Environment Protection Authority

Environmental management of landfill facilities

Solid waste disposal

EPA
South Australia

Environmental management of landfill facilities – solid waste disposal

This guideline supersedes and replaces the *Environmental management of landfill facilities (municipal solid waste and commercial and industrial waste)* [EPA 2007]. Any reference to the 2007 guidelines in any statutory instrument or other publication should now be read as a reference to the *Environmental management of landfill facilities – solid waste disposal* (EPA 2019).

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Disclaimer

This publication is a guide only and does not necessarily provide adequate information in relation to every situation. This publication seeks to explain your possible obligations in a helpful and accessible way. In doing so, however, some detail may not be captured. It is important, therefore, that you seek information from the EPA itself regarding your possible obligations and, where appropriate, that you seek your own legal advice.

Contents

List of tables

Abbreviations

APVMA	Australian Pesticides and Veterinary Medicines Authority
AWWA	Americal Water Works Association
CQA	Construction Quality Assurance
CSM	Conceptual Site Model
DEW	Department of Environment and Water
EIS	Environment Impact Statement
EMS	Environmental Management System
EP Act	Environment Protection Act 1993
EPA	South Australian Environment Protection Authority
EPP	Environment Protection Policy
GCL	Geosynthetic Clay Liners
GITA	Geotechnical Inspection Testing Authority
IQA	Independent Quality Assurance
ISO	International Standards Organization
LEMP	Landfill Environment Management Plan
LFG	LandFill Gas
MQA	Manufacturing Quality Assurance
MRRF	Materials Resource Recovery Facility
NATA	National Association of Testing Authorities
QA	Quality Assurance
PIRSA	Department of Primary Industries and Regions, South Australia

Interpretation

Definitions included in this document are defined in existing EPA legislation and guidance material which should be referred to for interpretation, in particular:

- *Waste definitions* (2019)
- Part 1 of the *Environment Protection Act 1993*.

1 Introduction

This guideline supersedes and replaces the *Environmental management of landfill facilities (municipal solid waste and commercial and industrial waste)* [EPA 2007]. Any reference to the 2007 Guidelines in any statutory instrument or other publication should now be read as a reference to the *Environmental management of landfill facilities – solid waste disposal* (EPA 2019).

Poor environmental practices have universally led to a degradation of the world's water, air and land resources. National and international environment protection authorities are continually refining policies, regulation, practices and procedures with the aim of minimising the risk of environmental harm as part of transitioning to a sustainable future.

Landfill has an important role to play as part of the transition required to achieve sustainable resource recovery and waste management. The role for landfill primarily involves accepting those wastes that are unable to be 'avoided, reduced, reused, recycled or recovered'. It is vital that a precautionary approach be adopted to adequately address the environmental risks of landfill facilities, recognising that residual waste composition has changed, and will continue to change over time in response to technological advances in recovery activities.

Development and operation of landfill facilities in South Australia are activities of environmental significance that require development approval under the *Development Act 1993* and an environmental authorisation in the form of a licence, as specified in section 36 of the *Environment Protection Act 1993* (EP Act). This document is intended to provide guidance to landfill operators, developers, planning authorities and regulatory bodies on the site selection, development, design, construction, operation, closure and post-closure management of solid waste landfill facilities which comply with the EP Act.

Landfill design comprises the following interconnected elements that are further explained in this guideline, together with operational requirements:

- liner system at the base and side of the landfill
- leachate collection system
- cover system
- gas collection system
- environmental monitoring system
- post-closure plan for maintenance and utilisation of the landfill after its closure.

This second edition of the guideline has been restructured to reflect each of the design and construction elements as an integrated system, together with regulatory and operational controls. This revision reflects contemporary best practice engineering design and construction, based on a revised classification system, together with the inclusion of new operational practices (including daily cover and resource recovery activities); updated regulatory references, in particular the *Environment Protection (Waste to Resources) Policy 2010* (Waste EPP) and *Environment Protection (Water Quality) Policy 2015* (Water EPP), and expanded guidance on closure and post closure and landfill gas obligations.

