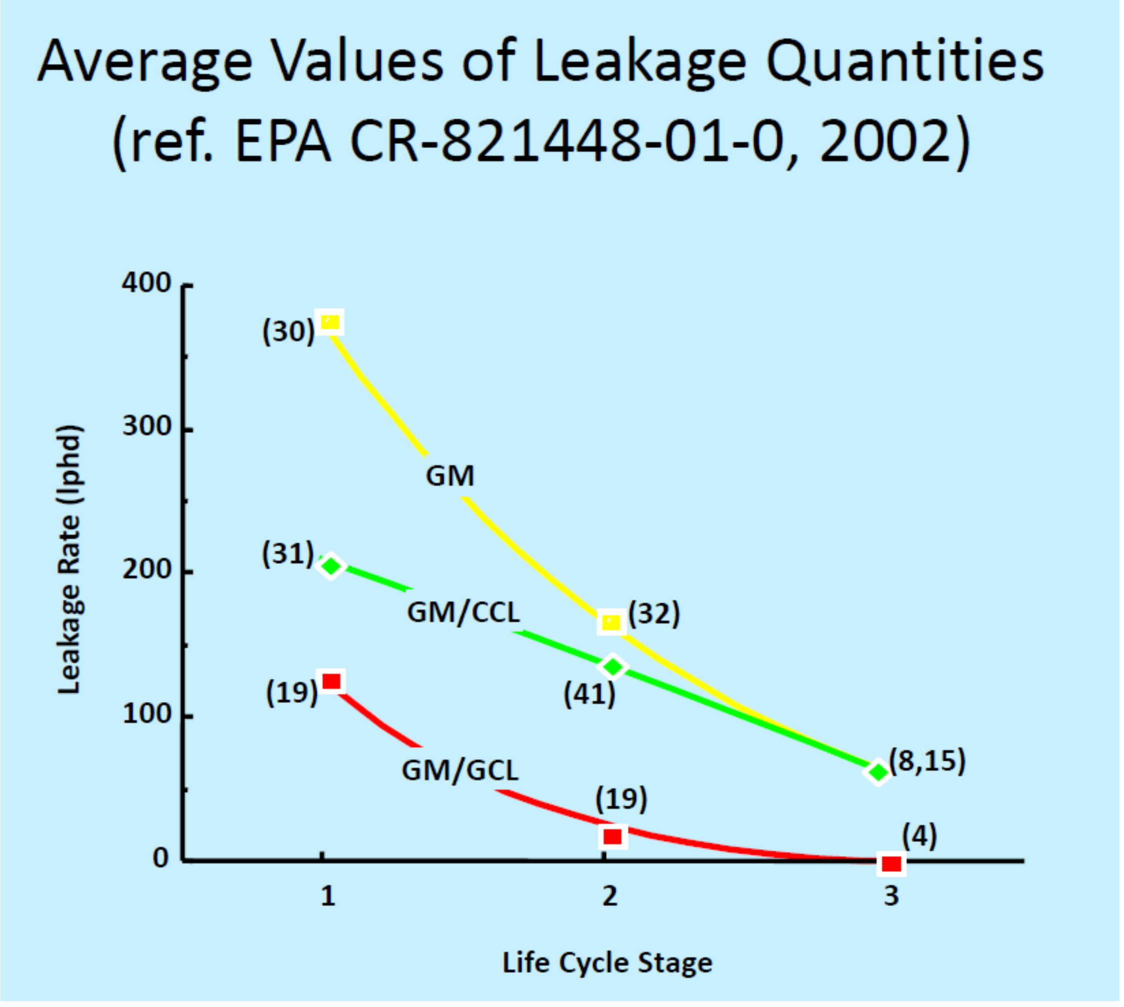
Theoretical Example 2

- Large, wet tailings facility proposed.
- Assume a Class C liner from the National Norms and Standards:



Theoretical Example2

- Have a look at some literature – find some historical leakage results.



Bonaparte, R., Daniel, D.E and Koerner, R.M., 2002. Assessment and Recommendations for Improving the Performance of Waste Containment Systems. Report EPA/600/R-02/099, United States of America

Theoretical Example 2 continued

- WOW – look at how low those geomembrane/ geosynthetic clay liner (GM/GCL) average leakage rates are compared to the geomembrane/ compacted clay liner (GM/CCL) ones – let's use a GCL!
- Use a leakage rate of 35 l/ha/day in your risk analysis for the whole facility, pollution control dam included.
- Risk analysis shows no significant impacts.
- Great! Recommend a Class C liner with a GCL replacing the CCL.

