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INCITEC FERTILIZERS LIMITED

Containment Cell Design, Cockle Creek, NSW

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REPORT

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Golder Associates

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APPENDICES

1.0 INTRODUCTION

A remediation program is being developed for the Incitec Fertilizers Limited (IFL) Cockle Creek facility in Boolaroo, NSW (the site). Remediation includes excavation of impacted fill and soil material across the site and placement within an on-site containment cell that will occupy the northern portion of the site, as described in the site *Conceptual Remediation Action Plan* (Soil and Groundwater Consulting, Oct 2008). IFL has commissioned Golder Associates Pty Ltd (Golder) to prepare the containment cell design.

This design report summarises the containment cell design, making extensive reference to the detailed design documents and supporting documents as listed in Table 1 below.

Table 1: Project Documents Relevant to Containment Cell Design

Document	Description
Detailed Design Documents	
1. Design Drawings	engineering drawings providing cell construction details (Appendix C)
2. Specifications	technical specifications for cell construction materials and construction works; includes construction quality assurance (CQA) requirements (Appendix D)
Supporting Documents	
3. Materials Compatibility Assessment	report on chemical characteristics of materials to be placed in the cell; report presents an assessment of potential interaction between these materials and their compatibility with the materials used for construction of the environmental containment systems within the cell. (Appendix E)
4. Geotechnical Reports	separate factual and interpretative reports on geotechnical conditions in the containment cell area (Appendices A and B)
5. Environmental Site Assessment Reports	report on environmental site conditions(surface and sub-surface); includes results and interpretation of sampling and testing to characterise soil and groundwater contamination across the entire site
6. Surface Water Management Plan	plan for management of surface water, across the entire IPL site, during the period of site remediation works, including cell construction
7. Validation Plan	plan for validation of areas where contaminated soils have been removed, including the validation sampling and testing approach
8. Construction Environmental Management Plan	plan describing required measures for protection of the environment during remediation works and construction of the containment cell

The remainder of this design report is organised as follows:

- site conditions that are relevant to containment cell design are presented in Chapter 2;
- design features of the containment cell are described in Chapter 3;
- key issues for construction of the containment cell are outlined in Chapter 4; and
- key issues for operation and maintenance of the containment cell are outlined in Chapter 5.

2.0 SITE CONDITIONS

2.1 Subsurface Conditions

The information in the following sections is primarily derived from the geotechnical investigation reports that are attached as Appendices A and B and from environmental site assessment reports prepared by Soil and Groundwater Consulting in April 2008 (“Environmental Site Assessment” and “Further Environmental Investigations”).

2.1.1 Geology

A review of published geological maps (Newcastle Coalfield 1968) indicates that the site is underlain by the Late Permian Newcastle Coal Measures, which typically comprise a sedimentary sequence containing 22 coal seams, several conglomerate members, numerous volcanogenic claystone units with interbedded sandstone, carbonaceous shale, laminites and siltstone. The Newcastle Coal Measures were formed in a tectonically active environment controlled by a mobile hinterland and an active border thrust.

Within the stratigraphic column of the Newcastle Coal Measures, the site is located within the outcrop zone of the Seahampton Sandstone Member, in particular the Reids Mistake Formation between the Upper and Lower Pilot Coal Seams. This formation is shown to comprise generally sandstone with some tuff and shale. The site may also extend into the Croudace Bay Formation, which lies just below the Fassifern Coal Seam.

2.1.2 Stratigraphy

Field investigations have identified that the majority of the containment cell area is currently covered by fill soil materials of variable thickness, overlying either colluvium (materials deposited as part of hillside erosion processes) and/ or residual soil derived from the underlying bedrock. The total thickness of fill and soil/colluvium ranges from 0 to 9 m across the containment cell area. Weathered rock comprising interlayered shale, claystone, sandstone, and conglomerate underlies the fill and soil/colluvium, with rock outcropping in some areas on the eastern steeper slopes of Munibung Hill.

Remediation of the entire IFL site, including the containment cell area, will generally include excavation of the impacted fill and placement within the containment cell. Therefore, the colluvium and residual soil materials that underlie the fill will form the upper foundation layer for the containment cell in some areas. The shear strength and compressibility of these materials have been assessed for the purpose of slope stability and settlement analyses that are discussed subsequently.

The field investigations indicate that excavation of fill, soil/colluvium, and extremely weathered rock horizons could be carried out by a medium sized (or larger) excavator. Excavation of less weathered rock (particularly shales and claystones) may be possible using large excavators at low production rates. Where medium and high strength rock is encountered, excavations would likely require rock breakers or a medium to large dozer with ripping tyne.

The field investigations indicate that excavation batter angles in fill and soil/colluvium should generally range from 1H:1V to 2H:1V for temporary batters and from 2H:1V to 3H:1V for permanent batters. Rock excavation batters should generally range from 0.5H:1V to 1H:1V for temporary batters and from 1H:1V to 2H:1V for permanent batters.

2.1.3 Groundwater

Field investigations have encountered groundwater in both the fill and natural materials at the site. A number of nested well installations have been installed as part of the investigations and these show a general downward gradient between the fill, shallow and the deep natural aquifer sequences. The groundwater flow direction in all aquifer sequences is inferred to be in a broadly westerly direction across the majority of the site, with flow in the general direction of Cockle Creek, which is 800 m from the site.

A reversal of the downward groundwater head gradient was apparent in one area in the north eastern portion of the site, but outside of the containment cell footprint, with artesian conditions reported at one well (BH19). These local effects are thought to be related to confined conditions in the shallow natural aquifer.

Groundwater levels encountered during field investigations indicate that at some locations the fill will need to be removed from below groundwater level. Earthworks operations will therefore include excavation and dewatering excavations below groundwater level. Wet fill will likely need to be moisture conditioned (dried or mixed with drier soil) prior to incorporation in the containment cell to improve handling and compaction.

2.1.4 Underground Services

Underground services are known to be present in the containment cell area, predominately in the southern portion as indicated in Design Drawing D004 (Appendix C). Known services comprise drainage pipes and culverts, water mains, communications cables, and underground water supply and power lines. All existing services will be decommissioned and removed when encountered during earthwork operations to excavate fill materials and prepare the cell base. This will include elimination of any potential groundwater flow paths associated with services (eg. gravel bedding within service trenches).

2.2 Surface Conditions

2.2.1 Existing Site Levels and Structures

Existing surface levels in the containment cell area are shown on Design Drawing D003 (Appendix C). This drawing also shows the location of existing structures. The northern portion of the containment cell area is largely undeveloped and has thin grass cover in most areas. The southern portion includes paved roadways, grassed areas, several single storey brick buildings, a portion of two large central site sheds (sheds 1 and 2), and a large single storey storage shed (shed 4) along the south-eastern boundary of the area.

Current surface levels range from RL 25, in the low lying area along the west-central site boundary (the former trestles area), to RL 45 in the northeast corner. The surface in the undeveloped areas generally rises to the east at inclinations from 1% to nearly 20%, becoming steeper along the eastern site boundary.

2.2.2 Surface Water Drainage

The containment cell area intercepts two natural drainage courses originating from the east on the slopes of Munibung Hill. These drainage courses extend into the north eastern corner of the site. A third drainage course, also extending from the slopes of Munibung Hill, terminates within a man-made dam located on the adjacent property, immediately east of shed 4. Within the containment cell footprint, two drainage ditches convey water towards a point along the northern site boundary.

2.2.3 Surface Services

Surface services known to be present in the containment cell area are indicated in Design Drawing D004 (Appendix C). These include dish drains, drainage ditches, and overhead power lines. The existing surface water drainage features will be removed when encountered during earthwork operations to excavate fill materials and prepare the cell base.

The overhead power lines cross through the north eastern portion of the containment cell area. These lines will be retained. Earthwork activities and cell construction in the vicinity of the power lines will comply with safety requirements for work near overhead power lines.

2.2.4 Easements

There are a number of easements that pass through the containment cell area. These easements are indicated in Design Drawing D005. These easements include Easements No. 7 to 15 for Railway, Drainage, Electricity, Bulk Hoppers, and Right of Carriage Way.

2.3 Other

2.3.1 Underground Mining

The closest underground mine workings to the site are those associated with the former shallow Sulphide Pit mine which was northwest of the site but entirely within the adjacent Pasminco property. There are no identified historical mine workings within the site boundaries. As discussed subsequently, the potential for subsidence from future coal mining beneath the containment cell footprint has been considered in the design process.

2.3.2 Seismicity

The site is adjacent to the town of Boolaroo, which was the epicentre (margin of error of 15 km) of the 1989 Newcastle earthquake (M=5.6) as well as the 1925 Boolaroo earthquake (M=5.3). The 1989 earthquake, which had a focal depth of 11km, may potentially have been associated with a NW-SE trending and NE dipping thrust fault that forms part of the Hunter-Mooki Thrust Fault System. The severity of shaking at the site, modified Mercali, was MM=VII in 1989 and MM=VI in 1925. In addition to the Boolaroo earthquakes, the 1994 Ellalong earthquake (M=5.4) occurred approximately 30km west of the site.

After the 1989 Newcastle earthquake, operating mines suffered negligible damage, if any, as a result of the earthquake. Furthermore, prominent structural features in the Newcastle region showed negligible or no ground rupture or other movement immediately after the earthquake[1]. However, earthquake related effects such as damage to water mains and sewage pipes laid parallel or at right angles to faults and dykes were reported.

Information from a publicly available Environmental Assessment for the adjacent Pasminco Cockle Creek remediation site, in particular rock coring information and records from underground coal mining works to the immediate north of the Pasminco property, indicates the possible existence of two faults potentially extending into the IFL site. Although no faults were encountered in the field investigation of the IFL site, it is not possible to definitively assess the presence or absence of faults, and if present whether or not these faults are recently active. In a worst case scenario, these hypothetical faults could be active and could have a north-south trend and extend through the containment cell footprint.

Site seismicity has been considered for the cell design presented in the next chapter of this report. The relevant design issues are slope stability and seismic displacements.

2.3.3 Slope Stability – Natural Slopes

Evidence of several previous land slides has been identified within the higher slopes of Munibung Hill[2]. Potential influences that have lead to the landsliding include the typically low shear strength of the tuffaceous layers, even when fresh, preferential erosion of weaker and softer rock from beneath fresher rock, coal seams acting as aquifers, and moderately to highly reactive soils. The landslides and erosion from the higher cliff lines has deposited colluvium over many of the slopes, although there are some spurs and ridgelines where the cliff lines and associated colluvium are largely absent, including those slopes above the Incitec site. However, evidence of previous slope instability within the western slopes of Munibung Hill immediately above the Incitec site was not identified from historical records or aerial photographs.

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[1] Sloan, S.W. & Allman, M.A. (ed), 1995, *Engineering Geology of the Newcastle-Gosford Region*, Conference Publications

[2] Landsliding in the Gosford – Lake Macquarie - Newcastle Area, R. Fell, School of Civil Engineering, the University of New South Wales

3.0 CELL DESIGN

3.1 Containment Approach

3.1.1 On Site Containment

Site contamination is described in the environmental site assessment reports prepared by Soil and Groundwater Consulting in April 2008.

Fill: These reports indicate that existing soil fill materials at the site have environmental characteristics as indicated below.

- The existing soil fill materials generally contain slag and typically have elevated concentrations of heavy metals, particularly lead and zinc, but occasionally arsenic, nickel and cadmium. The slag material is a metalliferous by-product of the former sulfidic ore smelting process at the adjacent Pasminco site and appears to have been mixed with soil for placement as fill across the Incitec site. Local areas have been identified within the slag fill with elevated nitrate, phosphate, sulphate and fluoride concentrations. These local areas are attributed to fertiliser production activities.
- Measured average concentrations of a number of metals in the slag fill exceed the relevant soil assessment criteria for both residential and commercial/industrial land use, most notably zinc and lead. Reported concentrations of organic contaminants were below the relevant assessment criteria for residential land use, and often below laboratory reporting limits.
- Results of a soil leachability assessment for the slag fill indicate leachability of heavy metals, particularly under slightly acidic conditions. In general, the leachable concentrations would result in leachate quality that exceeds the relevant groundwater assessment criteria.

Natural Soil: The environmental site assessment reports indicate that natural soils at the site, which typically underlie the slag fill, typically contain low contaminant concentrations and are generally suitable for residential and commercial/industrial land uses.

Other Materials: Demolition of existing structures on the remediation site will produce contaminated materials, notably roof sheeting containing asbestos with metal dust. Concrete slabs and pavements are expected to be largely uncontaminated; however, a portion of the slabs and slab bedding materials may be contaminated. In addition, sulphur impacted soils that are stockpiled within a portion of shed 4 have recently been sampled and tested[3].

Groundwater: Groundwater at the site has been impacted by the presence of the slag fill. The most significant groundwater contaminants at the site are considered to be heavy metals, and of these, zinc occurs at the highest concentrations.