The new information reflects the changing nature of residual waste composition in relation to disposal and the need to design and operate landfill facilities that take into account the changing chemical and physical composition of residual waste, now and into the future. This is especially relevant as South Australia strives to introduce new and innovative resource recovery activities to secure our position as a global leader in resource recovery and waste diversion from landfill.

1.1 Objectives

The principal objectives of this guideline are:

- To promote best practice landfill design, construction, operation, closure and post closure within South Australia.
- To minimise the risk of adverse impacts on the land, water and air environments associated with waste disposal.
- To provide direction, certainty and consistency for the site selection, development, operation, closure and post-closure management of landfill facilities.

1.2 Purpose

This guideline relates to the conduct of a landfill facility for the disposal of solid waste[1]. It sets out the EPA's expectations for the appropriate conduct of landfill activities in accordance with the EP Act. Compliance with this guideline will be relevant to the EPA's assessment of whether a person has complied with the legislation (including environment protection policies).

1.3 Scope

This guideline applies to:

- Development proposals for new landfill facilities.
- Operators of existing landfill facilities who currently hold a licence in accordance with section 36 of the EP Act.
- Applications to extend or amend existing landfill facilities that trigger development as defined under the *Development Act 1993* or as required by an existing condition of licence.
- Closed landfill facilities.

This guideline is applicable to landfill operators, developers, planning authorities and other regulatory bodies and provides guidance on site selection, development, design, operation, closure and post closure of landfill facilities that receive and dispose solid waste.

This guideline does not address the following activities:

- disposal of *liquid waste*
- disposal of *radioactive waste*
- filling of land with waste derived materials for beneficial reuse
- onsite containment of contaminated soil.

1.4 How the EPA will use this guideline

The EPA will use this guideline:

- As the basis for preparing comment or direction on development applications for proposed landfill facilities under the *Development Act 1993.*
- When making regulatory decisions under the EP Act relating to landfill operations, including the development of licence conditions.

This guideline recognises that existing and proposed landfill facilities are each subject to a different suite of individual site-specific circumstances. It will assist the EPA in maintaining best practice environmental standards that reflect particular site circumstances to further the objects and required outcomes of this guideline.

The EPA will assess each facility on a case-by-case basis when applying the suggested measures and minimum engineering requirements to further the guideline's objectives and required outcomes consistently across industry. Suggested measures and minimum requirements will be enforced through conditions of licence consistent with the environmental and regulatory risks presented by the site.

1.5 Regulatory and technical basis for this guideline

The EP Act is the legislation addressing pollution in South Australia. This guideline has been developed to advise industry on how the EPA will seek to apply section 25 and mandatory provisions of environment protection policies, in particular:

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1 Schedule 1 of the EP Act lists prescribed activities of environmental significance. Section 3(3) of Schedule 1 specifies 'the conduct of a depot for the reception, storage, treatment or disposal of waste'. This guideline details the requirements for the disposal of waste.

- Section 25 – which imposes a general environmental duty on all persons undertaking an activity that pollutes or might pollute the environment, to take all reasonable and practicable measures to prevent or minimise any resulting environmental harm.
- Section 10 – Objects of the Act:
  - To promote the principles of ecologically sustainable development, including avoiding, remedying or mitigating any adverse effects of activities on the environment.
  - To promote the circulation of materials through the waste management process and apply the waste management hierarchy to minimise waste disposal.
  - To require persons engaged in polluting activities to progressively make environmental improvements as such improvements become practicable through technological and economic developments.
- Environment Protection (Water Quality) Policy 2015
  - To take all reasonable and practicable measures to prevent or minimise environmental harm which includes a requirement to avoid activating trigger values relevant for waters at the landfill facility.
  - To comply with mandatory minimum requirements of this guideline to avoid polluting waters.
  - To have regard to recommendations in this guideline to avoid polluting waters.
- Environment Protection (Waste to Resources) Policy 2010
  - To require wastes to be treated prior to disposal at a landfill facility.
  - To prohibit certain wastes from disposal at a landfill facility.