BUT:

- You haven't checked the assumptions made in the 2002 study. (These are landfills, not wet tailings facilities, and the US requires CQA on site, chemical compatibility testing, etc etc etc).

Theoretical Example 2 continued

AND:

- You haven't considered chemical compatibility between the expected seepage from the tailings dam and the GCL, or the quality of the underlying soil pore water, or any likelihood of high head on the liner.

THEN:

- There is quality control on site, but the specification doesn't address wrinkle control of the geomembrane. So there is no wrinkle control on site, and the geomembrane is really wrinkled when it's time to cover it.

Theoretical Example 2 continued

THEN:

- Again, it’s really hard putting a 100mm sand layer over a geomembrane! Big plant is used, and machines nick the top of the geomembrane wrinkles.

PROBLEMS:

- There are some tears along the top of the wrinkles, which allow a lot of flow through to the GCL below, especially as the wrinkles are linked.
- Cation exchange occurs in the GCL: the sodium ions are replaced with calcium (or other) cations in the sodium bentonite. The GCL may now be up to 1 000 times or even 10 000 times more permeable than it was to start with.

Theoretical Example 2 continued

PROBLEMS:

- The liquid head on the liner rapidly builds up on the liner as the above liner finger drains can't cope, and easily reaches 15m with time.
- The leakage value used in the Risk Analysis wasn't accurate to start with for this case.

RESULT:

- The vast majority of the leakage from the tailings dam isn't collected, because there are only finger drains below the lining system. (The finger drains weren't designed to handle such high flows anyway.)

Theoretical Example 2 continued

RESULT:

- The actual leakage rate is 1 000 or so times the value used in the risk analysis, and major ground water pollution occurs as a result.
- Because fairly low leakage rates were picked up in the underperforming underliner finger drains, no-one questioned if the liners were working until groundwater pollution occurred.
- The client has wasted the money they did spend on liners that have made very little difference.

So what can we learn from this?

- You need to use recent literature for liner leakage equations.
- Not all liners are the same.
- Don’t use leakage rates from studies from countries with higher design specs and strict CQA requirements unless you plan on meeting those specs and requirements.
- The leakage rate range used in risk analyses should be calculated by specialists who understand what affects liner performance – head on liners, chemical compatibility, material specifications, construction specifications, construction quality assurance, operational risks and requirements, rehabilitation risks and requirements, etc etc.
- Assumptions must be carried through to the design, material specifications, construction, operation and rehab phases.
- Calculate leakage rates for dams separately.

HOW TO ESTIMATE LEAKAGE RATES

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1. Obtain facility information including size, chemistry and moisture content of residue, seepage info, climate, geotech etc

2. Consider whether comparable existing facilities are polluting

3. Theoretical liner design

4. Calculate likely range of leakage for theoretical liner design from formulae in <u>recent</u> literature, considering <u>chemical compatibility</u> etc

5. Cross-check with values in literature <u>if comparable</u>

6. Determine if impacts from the leakage range calculated would be acceptable or not *(RISK ANALYSIS)*

NO? Go back to Step 3.

YES!

7. State all assumptions regarding materials, construction, protection, operation and rehabilitation clearly

8. Ensure that all assumptions regarding materials, construction, protection, operation and rehabilitation are carried into subsequent document and are met

9. Compare measured leakage rates to estimated range

10. Monitor impacts, and mitigate where necessary

Other suggestions

- This needs to be multi-disciplinary and consultative.
- There may well need to be iterations.
- Rather than have a competent person who isn’t an engineer with experience and competence in liners recommend a barrier system from the risk analysis, a maximum leakage rate to environment should be recommended.
- The design, material sourcing, construction operation and rehabilitation should then aim to maintain leakage rates below the maximum specified through the life cycle of the facility.

Calculating liner leakage rates

1989!

Table 1 - 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	0.01	1	10	300
	Small Holes*	300	1,000	3,000	10,000
	Large Holes*	10,000	30,000	100,000	300,000
Composite liner (poor field conditions, i.e., waves)	Diffusion	0.01	1	100	300
	Small Holes*	0.8	6	50	400
	Large Holes*	1	7	60	500
Composite liner (good field conditions, i.e., flat)	Diffusion	0.01	1	100	300
	Small Holes*	0.15	1	9	75
	Large Holes*	0.2	1.5	11	85
		Values of leakage rate are in lphd (values can be divided by approximately 10 to obtain values expressed in gpad)			

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

These formulae don't take account of geomembrane wrinkles.

Beware - some modelling programmes use these formulae.