Remediation Approach: The site *Conceptual Remediation Action Plan* (Soil and Groundwater Consulting, Oct 2008) identifies that excavation of contaminated soils and placement within a lined containment cell on the site is the most appropriate remediation approach. The soils to be excavated comprise primarily the slag fill, to be managed as a single material type that does not require sub-classification. Contaminated materials from building demolition will also be placed in the containment cell. The removal of the contaminated soils will eliminate the primary ongoing source of groundwater contamination.

After site remediation is complete, the cell will be used as controlled open space.

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[3] Soil & Groundwater Consulting, 23 March 2010, letter report "Acid Base Soil Sampling Summary."

3.1.2 Environmental Protection Measures

The overall approach for containment of the impacted materials is to provide a containment cell with environmental protection measures as outlined in the table below. These measures are described in following sections of this chapter.

Table 2: Environmental Protection Measures incorporated into Containment Cell

System	Protection Measure	Function
Cell Base	under drain	reduce potential for groundwater to come into contact with the cell base
	base liner	contain contaminants
	leachate collection system.	remove leachate from above the base liner and thereby limit the potential for contaminant migration through the base liner
Cell Capping	barrier	limit infiltration of water and oxygen into the cell and contain contaminants
	subsurface drainage system	drain infiltrating rainwater from above the barrier liner
	vegetation growth medium	support vegetation growth to limit erosion from the cap and to provide visual amenity; provide sufficient thickness to reduce potential for human contact with cell materials
Surface Water	cap drainage	collect and convey runoff from rainfall on the cell
	perimeter drain	collect and control runoff from cap drainage and from IFL property upslope of the cell

A construction quality assurance system (refer Section 4.1) will be in place for cell construction because the performance of these environmental protection measures, particularly the base liner and cap barrier, is known to be highly dependent on the quality of their construction.

These measures are designed to be operated and maintained to provide long-term performance (refer Chapter 5).

The containment cell design has been prepared using materials and construction methods suitable to provide long-term containment. If constructed, operated and maintained as designed, cell design life will be in the order of 100 years.

3.1.3 Cell Landform

The containment cell landform is shown in Design Drawing 0054 (Appendix C). Overall characteristics of the landform are summarised in the table below.

Table 3: Containment Cell Landform Summary

Item	Description
Plan Dimensions	- sub-rectangular shape - plan dimensions of approximately 400m by 150m
Elevation	- maximum elevation of RL 45.5 m - minimum elevation of RL 23.5m
Batter Slopes	- batter slopes of 4H:1V - max. height of west batter is 19m with mid-slope bench (note 1) - max. height of east batter is 12m

Item	Description
Surface Grading	- the area at the top of the landform is graded with 5% slopes - the mid-slope bench is graded with a min. 1% longitudinal slope
Airspace	- available airspace (net volume) for cell material placement in the cell is approximately 300,000 cubic metres
Perimeter	- a surface water drainage swale is present along the cell perimeter - the drainage swale serves as a partial perimeter access track
Property Boundary Offsets	The cell is positioned with offsets from property boundaries to provide for general access, and for working space as a contingency for future works around the cell. The distance from the edge of the perimeter drainage swale to the property boundary is: (a) east: min 15m; (b) north: min 65m. Along the western side, the cell is positioned such that the minimum distance from contaminated soil placed within the cell to the site boundary is 30m.

Notes: 1. The cell landform will temporarily include a west batter with max. height of 22m (Design Drawing D0053). The max. batter height will reduce to 19m when additional fill is placed to match existing levels along the western site boundary (Design Drawing D0054).

3.2 Cell Materials

3.2.1 Materials and Placement Criteria

Contaminated fill materials will be placed and compacted into the cell with moisture and density controls equivalent to that for a structural earthwork fill. The following requirements will apply:

- Cell material will be compacted to at least 95% of Standard Maximum Dry Density (SMDD);
- Cell material that is excessively wet will be dried or mixed with other dry soil prior to compaction so that the maximum moisture is +3% wet of Standard Optimum Moisture Content;
- Large particles will be removed or screened out so that the maximum particle size is 200mm;
- Cell materials will be placed and compacted using a maximum lift thickness of 300mm; and
- The organic content of fill materials placed in the cell, particularly any contaminated topsoil from the site, will be restricted, as discussed in Section 4.3.

These requirements will provide for the cell material to develop high shear strength, low compressibility (settlement potential), and low potential for long-term leachate generation.

The initial 300m lift of cell material will be placed directly on the geocomposite drain layer of the leachate collection system. This initial lift will have a reduced maximum particle size of 20mm and a reduced density requirement of 90% of SMDD to reduce the potential for damage to the geocomposite drain layer and underlying HDPE geomembrane.

Asbestos roof sheeting from existing site structures will be placed within the cell, with an expected volume of less than 2000 m^3. Placement will be limited to two to three surveyed locations in the cell, with a requirement that a minimum thickness of 3m of cell material is placed above all asbestos roof sheeting. The removal, handling, and placement of these materials from the existing structures will be undertaken by an appropriately licensed contractor, and in accordance with specific regulatory requirements, work practices, personal protective equipment and handling procedures.

Sulphur impacted soils within shed 4 will be placed in the cell in maximum 300mm-thick compacted layers, with successive layers separated by at least 500mm of other contaminated soil materials. This method will avoid the creation of monolithic zones of the sulphur impacted soil within the cell.

3.2.2 Chemical Compatibility

A materials compatibility assessment has been performed to evaluate the physical and chemical properties of the cell filling materials and ascertain whether the materials (or reaction products derived from the materials) have the potential to create hazards or material degradation potential that that could pose a risk to the performance of the containment cell. The Materials Compatibility Assessment report is provided in Appendix E.

The slag fill material present at the site, which will comprise the vast majority of waste material to be stored in the cell, has essentially been exposed to the environment for in excess of 50 years, with significant leaching and exposure to atmospheric oxygen (or oxygen-enriched rainfall recharge) having occurred over that time. Acid-base accounting (ABA) and net acid generation (NAG) analyses have indicated a limited potential for acid generation, and the aggressivity assessment has indicated low to mild aggressivity potential towards concrete and moderate aggressivity potential towards steel. In addition, available information suggests that organic contaminants, strong acids or bases, oxidants or flammable materials will not be present in the waste material. Given this situation, there is a very limited range of reactions that could potentially occur within the slag fill, none of which are expected to produce a by-product or physical condition that is detrimental to the cell construction materials or cell performance. Nevertheless, the materials compatibility assessment identified the cell design and/or management items listed in the table below to limit the potential for unfavourable compatibility effects.

Table 4: Cell Design and Management Items from Materials Compatibility Assessment

Potential Issue	Concern	Design or Management Item
Generation of acidic leachate	oxidation of sulfidic minerals within the slag fill	geomembrane included in the capping system to limit oxygen infiltration into the cell
		geomembrane and GCL specifications for the cell liner and capping system to provide material compatible with low pH conditions (e.g. similar to municipal landfill conditions)
		GCL in cell liner to be partially hydrated with tap water prior to placement of overlying geomembrane to reduce the potential for a reduction in hydraulic performance of the GCL when exposed to leachate
Deterioration of concrete and steel cell components within the leachate collection system	leachate may be low to moderately aggressive due to dissolved sulphate and chloride	select corrosion resistant materials for the leachate collection system do not use crushed concrete as drainage media in the leachate collection system
		inspection schedule needed for any leachate collection system sumps
Fouling/Clogging within leachate collection system	precipitation of mineral phases in leachate	use non-reactive material for the drainage media in the leachate collection system design to include oversized leachate drainage system components to reduce the potential for fouling/clogging to fully block any components of the leachate collection system
		design to include clean out points for the leachate pipe system to provide access to all pipe segments
Gas generation	pressure build up within the cell and explosion risk	construction specification to incorporate measures to limit the amount of degradable organic material placed in the cell (refer Section 4.3)
Heat generation	damage to cell base liner and capping materials	geomembrane specification for the cell liner and capping system to provide material compatible with elevated temperature conditions (e.g. municipal landfill conditions)
Flammability	none	none

In addition, the materials compatibility assessment identified that minimising the amount of leachate generated within the cell, and rapidly removing any generated leachate that reports to the cell base, is an important overall design and management item. This is because free leachate will exacerbate any unfavourable reactions and act as a carrier for reaction products. Measures to minimise leachate generation are described in the design features of the cell capping system (refer Section 3.5) and in the management of cell materials prior to placement and compaction (refer Section 4.3).

The materials compatibility assessment concluded that the cell materials are considered to be chemically compatible with each other and with the proposed cell design. The recommended cell design and management measures that accompanied this conclusion are summarised in the above table. These items will be addressed in subsequent sections of this design report.

3.3 Design Issues

3.3.1 Settlement

Settlement of Cell Foundation

The proposed containment cell is up to about 13 m thick. The stress exerted by the cell materials may result in consolidation of the underlying foundation soils. This may not be an issue of significance where settlements are relatively uniform, but where poorer soils are located adjacent to areas of shallow rock the differential settlements may have an impact on the design of the containment cell. As a precautionary measure, the surface excavated for the cell base construction will be proof-rolled using a heavy roller to assess the presence or otherwise of soft soils.

An assessment of potential settlements at the site as a result of the construction of the proposed containment cell has been undertaken (refer Appendix B). The results of the settlement analyses indicate that predicted settlements range from near zero to up to 250 mm.

The implications of these settlements on the design and performance of the containment cell are related to areas where higher settlements are experienced in close proximity to areas of minor settlement. Based on the site investigations and settlement analyses we expect that maximum differential settlement under the cell would be in the order of 250 mm over a 10 m length. The resulting differential settlements would need to be considered for their effects on:

- The elongation or strain of the basal liner system. For a differential settlement of 250 mm over 10 m the resulting elongation would be approximately 0.03% average strain (= 0.3 mm/m).
- The reduction in drainage gradients over the basal liner and risk of ponding of leachate. A differential settlement of 250 mm over 10 m would result in a tilt, or reduction of gradient, of 1 in 40 (= 25 mm/m).
- The expression of foundation settlement at the elevation of the capping system would be over a wider area than at the base of the cell and, given the design grade for the cell batters (refer Section 3.1.3), has no practical implications for capping system design.

These items are considered in Sections 3.4 and 3.5.

Settlement of Cell Materials

The internal settlement of the materials placed in the containment cell will depend on the degree to which they are compacted during placement. For example, a poorly compacted material that is wet during placement could settle by up to about 4% of its internal thickness, or approximately 500 mm for the maximum cell thickness of 13 m. This would result in large settlements in the capping system, and also the generation of excess leachate within the cell.

However, based on the required compaction criteria for the design (refer Section 3.2.1), internal settlement should be limited to approximately 0.5% to 1% of total fill thickness following construction of the capping liner, with leachate production limited to low levels. This magnitude of settlement is considered to have no practical implications for capping system design.

3.3.2 Slope Stability

Global Stability of Cell

Analyses have been performed for the cell design/landform to consider the risk of large-scale slope instability mechanisms (refer Appendix B). Analyses focused on long-term conditions and included both static and earthquake stability. The results of the slope stability analyses are summarised in the table below.

Table 5: Results of Global Slope Stability Analyses for Long-Term Conditions

Mechanism	Case	Calculated Factor of Safety (FOS)	Comment
Global instability of hillside above the containment cell	Static	1.59	shallow failure in residual soils
	Earthquake	1.35	
Instability of the cell materials at the cell batters	Static	2.87	
	Earthquake	2.31	
Instability through the cell materials and cell foundation	Static	2.75	
	Earthquake	2.03	
Instability through the cell materials, with sliding on the cell base liner	Static	1.67	refer note 1
	Earthquake	1.28	

Note 1. The analysis was performed using shear strength parameters of friction angle, Φ=15° and cohesion, c=0 kPa to reflect the weakest material and/or material interface in the base liner system with an HDPE geomembrane that is textured on both sides. The Technical Specification (Appendix D) requires direct shear testing of construction materials to confirm these shear strength parameters. Initial analysis performed using lower values for shear strength parameters to reflect a smooth HDPE geomembrane did not produce suitable FOS values.

The table provides the calculated Factor of Safety (FOS) against slope instability for each case considered. For long term conditions a FOS of at least 1.5 is commonly accepted as providing an acceptably low risk of slope instability; for earthquake conditions with pseudo-static analysis a FOS of greater than 1.0 is acceptable, but a FOS of at least 1.1 is preferred (e.g., Duncan and Wright, *Soil Strength and Slope Stability*, 2005)..

The results of the analysis indicate that the containment cell design achieves the Factors of Safety for slope stability commonly accepted by the geotechnical profession. As a result we expect there to be a low risk of slope instability for the proposed containment cell.

Capping System Stability

Analyses have been performed to consider the risk of instability within the capping system on the cell batter slopes (4H:1V). The potential failure mechanism considered is downslope sliding of the capping system along a surface within the capping system. This mechanism is sometimes referred to as 'veneer' stability. The veneer stability of multi-layer capping systems on slopes is known to depend on the shear strength of capping materials, and interfaces between materials, and on subsurface drainage components. The capping system components are presented in Section 3.5 below.

