Victorian Landfill BPEM Comparison Table - Appendices

Item	BPEM Requirement	Comment
E	**Geosynthetic Clay Liner Use in Landfills**	
E1	**Introduction**	
	No technical content	
E2	**Background**	
	Background information on GCL usage	
E3	**Minimum Requirements for GCLs for Basal and Sideslope Liners**	
	The following parameters are considered minimum requirements for geosynthetic clay liners (GCLs) in landfill liners to maximise their service life:	
	1. The geosynthetic clay liner shall be a reinforced, multi-layered system comprising two layers of geotextiles encapsulating a layer of dry bentonite. To minimise the potential problems, for applications where there is a risk of internal erosion (such as when the GCL rests on a permeable layer such as a gravel or geonet layer) or may be subjected to wetting–drying, a GCL with a scrim-reinforced carrier and thermal treatment with properties similar to or better than those for which there is test data in the literature is recommended, unless it can be clearly demonstrated by test results that an alternative GCL is suitable.	Included in the construction specification.
	It is important to select or specify a bentonite that has been specially formulated to meet the specific, unique demands encountered by geosynthetic clay liners in landfills. As a minimum, the bentonite shall meet the specifications indicated below: • Montmorillonite content > 70 wt%. • Carbonate content*, 1-2 wt%. • Bentonite form – Natural Na-bentonite or >80 wt% Sodium as activated bentonite. • Particle size - Powdered (e.g. 80% passing 75 micron sieve) or Granulated (e.g. < 1% passing 75 micron). • Cation exchange capacity ≥ 70 meq/100 g (or cmol/kg). • Free swell index ≥ 24 cm3/2g. * Carbonate here implies calcite, calcium carbonate or other soluble or partially soluble carbonate minerals.	Included in the construction specification.
	3. Other design requirements and technical specifications for the geosynthetic clay liner (for example, Atterberg limits, organic carbon content, mass area of bentonite, mineralogy, shear strength and hydraulic conductivity under expected field stresses to water and permeant with	Included in the construction specification.

	chemical composition similar to expected leachate).	
	4. Provide a statement (with justification) on the chemical compatibility of the GCL liner and the leachate. In particular, unless relevant testing has previously been conducted for very similar conditions (such as proposed GCL, stress level, leachate), the hydraulic conductivity tests supporting the design hydraulic conductivity should be conducted on samples hydrated to simulate expected field hydration and stresses and permeated with a simulated leachate that approximates that expected in the landfill until the ratio of the chemical composition in permeant influent and effluent is ≥ 0.9 (see Petrov and Rowe 1997; Rowe et al. 2004). Similar compatibility studies should be conducted for compacted clay liners.	GCL is deemed the most acceptable substitute for compacted clay liners for modern putrescible landfill construction and as such, is commonly used and represents current best practise. GCL has been reliably proven to be chemically compatible with leachate produced from low hazard putrescible landfills. The design incorporates the GCL in direct contact with the substrate soil. This allows the GCL to gradually hydrate using the available moisture within the soil, so that in the event that there is a leak in the liner, the GCL would already be hydrated and hence, provide the most effective barrier to the leachate movement (GCL hydrated by fresh water provides improved impermeability in comparison to GCL hydrated by leachate).
	5. Provide a statement (with justification) on diffusion coefficients, partitioning coefficients and any other parameter used in the design or analysis (for example, see Rowe et al. 2004).	The design does not propose any deviation from the standard liner material properties as required within the BPEM and the facility is only proposed to be a Class II putrescible landfill. Consequently, no comparative analysis of the chemical compatibility of the liner has been undertaken (due to there being no difference between the BPEM recommended liner materials and the proposed liner materials).
	6. Equivalency comparisons between CCL and GCL base liner systems should incorporate a contaminant transport impact assessment (for example, see Rowe and Brachman 2004);	There is no equivalency comparison between CCL and GCL. Simply an equivalency comparison between the proposed lining system and the BPEM leakage rate of 10 L/ha/day.
	7. The design of the liner needs to consider the various potential stresses imposed on the geosynthetic clay liner by the in-service configuration and conditions. It is necessary to include the calculations of the physical stresses due to: • Strains imposed at the anchor trench. • Strains imposed over long, steep side slopes. • Differential settlement of the subgrade and foundation soils, if any.	This assessment has been undertaken by Golder Associates and includes the required considerations.
	8. A statement on the effect of thermal gradients on the liner during installation and construction, and effect of temperature during operation (for example, the effect of waste temperatures). Describe how the waste temperature and the thermal gradients will be taken into account (for example, see Rowe 2005).	Putrescible landfills generate some heat as a result of waste decomposition. There are numerous factors that influence heat generation, including the following: seasonal variations in temperature, placement of waste, age of waste, depth and location of waste and available moisture content. Typically, temperatures at the liner are below 30 degrees, but in actively decomposing relatively fresh waste, these temperatures can be in the range of 30 to 40 degrees, 40 degrees being an extreme value. The liner materials that have been incorporated into the design are standard materials used in putrescible landfills and have been selected due to their ability to withstand elevated temperatures and retain long-term integrity.
	9. A statement on the effect of equipment traffic during installation. In particular the stresses resulting from application of the overlying layers. Describe how these stresses will be taken into account.	It is not reasonably possible to construct the landfill lining and capping systems without having vehicles trafficking over previously laid liner layers. The construction specification provides guidance and direction to the contractor on how to traffic over previously placed liners. The CQA Plan