Giroud, J.P. and Bonaparte, R. (1989). Leakage through Liners Constructed with Geomembranes – Part I. Geomembrane Liners. Part II. Composite Liners Geotextiles and Geomembranes, Vol. 8 No's 1&2.

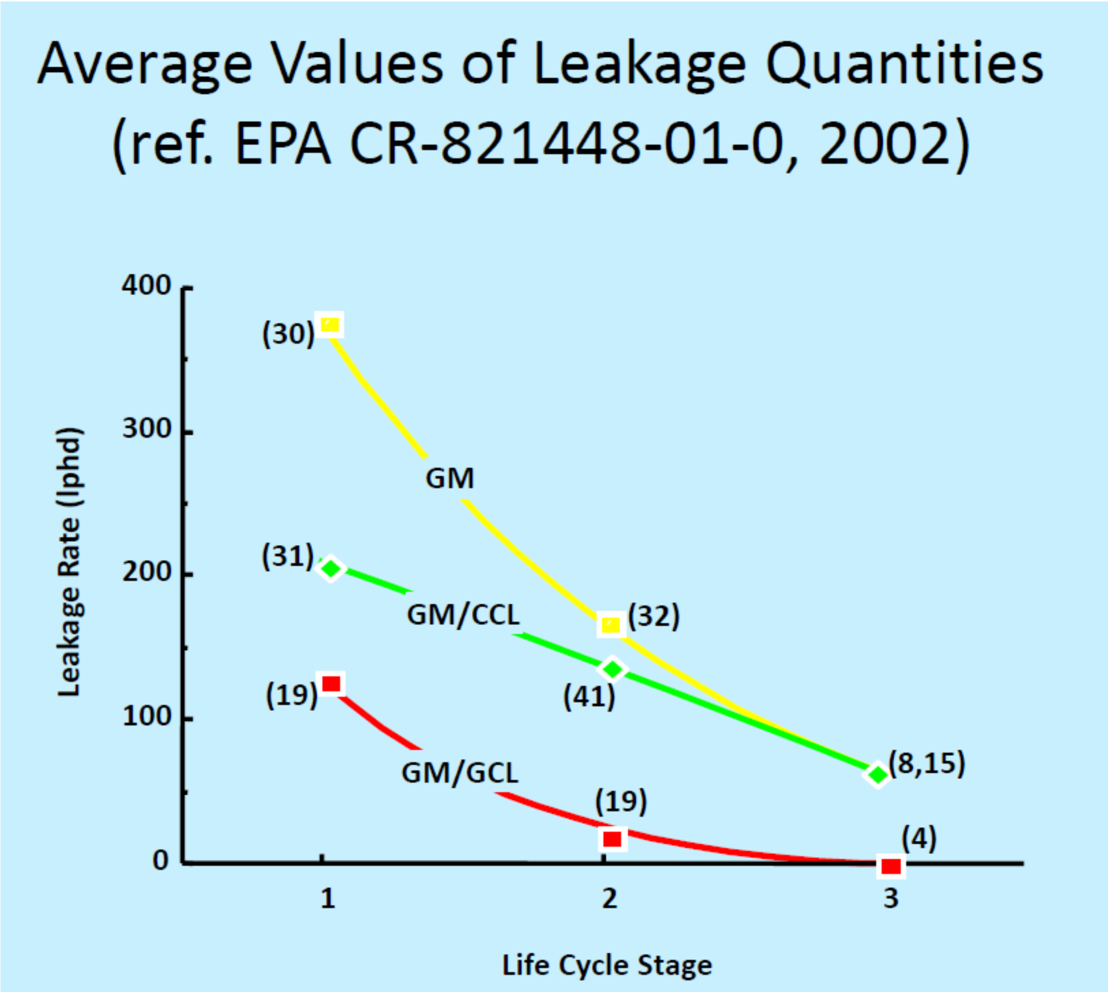
Calculation developments

- Rowe and Booker (1998) developed formulae that included transmittivity effects between a geomembrane and underlying clay/GCL, and took the thickness of the clay layer into account, and wrinkles.

Rowe, R.K. and Booker, J.R. (1998). Theoretical Solutions for Calculating Leakage through Composite Liner Systems. Geotechnical Research Centre Report GEOT-18-98.

Theoretical versus actual leakage rates

- EPA noted that there were big discrepancies between theoretical and measured leakage rates.



Bonaparte, R., Daniel, D.E and Koerner, R.M. (2002) Assessment and Recommendations for Improving the Performance of Waste Containment Systems. Report EPA/600/R-02/099, United States of America

Calculation developments

- Rowe (2005) again presented calculation of leakage through composite liners, taking linked, linear wrinkles into account.
- These calculations provide a much more realistic range for leakage from composite liners than 1989 calculations.

