Forensic examination of field GCL performance in landfill capping and mining containment applications

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Geosynthetic clay liners (GCLs) have been used extensively in landfill capping and mine containment applications in the Australian environment over the last 14 years (Gates et al., 2009). Their use as hydraulic / gas barriers has been widely accepted by regulatory authorities and design engineers over this time. In Australia, there exists a knowledge gap in the behaviour of GCLs in the field due to difficulties associated with accessing sites for exhumation as well as universal industry acceptance that the key GCL performance parameters are geotextile related. This paper outlines an exhumation program of GCLs from landfill capping and mining tailing pond applications within Australia and presents results from selected sites in various states around the country. The aim is to relate manufacturing specification parameters to in-field attributes of GCLs, which will provide a basis to improve both GCL performance and testing.

Most GCL's consist of a layer of sodium bentonite clay secured between two layers of geotextile. The primary function of the bentonite component is to limit the migration of fluids (Bouazza et al., 2006). The geotextile component is essentially (i) the carrier which allows the placement of a uniform barrier layer of processed bentonite (generally ~3-6mm thick), (ii) a physical network that provides internal confining stress to restrict free swelling and (iii) a reinforcement to improve hydrated internal shear strength characteristics. Site selection (Table 1) for each exhumation was influenced by factors such as age of installation, average annual rainfall and accessibility of GCL, and at least one site was selected from most states within Australia.

Previous literature (Meer and Benson, 2007) has stated that Ca for Na exchange within cover GCLs can occur within 5 years in temperate North America. Older studies (Dobras and Elzea, 1994) showed that Ca for Na exchange in base liners is probably common and occurs within a few years. The ages of the exhumation sites varied between 3 to 8 years and all exhumation sites were selected on the basis that any potential cation exchange could occur in a minimum of 3 years and ideally at least 5 years, in Australia. The sodium bentonite powder used at all sites was designated as a civil engineering grade, Wyoming-type bentonite. The chemical composition analyses showing the exchangeable cation concentrations of the leachate from the cover and subgrade soils for each site are shown in Table 2.

Table 1. Details of Australian GCL exhumation sites.

Site	Exhumation date	State	GCL grade[1]	Year constructed	Type of installation	Mean annual rainfall (mm)[2]
WA-1	Feb 08	WA	Type 2	2002	Landfill cap	785
QLD-1	Aug 09	Nth QLD	Type 3	Sep-2001	Landfill cap	4235
WA-2a	May 09	WA	Type 2	May-2006	Mineral processing recovery dam	447
WA-2b	Sep 09	WA	Type 2	May-2004	Mineral processing settling dam	447
SA-1	Feb 10	SA	Type 3	Jul-2000	Cellulose waste Cap	705
NSW-1	Feb 10	NSW	Type 1	2000 / 2001	Landfill Cap	1502

[1] GCL grades are described below:

Type 1 GCL - carrier = woven geotextile, cover = non-woven geotextile, dry bentonite mass = approx $3.6 kg/m^2$

Type 2 GCL - carrier = woven geotextile, cover = non-woven geotextile, dry bentonite mass = approx $4.0 kg/m^2$

Type 3 GCL - carrier = woven/non-woven composite, cover = non-woven geotextile, dry bentonite mass = approx $3.7 kg/m^2$

[2] Mean annual rainfall is based on the average of all historical rainfall data at the station nearest to the site

Table 2. Chemical properties of the subgrade and cover soil materials exhumed.

Properties of Soil Leachate	WA-1		QLD-1		WA-2a	WA-2b	SA-1		NSW-1	
	Sub[1]	Cov	Sub	Cov	Sub	Sub	Sub	Cov	Sub	Cov
Exchangeable Ca (meq/100g)	1.9	7.7	1.0	3.1	3.7	4.2	20.9	2.9	11.5	7.9
Exchangeable Mg (meq/100g)	0.2	0.5	0.1	0.4	1.4	3.0	1.2	0.9	4.5	3.0
Exchangeable Na (meq/100g)	0.2	0.2	<0.1	<0.1	2.2	1.0	1.4	1.4	9.7	12.3
RMD ($M^{1/2}$)	0.04	0.02	0.02	0.01	0.26	0.10	0.08	0.19	0.66	1.01
CEC (meq/100g)	2.5	8.5	1.4	4.2	8.0	8.8	23.8	5.4	27.5	24.6

[1] Sub = subgrade, Cov = cover

There was no cover soil present at sites WA-2a and WA-2b as the GCL was directly overlain by a geomembrane. Table 2 shows that the cover soils for WA-1, QLD-1 and SA-1 contained high concentrations of calcium (& magnesium) relative to sodium, while the subgrade soils at WA-2a and WA-2b, and cover soil at NSW-1 had moderate concentrations of Ca and Mg compared to sodium. Therefore, it is likely that Ca for Na exchange has been significant in the GCLs at WA-1, QLD-1 and SA-1 and less severe at WA-2a, WA-2b and NSW-1.