		also includes this aspect of the construction activity for the liner consultant to monitor. The landfill has been designed to ensure that all slopes are readily accessible to construction plant (max. 1 in 3) so that there is no addition strain imposed on the liner by vehicles trying to track up steep slopes.
	10. Specification for the geosynthetic clay liner protrusions and penetrations. Describe how the geosynthetic clay liner will be attached to penetrations and structures.	This aspect only applies to the landfill capping system and specifically when landfill gas wells penetrate through the capping system. Included in the construction specifications.
	11. Demonstrate that there is adequate friction between the various components of the liner system to prevent slippage or sloughing on the slopes and there is adequate internal shear strength to prevent internal failure of the geosynthetic clay liner during construction and waste placement. In particular, the following must be assessed: • The ability of the geosynthetic clay liner to support its own weight on the side slopes. • The ability of the geosynthetic clay liner to withstand down drag during and after waste placement. • The suitability of the anchorage configuration for the geosynthetic clay liner. • The ability to maintain a stable configuration when a geomembrane is placed on top of the geosynthetic clay liner. • The ability to maintain a stable configuration when other geosynthetic components such as geotextiles or geocomposites or soils are placed on top of the geosynthetic clay liner. • The ability to maintain a stable configuration when installed on top of the subgrade soil. • The ability to maintain a stable configuration during construction and waste placement.	The assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.
	12. A specification for liner strength and the calculations defining the minimum strength requirements: • Stresses resulting from settlement, compression or uplift. • Installation stresses. • Operating stresses. • Thermal gradients. • Climatic conditions.	The assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.
	13. Installation specifications should include details regarding: • Subgrade condition (including cracking and other irregularities) and suitability. • Geosynthetic clay liner labelling. • Methods of protecting the geosynthetic clay liner during shipping, storage and handling. • Panel deployment layout plan, panel identification, method of	Included in the construction specification.