The analyses considered potential slip surfaces both above and below the textured LLDPE geomembrane component and included both static and earthquake stability. Potential slip surfaces above the geomembrane could potentially be subjected to destabilising water forces from infiltrating rainwater (pore pressures and seepage forces), although no significant pore pressure build up is anticipated in the cell given the geocomposite blanket subsurface drainage system design (refer Section 3.5.5). Potential slip surfaces below the geomembrane can potentially be subjected to destabilising gas pressures from within the cell, although no significant gas pressure accumulation is anticipated as described in Section 3.5.1.

The results of the capping system stability analyses are summarised in the table below.

Table 6: Results of Capping System Stability Analyses

Mechanism	Case	Calculated Factor of Safety (FOS)	Comment
Veneer stability above geomembrane	Static	1.94	
	Static with water pressure	not analysed	destabilising water pressure taken as negligible based on capping drainage design (refer Section 3.5.5)
	Static with gas pressure	not analysed	not applicable above geomembrane
	Earthquake	1.28 to 1.55	acceleration coefficient= 0.12g to 0.24g
Veneer stability below geomembrane	Static	2.25	
	Static with water pressure	not analysed	not applicable below geomembrane
	Static with gas pressure	1.50 to 1.88	gas pressure= 2 kPa to 4 kPa
	Earthquake	not analysed	less critical than above geomembrane case

Note 1. The analysis was performed using shear strength parameters of friction angle, $\Phi=25^\circ$ and cohesion, c=0 kPa to reflect the weakest material and/or material interface in the capping system above the textured LLDPE geomembrane (i.e. the interface between textured LLDPE and geocomposite drain). Further, the analysis was performed using shear strength parameters of $\Phi=29^\circ$ and c=0 kPa to reflect the weakest material and/or material interface in the capping system below the textured LLDPE (i.e., the interface between textured LLDPE and seal bearing layer soil). The Technical Specification (Appendix D) requires direct shear testing of construction materials to confirm these shear strength parameters.

The table provides the calculated Factor of Safety (FOS) against veneer instability for each case considered. These results indicate that the capping system meets the Factors of Safety for veneer stability commonly accepted by the geotechnical profession for the range of variables considered. As a result we expect there to be a low risk of capping instability for the containment cell

3.3.3 Mine Subsidence

There are no known historical mine workings within the site boundaries (refer Section 2.3.1). However, it is hypothetically possible that future coal mining could occur beneath the containment cell footprint, and that subsidence induced by such mining could result in distortions in the cell base liner system.

This issue has been addressed by considering the mechanical extensibility of the cell base liner materials. Both the textured HDPE geomembrane and the GCL are highly strain-tolerant materials (refer Section 3.4.3). Both are able to tolerate extension strains in the order of 10% (100 mm/m) without loss of function as low-permeability barrier material. Further, pipe work in the cell base comprises extensible polymer pipes.

The Mine Subsidence Board has indicated that the containment cell should be constructed to so as to not be damaged by the levels of predicted mine subsidence given below.

- *Maximum final subsidence of 200mm*. The cell is essentially a flexible and independent earthwork structure, is not rigidly connected to any services or external drainage structures, and therefore can subside without creating damaging stress concentrations. The value of 200mm is less than the calculated possible foundation settlement due to soil compression of 250mm that is accommodated in the design (refer Section 3.3.1). Therefore, the containment cell will not be damaged by subsidence of 200mm.

- *Maximum ground strains of ±2mm/m.* As indicated above, the allowable extension strain of both of the key materials of the cell liner system, the textured HDPE geomembrane and the GCL, is in the order of 100 mm/m. In addition, compressive strains are not damaging to these materials. Therefore, the containment cell will not be damaged by ground strains of ±2 mm/m.
- *Maximum tilt of 2mm/m.* The leachate drainage system at the cell base could be affected by tilt. However, because the system is a blanket drain with slopes ranging from 4% to 12%, even the flattest slopes at 4% equate to tilt of 40 mm/m which is greatly in excess of the nominated value of 2 mm/m. Therefore, because cell drainage would not be significantly affected, the containment cell will not be damaged by tilt of 2mm/m.

3.3.4 Seismic Displacement

Hypothetically, a large earthquake could cause ground surface rupture which could extend under the containment cell and breach the cell integrity. The overall risk of occurrence of this scenario is considered below.

1) Event: *a significant earthquake occurs in the site vicinity*
Two notable earthquakes have occurred in the site vicinity in the historical past (i.e. 1925 and 1989). A third occurred in 1994 within 30 km of the site. It is therefore considered that the annual probability of a significant earthquake in the site vicinity can be suitably characterised as 1:30.

2) Condition*: earthquake causes ground surface rupture*.
As noted in Section 2.3.2, no ground rupture or fault movement was reported in the 1989 Newcastle earthquake. Therefore, this condition is considered unlikely with a conditional probability of 1:10.

3) Condition: *ground surface rupture extends under the containment cell*.
The likelihood that a ground surface rupture would occur directly under the containment cell is generally considered extremely unlikely, given the area of the containment cell, 4 ha, relative to the total area of the Boolaroo region, 15 km radius or 70,700 ha. The conditional probability is considered equal to the spatial ratio of 1:17,670 (i.e. 4 ha ÷ 70,700 ha), with an increase to 1:10,000 in consideration of the suggestion that faults may be present on the adjacent site near the containment cell area (refer Section 2.3.2).

4) Condition*: ground surface rupture under the cell results in a significant liner breach*.
Due to the extensible nature of the liner system components (refer Section 3.4.3 below), and because the liner system will be under significant confining stress from the weight of the cell materials that will tend to reduce any breaching effects, this condition is considered possible, but not certain, with a conditional probability of 1:2.

The overall annual risk of occurrence can be estimated as the product of the above factors, or 1:6,000,000 (i.e. (30)(10)(10,000)(2)). This level of risk is extremely low. This risk is considered tolerable for the cell design, without the need for any specific design or management measures to be implemented, other than the use of extensible components in the liner system.

3.4 Cell Base

3.4.1 Cell Base Elevation

The elevation of the containment cell base has been established as described below using the ‘shallow burial’ approach nominated in the site *Conceptual Remediation Action Plan* (Soil and Groundwater Consulting, Oct 2008). With this approach the cell base is positioned above the post-remediation groundwater level to reduce potential interaction between cell materials and groundwater.

Post-Remediation Groundwater Level

The post-remediation groundwater level refers to the water table that will exist in the future in the shallow natural aquifer after excavation of the contaminated fill layer (and the fill aquifer) and after cell construction and capping. Available groundwater modelling results (Heritage Consulting, 2008) indicate that the elevation of this future groundwater level will be below current groundwater levels and will vary with rainfall patterns. There is, however, uncertainty in future groundwater level prediction.

The uncertainty in post-remediation groundwater levels has been addressed by including an underdrain system in the cell design. The underdrain system is described in Section 3.4.2 below.

Remediation Surface

The process of establishing the design cell base elevations first involved developing an indicative remediation surface in the cell area. This represents the anticipated surface of the base of excavation that is needed to remove the existing contaminated soils. The indicative remediation surface shown in Design Drawing D0011 was developed as described below.

1) Soil and Groundwater Consulting has developed "HIL-A" excavation depths at borehole locations in the cell area based on drilling and laboratory investigation and testing results from the 2008 environmental site assessment. Golder understands that these excavation depths reflect the depth to the top of the first recovered soil sample that met the NEPM HIL-A soil investigation level criteria.

2) The "HIL-A" excavation depths were increased by *0.2m* to make allowance for a base scrape that may be needed to provide a surface that could be successfully validated to meet site remediation criteria. In areas where no fill materials are present (i.e. the hillside in the northeast portion of the property), the allowance for a 0.20 m base scrape below current surface levels was assumed to appropriately represent the remediation surface.

3) The resulting base scrape depths were used along with the current survey of site surface elevations to generate preliminary remediation surface elevation contours. During this process, judgement was applied regarding base scrape depths that were inconsistent with other nearby values. For example, in cases where a base scrape depth appeared to be anomalously shallow, the deeper values from nearby boreholes were conservatively adopted; or where a base scrape depth appeared to be anomalously deep, the deep value was disregarded in favour of nearby shallower values with the assumption that a deep pocket of impacted soil could be managed by local excavation and backfill rather than by overall lowering of the remediation surface.

4) The preliminary remediation surface elevation contours were then modified to:

    a. smooth the contours slightly to create a constructable surface;

    b. exclude excavation of assumed uncontaminated rock material forming: (i) a noticeable grassy "hill" feature immediately to the west of shed 4; and (ii) a smaller grassy "hill" feature between the current site office building and shed 4; and

    c. a subcrop area of high rock, assumed uncontaminated, has been detected where indicated by the red shaded area on Design Drawing D0011; however, the remediation surface contours have not been adjusted at this local feature due to lack of detailed definition of the extent of the feature.

5) The result of this process is the indicative remediation surface in Design Drawing D0011 (Appendix C). The surface ranges in elevation from RL 44m (north-eastern corner) to RL 23.5m (west central boundary).

The remediation surface in Design Drawing D0011 can be compared to the existing ground surface in Design Drawing D0003. This comparison indicates that excavation to the remediation surface will vary from a minimum depth of 0.2m in the northeast cell area to a maximum depth of approximately 5m behind the existing retaining wall near the west central property boundary. The volume of excavation is in the order of a total of 134,000 m^3 (comprising approximately 116,000 m^3 of contaminated fill soil and 18,000 m^3 of presumed clean soil in the 0.2 m base scrape).

It is recognised that changes to the remediation surface in Design Drawing D0011 will be needed during construction. For example, in some areas it may be necessary to excavate deeper than the remediation surface in order to remove all impacted soils and reach a clean surface - these areas will generally need to be backfilled with clean soils to restore the remediation surface. In other areas, it may not be necessary to excavate all the way to the remediation surface to reach a clean surface. The Technical Specification (Appendix D) includes a process to confirm and refine the remediation surface based on actual excavation conditions.

Subgrade Surface

The subgrade surface plan is shown in Design Drawing D0021 and reflects the prepared surface on which cell construction will be initiated. The subgrade surface will be formed by cutting and filling from the remediation surface (Design Drawing D0011) after the remediation surface is validated.

Within the cell base liner area, the subgrade surface represents the bottom of the bearing layer. The bearing layer comprises a 200 mm-thick engineered fill that provides an appropriately smooth and even surface for deployment of the bottom component of the base liner, i.e., the GCL. In this area the subgrade surface will have regular slopes suitable for base liner and leachate collection system function; the slopes range from 4% to 12%, sloping down to the west, with a maximum average slope across the cell width of 10%.

Outside of the cell base liner area, the subgrade surface represents the following design elements (refer details on Design Drawings D0032 and D0033):

- the foundation surface for the cell perimeter bund – a flat base with a width of 10.6 m formed by cutting or filling;
- the surface of the cell perimeter drainage swale - a v-drain for surface water formed by cutting and positioned outside of the cell perimeter bund; width of 4 m and suitable as a cell perimeter access track for light vehicles during no-flow conditions;
- the surface of cutting needed along the eastern and north-eastern cell perimeter to provide space for the perimeter swale – these are permanent cuttings with batter slope of 2H:1V to 3H:1V.

The cut-fill balance for the subgrade surface reflects that a net excess of cut of approximately 23,000 m^3 of presumed clean material will be generated during formation of the subgrade surface (Design Drawing D0021) from the remediation surface (Design Drawing D0011). Much of the excess cut can be attributed to excavation of the two “hill” features near shed 4 identified in the “Remediation Surface” portion of this section.

Perimeter Bund

The cell design includes a perimeter bund. The perimeter bund provides a physical boundary for the limit of placement of contaminated soil within the cell and also provides a termination point for both the base liner system and the barrier layer in the capping system. The perimeter bund is approximately 900 m long, 1 m high with 2H:1V batters, and is constructed of clayey soil (refer Design Drawings D0022 and D0055). Additional description of the perimeter bund is provided in Section 3.4.3.

Bearing Surface

The bearing surface, as shown in Design Drawing D0023, is present within the cell base liner area and represents the top of the bearing layer. This is the surface where the bottom component of the base liner, i.e., the GCL, will be deployed. The bearing surface simply reflects a surface 200 mm higher than the subgrade surface (Design Drawing D0021). Construction of the 200 mm thick bearing layer above the subgrade will require placement of approximately 8,000 m^3 of clean clayey soil material, presumably sourced from the 23,000 m^3 of excess cut material generated during formation of the subgrade surface.

3.4.2 Underdrain System

Purpose

Soil & Groundwater Consulting indicated the need for an underdrain in a portion of the containment cell and presented the design intent and rationale for the system in their letter of 18 March 2010 to IFL. The underdrain has been included in the design as a precautionary measure in the lowest elevation portion of the cell because there is uncertainty as to whether groundwater levels beneath the cell could intermittently rise to the level of the cell base during future wet weather periods.