This guideline has been developed following the review and consideration of existing guidance documentation including:

- *Wastewater lagoon construction (EPA 2018)*
- *Waste definitions (EPA 2009)*
- *Current criteria for the classification of waste – including industrial and commercial waste (listed) and waste soil (EPA 2010)*
- *Guideline for stockpile management (EPA 2017)*
- *Regulatory monitoring and testing groundwater sampling (EPA 2007)*
- *Landfill gas and development near landfills advice for planning authorities and developers (EPA 2012)*
- *Waste management: regulatory framework and objectives (EPA 2008)*
- *Waste and the South Australian planning system (EPA 2016)*
- *Industry code of practice for the management of clinical and related wastes (EPA 2007)*
- *Guidelines for liquid waste classification test (EPA 2003)*
- *Environmental guidelines on solid waste landfills (NSW EPA 2016)*
- *Siting, design, operational and rehabilitation of landfills (VIC EPA 2015)*
- *Guidance on the Management of Landfill Gas (UK Environment Agency 2004)*

1.6 Implementation

The guideline will apply to all new development applications, including amendments to existing development approvals, upon publication. All existing licensed landfill facilities must comply with the guideline for all future cell developments, or within 12 months of publication, whichever comes first. Existing leachate lagoons that do not meet the minimum specification of this guideline do not need to be updated within 12 months of publication, unless it is demonstrated that they are leaking or they are no longer serviceable. The EPA will assess the applicability of amended requirements of the guideline on a site-specific basis, taking into consideration existing approvals and site-specific risks. The EPA will amend conditions of licence where applicable.

The technical requirements outlined in this guideline that draw upon external published standards may be subject to revision from time to time. It is expected that proponents will adopt the updated requirements as specified in the current external published standard and not rely on the frequencies and test methods prescribed in this version of the guideline.

2 Regulatory environment

The operation of a landfill facility for solid waste disposal in South Australia is a prescribed activity of environmental significance and requires an environmental authorisation in the form of a licence in accordance with section 36 of the EP Act. The location, geological characteristics of the site, proximity to sensitive receivers, and the type and volume of waste proposed to be received at a landfill facility will, to a large extent, dictate design, operational, management and monitoring controls that will be required to be implemented at the facility during operation and post cessation of disposal.

The regulatory environment in South Australia extends beyond the EP Act and it is the responsibility of landfill operators to familiarise themselves with relevant legislative requirements during the establishment and scoping phase of their development and throughout the operational, closure and post-closure period. This section outlines the regulatory setting for landfill facilities and will assist in the selection and best practice management for such facilities.

2.1 Siting

Objectives

The objectives of siting landfill facilities are to:

- Assess the relative suitability of potential sites based on consideration of capacity, potential risks to the environment, natural resources, transport access, infrastructure, and social and economic factors.
- Identify sites that are not suitable because of unacceptable risks to the environment or other factors.

Required outcomes

The required outcomes of siting landfill facilities include:

- Plan the site access for efficient site operation, to protect local amenity and to prevent unauthorised access to the site and the active tipping face.
- Plan the site and design appropriate engineering measures to optimise site operations and minimise emissions associated with the disposal of waste (including landfill gas, leachate, air quality, surface and groundwater).

The location of a landfill and the type and amount of waste it is to receive are the primary determinant of the extent to which the landfill will pose an environmental risk. The aim of choosing a suitable site is to avoid the need to take action to reduce environmental impacts where natural features already protect environmental quality and minimise the risk to the environment. In an ideal situation, these barriers would be the primary mechanism used to protect the environment and avoid nuisance to the host community. Engineering and management measures will be considered as a secondary factor to prevent the potential for adverse impact to human health, the environment and amenity.

At the screening stage, consideration should be given to the requirements for a baseline environmental assessment. Sufficient investigation should be undertaken to provide adequate details for screening and assessment purposes and to determine the landfill classification.