Rowe, R.K. (2005). Long-term performance of containment barrier systems. 4th Rankine Lecture. Géotechnique 55, No 9, pp 631-678.

Calculation developments

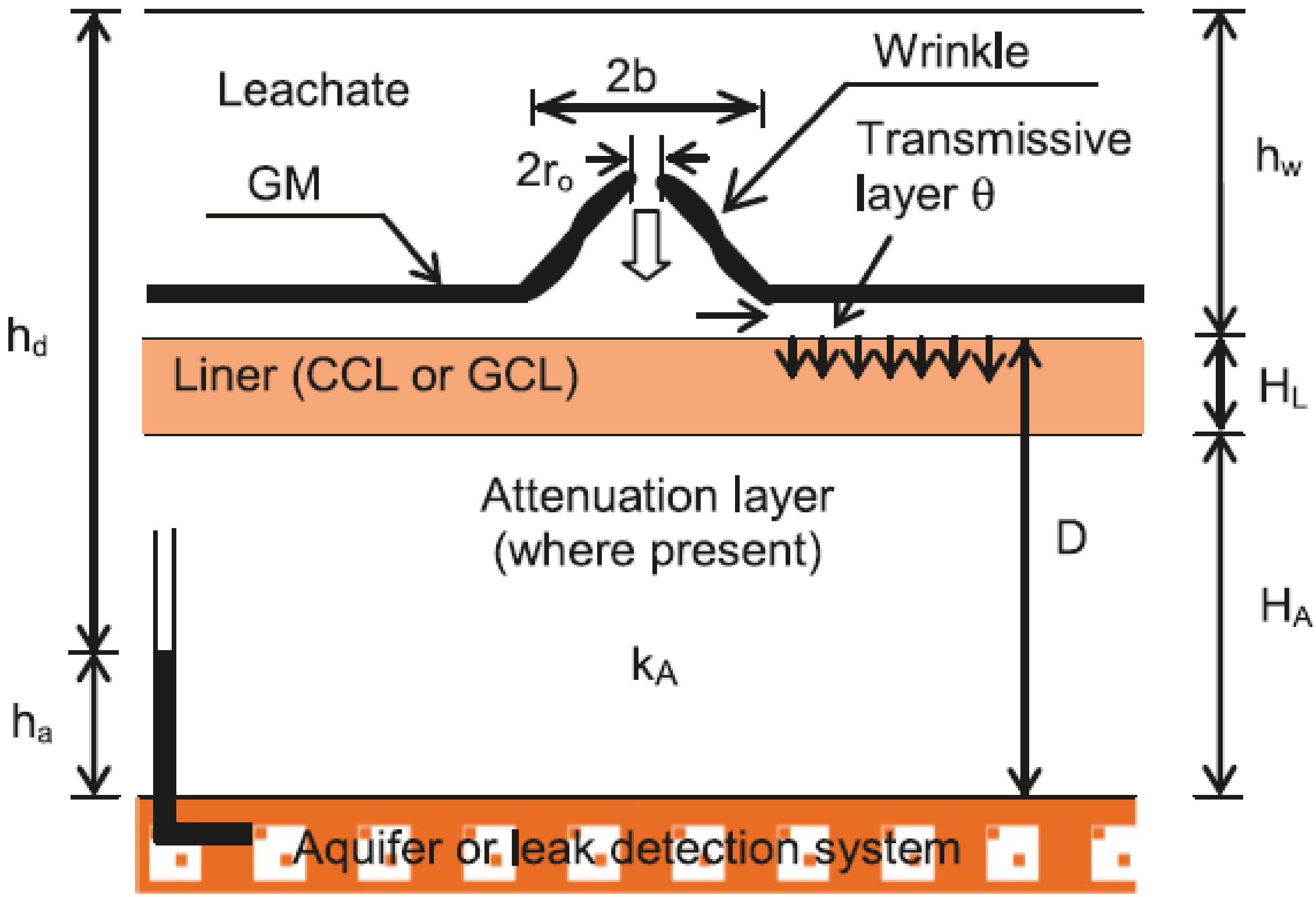
- Rowe (2012) provides an excellent overview of the factors to be taken into account in determining short- and long-term leakage through composite liners.

KEY PAPER

Rowe, R.K. (2012). Short- and long-term leakage through composite liners. The 7th Arthur Casagrande lecture, Canadian Geotechnical Journal, Vol. 49 pp 141-169.