	deployment and placement, overlap orientation, overlap preparation, overlap methods. • Procedures to be adopted to ensure hydration of the GCL. • Procedures to be adopted to prevent premature hydration of the GCL. • Procedures to be adopted to provide confinement to the GCL. • Procedures to be adopted to prevent opening of the overlaps due to placement of overlaying layers or wet-dry cycle(s). • Procedures to be adopted to minimise the effect of trafficking by vehicles. • Methods of placement in a trench. • Procedures to deal with damages and defects. • Procedures to deal with inclement weather. • Methods of dealing with or managing wrinkles (waves). • Methods of dealing with installation around protrusions and penetrations. • Procedures to be adopted to prevent desiccation of geosynthetic clay liner and/or any underlying subgrade material. • Procedures to be adopted to install a geomembrane on top of the GCL.	
	14. Inspection activities, describe how the following will be taken into account: • Skill of the installation crew. • Supervision of installation. • Inspection and approval of the overlaps. • Weather and temperature conditions during GCL deployment and overlapping. • Wrinkles. • Inspection of the surface of the GCL. • Presence of damages and defects. • Action on damages. • Repair method.	Included in the construction specification.
	15. CQC/CQA plan.	The CQA Plan covers all required aspects within the BPEM.
E4	**Minimum Requirements for GCL Liners for Landfill Cover Systems**	
	The following parameters are considered minimum requirements for geosynthetic clay liner in landfill cover systems to maximise their service life:	Different grades of GCL is proposed for different components of the landfill development.
	1. The geosynthetic clay liner shall be a reinforced multi-layered system comprising two layers of geotextiles encapsulating a layer of dry bentonite. To minimise the potential problems, for applications where there is a risk of internal erosion (such as when the GCL rests on a permeable layer such as	The construction specification stipulates these requirements.

	a gravel or geonet layer) or may be subjected to wetting-drying, a GCL with a scrim-reinforced carrier and thermal treatment with properties similar to or better than those for which there is test data in the literature is recommended unless it can be clearly demonstrated by test results that an alternative GCL is suitable.	
	2. It is important to select or specify a bentonite that has been specially formulated to meet the specific, unique demands encountered by geosynthetic clay liners in landfills. As a minimum, the bentonite shall meet the specifications indicated below: • Montmorillonite content > 70 wt%. • Carbonate content*, 1-2 wt%. • Bentonite form – Natural Na-bentonite or >80 wt% Sodium as activated bentonite. • Particle size - Powdered (e.g. 80% passing 75 micron sieve) or Granulated (e.g. < 1% passing 75 micron). • Cation exchange capacity ≥ 70 meq/100 g (or cmol/kg). • Free swell index ≥ 24 cm3/2g. • * Carbonate here implies calcite, calcium carbonate or other soluble or partially soluble carbonate minerals.	The construction specification stipulates these requirements.
	3. Other design requirements and technical specifications for the geosynthetic clay liner (for example, Atterberg limits, organic carbon content, mass area of bentonite, mineralogy, shear strength and hydraulic conductivity under expected field stresses).	The construction specification stipulates these requirements.
	4. Provide a statement (with justification) on the chemical compatibility of the GCL liner and any cover soil used in conjunction with capping GCLs. Ca2+ for Na+ exchange reactions can take place rapidly in cover-liner GCLs when exposed to liquids containing soluble Ca2+.	The cap design incorporates a LLDPE geomembrane over the GCL to reduce wetting and drying cycles in the GCL and contact from the soil above. This configuration will retain the moisture in the GCL and reduce the impact of cation exchange from the soil; hence, maintaining the low permeability properties of the GCL.
	5. Provide a statement (with justification) on gas permeability, and any other parameter used in the design or analysis.	The cap design incorporates a LLDPE geomembrane over the GCL. This configuration provides a robust capping layer with a very low permeability and significant longevity to control fugitive landfill gas emissions. In addition, there is an active landfill gas extraction system to reduce the gas volume and pressure; hence, further reducing fugitive gas emissions through the cap.
	6. The design of the liner needs to consider the various potential stresses imposed on the geosynthetic clay liner by the in-service configuration and conditions. It is necessary to include the calculations of the physical stresses due to: • Strains imposed over steep side slopes, if cover is slopped and consequently strains imposed at the anchor trench. • Differential settlement of the waste.	The assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.