The RMD values reported in Table 2 reflect the capacity of leachates in equilibrium with the soil material to initiate cation exchange within the bentonite in the GCL. RMD values $\leq 0.07 M^{1/2}$ are considered to present a high risk of loss of Na saturation in Na-bentonites, whereas smaller changes are observed for RMD values $\geq 0.14\ M^{1/2}$ (Benson and Meer, 2009). Therefore, low RMD values can have a significant impact on GCL hydraulic conductivity and swelling performance, particularly where there is potential for wet-dry cycling. With the exception of WA-1 and QLD-1, the RMD values for the cover soils were greater than for the subgrade soils, therefore, WA-1 and QLD-1 are the sites with the highest potential impact on GCL hydraulic performance depending on the site rainfall / evaporation climate.

Table 3 indicates that the GCL hydraulic conductivities of WA-2a and NSW-1 are within the original GCL specification. The RMD values at WA-2a and NSW-1 were the highest of all the sites, therefore explaining the negligible change in GCL hydraulic conductivity. The hydraulic conductivity results for WA-1, WA-2b and SA-1 are within one order of magnitude of the specification. The RMD values at WA-2b and SA-1 are above Benson and Meer's (2009) recommendation of $0.07M^{1/2}$, however the hydraulic conductivity at WA-1 is in the same order of magnitude as the specification, even though the RMD for the cover soil is only $0.02\ M^{1/2}$.

Table 3. Moisture content, swell index and hydraulic conductivity results from exhumed GCL samples

Properties of Exhumed GCL	GCL Spec Values	WA-1	QLD-1	WA-2a	WA-2b	SA-1	NSW-1
GCL Moisture Content (%)	15	35.0	54.5	20.5	56.1	113.6	86.5
Swell Index (mL/2g)	27	7	5	21	13	6	18
Hydraulic Conductivity (m/s)	3×10^{-11}	5.6×10^{-11}	5.3×10^{-8}	2.1×10^{-11}	2.9×10^{-10}	3.0×10^{-10}	2.2×10^{-11}
Root Penetration	N/A	N	Y	N	N	N	N

The RMD value for QLD-1 is the lowest of all sites, ie. $<0.07M^{1/2}$ and the average measured hydraulic conductivity of 5.3×10^{-8} m/s is over 3 orders of magnitude higher than the specified hydraulic conductivity. The cause of this significant increase in hydraulic conductivity appears to be related to contributing factors other than cation exchange and desiccation history. This warrants further investigation with an elution test similar to the one described in Meer and Benson (2007), using site cover soil and rainwater to replicate generation of leachate in the field.

The GCL moisture content of 54.5% at QLD-1 was below the value of 85% mentioned by Meer and Benson (2007), below which significant detrimental hydraulic effects occurred as a consequence of cation exchange. To reiterate their findings, GCL's with field moisture contents below 85% are more susceptible to the combined detrimental effects of desiccation and cation exchange, resulting in higher GCL hydraulic conductivities. However, GCL's with field moisture contents above 100% maintained lower hydraulic conductivities, and in some instances, within specification limits. Sites with GCL moisture content >85%, ie.SA-1 and NSW-1, had hydraulic conductivities within one order of magnitude of specification.

Suggested measures to minimise the detrimental effects of cation exchange, desiccation and root penetration include:

- Prohibit GCL cover soils with high calcium / magnesium contents in landfill caps
- Prohibit cover soils with high organic loading or sugar cane residue contents
- Up-front mineralogical analysis of soils
- Up front chemical analysis of soil leachate soluble and exchangeable cations of suspect cover soils
- Supply laminated GCL product with butyl tape jointing system into landfill cap applications
- Pre-hydration of subgrade to enable faster hydration of GCL
- Limit vegetation above GCL to species with non-aggressive root systems
- Maintain best practice minimum cover soil thickness requirements for landfill caps, ie. Minimum = 600mm, Ideal = 1000mm

Further research into GCL field performance is required and landfill cap exhumations are programmed for Victoria and south-east Queensland.

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