Design Features

The underdrain as shown on Design Drawing D0016 will be located in the north western corner of the cell adjacent and parallel with the western boundary of the cell and extending eastward from the edge of the perimeter berm for a distance of 20m. The underdrain function will not be installed all the way to the edge of the perimeter berm but will terminate 4 m from the edge due to uplift pressure management requirements as outlined below. The underdrain will not extend into the immediate area of the two leachate sumps. The underdrain will drain to a single outlet in the vicinity of Leachate Sump B.

The area of the underdrain represents approximately 10% of the cell base liner footprint and includes the design features outlined below, and as shown in Design Drawings D0016 and D0017.

- A series of parallel gravel-filled collection trenches installed into the subgrade surface in an east-west orientation. The trenches will be 500 mm deep and will be on 5 m centres. The upper 200 mm of each trench will be backfilled with bearing layer material (clayey soil). Modeling indicates that a 5 m centre-to-centre spacing is sufficient to effectively drain upwelling groundwater (Appendix F).
- A perforated collection pipe (75 mm diameter) will be installed within each gravel-filled trench.
- The collection pipes will be connected to solid wall drainage pipe(150 mm diameter) positioned under the centerline of the perimeter bund. The solid wall drainage pipe will be installed in a trench similar to those for the collection pipes, but backfilled with low-permeability material to minimise trench seepage flow.
- The solid wall drainage pipe will drain to one underdrain outlet point. The outlet point will be connected via an underground pipe to the existing western boundary trench for infiltration to the groundwater system under gravity drainage.

Uplift Pressure

Destabilising uplift pressures on the cell base liner could potentially develop within the underdrain system under a scenario in which the system outlet is blocked or restricted. In this scenario, it is hypothetically possible for the gravel-filled trenches in a subsystem to become saturated with groundwater entering at the highest point in the underdrain system. This could occur if groundwater outflow in the lower elevation portions of the underdrain is slower than groundwater inflow at higher elevation portions. If the underdrain became fully saturated, then hydrostatic conditions would be present in the underdrain with pressures corresponding to the elevation of the highest point in the underdrain system.

The design approach for uplift pressure management for this scenario is to discontinue the gravel-filled trenches along the western edge of the cell so that they only extend to the west to an elevation where maximum hydrostatic uplift pressure within the subsystem is equal to the vertical stress on the top of the HDPE geomembrane, with an uplift safety factor of 1.5. Calculations on this basis indicate that the gravel-filled trenches with perforated collection pipes need to terminate 4 m from the inboard toe of the perimeter bund. This arrangement is shown on Design Drawing D0017.

Liner Leak Detection

This underdrain system is not considered to be a leak detection system for the cell liner due to its design being collection trenches on 5m spacing and only covering 10% of the cell area. Specifically, the underdrain system will not be effective in collecting leachate leaking through the cell base, except perhaps if the leakage point was directly over a collection trench. This is because under normal conditions, i.e. with groundwater levels well below the liner, any leakage exiting the liner would travel preferentially downward to the water table rather than laterally to the nearest underdrain collection trench, thereby bypassing the underdrain system.

3.4.3 Base Liner

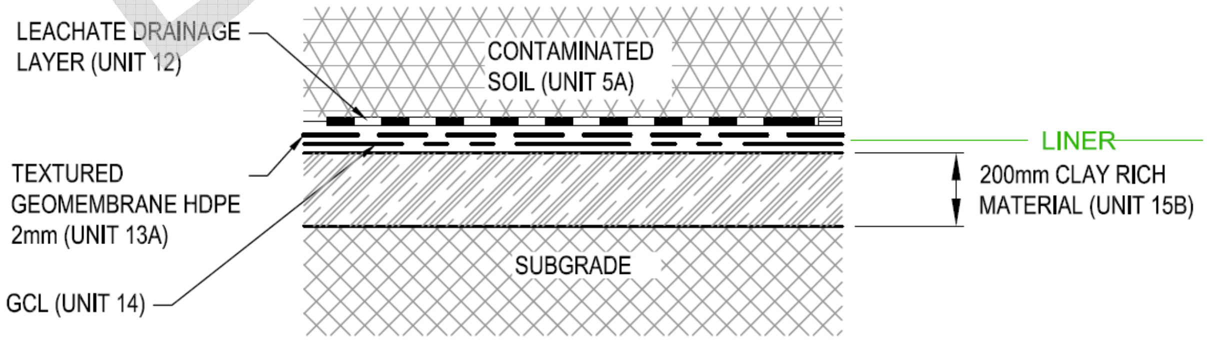
Purpose

The primary purpose of the cell base liner is to provide a continuous barrier at the base of the cell to limit contaminant migration from the cell. The cell base liner, in conjunction with the underdrain, has a secondary purpose to limit contact between cell materials and groundwater during potential rising groundwater conditions.

The base liner is a single composite liner comprising a welded high-density polyethylene (HDPE) geomembrane with an overlying leachate drainage layer (a two-sided geocomposite drain) and with an underlying geosynthetic clay liner (GCL) and soil bearing layer. A two-sided geocomposite drain is a manufactured product made up of an HDPE geonet drainage core sandwiched between two geotextile layers. A GCL is a manufactured product made up of a layer of bentonite clay sandwiched between two geotextile layers. Liner materials have been selected to be: (i) robust to withstand installation stresses; (ii) flexible to accommodate strains from foundation settlement and other post-construction displacements; and (iii) durable and resistant to degradation from long-term exposure to cell leachate in the temperature and pressure range expected at the cell base.

Liner Profile

The design base liner profile is shown below (refer Design Drawing D0034). The total footprint area of the base liner is approximately 40,300 m^2.



NOTE: GCL DENOTES
GEOSYNTHETIC CLAY LINER

TYPICAL BASELINER PROFILE

Design Features

Each component of the base liner is described in the following table. Additional material requirements are provided in the Technical Specification document (Appendix D).

Table 7: Base Liner Components

Key Material Requirements	Discussion
Bearing Layer [200mm thickness] [refer Design Drawing D0023]	
▪ Clean (uncontaminated) clayey soil; free of organic matter ▪ Compacted to > 98% std. max. dry density and within ±2% of std. optimum water content ▪ Gradation: ○ Max. particle size 9.5 mm; ○ Passing 2.4 mm sieve>90% ○ Fines > 30% ▪ Index properties: Plasticity index>15% and Liquid Limit>25% ▪ Emerson crumb classification>4	*Surface Preparation*: The bearing layer material must be compacted and prepared to provide an appropriately smooth and even surface for deployment of the GCL. The maximum particle size limitation will minimise installation damage to the GCL. *Clayey Soil*: A clayey soil is specified for the bearing layer to provide an additional layer of relatively low-permeability soil to enhance the barrier function of the base liner. It is anticipated that the material gradation criteria can be met by clean material sourced from cell excavations. *Slopes*: The bearing layer surface will have regular slopes ranging from 4% to 12%, with a maximum average slope across the cell width of 10% (refer Section 3.4.1 above).
GCL [Geosynthetic Clay Liner - comprising a layer of bentonite clay sandwiched between geotextile layers] [refer Design Drawing D0034] [installed as overlapped sheets]	
▪ Bentonite clay: swell index >24 ml/2g and fluid loss < 18 ml ▪ Product includes a nonwoven geotextile layer and is reinforced by needle punching; free of broken needles ▪ Total mass (dry) > 4000 g/m^2 ; Bentonite mass (dry) >3700 g/m^2 ▪ Tensile strength > 4 kN/m ▪ Peel strength > 360 N/m ▪ Permeability : testing using 100kPa effective confining stress a. tap water: $k < 5 \times 10^{-11}$ m/s b. deionised water with 0.1M $CaCl_2$: $k < 5 \times 10^{-10}$ m/s c. deionised water with H_2SO_4 at pH=3: $k < 5 \times 10^{-10}$ m/s Tests b. and c. conducted after permeation with deionised water.	Refer to the Technical Specification regarding requirements for: - *GCL deployment*: overlap dimensions and treatment between adjacent sheets; placement orientation such that the upper surface of the GCL comprises a non-woven geotextile to enhance interface shear strength with the overlying textured HDPE geomembrane - *Initial Hydration*: Tap water will be spray-misted on the surface of the bearing layer prior to GCL placement to provide a water source for the GCL to hydrate to 50% to 70% moisture content over a period of approximately 7 days. This limited amount of hydration will enhance future performance of the GCL upon exposure to leachate without triggering free swell and softening of the material that could result in GCL rutting during installation of the overlying geomembrane. As indicated in the Materials Compatibility Assessment (Appendix E), technical literature identifies that GCLs that are initially hydrated with fresh water often have significantly better performance in limiting leachate migration than GCLs that are initially hydrated by leachate. - *Covering*: immediate placement of overlying HDPE geomembrane and placement of soil cover within required time period; and restriction on trafficking on GCL The permeability of GCLs is known to be adversely affected (i.e., the permeability increased) by sustained permeation with water containing high calcium or magnesium concentrations, with the effect potentially being severe if the GCL is also subjected to repetitive saturation and desiccation cycles. Although significant calcium and magnesium concentrations are possible in cell leachate, as discussed below, the saturation-desiccation effect is not considered relevant to the performance of the GCL as the lower component of the composite base liner because cyclic saturation and desiccation will not be experienced by the GCL at the cell base. The cell base is well protected from atmospheric exposure and the GCL is isolated by the overlying geomembrane.

Key Material Requirements	Discussion
	Material requirements include permeability testing at an effective confining stress that is representative of base liner conditions. The permeability testing includes permeation with a calcium chloride solution to confirm that any increase in GCL permeability upon exposure to divalent cations (i.e. calcium) is relatively small. The concentration of the solution, 0.1M, is often used for GCL testing and represents approximately 4000 mg/L of calcium and 7000 mg/L of chlorine. These concentration levels are higher than those adopted in the Materials Compatibility Assessment (Appendix E) to conservatively represent potential cell leachate and are considered conservative for testing GCL materials for the cell design. The permeability testing also includes permeation with a pH=3 solution of sulphuric acid to confirm that any increase in GCL permeability upon exposure to acidic conditions is relatively small. The use of pH=3 for this testing reflects the value adopted in the Materials Compatibility Assessment (Appendix E) to conservatively represent potential cell leachate and is considered conservative for testing GCL materials for the cell design. The GCL material requirements for physical characteristics (i.e., total mass, bentonite mass, tensile strength, peel strength) are consistent with international standards and reflect a high quality "standard" GCL product of the type that has been available for more than 10 years. Technical publications indicate that these requirements will provide GCL physical performance as indicated below: - *Extensibility:* The required GCL product is expected to be capable of undergoing at least 10% tensile strain without significant reduction in its ability to maintain very low permeability performance, including performance across GCL overlap joints. This degree of extensibility is sufficiently high to accommodate anticipated foundation settlements (refer Section 3.3.1), hypothetical mining subsidence (refer Section 3.3.3), and hypothetical seismic displacements (refer Section 3.3.4). - *Internal Shear Strength:* The required GCL product, under confining stress levels representing base liner conditions, is expected to develop an internal shear strength that exceeds that reflected by the shear strength parameters of friction angle=15° and cohesion=0 that have been used in slope stability analyses to reflect the weakest material and/or material interface in the base liner system (refer Section 3.3.2). - *Interface Shear Strength:* The required GCL product, under confining stress levels representing base liner conditions, and with placement orientation as indicated above (non-woven geotextile in contact with the overlying textured HDPE geomembrane), is expected to develop interface shear strength exceeding that reflected by the shear strength parameters of friction angle=15º and cohesion=0 that have been used in slope stability analyses to reflect the weakest material and/or material interface in the base liner system (refer Section 3.3.2). This applies to the upper interface with the textured HDPE geomembrane and to the lower interface with the bearing layer soil.
HDPE Geomembrane [2mm high-density polyethylene, textured on both sides] [refer Design Drawing D0034] [installed as welded sheets]	
▪ HDPE density> 0.94 g/cm3 ▪ Product textured on both sides with asperity height >0.25mm	Refer to the Technical Specification regarding requirements for: - *Deployment*: extensive installation requirements are provided to protect the geomembrane from puncture, scratching or other