	7. Provide a statement (with justification) on the effect of settlement on the overlaps,	The landfill cap is at a gentle slope of maximum 1 V in 5 H. This is a stable slope which does not require anchor trenches at joins between rolls of material; consequently, the liner material is not under undue tension. There is a minimum roll-end overlap of 1.5 m on the slope and the GCL is covered by a textured geomembrane. Effectively, the GCL and the geomembrane act as a single system to resist any differential settlement. In addition, there is a minimum of 1 m of cover material on top of the geosynthetic liners providing a substantial vertical load to hold the GCL join together. With the waste mass being well compacted by a landfill operators and the landfill being relatively deep, any settlement will typically be relatively uniform and be able to be accommodated by the landfill capping system, including the GCL material.
	8. A statement on the effect of thermal gradients/cycles on the liner during installation and construction, and effect of temperature during operation (such as the effect of thermal cycles that could cause desiccation). Describe how thermal gradients/cycles will be taken into account.	There is no limitation on the maximum site temperature at which the GCL can be laid as the GCL is not affected by elevated ambient temperatures that are anticipated on site as the material is generally lighter on colour and hence does not absorb solar energy and heat up to the extent that geomembrane does. The material is also relatively unaffected by thermal expansion. Site operations will cease due to health and safety concerns long before the elevated site temperature will negatively impact on the GCL material. Low temperatures are to a concern at this location. Putrescible landfills generate some heat as a result of waste decomposition. There are numerous factors that influence heat generation, including the following: seasonal variations in temperature, placement of waste, age of waste, depth and location of waste and available moisture content. Typically, temperatures at the liner are below 30 degrees, but in actively decomposing relatively fresh waste, these temperatures can be in the range of 30 to 40 degrees, 40 degrees being an extreme value. The liner materials that have been incorporated into the design are standard materials used in putrescible landfills and have been selected due to their ability to withstand elevated temperatures and retain long-term integrity.
	9. A statement on the effect of equipment traffic during installation. In particular the stresses resulting from application of the overlying layers. Describe how these stresses will be taken into account.	It is not reasonably possible to construct the landfill lining and capping systems without having vehicles trafficking over previously laid liner layers. The construction specification provides guidance and direction to the contractor on how to traffic over previously placed liners. The CQA Plan also includes this aspect of the construction activity for the liner consultant to monitor. The landfill has been designed to ensure that all slopes are readily accessible to construction plant (max. 1 in 3) so that there is no addition strain imposed on the liner by vehicles trying to track up steep slopes.
	10. Specification for the geosynthetic clay liner protrusions and penetrations. Describe how the geosynthetic clay liner will be attached to penetrations and structures. Describe how the effect of differential	This aspect only applies to the landfill capping system and specifically when landfill gas wells penetrate through the capping system.

	settlement and/or lateral movement of the materials around the protrusions/penetrations will be taken into account.	Included in the construction specification.
	11. In the case of installations with sloping sides, it needs to be demonstrated that there is adequate friction between the various components of the liner system to prevent slippage or sloughing on the slopes of the installation and adequate internal shear strength to prevent internal failure of the geosynthetic clay liner. In particular, the following must be assessed: • The ability of the geosynthetic clay liner to support its own weight on the side slopes. • The ability of the geosynthetic clay liner to withstand down drag during and after waste placement. • The suitability of the anchorage configuration for the geosynthetic clay liner. • The ability to maintain a stable configuration when a geomembrane is placed on top of the geosynthetic clay liner. • The ability to maintain a stable configuration when other geosynthetic components such as geotextiles or geocomposites or soils are placed on top of the geosynthetic clay liner. • The ability to maintain a stable configuration when installed on top of the subgrade soil.	The assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.
	12. A specification for liner strength and the calculations defining the minimum strength requirements: • Stresses resulting from differential settlement. • Installation stresses. • Thermal gradients. • Climatic conditions	Included in the construction specification. In addition, the assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.
	13. Installation specifications should include details regarding: • Subgrade condition (including cracking and other irregularities) and suitability. • Geosynthetic clay liner labelling. • Methods of protecting the geosynthetic clay liner during shipping, storage and handling. • Panel deployment layout plan, panel identification, method of deployment and placement, overlap orientation, overlap preparation, overlap methods. • Procedures to be adopted to ensure hydration of the GCL. • Procedures to be adopted to provide confinement to the GCL. • Procedures to be adopted to prevent premature hydration of the GCL. • Procedures to be adopted to prevent potential desiccation of the GCL and/or any underlying material.	Included in the construction specification.