From Rowe (2012)

Fig. 10. Schematic showing leakage through a wrinkle of length L and width $2b$ with a hole of radius r_o (adapted from Rowe 1998).



From Rowe (2012)

Rowe (1998) had developed a simple equation to predict leakage through a hole in a GM coincident with (or adjacent to) a wrinkle (Fig. 10) which, in its simplest form (assuming no interaction between adjacent wrinkles), can be written:

$$[6] \qquad Q = 2L[kb + (kD\theta)^{0.5}]h_d/D$$

where Q is the leakage (m^3/s); L is the length of the connected wrinkle (m); k is either the hydraulic conductivity (m/s) of the clay liner, k_L, if there is no AL or the harmonic mean of the CL and AL hydraulic conductivities, k_s, if there is an AL; $2b$ is the width of the wrinkle (m); $D = H_L + H_A$ is the thickness of the CL and AL (m); θ is the transmissivity of the GM–CL interface (m^2/s); and $h_d = (h_w + H_L + H_A - h_a)$ is the head loss across the composite liner (m). All of these parameters except the connected wrinkle length and wrinkle width are as previously discussed. What is needed to use eq. [6] is an indication of the likely values of L and $2b$.

Class A Primary Liner: Tight control

Controlling for small wrinkles

600mm CCL 2mm HDPE geomembrane composite Primary Liner

L	14	m	length of wrinkle
k	0.000000001	m/s	permeability of underlying liner
b	0.05	m	half the width of the wrinkle
D	0.6	m	thickness of the liner and attenuation zone
Theta	0.000000016	m2/s	transmissivity of the interface
hd	1.5		head loss across composite liner
Leakage	2.20387E-07	m3/s	Rowe (2012)
Leakage	19.04	litres per wrinkle per day	
Say you have 3 wrinkles with holes per hectare			
57.12	litres per hectare per day		

Class A Primary Liner: Less control

Much bigger wrinkles

600mm CCL 2mm HDPE geomembrane composite Primary Liner

L	500	m	length of wrinkle
k	0.000000001	m/s	permeability of underlying liner
b	0.1	m	half the width of the wrinkle
D	0.6	m	thickness of the liner and attenuation zone
Theta	0.000000016	m2/s	transmissivity of the interface
hd	1.5		head loss across composite liner
Leakage	7.99597E-06	m3/s	Rowe (2012)
Leakage	690.85	litres per wrinkle per day	
Say you have 10 wrinkles with holes per hectare			
6908.52	litres per hectare per day - *liquid outputs could be limited by liquid inputs*		

Class C with Compacted Clay Liner (CCL): Tight Control

Controlling for small wrinkles

Class C Liner 300mm CCL 1.5mm HDPE geomembrane composite liner

L	14	m	length of wrinkle
k	0.00000001	m/s	permeability of underlying liner
b	0.1	m	half the width of the wrinkle
D	0.3	m	thickness of the liner and attenuation zone
Theta	0.000000016	m2/s	transmissivity of the interface
hd	2		head loss across composite liner
Leakage	1.47993E-06	m3/s	Rowe (2012)
Leakage	127.87	litres per wrinkle per day	
Say you have 5 wrinkles with holes per hectare			
639.33	litres per hectare per day - *liquid outputs could be limited by liquid inputs*		

Class C with CCL: Less Control

Much bigger wrinkles

Class C Liner 300mm CCL 1.5mm HDPE geomembrane composite liner

L	500	m	length of wrinkle
k	0.00000001	m/s	permeability of underlying liner
b	0.2	m	half the width of the wrinkle
D	0.3	m	thickness of the liner and attenuation zone
Theta	0.000000016	m2/s	transmissivity of the interface
hd	2		head loss across composite liner
Leakage	5.95214E-05	m3/s	Rowe (2012)
Leakage	5142.65	litres per wrinkle per day	
Say you have 10 wrinkles with holes per hectare			
25713.23	litres per hectare per day - *liquid outputs could be limited by liquid inputs*		

Class C with GCL: Tight Control: No cation exchange or erosion of bentonite

Controlling for small wrinkles

Class C Liner 10mm GCL 1.5mm HDPE geomembrane composite liner

L	14	m	length of wrinkle
k	5E-11	m/s	permeability of underlying liner
b	0.1	m	half the width of the wrinkle
D	0.01	m	thickness of the liner and attenuation zone
Theta	2E-11	m2/s	transmissivity of the interface
hd	31		head loss across composite liner
Leakage	7.08486E-07	m3/s	Rowe (2012)
Leakage	61.21	litres per wrinkle per day	
Say you have 5 wrinkles with holes per hectare			
306.07	litres per hectare per day - *liquid outputs could be limited by liquid inputs*		