2.1.1 Suggested measures

Community considerations

Assessment of potential landfill sites will need to consider the concerns of the host community. This will allow information sharing and early identification of issues of interest that can be considered in the screening process. A program of community participation can also be continued for subsequent phases of the project.

Guidance for considering the concerns of the host community is presented in the *Guidelines for community engagement* (EPA 2018).

Consideration needs to be given to planning issues including site access, land zoning and acceptable land uses for selected sites and adjacent areas.

Environmental considerations

Screening and assessment of the suitability and relative merits of potential landfill sites will require a preliminary assessment of site conditions and potential impacts on the environment. This includes consideration of topography, surface water, drainage, hydrogeology (groundwater), geology, climate, background concentrations of pollutants and distance to sensitive receptors/land users.

Assessment of site conditions typically includes a review of available information and a program of site investigation to establish baseline environmental conditions, the location and separation from sensitive receptors and beneficial users of surface and groundwater.

Evaluation distances

Evaluation distances provide an envelope around an activity (or multiple related activities) within which environmental risks need to be assessed, to ensure that activities are appropriately sited and that risks are reduced to acceptable levels (eg below appropriate environmental criteria). The separation distance that results from the evaluation process, which may also be referred to as buffer distances or zones, may differ from the recommended evaluation distance. Further information on evaluation distances area available in *Evaluation distances for effective air quality and noise management* (EPA 2019).

Separation between the landfill and sensitive land uses acts as a primary control of potential adverse impacts. Appropriate site management practices during site development, the operational stage and for closed landfills will also be required to protect sensitive land uses.

Waste management facilities should be appropriately separated from sensitive land uses and environmentally sensitive areas. The evaluation distance (or separation distance determined through an assessment/evaluation process) should be incorporated within the allotment (premises) containing the waste management facility. The evaluation/separation distance should be measured from the boundary of the waste operations area (or landfill facility) and includes all closed, operating and future cells.

The intervening area (buffer zone) may be suitable for planting of vegetation as a visual screen and to assist in control of litter, dust and odour. The following evaluation distances are recommended at landfill facilities:

- 500 m to 'sensitive land' as defined in the EP Act. A lesser buffer may be acceptable where it is considered compatible with the surrounding area and land uses so that there will be an effective buffer of 500 m between the landfill and any sensitive or incompatible land use.
- 3,000 m between an airport utilised by turbojet aircraft and 1,500 m between an airport utilising piston aircraft respectively, and a landfill that attracts birds (due to food or other wastes). Landfills that abut this buffer zone will need to demonstrate compliance with the requirements of the Civil Aviation Authority and approved by the EPA.

Surface water

Landfills are generally not permitted in sensitive water catchment areas or near marine or coastal reserves. If a new site is required in one of these areas or an old site already exists, they may require significant engineering and management controls to protect the environmental values of water.

A minimum buffer distance of 500 m shall be maintained between areas dedicated for waste disposal and the nearest surface water (whether permanent or intermittent) and the '100-year flood plain'.

Greater separation distances or increased management controls may be required based on assessment of surface water conditions at the site(s) and the potential consequences of uncontrolled discharges to surface waters.

Groundwater

Landfill facilities are not encouraged in areas of karstic terrain, where waste is proposed to be placed below the groundwater table, with groundwater springs or seeps, or sensitive groundwater values (for aquatic ecosystems or potable use) or groundwater protection zones. Sites in these areas would require significant engineering and management controls to protect the environmental values of waters.

Appendix 1 sets out recommended separation distances for landfill facilities, based on their classification. The separation distances apply to the seasonal high water table at the site. Greater separation distances may be required by the EPA based on site-specific conditions.

Preferred sites for landfill facilities are those that reduce the risk of pollution of groundwater by providing a natural unsaturated attenuation zone beneath the base liner for contaminants that may infiltrate through the liner. Natural unsaturated zones which retard flow of water that infiltrates through the liner are also preferred. For example, sites with clay soils that have low permeability and natural attenuation properties are preferred to those with sandy soils.