	• Procedures to be adopted to prevent opening of the overlaps due to placement of overlaying layers. • Procedures to be adopted to minimise the effect of trafficking by vehicles. • Procedures to deal with damages and defects; • Procedures to deal with inclement weather. • Methods of dealing with or managing wrinkles (waves). • Methods of dealing with installation around protrusions and penetrations. • Procedures to be adopted to install a geomembrane on top of the GCL.	
	14. Inspection activities. Describe how the following will be taken into account: • Skill of the installation crew. • Supervision of installation. • Inspection and approval of the overlaps. • Weather and temperature conditions during GCL deployment and overlapping. • Wrinkles. • Inspection of the surface of the GCL. • Presence of damages and defects. • Action on damages. • Repair method.	Included in the construction specification.
	15. CQC/CQA plan.	The CQA Plan covers all required aspects within the BPEM.
E5	**Minimum Requirements for the Installation of Geosynthetic Clay Liners to be used in Landfills**	
E5.1	**Transportation, Handling and Storage**	
	The GCLs shall be delivered to the site, handled and stored in such manner that no damage occurs to the GCLs. They shall be wrapped with weather and moisture-proof wrapping to prevent any contact with water prior to installation. In the event that it is suspected that the GCL may have come into contact with water, the CQA engineer should check the moisture content of the bentonite and make the decision on the course of actions to take.	Included in the construction specification.
	The roll cores shall be sufficiently strong to ensure that they do not deflect by more than half their diameter during transit and handling.	Included in the construction specification.
	The geosynthetic clay liner rolls should be stored in a location away from construction traffic but sufficiently close to the active work area to minimise handling. The storage area should be level, dry, well-drained and stable, and should protect the product from precipitation, chemicals, excessive heat, UV radiation, standing water, vandalism and animals.	Included in the construction specification.

	GCL roll stacks shall be limited to the height at which installation personnel can safely manoeuvre the handling equipment; recommended maximum stack height is three rolls.	Included in the construction specification.
	Best practice for handling GCLs is to use a spreader stinger bar (a bar protruding from the front end of a forklift or other equipment). The bar must be capable of supporting the full weight of the geosynthetic clay liner without significant bending. Under no circumstances may the GCL rolls be dragged, lifted from one end, lifted in the middle of the roll, lifted with the forks of a forklift or pushed to the ground from the delivery vehicle.	Included in the construction specification.
E5.2	**Geosynthetic Clay Liner Installation**	
	In most cases, the lining task involves large areas, therefore it is important to proceed stage by stage in the geosynthetic clay liner installation process. It is suggested that this latter be composed of the following phases: 1. Installation planning and pre-installation conformance testing. 2. Construction and preparation of the subgrade. 3. Placement of the geosynthetic clay liner including transport, unrolling and placing, anchorage. 4. Overlapping of the geosynthetic clay liner panels, connection to structure penetration systems. 5. Placement of the overlying material.	Included in the construction specification.
E5.2.1	**Planning and Pre-Installation Conformance Testing**	
	The installation process must be preceded by a planning phase which should result in a detailed panel layout irrespective of the type of application. The layout should specify to scale the arrangement of the geosynthetic clay liner panels in the area to be lined, and the penetrations and connections.	The specification includes the requirement for a pre-construction meeting before any liner works are carried out.
	Each roll of geosynthetic clay liner shall be labelled to provide the following identifying data: • Product name, grade and name of manufacturer. • Date of manufacture, batch number. • Roll number. • Roll length. • Roll weight. • Roll width. • Label with handling guidelines.	Included in the construction specification.
	MQC documentation from the manufacturer of the GCL supplied must be submitted for approval by CQA Engineer. Submissions shall include: • Date of manufacture. • Lot number, roll number, length and width. • Bentonite manufacturer quality documentation for the particular lot of clay used in the production of the rolls delivered.	Included in the construction specification.