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Class C with GCL: Less Control: No cation exchange nor erosion of bentonite

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Much bigger wrinkles

Class C Liner 10mm GCL 1.5mm HDPE geomembrane composite liner

L	500	m	length of wrinkle
k	5E-11	m/s	permeability of underlying liner
b	0.2	m	half the width of the wrinkle
D	0.01	m	thickness of the liner and attenuation zone
Theta	2E-11	m2/s	transmissivity of the interface
hd	31		head loss across composite liner
Leakage	4.08031E-05	m3/s	Rowe (2012)
Leakage	3525.38	litres per wrinkle per day	
Say you have 10 wrinkles with holes per hectare			
17626.92	litres per hectare per day – *liquid outputs could be limited by liquid inputs*		

Dam with CCL: Tight control

Controlling for small wrinkles

Dam: 600mm CCL with 2mm HDPE geomembrane composite liner

L	14	m	length of wrinkle
k	0.000000001	m/s	permeability of underlying liner
b	0.05	m	half the width of the wrinkle
D	0.6	m	thickness of the liner and attenuation zone
Theta	0.000000016	m2/s	transmissivity of the interface
hd	9.33		head loss across composite liner
Leakage	1.3713E-06	m3/s	Rowe (2012)
Leakage	118.48	litres per wrinkle per day	
Say you have 5 wrinkles with holes per hectare			
592.40	litres per hectare per day		

Dam with CCL: Less control

Much bigger wrinkles

Dam: 600mm CCL with 2mm HDPE geomembrane composite liner

L	500	m	length of wrinkle
k	0.000000001	m/s	permeability of underlying liner
b	0.05	m	half the width of the wrinkle
D	0.6	m	thickness of the liner and attenuation zone
Theta	0.000000016	m2/s	transmissivity of the interface
hd	9.33		head loss across composite liner
Leakage	4.89749E-05	m3/s	Rowe (2012)
Leakage	4231.43	litres per wrinkle per day	
Say you have 10 wrinkles with holes per hectare			
21157.16	litres per hectare per day		

Dam with GCL: Tight control: No cation exchange: No erosion of bentonite

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Controlling for small wrinkles

Dam: 10mm GCL with 2mm HDPE geomembrane composite liner

L	14	m	length of wrinkle
k	5E-11	m/s	permeability of underlying liner
b	0.1	m	half the width of the wrinkle
D	0.01	m	thickness of the liner and attenuation zone
Theta	2E-11	m2/s	transmissivity of the interface
hd	51		head loss across composite liner
Leakage	1.16557E-06	m3/s	Rowe (2012)
Leakage	100.71	litres per wrinkle per day	
Say you have 5 wrinkles with holes per hectare			
503.53	litres per hectare per day		

Dam with GCL: Less control: No cation exchange: No erosion of bentonite

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Much bigger wrinkles

Dam: 10mm GCL with 2mm HDPE geomembrane composite liner

L	500	m	length of wrinkle
k	5E-11	m/s	permeability of underlying liner
b	0.2	m	half the width of the wrinkle
D	0.01	m	thickness of the liner and attenuation zone
Theta	2E-11	m2/s	transmissivity of the interface
hd	51		head loss across composite liner
Leakage	6.71276E-05	m3/s	Rowe (2012)
Leakage	5799.83	litres per wrinkle per day	
Say you have 10 wrinkles with holes per hectare			
28999.13	litres per hectare per day		

Dam with GCL: Less control: Cation exchange: No erosion of bentonite

Fewer wrinkles, but with cation exchange

Dam: 10mm GCL with 2mm HDPE geomembrane composite liner

L	100	m	length of wrinkle
k	0.00000002	m/s	permeability of underlying liner
b	0.2	m	half the width of the wrinkle
D	0.01	m	thickness of the liner and attenuation zone
Theta	2E-11	m2/s	transmissivity of the interface
hd	51		head loss across composite liner
Leakage	0.00414451	m3/s	Rowe (2012)
Leakage	358085.70	litres per wrinkle per day	
Say you have 2 wrinkles with holes per hectare			
716171.41	litres per hectare per day – *liquid outputs may be limited by emptying the dam*		

Rowe (2012)