Key Material Requirements	Discussion
▪ Tensile strength at yield > 29 kN/m ▪ Elongation at yield > 12% ▪ Tear resistance > 249 N ▪ Puncture resistance > 534 N ▪ Oxidative Induction Time (OIT): >100 minutes at std. pressure >400 minutes at high pressure ▪ Oven aging at 85ºC for 90 days: OIT retained >55% at std. pressure OIT retained >80% at high pressure ▪ Environmental Tensile Load Crack Resistance (performed on smooth portion of sheet) >300hr	construction damage during deployment on the GCL, and also to protect the GCL from damage; - *Wrinkles:* Wrinkles will form in HDPE geomembranes prior to covering due to installation stresses and to thermal expansion of the material. The Technical Specification includes requirements to reduce and manage wrinkle formation - *Seaming:* extensive CQA requirements are provided for seam welding, seam testing and other geomembrane installation documentation - *Covering*: requirements are provided to protect the geomembrane from puncture, scratching or other construction damage during placement of the leachate drainage geocomposite and leachate collection pipes; restriction of trafficking on geomembrane - *Intimate Contact*: The performance of composite liner systems in minimising leachate escape from waste containment cells has been shown to be significantly better than that of single-component liner systems (e.g., Rowe (2005) "Long-Term Performance of Contaminant Barrier Systems") This is particularly true of liner systems using a GCL as the lower component. Intimate contact must be achieved between the upper geomembrane and the lower GCL to achieve the favourable composite liner effect. The requirements described above for GCL construction will promote the formation of intimate contact. The geomembrane material requirements for chemical and durability characteristics (i.e., density, OIT, oven ageing, and environmental tensile load crack resistance) are consistent with international standards and reflect a high quality material with enhanced durability and resistance to oxidation. Such materials are suitable for long-term service in conditions, such as municipal waste landfills liners, that are more severe than the containment cell in terms of having more aggressive leachate and significantly higher sustained liner temperature. With respect to resistance acidic leachate, it is noted that the technical literature such as Scheirs (2009, "A Guide to Polymeric Geomembranes: A Practical Approach") typically indicates that HDPE geomembranes, of the type that comply with the material requirements given above for the containment cell, are not attacked to a significant degree by concentrated acids and bases. For example, Scheirs reports on results from German studies showing that HDPE geomembranes immersed in pure sulphuric and nitric acid for 90 days experienced only minor changes in mass and strength and elongation at yield. The geomembrane material requirements for physical characteristics (i.e., texturing (asperities), yield strength and elongation, tear and puncture resistance) are consistent with international standards and reflect a high quality product with suitable robustness and strength. Technical publications indicate that these requirements will provide geomembrane physical performance as indicated below: - *Extensibility:* The required HDPE geomembrane product is expected to be capable of undergoing at least 10% tensile strain, both linear strain and biaxial strain, without significant reduction in its ability to maintain very low permeability performance, including performance across welds. This degree of extensibility is sufficiently high to accommodate anticipated foundation settlements (refer Section 3.3.1), hypothetical mining subsidence (refer Section 3.3.3), and hypothetical seismic displacements (refer Section 3.3.4) - *Interface Shear Strength:* The required HDPE geomembrane (textured on both sides) is expected to develop interface shear

Key Material Requirements	Discussion
	strength exceeding that reflected by the shear strength parameters of friction angle= 15º and cohesion= 0 that have been used in slope stability analyses to reflect the weakest material and/or material interface in the base liner system (refer Section 3.3.2). This applies to the upper interface with the leachate drainage geocomposite and to the lower interface with the non-woven geotextile component of the GCL.

Additional features of the base liner are described below.

- The base liner design is enhanced at the location of the two leachate collection system sumps. Although the footprint area of the sumps is small, approximately 64m^2 each, the sumps are considered high risk areas for leachate leakage for the following reasons: (i) there is likely to be shallow standing leachate present on the sump floor for extended periods of time; this differs markedly from conditions over the vast majority of the cell base area where rapid removal of any leachate is expected; and (ii) the geometry of the relatively small sump area increases the likelihood of geomembrane defects. The base liner enhancements at the leachate sumps are indicated in Design Drawing D0035, and comprise the placement of a double thickness of GCL (i.e. two layers placed together) with the addition of a 500 mm thick low-permeability (i.e., $k=-1x10^{-9}$ m/s) compacted clay liner below the double GCL layer.
- Internal bunds between sub-cells will be constructed in the containment cell to provide a physical barrier to contaminated soil and water movement during sequential excavation, lining, and filling of the cell. The location of the internal bunds is shown on Design Drawing D0023. A detail showing how the base liner system will be constructed at the internal bunds is provided in Design Drawing D0034.
- The cell perimeter bund provides the perimeter termination point for the cell base liner, and also for the cell capping barrier. The bund is 1 m high in all areas and will be not only a barrier to contaminated soil and water movement during cell construction, but also a prominent physical feature indicating the limit of placement for material within the containment cell. The perimeter bund is illustrated in Design Drawings D0056 and D0057. The cell perimeter bund material will be clayey soil that meets the same specification as that for the bearing layer material (refer Table 6 above), with the following exceptions: (i) the perimeter bund material will have a maximum particle size of 26.5 mm, which is larger than the corresponding value of 9.5 mm for the bearing layer material; and (ii) the perimeter bund material will require specific surface preparation (smoothing) with maximum particle size restricted to 9.5mm on the inboard slope of the bund in all areas where the GCL will be placed on the bund material.

3.4.4 Leachate Collection System

Purpose

The primary purpose of the leachate collection system is to remove leachate from above the base liner and thereby limit the potential for contaminant migration through the base liner. The system is designed to convey collected leachate to sumps where it can then be pumped out of the containment cell and treated or disposed appropriately. Specifically, a blanket leachate collection system will be installed overlying the composite base liner. The system will comprise a geocomposite drain with double sided geotextile filter. A network of slotted pipes within the gravel layer will drain toward two sumps along the western edge of the cell.

The leachate collection system is also considered capable of serving indirectly to collect and release excess gas pressure, if any, within the cell. This indirect function could occur via collection of gas by the blanket leachate collection layer, in the typical state where the layer is not saturated with leachate, and subsequently through release at the leachate collection sump manholes, which are not sealed to the atmosphere.

Leachate collection system materials have been selected to be: (i) non-reactive with potentially low pH leachate; (ii) resistant to corrosion; and (iii) with dimensions to reduce the potential for fouling/clogging.

Design Features

Each component of the leachate collection system is indicated in the figure in the preceding section and described in Table 7 below. Additional material requirements are provided in the Technical Specification document (Appendix D).

Table 8: Leachate Collection System Components

Key Material Requirements	Discussion
Leachate Collection Layer [geocomposite drain blanket layer] [refer Design Drawings D0024 and D0034]	
▪ Geocomposite material comprising HDPE triplanar geonets and double-sided non-woven, polyester, polypropylene, or polyethylene needle punched, resin or heat bonded geotextiles ▪ Thickness > 7.3 mm at 20 kPa and > 6.8 mm at 200 kPa ▪ Mass > 1,500 g/m^2 ▪ Hydraulic flow rate > 1.2 x 10^{-3} m^2/s at 200kPa with hydraulic gradient I = 1 ▪ Tensile strength > 26 kN/m ▪ Elongation at peak > 58% ▪ Ply adhesion (peel strength) >180 g/cm The non-woven geotextiles shall have the following properties: ▪ Mass > 130 g/m^2 ▪ Equivalent Opening Size < 90 μm	Refer to the Technical Specification regarding material requirements. *Deployment:* The leachate collection layer material will be placed directly on the HDPE geomembrane. The layer will be placed by approved professional installer, as indicated in the Technical Specification to avoid damage to the geomembrane. The required properties for the leachate collection layer material provide for durable material that will be essentially non-reactive with anticipated cell leachate. The required material properties also provide a durable, uniform drainage system that will have very high initial permeability, high clogging resistance due to the large spaces in uniform net, and ability to withstand long-term stresses with negligible net breakdown. With respect to clogging resistance, the inherent redundancy of flow paths within a blanket drainage layer greatly reduces the likelihood of widespread head build up due to blockage or clogging of the system. *Slopes*- The slope of the leachate collection layer will mirror the bearing layer surface, i.e., 4% to 12%, with a maximum average slope across the cell width of 10% (refer Section 3.4.1). These are relatively steep slopes that will promote rapid leachate drainage to collection pipes and minimise ponding, provided that collected leachate is removed from the sumps. The geocomposite layer protects the underlying HDPE geomembrane from damage by the net. Protection is required during cell construction from dynamic loads from construction plant, compaction stresses, and placement of the first layer 400 mm thick waste. Protection is also required for long-term conditions in which stress from the full weight of emplaced cell materials is acting on the liner. *Filter Layer* - The upper geotextile filter acts as a filter layer restricting migration of fine particles from emplaced cell materials into the leachate collection system. This provides protection against blinding and/or clogging of the leachate collection system. The required properties of this layer have been assessed to prove the necessary filtration function and to have sufficient mass and robustness to withstand construction stresses.

Key Material Requirements	**Discussion**
	Interface Shear Strength – Use of a geocomposite drain that includes a non-woven geotextile bonded to each side will maintain acceptable interface shear strength, particularly between the geocomposite drain and the underlying textured HDPE geomembrane (refer Section 3.3.2). The specification includes a peel strength requirement to ensure that the geotextiles are well bonded to the geonet core. *Resistance to creep under compressive load* – Manufacturers' test data indicates that tri-planar geonet materials, as well as other products, can safely sustain the maximum long-term compressive loads anticipated within the cell, in the order of 300 kPa. An important consideration in this respect is that while creep resistance decreases under elevated temperatures, the materials compatibility assessment for the cell materials indicates that there is negligible heat generation risk within the containment cell. *Clogging Resistance* - of the geocomposite drain is considered Suitable based on the following site specific factors. 1) The polymer materials making up the geocomposite drain are considered to be non-reactive with potential cell leachate 2) The favourable configuration of the leachate collection system, being a full blanket drain with inherent high redundancy of flow paths. 3) The favourable geometry of the leachate collection system, having relatively steep base slopes of 4 to 12% to promote leachate drainage. These slopes, when considered along with the high hydraulic efficiency of the geocomposite drain, will result in relatively high velocity leachate flow with correspondingly low potential for suspended solids deposition and accumulation.. 4) The flow capacity of the geocomposite drain is greatly in excess of that required to convey predicted leachate flows. For example, HELP model results for a severe long-term leachate generation scenario, indicate that peak leachate head build up within the geocomposite drain over most of the cell would be limited to less than 2 mm for a partially-clogged geocomposite drain. Note that partial clogging was modelled by assuming a factor of 10 reduction in drain permeability. 5) The HELP model results also indicate that long-term leachate generation rates within the containment cell are negligible, due primarily to the design of the capping system, and to a lesser extent to the capacity for moisture to be held in the pores of the emplaced cell materials. This suggests that the potential for ponding of leachate on the cell base liner may be negligible for any type of leachate collection layer design and clogging scenario.
Leachate Collection Pipes [160mm diameter HDPE with perforated wall] [refer Design Drawings D0024 and D0034]	
▪ PE100 material ▪ Perforations – 15mm diameter ▪ No filter sock	Refer to the Technical Specification regarding requirements for: *Perforations:* Perforations shall be 15 mm diameter drilled holes with 10 to 15 perforations per linear metre of pipe. All drill cuttings, burrs, and loosened pipe material from the drilling activity are to be removed before installation. *Joins*: Pipe joins shall be made using full face fusion welding. *Placement:* Pipes will be placed on the cushion geotextile with the requirement to avoid damaging the underlying HDPE geomembrane.

Key Material Requirements	Discussion
	The leachate collection pipes will be manufactured from high quality polyethylene polymer with excellent chemical durability (PE100). All connections and fittings for the pipes shall be manufactured with the same polymer and wall thickness as the pipe, and shall be solid wall units. The pipes will be 160 mm diameter PN 12.5 and SDR<14. The pipe diameter, nominal 160 mm, is significantly larger than needed to convey collected leachate to the sumps. The relatively large pipe diameter will provide substantial clogging resistance, as will the large diameter (15mm) of the pipe perforations. The pipe system design provides for access for pipe cleaning tools, such as water jetting jigs, at three perimeter points and at the two leachate sumps. These access points allow all segments of the pipe system to be accessed without having to negotiate sharp bends or corners.

Leachate Sumps

The cell design includes two leachate sumps on the western edge of the cell as indicated in Design Drawing D0024. The sumps are essentially depressions within the leachate collection system that are filled with the leachate collection materials (gravel) and fitted with manhole risers. Collected leachate flows to the sumps and accumulates there for removal through the manholes. Details of the sumps are provided in Design Drawings D0035 and D0036. Design features of the sumps are described below.

- Sump geometry:
  - depth of 1.25 m (below the adjacent base liner);
  - plan dimensions: at top of sump – approximately 7m x 7m , at base of sump - 2 m x 2 m; and
  - side slopes inclined at 2H:1V.
- Manhole Riser:
  - 1.2 m diameter concrete manhole pipe with base slab, 6 m total pipe length;
  - lower portion of manhole pipe has large perforations (50 mm holes) for leachate entry;
  - manhole pipe to be epoxy coated, including in perforations, to provide increased resistance to leachate attack;
  - manhole pipe penetrates through the capping system barrier layer; sealing measures are to maintain the integrity of the barrier layer;
  - manhole cover will permit air movement in/out of the manhole pipe to minimise the risk of gas pressure build up within the sump;
  - leachate collection pipes extend into manhole to provide access for pipe clean out; and
  - equipped with leachate level monitors and alarms at various leachate levels.
- Leachate storage capacity within the sump depth of 1.25m is approximately 10 m^3, comprising 8.5 m^3 within the pore space of the gravel and 1.5 m^3 within the manhole pipe.
- The sumps have an enhanced base liner system as described in Section 3.4.3.