	• Geotextile manufacturer quality control documentation for the particular lots of geotextiles used in the production of the rolls delivered. • Cross-referencing list delineating the corresponding geotextile and bentonite lots for the materials used in the production of the rolls delivered. • QC program laboratory certified reports. • The manufacturer's approved QA stamp and the technician's signature.	
	The geosynthetic clay liner should be tested for all critical properties by a third-party accredited independent laboratory before installation.	The liner CQA consultant will carry out the necessary conformance testing on the material delivered to site to confirm the critical material properties against the specified material properties.
E5.2.2	**Subgrade**	
	The surface on which a geosynthetic clay liner will be deployed shall be firm and free of any sharp objects, stones, debris, standing water, sudden changes in grade (including indentations due to tyre tracks), or desiccation cracks. Under some circumstances the grain size distribution, dry density and moisture content of the subgrade may be specified to ensure appropriate subgrade stiffness/strength and moisture uptake by the GCL.	Included in the construction specification.
	The geosynthetic clay liner shall not be installed until inspection of the subgrade has been undertaken and deemed suitable and in accordance with the specifications by the CQA engineer.	Included in the construction specification.
E5.2.3	**Panel Placement, Overlaps**	
	The GCLs shall be installed such that the panels are anchored at the crest of the slope and are continuous down side walls/slopes. The panels should also be continuous across the base or the cover. The arrangement of the GCL panels should be according to a predetermined layout plan to minimise the amount of end overlaps.	Included in the construction specification.
	Overlap joints between panels shall be formed by overlapping the panels by a minimum of 300 mm and sealed by bentonite paste or powder/granules (sometimes referred to as accessory bentonite). The overlap zone shall be kept clean and shall not be contaminated with loose soil or other debris. There shall be no folds or wrinkles in the overlap zone and no traffic or walking shall occur on the completed overlap.	Included in the construction specification.
	Bentonite used for overlapping shall comply with the same specifications as the bentonite used in the GCL delivered to the site (same rule applies for sealing penetrations and repairs).	Included in the construction specification.
	In the case of composite liners, particular care should be taken to avoid contaminating the upper surface of the GCL with bentonite powder. The presence of loose bentonite may affect welding of overlying geomembranes and may also influence interface friction.	Included in the construction specification.

	If the slope design includes any transverse overlaps, intermediate anchorage of the panels on the slope will be needed. In this case, panels should be placed in a roofing tile fashion. The sealing of the panels shall be conducted in the same fashion as for parallel overlaps. Overlaps must be at least 1500 mm for any transverse overlaps (across the slope) and 300 mm for parallel overlap (downslope) to cater for possible movement. If settlement is likely to be significant such as in capping, the overlaps should be increased to allow for the predicted settlement.	Included in the construction specification.
	The entire surface area of every roll shall be inspected by the CQA engineer (for example, during unrolling/installation) to ensure that there is no damage or other faults in the material (such as significant and obvious variability in thickness/mass per unit area, initial moisture content of the GCL). If damage is identified, it will need to be repaired according to the specifications put in place for the site.	Included in the construction specification.
	Wrinkles are in general undesirable, as they increase the likelihood of poor intimate contact between the GCL and the geomembrane or subgrade material. In the event that wrinkles occur in the GCL or where wrinkles extend to the edge of the roll due to manufacturing tolerances, they will need to be removed prior to installation of any material cover.	Included in the construction specification.
	Geosynthetic clay liners installed on slopes are required to be fixed in anchor trenches. This is done to secure the geosynthetic clay liner and prevent it from sloughing or slipping down the inside side slopes during construction or service. A normal minimum requirement is that the anchor trench must be at least one meter back from the top edge of the slope. The front edge of the trench is to be rounded to prevent the development of stress concentrations on the GCL or any other geosynthetics for that matter.	Included in the construction specification.
	The geosynthetic clay liner should be laid on the inside wall and base of the trench only and the trench should be cleared of any debris, gravel or loose material before the GCL is installed. The trench should be backfilled and compacted with low hydraulic conductivity soils.	Included in the construction specification.
	GCLs shall not be installed in wet weather or windy conditions.	Included in the construction specification.
	It is very important to ensure that the GCL is not left exposed to rain. In this respect, it is essential that covering and confinement activities be coordinated with GCL installation. If the deployed GCL panels have hydrated prematurely (for example, during rainfall) without confinement, then the GCL panels shall be replaced.	Included in the construction specification.
E5.2.3.1	**Soil Cover Placement**	
	Where a soil cover is placed directly on the GCL, the soil cover specification shall account for the compatibility of the GCL and the cover soil. The soil shall also be free of debris, roots, sharp objects and any other item which may under the overburden stress penetrate or tear the GCL.	Included in the construction specification.
	Disturbance of the overlap area during placement must be avoided. It may	Included in the construction specification.