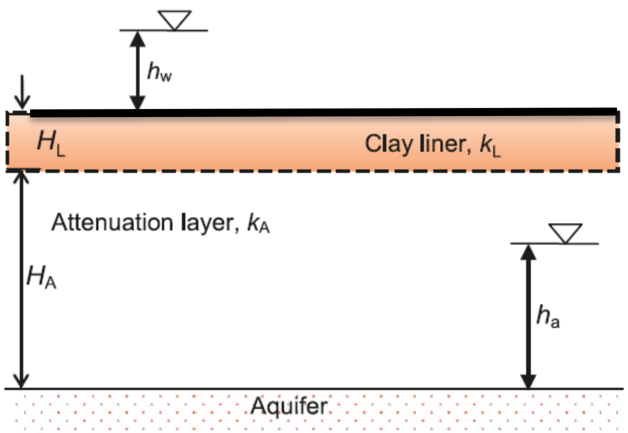

Table 12. Calculated leakage, Q, through selected composite liners for a hole in a connected wrinkle of length L for $h_w = 5$ m.

			Q (lphd)		
Case	k_L (m/s)	θ (m^2/s)	L = 100 m	L = 200 m	L = 700 m
CCL[a]	1×10^{-9}	1.6×10^{-8}	510	100	3600
	1×10^{-8}	1.0×10^{-7}	4100	8200	≥24 000
GCL[b]	5×10^{-11}	2×10^{-11}	70	140	490
	2×10^{-10}	2×10^{-11}	230	450	1600
	2×10^{-8}	2×10^{-11}	18 000	36 000	≥100 000
CCL[c]	1×10^{-9}	1.6×10^{-8}	510	1000	3600
	1×10^{-8}	1.0×10^{-7}	3400	6800	≥24 000
GCL[d]	5×10^{-11}	2×10^{-11}	70	140	490
	2×10^{-10}	2×10^{-11}	160	320	1100
	2×10^{-8}	2×10^{-11}	330	670	2300
GC–CC[e]	2×10^{-8}	2×10^{-11}	32	63	220

Note: Leakage calculated using eq. [6] and geometry as per schematic in Fig. 10 with $2b = 0.1$ m, hole $r_o = 5.6$ mm; calculated leakages have been rounded to two significant digits.

[a] $h_a = 0$ m, $H_L = 0.6$ m.

[b] $h_a = 0$ m, $H_L = 0.01$ m.

[c] $h_a = 3$ m, $H_L = 0.6$ m; $H_A + H_L = 3.75$ m.

[d] $h_a = 3$ m, $H_L = 0.01$ m; $H_A + H_L = 3.75$ m.

[e] 0.01 m GCL ($k_L = 2 \times 10^{-8}$ m/s) + 0.6m CCL ($k_L = 1 \times 10^{-9}$ m/s) + 3.14 m AL ($k = 1 \times 10^{-7}$ m/s).

Rowe, R.K. (2012). Short- and long-term leakage through composite liners. The 7th Arthur Casagrande lecture, Canadian Geotechnical Journal, Vol. 49 pp 141-169.

Beware exposed dam liners

- Wrinkling is essentially uncontrolled.
- Wrinkles tend not to creep back up slopes, so you often end up with a big wrinkle all along the inner toe, where the slopes meet the floor.
- Leakage rates from exposed liners are much higher than for covered liners with fewer wrinkles.
- Lots of other reasons to cover liners (durability, protection from mechanical damage, protection to underlying layers, theft less likely, etc, etc.)

Issues with the Nov 2016 Draft Regulations for Residue Deposits and Residue Stockpiles

In terms of 2015 Regulations for Residue Deposits and Residue Stockpiles **“competent person”** means a person who-

(i) is qualified by virtue of his or her knowledge, expertise, qualifications, skills and experience; and

(ii) is knowledgeable with the provisions of the National Environmental Management Act, 1998 (Act No. 107 of 1998), National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008), Mineral and Petroleum Resources Development Act, 2002 and other related legislation;

(iii) has been trained to recognise any potential or actual problem in the performance of the work; and

(iv) is registered with legislated regulatory body for the natural scientific profession or an appropriate legislated professional body.

Issues with the Nov 2016 Draft Regulations for Residue Deposits and Residue Stockpiles

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Addition of sub-section 3(5)

"A competent person must recommend a pollution control barrier system suitable for a specific residue stockpile or residue deposit on the basis of a risk analysis as contemplated in regulations 4 and 5 of the Regulations."

So you can have a non-engineer recommending your pollution control barrier system, who doesn't know what he/she doesn't know. Same applies for engineers don't understand the complexities of liner performance.

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Issues with the Nov 2016 Draft Regulations for Residue Deposits and Residue Stockpiles

Circular reference would exist between 3(3) and 5(3)e:

- 3(3) "A risk analysis based on the characteristics and the classification set out in regulation 4 and 5 must be used to determine the appropriate mitigation and management measures."
- 5(3) "The classification of residue stockpile and residue deposit must be undertaken on the basis of the-

  e) pollution control barrier system determined as a result of the risk analysis as contemplated in regulations 4 and 5 of these Regulations."