The leachate sumps are not equipped with permanent leachate pumps due to anticipated long-term leachate collection rates being very low (refer Section 3.5.5below). The intended operation of the leachate system is with continuous passive leachate drainage into the sumps, and periodic leachate removal with pumps or vacuum hoses lowered into the sump without the need for personnel to enter the manhole. Under long-term conditions, pump out of the sumps may be needed approximately four times per year. More frequent pump out may be needed in the initial years after cell construction. Personnel will need to periodically enter the manhole for inspections and to access the leachate collection pipes for pipe clean out (confined space entry protocols to apply).

Summary

The overall design and planned operation of the leachate collection system, including features to address material compatibility issues identified in the Materials Compatibility Assessment (Appendix E), is expected to promote rapid removal of collected leachate throughout the cell design life. This expected performance can be considered along with the limited long-term leachate generation rate expected due to the design features of the cell capping system (refer Section 3.5). Such consideration indicates that, under long-term conditions, the likelihood for sustained leachate head to develop over widespread areas of the cell base is very low.

3.4.5 Assessment of Geocomposite Leachate Drain

HELP Modelling was undertaken to evaluate the rate of surface water infiltration using the capping system (Refer Section 3.5) and lining system designs presented in this design report. For the lining system the following specific parameters were considered in addition to the typical HELP model inputs:

- Geomembrane placement quality of 6 for "geotextile separating geomembrane liner and drainage limiting soil". An interface transmissivity of 2×10^{-10} m^2/s was used for the GCL-interface and was taken from observed values for a GCL in contact with a geomembrane as discussed by Rowe (2005).
- The bentonite component of the GCL was simulated using a 10 mm thick barrier soil liner underlying the HDPE geomembrane. The typical hydraulic conductivity for a GCL in the cap was increased by a factor of ten to reflect potential degradation of the GCL over time. The lower k value (reflecting 'new' GCL properties) was used in the base liner calculation in order to produce a conservative value for the maximum head on liner.
- reduction factors were used to allow for performance of the geonet over time (intrusion, creep deformation and clogging) with a total reduction factor of 19.8.

The use of LLDPE in the capping layer results in very low levels of leachate generated in the model (refer Section 3.5). In order to assess the performance of the geocomposite drain, higher leachate generation volumes were modelled. To achieve this, the barrier layer(s) (LLDPE, GCL) and infiltration drainage layer in the capping system were removed. This profile produces a severe long term leachate generation scenario. This scenario produces much greater rates of leachate generation than actual design scenarios. Profile B uses a geonet for leachate drainage (current design), and Profile C uses a partially clogged geonet (current design with partial clogging).

The contaminated soil permeability (layer 7) was increased by a factor of ten to $k = 1\times10^{-7}$ m/s for the severe scenario. The permeability, k, of the geonet for the severe scenario was selected based on geonet flow rates for a hydraulic gradient of one which is considered conservative for leachate drainage simulations as this will result in a lower value of k than if a more realistic (i.e., smaller) gradient were used. .

Severe Long-Term Leachate Generation Scenario

With the severe scenario, average annual infiltration through the capping system and into the containment cell materials was 28% of annual rainfall.

Table 9: Model Results for Leachate Drainage System for Severe Leachate Generation Scenario

	Profile Base-B (current design- geonet drainage layer)			**Profile Base-C** (current design with partially clogged geonet drainage layer)		
Item	**(mm)**	**(m^3/ha)**	**%**	**(mm)**	**(m^3/ha)**	**%**
Average annual lateral drainage collected from leachate collection layer	289	2890	28	289	2890	28
Average annual head on top of HDPE	0.118	-	-	0.269	-	-
Maximum daily head on top of HDPE	0.170	-	-	1.696	-	-

*Note: % of annual precipitation

The results show the maximum head on the HDPE liner for a clogged geonet is greater than for the unclogged geonet.

The profiles examined in the table above are built with average slopes and slope lengths. In order to assess the performance of Profile Base-C in localised areas of the cell with flatter slopes or longer drainage slopes, a further two cases were considered. These cases are modified profiles of Base-C and are summarised below.

Table 10: Profile Base-C - Current Design with Partially Clogged Geonet, Severe Leachate Generation Scenario, Worst-Case Leachate Drainage Paths

Item	**Profile Base-C**	**Profile Base-C1**	**Profile Base-C2**
Slope (%)	10	4	10
Slope Length (m)	50	65	80
Average annual head on top of HDPE (mm)	0.269	0.867	0.431
Maximum daily head on top HDPE (mm)	1.696	5.110	2.660

These results indicate that the predicted maximum daily head (i.e. largest value occurring during 100-year simulation) in the geocomposite drainage layer in the leachate collection system is less than 2 mm for typical leachate collection system geometry, and 5 mm for worst-case local geometry. These values are for a severe long-term leachate generation scenario and also assume that the permeability of the geocomposite has been reduced by a factor of 10 due to clogging. These values are less than the thickness of the geocomposite (approximately 7 mm) indicating that free drainage is predicted to be maintained in the geocomposite drain even under very severe modelling assumptions.

3.4.6 Contaminant Transport

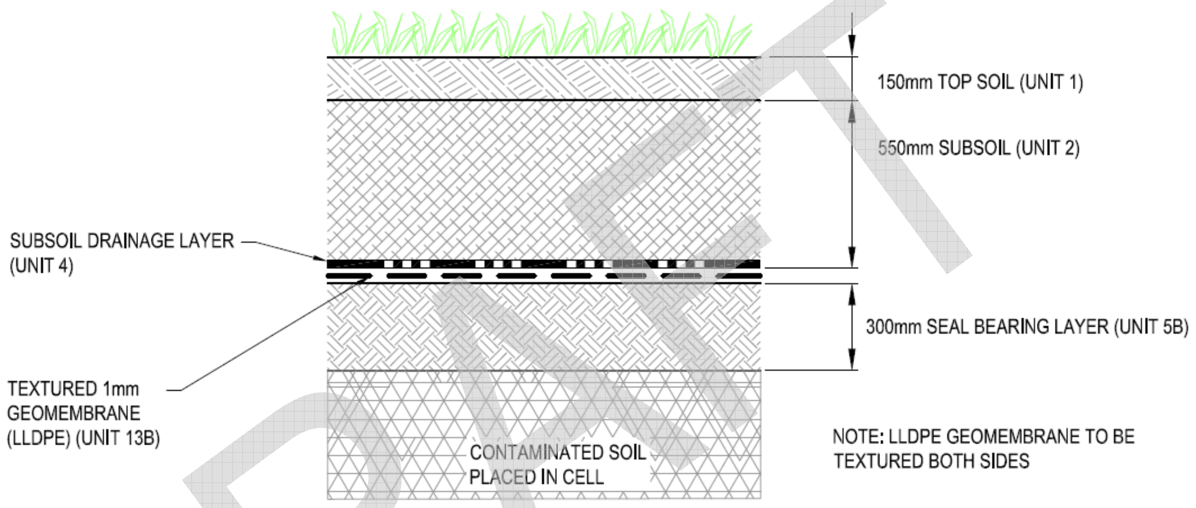
The Materials Compatibility Assessment (Appendix E) included an assessment of the potential for contaminant transport through the cell base via leakage and diffusion, including leakage through flaws in the base liner system that may be present despite the Technical Specification and Construction Quality Assurance (CQA) requirements. This contaminant transport assessment is considered to be very conservative for a number of reasons, but particularly because it assumes continuous leachate ponding over the entire cell base area. However, as indicated in the preceding section, the design of the leachate collection system, underdrain system, and capping system indicates that the likelihood for sustained leachate ponding over widespread areas of the cell base is very low.

The results of the (conservative) contaminant transport assessment are that the estimated total long-term combined flux of the major contaminants of concern, i.e. lead, cadmium, and zinc, through the base liner of the containment cell ranges from 0.4 kg to 1.6 kg per year. Golder understands that this magnitude of flux is not considered to be environmentally significant.

3.5 Cell Capping

3.5.1 Capping System Profile

The capping system profile is shown below (refer Design Drawing D0056). The total footprint area of the capping system liner is approximately 50,000 m^2.



TYPICAL CAP PROFILE

The capping system design does not include a gas collection system below the liner. A gas collection system is not considered necessary based on the evaluation of gas generation potential in the Materials Compatibility Assessment (Appendix E). The evaluation was based on the planned measures to limit organic content of cell materials as described in Section 4.3; and concluded that potential gas generation will be restricted to rates that can escape through the leachate collection system sumps and thereby limit internal pressure build up under the capping system to acceptable levels of less than approximately 2 kPa to 4 Kpa (refer Table 6).

3.5.2 Barrier

Purpose

The primary purpose of the capping system barrier is to provide a continuous barrier over the emplaced cell materials to limit rainwater infiltration into the cell, thus reducing the potential for leachate generation. The capping system barrier will also serve to limit infiltration of oxygen (atmospheric oxygen and oxygen-enriched rainwater) into the cell, thus reducing the reactivity and flammability potential of the emplaced cell materials.

The capping system barrier is a single liner comprising a welded linear low-density polyethylene (LLDPE) geomembrane, supplemented with an underlying seal bearing layer of well compacted clayey soil. Barrier materials have been selected to be: (i) robust to withstand installation stresses; (ii) flexible to accommodate strains from foundation settlement and other post-construction displacements; and (iii) durable and resistant to degradation from long-term exposure to expected conditions in the capping system.

Design Features

Each component of the capping system barrier system is indicated in the figure in the preceding section and described in the table below. Additional material requirements are provided in the Technical Specification document (Appendix D).

Table 11: Capping System Barrier Components

Key Material Requirements	Discussion
Seal Bearing Layer [300mm thickness] [refer Design Drawing D0051]	
▪ Clean soil for upper 100mm, potential to use contaminated soil from site for lower 200mm ▪ Compacted to > 98% std. max. dry density and within ±3% of std. optimum water content ▪ Gradation for upper 100mm: ○ Max. particle size 2.4 mm; ○ Passing 0.6 mm sieve>90% ○ Fines > 30% ▪ Index properties: Plasticity index>15% and Liquid Limit>25% ▪ Emerson crumb classification > 4	*Clayey Soil (contaminated)*: A clayey soil is specified for the seal bearing layer to provide an additional layer of relatively low-permeability soil to enhance the barrier function of the capping system. It is anticipated that the material gradation criteria can be met by selection of appropriate on-site contaminated material. *Surface Preparation*: The seal bearing layer material must be compacted and prepared to provide an appropriately smooth and even surface for deployment of the LLDPE. The maximum particle size limitation will minimise installation damage to the LLPDE. *Slopes*: The seal bearing layer will have regular slopes that reflect the final landform slopes, i.e., 4H:1V inclination on cell batters and 5% slope on the top of the cell (refer Section 3.1.3).
LLDPE Geomembrane [1mm linear low-density polyethylene, textured on both sides] [refer Design Drawing D0056] [installed as welded sheets]	
▪ LLDPE density < 0.939 g/cm3 ▪ Product textured on both sides with asperity height >0.25mm ▪ Tensile strength at break > 11 kN/m ▪ Elongation at break > 250% ▪ Modulus at 2% strain < 420 kN/m ▪ Tear resistance > 100 N ▪ Puncture resistance > 200 N ▪ Axi-symmetric break resistance strain > 30% ▪ Oxidative Induction Time (OIT): >100 minutes at std. pressure >400 minutes at high pressure ▪ Oven aging at 85ºC for 90 days: OIT retained >35% at std. pressure OIT retained >60% at high pressure	Requirements for LLDPE geomembrane installation, including deployment, wrinkle management, seaming, record keeping and covering will be similar to those for the HDPE geomembrane in the base liner system (refer Table 6). An additional requirement for deployment on the cell landform batters is that the LLDPE geomembrane will be rolled out in an upslope-downslope alignment to avoid seaming in a cross slope orientation. The LLDPE geomembrane material requirements for chemical and durability characteristics (i.e., OIT and oven ageing) are consistent with international standards and reflect a high quality material with enhanced durability and oxidation resistance. This material is suitable for long-term service in conditions similar to the cell capping system. The geomembrane material requirements for physical characteristics (i.e., texturing (asperities), break strength and elongation, modulus, tear and puncture resistance, axi-symmetric break strain) are consistent with international standards and reflect a high quality product with suitable robustness, strength, and high extensibility. Technical publications indicate that these requirements will provide geomembrane physical performance as indicated below: - *Extensibility:* The required LLDPE geomembrane product is expected to be capable of undergoing at least 30% tensile strain, both linear strain and biaxial strain, without significant reduction in its ability to maintain very low permeability performance, including performance across welds. Although settlement of the capping system is expected to be limited to relatively minor values in the order of 100mm (refer Section 3.1.1), LLDPE geomembrane extensibility will be protective against any unexpectedly large differential settlements. - *Interface Shear Strength:* The required LLDPE geomembrane (textured on both sides), under low confining stress levels representing capping system conditions, is expected to develop interface shear strength exceeding that reflected by the shear strength parameters of friction angle=25º and cohesion=0 that have been used in slope stability analyses to reflect the weakest material and/or material interface in the capping system (refer Section 3.3.2). This applies to the upper interface with the subsoil drain geocomposite and the lower interface with the seal bearing layer.