	be necessary to place the cover soil in this area manually. The cover should not be pushed or graded in a direction that may cause the overlap to move. The geosynthetic clay liner shall not be trafficked directly.	An exception to this requirement is that the construction contractor is allowed to drive directly on the GCL in order to place the subsequent geomembrane layer (this is unavoidable). The construction specification sets parameters to be complied with in order for the construction contractor to be able to drive on the GCL. The CQA Plan covers this aspect of construction. The lining CQA consultant will ensure that the appropriate care is taken to prevent any damage to the underlying liner.
E5.2.3.2	**Geomembrane Cover Placement**	
	Where a geomembrane is placed directly on the GCL, it should be placed immediately following deployment and acceptance of the GCL.	Included in the construction specification.
E5.3	**Repairs**	
	If the GCL has been damaged during installation, it can be repaired by patching a new piece of GCL of the same material type and thickness extending 500 mm beyond the damaged area in each direction. The patched area must be augmented with bentonite powder or granules/paste as per normal jointing requirements.	Included in the construction specification.
E6	**Quality**	
E6.1	**Manufacturing Specifications and Quality Control**	
	The quality of the geosynthetic clay liner (GCL) shall be in accordance with the requirements of the Geosynthetic Research Institute (GRI) — GCL3. The minimum specifications for quality GCL products are contained in GRI Test Method GCL3 Standard Specification for 'Test Methods, Required Properties, and Testing Frequencies of Geosynthetic Clay Liners (GCLs)'. These specifications were developed by the Geosynthetic Research Institute (GRI), with the cooperation of geosynthetic clay liner manufacturers. The specifications set forth a set of minimum physical and mechanical properties that must be met, or exceeded by the geosynthetic clay liner being manufactured.	Included in the construction specification.
	In addition to the above, the following bentonite specifications shall be verified every 50 tonnes of the product: • Montmorillonite content > 70 wt%. • Carbonate content*, 1-2 wt%. • Bentonite form – Natural Na-bentonite or >80 wt% Sodium as activated bentonite. • Particle size - Powdered (e.g. 80% passing 75 micron sieve) or Granulated (e.g. < 1% passing 75 micron). • Cation exchange capacity ≥ 70 meq/100 g (or cmol/kg). • Free swell index ≥ 24 cm3/2g. * Carbonate here implies calcite, calcium carbonate or other soluble or partially soluble carbonate minerals.	Included in the construction specification.