Does this imply an iterative process?

Issues with the Nov 2016 Draft Regulations for Residue Deposits and Residue Stockpiles

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3(3). requires a risk analysis in terms of 4 and 5.

3(5). requires recommendation of a pollution control barrier system by a competent person.

5(3). requires that the classification of the residue stockpile or residue deposit takes into account the pollution control barrier system determined as a result of the risk analysis.

7. covers the design of the residue deposit and residue stockpile but does not require that the engineer takes into account the risk analysis, classification or the recommendation of the pollution control barrier system.

9. requires the right or permit holder ensures the design is followed. *Do they have the expertise to know what is critical to liner performance and why?*

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Issues with the Nov 2016 Draft Regulations for Residue Deposits and Residue Stockpiles

By deleting all references to the NEMWA National Norms and Standards for Disposal of Waste to Landfill, not only the liner designs are deleted, so are other requirements, such as:

- Service life considerations
- Efficiency of drainage layers
- Construction Quality Assurance
- Consideration of the compatibility of liner material with the waste stream, in particular noting the compatibility of natural and modified clay soils exposed to salts.

<u>These aspects are key to managing risk.</u>

Issues with the Nov 2016 Draft Regulations for Residue Deposits and Residue Stockpiles

- By removing references to the National Norms and Standards for the Assessment of Waste for Landfill Disposal, there is no clear classification system given in the draft.
- There are no requirements listed for what the risk analysis must include and the level of detail required.
- It's going to be difficult for the risk assessments to be reliable if inputs are not reliable, to put these risk assessments out to market, and for the authorities to assess them.

Beware…

Big money at stake – dishonesty could occur throughout the process, including by "professionals".

Measuring leakage rates

- Consider where, how and how often leakage rates need to be measured.
- Health and safety is key.
- Must have safe procedures in place.
- Use of flow meters is ideal but flow may be below range for some sites.
- Undertake considered design.

Management of leakage rates

- Systems engineering approach
- Design
- Construction
- Operation
- Monitoring

Systems engineering approach

- Rowe and Hosney (2010) advocate adopting a systems engineering approach to landfill design.
- Any evaluation of leakage must consider how the interaction between different components of the landfill system affects leakage.
- Paper lists 10 factors to consider.

Rowe, R.K. and Hosney, M.S. (2010). A systems approach to minimizing leachate leakage from landfills, 9th International Conference on Geosynthetics, Brazil, 2010, pp 501-510.

Design

- Separate clean and dirty water.
- Design efficient drainage systems.
- Separate leachate and leakage drainage systems to avoid short-circuiting.
- Consider slope stability, and design to avoid liner tears.
- Avoid exposed geomembranes to limit wrinkling and increase service life.

Design

- Select & specify good quality materials.
- Consider chemical compatibility.
- Consider material-specific limitations.
- Design for reduced performance with time.
- Consider links between elements.
- Consider constructability.
- Temperature effects?

Construction

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- Appoint experienced contractors.
- Appoint knowledgable, diligent quality assurance personnel.
- Develop and implement thorough construction quality assurance plans.
- Foster a culture where honesty is the best policy.

Construction

- Ensure specifications are adhered to.
- Store materials properly.
- Limit geomembrane wrinkling as much as possible.
- Don’t allow uninformed design changes.
- Implement reasonable working hours.
- Collect and report on statistics.

Operation

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- Include assumptions from design in operating documentation.
- Supervise initial filling over liners.
- Maintain systems to work efficiently.
- Know where the lined area is, and mark infrastructure clearly.
- Cover exposed liners to avoid damage and theft.

Operation

- Train, retrain and retrain all site staff so they understand why and how liners should be protected, why and how the site drainage systems work, etc.
- Fire breaks, emergency planning and fast emergency response times are necessary to avoid fire damage.

Monitoring

- Use the actual versus action leakage rates to determine if there are issues with the facility.
- May allow intervention before environmental impacts occur.
- Use results to improve design for subsequent phases.

In summary

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- Leakage rate ranges can and should be determined in the assessment, design and application process.
- Leakage rates can and should be managed through good design, construction, operation, rehabilitation and monitoring.

GIGSA

- Geosynthetic Interest Group of South Africa provides a lot of information and annual training courses on various aspects of geosynthetics including liners.
- www.gigsa.org

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THANK YOU
QUESTIONS?

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