Additional features of the capping system barrier are described below.

- The cell perimeter bund provides the perimeter termination point for the cell capping barrier, and also for the cell base liner. The LLDPE geomembrane, will be terminated in a 500mm deep anchor trench (refer Design Drawings D0056 and D0057).
- Anchor trenches for the cell capping barrier will also be used at the following locations to enhance capping barrier stability on the sloping (4H:1V) batters of the cell landform : (i) at the mid-slope bench on the cell western batter; and (ii) at the top of the cell landform at the transition point between the 4H:1V batter and the upper 5% slope.

3.5.3 Subsurface Drainage

Purpose

The primary purpose of the subsurface drainage system is to remove infiltrating rainwater from above the capping system barrier and thereby limit the potential for water infiltration into the cell materials and associated leachate production. A secondary benefit of the system is that removal of infiltrating rainwater from above the capping system barrier increases the slope stability of the capping system on the cell batters through reduction in downslope seepage forces.

The system comprises a blanket drainage layer installed overlying the capping system barrier. The drainage material will be a geocomposite drain. A slotted collection pipe with closely spaced (10m centres) outlet pipes are included along the toe of the 4H:1V cell batters, and along the mid-slope bench on the western side of the cell, to discharge collected infiltration water to the surface drainage system.

Design Features

Each component of the subsurface drainage system is indicated in the preceding figure in Section 3.5.1and described in the table below. Additional material requirements are provided in the Technical Specification document (Appendix D).

Table 12: Subsurface Drainage System Components

Key Material Requirements	Discussion
Subsoil Drainage Layer [refer Design Drawings D0052 and D0056]	
▪ Geocomposite material comprising HDPE biplanar or triplanar geonets and double-sided non-woven, polyester, polypropylene, or polyethylene needle punched, resin or heat bonded geotextiles ▪ Thickness > 6.0 mm at 20 kPa ▪ Mass > 1,000 g/m^2 ▪ Hydraulic flow rate > 0.75×10^{-3} m^2/s at 20kPa with hydraulic gradient i = 0.25 ▪ Tensile strength > 15 kN/m ▪ Elongation at peak > 58% ▪ Ply adhesion (peel strength) >180 g/cm The nonwoven geotextiles shall have the following properties: ▪ Mass > 130 g/m^2 ▪ Equivalent Opening Size < 90 µm	Requirements for installation of the subsoil drainage layer, including placement of geocomposite layer to avoid damage to the underlying LLDPE geomembrane, and subsoil drainage pipe support, will be similar to those for the leachate drainage layer in the leachate collection system (refer Table 8). The required material properties for the subsoil drainage layer provide for system that will efficiently collect rainwater that infiltrates through the overlying topsoil and subsoil for discharge back to the surface. The required material properties also provide a durable, uniform combination layer that will have very high initial permeability and high clogging resistance due to the large pore spaces in the geonet. With respect to clogging resistance, the inherent redundancy of flow paths within a blanket drainage layer greatly reduces the likelihood of widespread head build up due to blockage or clogging of the system. The geocomposite layer protects the underlying LLDPE geomembrane from damage by subsoil material. Protection is required during cell construction from dynamic loads from construction plant, compaction stresses, and placement of the first lift of subsoil material.

Key Material Requirements	Discussion
	The upper geotextile filter acts as a filter layer restricting migration of fine particles from subsoil material into the drain. This provides protection against blinding and/or clogging. The required properties of this layer have been assessed to prove the necessary filtration function and to have sufficient mass and robustness to withstand construction stresses. -*Slopes*: The slope of the subsoil drainage layer will reflect the final cell landform surface, i.e., generally 4H:1V. Such steep slopes will promote rapid drainage and collection of infiltrating rainwater. *Interface Shear Strength* – Use of a geocomposite drain that includes a non-woven geotextile bonded to each side will maintain acceptable interface shear strength, particularly between the geocomposite drain and the underlying textured LLDPE geomembrane (refer Section 3.3.2). The specification includes a peel strength requirement to ensure that the geotextiles are well bonded to the geonet core.
Subsoil Drainage Pipes [100mm diameter HDPE with perforated wall] [refer Design Drawing D0056]	
▪ Draincoil material (heavy grade) ▪ Collection pipes – slotted Outlet pipes – solid wall ▪ No filter sock	Refer to the Technical Specification regarding requirements for slotting, joins, and pipe placement. Requirements include placement of pipes on the cushion geotextile to damaging the underlying LLDPE geomembrane. Outlet pipes are positioned relatively close together, i.e., on 10m centres. The pipe diameter, nominal 100 mm, is significantly larger than needed to convey collected water to the nearest outlet pipe. The pipe wall thickness will be specified considering the long-term stresses on the pipe.

3.5.4 Vegetation Growth Medium

Purpose

The primary purpose of the vegetation growth medium is to support vegetation growth that will: (i) limit erosion from the cell landform; and (ii) provide suitable visual amenity. The medium also serves a secondary purpose by providing a layer with substantial thickness that will reduce the potential for inadvertent human contact with emplaced cell materials. Further, the combination of vegetation growth, layer thickness, and capillary break achieved at the interface with the subsurface drainage layer, will enhance removal of infiltrating rainwater by plant evapotranspiration, thus reducing leachate generation potential within the cell.

Design Features

The vegetation growth medium comprises two layers as described below (refer figure in Section 3.5.1):

- *Subsoil*: A subsoil layer with the following characteristics will be placed on top of the geocomposite drain in the subsurface drainage system:
  - thickness - 550mm;
  - material – clean (uncontaminated) soil with physical characteristics and nutrient content appropriate for deep support of the plant species planned for revegetation of the cell landform;

  - placement - placement directly on the filter geotextile component of the subsurface drainage system with placement measures to reduce the potential for geotextile damage; and
  - compaction – only light compaction by tracking will be permitted such that the potential for damage to the underlying filter is minimised and the vegetation support capability of the material is preserved.
- *Topsoil*: A topsoil layer with the following characteristics will be placed on top of the subsoil:
  - thickness - 150mm;
  - material - clean (uncontaminated) soil with physical characteristics and organic and nutrient content appropriate for germination and shallow support of the plant species planned for revegetation of the cell landform; organic content may be supplemented by composted on materials; and
  - placement and compaction - topsoil will be spread on top of the subsoil with no compaction.

The combined thickness of the subsoil and topsoil layers is 700mm. This is also the total separation distance between the surface and the emplaced cell materials..

Revegetation

The cell landform will be revegetated with plant species that are selected based on the following concepts:

- plants to be primarily grasses, native to the region and/or site vicinity;
- established plants to be low maintenance, with no regular mowing required;
- plants to have rooting depth that will be generally within the vegetation growth medium (700mm); and
- species may be varied and/or grouped to enhance the visual appearance of the landform.

Plant species will be selected and seeding patterns will be developed to be consistent with final landscape design concepts. Final revegetation specifications will include weed management protocols and requirements for initial watering and plant density achievement.

Engineered erosion and sediment control measures should not be required for the cell landform once revegetation is successfully completed.

3.5.5 Infiltration

HELP Modelling was undertaken to evaluate the rate of surface water infiltration using the capping system design presented in this design report. Specifically:

- the transmissivity of the geonet in the cap was adjusted to reflect the hydraulic gradient of the geonet when placed at 25% slope in the cap (reflecting a hydraulic gradient of 0.25).
- reduction factors were used to allow for performance of the geonet over time (intrusion, creep deformation and clogging) with a total reduction factor of 3.64.
- Williamtown Average weather data was used to generate daily data synthetically sing the HELP model for a period of 100 years. Data was modified for the site coordinates and average monthly rainfall from the Newcastle Nobbys Signal Station.
- It was assumed a' good stand of grass' is achievable.

Model results for the capping system presented in this design report are summarised as follows**:**

Table 13: HELP Modelling Results for Capping System

Item	mm	m3/ha	% of annual precipitation
Average annual lateral drainage collected from infiltration drainage layer	617	6172	61
Average annual infiltration though LLDPE	<<1	0.007	0.00007
Average annual head on top of LLDPE	0.015	-	-
Maximum daily head on LLDPE	0.987	-	-

These results indicate extremely low infiltration. For design purposes we consider that the capping system design is expected to limit average infiltration into the cell to less than 0.1% of total annual rainfall, corresponding to an average infiltration rate of approximately 1mm per year. This will be achieved through a combination of evapotranspiration, runoff, and subsurface drainage.

Considering the footprint area that is relevant to infiltration, the adopted average infiltration rate corresponds to 50 m^3 of rainwater infiltration per year. In the long-term, the rainwater infiltration rate should be approximately equal to the rate of leachate collection in the leachate sumps.

The results indicate that the predicted maximum daily head (i.e. largest value occurring during the 100-year simulation) in the geocomposite drainage layer in the capping system is approximately 1 mm. This value is less than the thickness of the geocomposite (approximately 6 mm) by a factor of six, indicating that free drainage is predicted to be maintained in the geocomposite without pressure head build up in the geocomposite or development of downslope seepage forces in the cover soil. Maintaining free drainage is important to maintaining stability of the capping system on the cell batter slopes.

It is known that use of the HELP Model to assess drainage issues in cap system stability is not always appropriate because HELP works with a daily (24-hour) water balance while high intensity storms can occur over shorter than 24-hour duration and result in higher peak flows in the cap drainage system. The following factors are relevant to assessing the applicability of the HELP peak daily head prediction:

- The modelled cover soil layer above the geocomposite drain is 700 mm thick with a saturated hydraulic conductivity of $1x10^{-5}$ m/s, a field capacity of 0.131 v/v and a total porosity of 0.457 v/v.
- The highest daily rainfall from the HELP 100-year simulation was 127 mm, with a peak daily collection rate in the geocomposite drain of 55 mm/day, or 2.3 mm/h. Given the factor of safety of six for the hydraulic capacity of the geocomposite as mentioned above, this suggests that an infiltration rate of up to approximately 12 mm/h would be the capacity of the geocomposite drain. It is also noted that BOM data shows 283.7 mm as the maximum daily rainfall (between 1862 and 2010) at Newcastle so the HELP simulation value of 127 mm may be lower than desirable, although the HELP simulation produced appropriate average annual rainfall of 1017 mm.
- The absolute maximum water content in the cover soil from the 100-year HELP simulation was only 0.336 v/v (74% saturation). Detailed analysis of the first 20 years of output from the simulation indicates that the water content in the cover soil was less than 0.23 v/v (50% saturation) more than 98% of the time, and the value was less than field capacity 0.131 v/v (29% saturation) more then 86% of the time. The maximum number of days in a row that the water content stayed at or around 50% saturation was approximately 5 days.

- If the cover soil layer was fully saturated immediately before a very heavy rainfall occurred it could potentially transmit infiltrating rainwater water (at gravity drainage gradient=1) into the geocomposite drain at a rate equal to its saturated hydraulic conductivity, $1x10^{-5}$ m/s or 36 mm/h. Such a high infiltration rate, 36 mm/h, if actually possible to develop, is more than 15 times the HELP Model average rate of 2.3 mm/h.
- If the cover soil layer was not fully saturated then the infiltration rate into the geocomposite drain would be much smaller and significant rainfall would have to occur to saturate the layer before high infiltration rates could potentially develop. For example, if the cover soil was at 50% saturation, which may be the case less than 2% of the time, then a very large rainfall infiltration of I= (Total Porosity – starting moisture content)(Thickness)= (0.457-0.23)(700mm)= 160mm would have to occur to cause saturation. Adopting a runoff coefficient of 0.5 for a large storm on the landfill batters (25% slope) – an extended rainfall event of 160mm / (1-0.5) = 320mm may be required. Considering that some infiltration and drainage will occur under unsaturated conditions, the total rainfall event needed for saturation of the cover soil may be in the order of 350mm. This rainfall volume is equivalent to the total rainfall depth of a 100-year average recurrence interval (ARI) 48-hour event (determined from intensity-frequency-duration (IFD) data calculated in accordance with Australian Rainfall and Runoff (IEAust, 1987 Vol .2)) and would have to start on a day when water content is already unusually high (i.e. at 50% saturation). This would then have to be followed closely by another heavy rainfall event with greater than 12 mm/h infiltration rate (i.e. approximately 25mm/h rainfall) to overload the geocomposite drain.