	A statement on the origin of the bentonite must be included, as well as certified copies of the quality control certificates issued by the bentonite supplier and reports on the tests conducted by the manufacturer to verify the quality of the bentonite used to manufacture the geosynthetic clay liner (GCL) rolls assigned to the project.	Included in the construction specification.
	The geotextile components of the GCL must also have been through a QC programme. The manufacturer's geotextile QC program should be available for auditing.	Included in the construction specification.
E6.2	**Construction Quality Control (CQC)**	
	Installation of the geosynthetic clay liners must be undertaken by GCL installers with extensive installation experience and competence with the specified GCL. In the case of installation of multicomponent liners composite, they shall provide sufficient evidence of installation experience and competence with other geosynthetics. In either case, they must provide experience records prior to any installation.	Included in the construction specification.
E6.3	**Third-Party CQA Consultant**	
	An independent, third-party CQA consultant having experience with geosynthetic clay liners and knowledgeable of geosynthetic clay liner characteristics must be appointed to verify that the works have been carried out to the agreed standards.	An appropriately experienced third-party CQA consultant will be appointed to verify that the works have been carried out to the agreed standards. The Synthetic Liner CQA Plan sets out the aspect of the works that are to be verified.
	The duties of the third-party CQA consultant include inspections, verifications, audits and evaluation of materials and workmanship, provision of advice on installation, testing, repair and covering of the geosynthetic clay liner system, and issuing a final CQA report documenting the quality of the constructed facility.	Included in the Liner CQA Plan.
E6.4	**CQA Plan**	
	A CQA plan shall be submitted to EPA prior to the geosynthetic clay liner installation. The CQA plan needs to provide procedures for identifying non-conformance and for corrective action.	The CQA Plan is included in the Works Approval application documentation.
E6.4	**Conformance Testing**	
	Table E3 (refer below) provides guidance on the test properties and recommended minimum testing frequencies:	Included in the CQA Plan.
E6.6	**CQA Report**	
	A CQA report must be prepared by the CQA consultant to demonstrate that all requirements of the project specifications and CQA plan have been complied with.	The CQA consultant will provide a CQA Verification Report, which will be included in the Works Approval Compliance Certification documentation sent to the DER on completion of the works.

Table E3: Guidance on CQA testing for geosynthetic clay liners

Item	Property	Standards	Frequency
Conformance testing (upon shipment of GCL to the site)	Thickness (dry)	ASTM D1777	Each roll
	Mass per unit area of bentonite component of GCL	ASTM D5993	1 sample per 2,500 m^2
	Mass per unit area of GCL	ASTM D5993	1 sample per 500 m^2
	Montmorillonite content (X-ray diffraction method)		1 sample per 10,000m^2
	Cation exchange capacity of bentonite (methylene blue method)		1 sample per 500 m^2
	Mass/unit length of bentonite in overlaps (visual inspection and weighting)		1 sample per 40 m overlap
	Moisture content of bentonite	AS 1289.2.1.1	1 sample per roll or 500 m^2
	Swell index/free swell of clay	ASTM D5890	1 sample per roll or 500 m^2
	Water absorption	ASTM D5891	1 sample per roll or 500 m^2
	Peel strength (for needle-punched products only)	ASTM D6496	1 sample per roll or 500 m^2
	Tensile strength	ASTM D4595	As specified in CQA plan
	CBR of geotextile	AS 3706-4	As specified in CQA plan
	Puncture resistance of geotextile	AS 3706-5	As specified in CQA plan
	Index flux	ASTM 5887	1 sample per 10,000 m^2
Visual inspection of GCL	Colour, thickness, needle punching, presence of needles or broken needles, and sewing density or other faults in the material.		Every roll
Thickness of GCL (i.e. uniformity of bentonite distribution) and apparent variations in the as placed moisture distribution.	On-site		Each roll during placement. If thickness appears to be variable a check of the variability of the mass per unit area should be conducted

Note:

1 All conformance tests must be reviewed, accepted and reported by a CQA consultant before deployment of the geosynthetic clay liner

2 All testing must be performed on samples taken from the geosynthetic clay liner delivered to site under the CQA consultant supervision

3 All laboratory tests must be performed in a third party independent accredited laboratory

4 The required testing frequencies may be revised by the CQA consultant to conform with improvements in testing methods and/or in the state of the art practice and/or to account for the criticality of the application (i.e to account for the importance of the geosynthetic clay liner for the safety of works). Revisions must be approved by the relevant authorities before application