Based on the above discussion, the sequence of events that would be necessary to create a situation where infiltration into the geocomposite drain would exceed the drain capacity (i.e. > 12 mm/h infiltration) is considered highly unlikely. The geocomposite drain properties identified for the HELP Model analysis, as given above, are therefore considered appropriate for design with a low risk of capping system instability developing due to inadequate geocomposite drainage capacity. This conclusion also depends on subsoil drain collection and outlet pipes functioning effectively so as to not impede drainage flows. Appropriate design details have been included to address this.

3.6 Surface Water

3.6.1 Cap Drainage

The design of the cell landform includes positive grades in all areas, batters (4H:1V), cell top (5%), and bench (1%), to collect and convey runoff generated from rainfall on the cell. Runoff will be primarily by surface water sheet flow, with surface water drainage patterns shown on Design Drawing D0054. The mid-slope bench on the western batter is designed with an inboard cross-slope of 10% (refer Design Drawing D0056) so that it can locally convey runoff from the upper cell batter.

The design includes an engineered drop structure, as shown in Design Drawings D0058 and D0059, for controlled flow of collected water from the mid-slope bench down to the landform toe.

3.6.2 Perimeter Drain

The cell design includes a perimeter drainage swale which serves to collect and convey runoff water from cap drainage as discussed above. This perimeter drain is designed to carry only the cap runoff and no allowance has been made for the collection of run-on water from Munibung Hill. The perimeter drain discharges to the Central Easement at current ground levels to the south western edge of the cell.

The perimeter drain design is presented in Design Drawings D0041 to D0047, with key design features indicated below.

- Length – 980m
- Section - V-drain shape, primarily 4m wide with depth ranging from 300mm to 500 mm; shape suitable for use as a cell perimeter access track for light vehicles during no-flow periods

- Surface - turf lining;
- Invert slope – primarily in the range of 0.5% to 5.0%

3.6.3 Design Details

The cell was divided into runoff sections, based on the drainage channel direction and slope. Runoff estimates were made using the standard procedures as provided in AR&R. The width of the drain was kept at 4 m and depth increased moving downstream to cater for progressively increasing runoff from the cap.

The drain design was undertaken for different design rainfall events up to the 100 year event. It was found that the required size for the drain did not vary significantly between the 20 year and 100 year ARI events. To reduce the risk of uncontrolled flow from these drains, the 100 year ARI standard was adopted.

A factor of safety was also provided in the design by increasing the runoff estimates by 50%.

3.6.4 Erosion Potential

The sheet flow generated over the cap batters can potentially result in erosion. Assuming a well vegetated (grassed) surface, velocity estimates were made for the design rainfall events. These estimates indicate velocity in the range of 0.6-0.8 m/s at the peak flow. This velocity range is not likely to cause any erosion and hence any engineered measures may not be required.

However, during the construction and vegetation establishment phase, there may be some erosion along the slopes. Appropriate erosion control measures would be required during the construction period. Reinforcement of the surface will also be required during the vegetation establishment phase.

4.0 CELL CONSTRUCTION

4.1 Construction Quality Assurance

A construction quality assurance (CQA) system will be in place for cell construction because the performance of these environmental protection systems, particularly the base liner and cap barrier, is strongly dependent on the quality of their construction. Full, detailed CQA requirements are embedded in the Technical Specification (Appendix D).

The CQA system comprises a combination of approval and documentation requirements for the cell construction contractor, inspection by the construction Superintendent appointed by IFL, and independent material testing (audit testing). Key elements of the CQA system are described below.

- *Materials Approval*: Properties of construction materials, particularly base liner and capping system materials, will be documented not only at their point of manufacture or supply, but also confirmed by sampling and testing upon delivery to site.
- *Compaction*: Compaction testing for density and moisture content will be routinely performed on all soil construction materials, as well as on the emplaced cell materials. The cell construction contractor will be required to engage an independent Geotechnical Inspection and Testing Authority to inspect earthworks construction and perform compaction testing.
- *Audit Testing*: The Superintendent will sample and test construction materials, including soils and geosynthetics, at their discretion to provide material property measurements that are independent of measurements by the cell construction contractor.
- *Hold Points*: The Technical Specification identifies numerous Hold Points which define points during the cell construction process where the cell construction contractor must halt work until the Superintendent approves previous work and/or contractor construction or testing documentation.
- *Full Time Inspection*: The Superintendent will be present on a full-time (continuous) basis for certain cell construction activities to provide additional confidence that construction is proceeding in accordance with specification requirements and design intent.
- *Field Testing*: Certain cell construction activities will require real-time field testing during construction. One example of this item is the required testing of all geomembrane welds.
- *Survey*: Numerous requirements for surveying of constructed alignments, inverts, and constructed soil and geosynthetic material surfaces are include in the Technical Specification. The survey provides data for Works-as-executed documentation and for confirming that design layer thicknesses have been achieved in the base liner and copping systems.

An overall outline of the major elements of the CQA system is provided in the table on the following page.

Table 14: Outline of Construction Quality Assurance (CQA) for Containment Cell

No.	Activity/Material	Material Testing				Construction Inspection				
		Supply Approval	Delivery	Compaction	Audit Testing	Hold Point	Full-time Inspection	Field Testing	Survey	Audit Testing
1	Excavation of Contaminated Soil and Formation of Subgrade			x		x	x		x	
2	Cell Base Liner									
	Underdrain	x	x	x	x	x		x	x	x
	Bearing Layer		x	x		x	x		x	
	Perimeter Bund		x	x		x			x	
	GCL	x	x		x	x	x			x
	Geomembrane HDPE	x	x		x	x	x	x		x
3	Leachate Collection System									
	Geocomposite Drain	x	x		x	x	x		x	
	Leachate Collection Pipe	x	x			x	x		x	
	Leachate Sump	x	x	x	x	x	x		x	
4	Cell Filling									
	Contaminated Soil			x	x				x	
	Bearing Layer for Cap		x	x		x	x		x	
5	Capping System									
	Geomembrane LLDPE	x	x		x	x	x	x		x
	Geocomposite Drain	x	x		x	x	x		x	
	Subsoil	x	x	x		x			x	x
	Topsoil	x	x			x	x	x	x	x
	Revegetation	x	x			x			x	

As an example of CQA system requirements, the following items will be included during construction of the base liner system.

- Continuous inspection will be performed during GCL installation to confirm that subgrade (bearing layer) conditions meet specification requirements and that the GCL pre-hydration is being effectively carried out.
- Field testing will be performed to confirm the continuity of the entire length of every weld made during HDPE geomembrane installation. Further HDPE weld testing will be performed in the leachate collection sumps. All personnel that are welding HDPE geomembrane will be required to demonstrate their competence through trial welds performed each day.
- HDPE geomembrane installation will be restricted to appropriate times of day to minimise the potential for wrinkle generation through thermal expansion of the geomembrane. Continuous inspection will be performed during HDPE geomembrane installation to confirm that geomembrane wrinkles are limited to specified dimensions.
- Continuous inspection will be performed during placement of geocomposite drain above the HDPE geomembrane to identify any geomembrane damage and confirm repair of all damaged geomembrane areas.

4.2 Environmental Management

A Construction Environmental Management Plan (CEMP) for overall site remediation works, including containment cell construction, is in preparation by others and will be informed by this Containment Cell Design Report.

4.3 Materials Management

In addition to the range of materials management requirements that will be included in the CEMP, the following construction management measures are included in the Technical Specification to limit the potential for short-term leachate generation within the cell.

- Limiting the exposure of excavated material to rainfall infiltration. Rainfall pH was reported to range between approximately 5.0 and 6.5, and would be saturated with respect to oxygen, and would therefore increase the potential for leaching of metals from slag fill. Any material required to be stockpiled prior to emplacement within the cell should be 'sealed' by surface compaction with plant to limit the infiltration of rainwater; this management approach would also limit dust emissions from the stockpile; and
- Efficient management of stormwater runoff within the containment cell footprint during construction, such that runoff is directed away from contaminated fill material to the extent practicable.

The Technical Specification incorporates the measures outlined below to reduce the amount of degradable organic material placed in the cell and thereby limit decomposition and gas generation potential.

- Trees/shrubs will be cleared and disposed off site as green waste or composted for use on site.
- Grass growing on the unpaved areas of the site will be slashed in a controlled manner that minimises dust generation and allows removal of grass cuttings down to the ground surface, with minimal soil recovery. This will be accomplished prior to the general surface soil scrape that will occur in all areas to be remediated. The grass cuttings will be considered potentially contaminated due to their proximity to the ground surface and possible presence of metal-contaminated dust with surface dust. Management of grass cuttings will therefore be by composting to eliminate degradable organic content and then mixing with soil and placement into cell (if contaminated), or by management with the trees/shrubs (if uncontaminated).

- Shallow excavated soil from vegetated areas of the site (i.e. topsoil within 150mm depth) will be presumed to be contaminated, primarily through metal dust deposition. The amount of organic matter in this material, for example grass roots, will be reduced by composting prior to placement in the cell. The composting specification will require that soil organic content will be reduced to less than 1% by weight.

4.4 Surface Water Management

A surface water management plan for overall site remediation works, including containment cell construction, is in preparation by others and will be informed by this Containment Cell Design Report.

5.0 CELL OPERATION AND MAINTENANCE

5.1 Overview

Operation and maintenance activities are required for some of the containment cell systems in order to promote acceptable long-term cell performance. A cell operation and maintenance plan (Cell O&M Plan) will be prepared at a later stage as part of long-term cell management documentation.

The Cell O&M Plan will include a combination of inspection, monitoring and maintenance and/or repair activities to be performed on a scheduled basis. An overall summary of key items for the Cell O&M Plan is provided in the table below.

Table 15: Summary of Containment Cell Operation and Maintenance Requirements

ITEM	ACTIVITY	FREQUENCY
Cell Cap		
Vegetation		
Vegetation and erosion inspections	▪ Locate, document & remediate erosion areas > 2 sq.m. ▪ Reseed areas without vegetation > 2 sq.m.	Quarterly during year 1, then annually
Weed Control	▪ Target invasive and/or deep rooted species and trees	Monthly during year 1, then annually
Mowing	▪ Mow grass if required (no need for mowing anticipated with appropriate grass species selection)	if required
Tree and Shrub Sapling Removal	▪ Remove tree and shrub saplings	24-monthly
Surface Levels and Cap Drainage		
Site Walkover Inspection	▪ Backfill depressions > 200 mm; Remediate Depressions > 500 mm including geomembrane replacement; Assess additional remedial measures if re-occurring ▪ Identify and document wet areas or seepage and assess remedial measures if re-occurring ▪ Inspect cap following strong earthquakes and maintain and repair cap if required	Quarterly during year 1, then 6-monthly within 24 h of heavy rain (>50 mm/d)
Inspect subsurface drain pipe outlets within 24 h of heavy rain (>50 mm/d)	▪ Visually assess flow and document outlets with anomalously low flow; Assess additional remedial measures if re-occurring	within 24 h of heavy rain (>50 mm/d)
Under Drain		
Measure Flow Rate at gravity drain outlet	▪ Verify pipes not blocked	6-monthly for first 3 years, then annually
Leachate Collection System		
Sump Inspection	▪ Confined space entry; dewater sump ▪ Inspect general conditions of sump and inlet pipes ▪ Inspect manhole for concrete attack and assess remedial measures	After 2 months, then annually

ITEM	ACTIVITY	FREQUENCY
	▪ Inspect and test level monitor and alarm hardware ▪ Desist if > 75mm silt present	
Leachate Collection Pipe Cleaning	▪ Water jetting (or similar) over full pipe length ▪ Use perimeter access points ▪ Use leachate sump for access; requires confined space entry and sump dewatering	After 1 year, then 5-yearly
Pump Out	▪ Pump out leachate collected in sumps for treatment and/or off site disposal	as required (anticipated quarterly)
Perimeter Swale		
Inspect Swale Drain	▪ Remove thick vegetation ▪ Remove sediment >75mm ▪ Repair areas of erosion; Install erosion control mats where >100mm of erosion ▪ Repair drop structures or replace disturbed sections if required	6-monthly and within 24 h of heavy rain (>50 mm/d)
Other Maintenance		
Maintain Security of the Cell	▪ Maintain fencing, gates, locks ▪ Review and/or maintain other security measures	Ongoing
Groundwater Monitoring		
Groundwater Levels and Quality and Monitoring	requirements to be determined by others	requirements to be determined by others

5.2 Groundwater Monitoring

A groundwater monitoring plan for the entire site, including the containment cell area, is in preparation by others and will be informed by this Containment Cell Design Report.

Report Signature Page

Your attention is drawn to the document "Limitations", which is included in Appendix G of this report. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be. The document is not intended to reduce the level of responsibility accepted by Golder Associates, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

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APPENDIX A

Geotechnical Report – Field Investigation and Laboratory Testing

APPENDIX B

Geotechnical Report - Interpretation

APPENDIX C

Design Drawings for Containment Cell

APPENDIX D

Technical Specification for Containment Cell

APPENDIX E

Materials Compatibility Assessment

APPENDIX F

Underdrain System Modelling

APPENDIX G

Study Limitations

STUDY LIMITATIONS

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