Aboriginal and heritage responsibilities

Landfill screening and siting must consider the effect on any Aboriginal sites of archaeological, anthropological or other significance including any sites listed in the registers maintained under the *Aboriginal Heritage Act 1988* including the *Register of Recognised Aboriginal Representative Bodies, Register of Aboriginal Sites and Objects* and *Register of Agreements*.

Flora and fauna, heritage and natural resources

Screening and siting of facilities and management strategies should consider potential impacts on flora and fauna from clearing of vegetation, modification of surface water conditions or other aspects of landfill development. Potential impacts include loss of habitat, displacement of fauna, loss of biodiversity, spread of plant diseases and weeds, litter, creation of new habitats for scavenger or predatory species, or erosion. It is the responsibility of the proponent to check their obligations under the relevant legislation, including the *Native Vegetation Act 1991*, *Native Vegetation Regulations 2017*, *Heritage Places Act 1993* and *National Resources Management Act 2004*.

Infrastructure

Infrastructure will need to sustain landfill activities. Screening and siting will need to consider the following:

- The capacity and safety of access roads for the anticipated vehicle traffic.
- Water supply for firefighting, potable use and other site purposes.
- Power and sewerage disposal facilities.

Amenity

Consideration should be given to potential impacts on amenity for affected parties surrounding the site including vehicle traffic on the access road to the site, visual aspects, odour, litter and dust.

Unstable areas

Landfills must not be located in areas susceptible to ground movements that may adversely impact on the integrity of the landfill and engineering systems such as the liners, leachate collection system, landfill gas collection system and final cover.

Consideration should be given to existing conditions or potential changes to site conditions from progressive landfill development that may impact on stability including topography, surcharge loads, drainage and surface water.

Potential unstable areas include areas that are susceptible to undergo ground movements due to the following:

- Landslides or other ground movements associated with slopes.
- Seismic (earthquake) events that cause displacement at fault lines or in zones of liquifaction.
- Excessive differential or total settlement from uncontrolled fill, collapse of low density soils or consolidation of compressible soils.
- Collapse of voids or settlement of low strength zones associated with karstic terrain or former mining operations.

2.2 Environmental assessment for development

Objective

To gain a comprehensive understanding of the environment where the landfill is located, so that management strategies can be designed to safeguard surface and groundwater together with preservation of air quality.

Required outcomes

The required outcomes include:

- Development of a conceptual site model (CSM) that characterises the source, pathway, receptors and exposure for all contaminants associated with the proposed activities for the site taking into consideration the geology, buffer and climate of the site.
- Development of suitable management strategies to safeguard surface water, groundwater and air quality.

A comprehensive baseline environmental assessment of the site is required prior to approval of the facility for operation, usually as part of the planning application process, so that the landfill proposal can be assessed for compliance with the minimum requirements of this guideline and risk of adverse impact on the environment.

Sufficient detail is required to demonstrate that the site is suitable for the development of the landfill in the form presented. Detailed guidance is presented within the relevant sections 3, 4, 5 and 6. More detailed investigation and assessment may be required where:

- required for detailed design purposes
- siting and proposed classification vary from the minimum requirements of this guideline
- a site is located close to existing or potential sensitive receptors and groundwater resources
- an application is made to vary landfill classification or existing approval

2.2.1 Suggested measures – site assessment

Conceptual site model

A conceptual site model (CSM) should be developed for the site to describe the environmental setting, identifying contaminant sources, modes of contaminant movement (migration pathways), potential receptors and how exposure may occur. The development of a CSM is an iterative process where the initial model is developed in the first stage of site assessment and continually revised as site practices change. The CSM should be reviewed over time following monitoring to inform landfill management practices before impacts occur.

The complexity of the CSM corresponds to the scale and complexity of the landfill activities and include the following elements:

- Site history – ownership, past and current aerial photography, local and state government records, past and current activities, potentially contaminating activities that have been carried out at the site, and identification of ecological receptors.
- Local and regional geology – surface elevation and topography, regional and site-specific soil and geological records, geophysical data, drilling wells, groundwater flow, direction and rate, quality and current or future use, aquifer type, survey of existing groundwater wells, and groundwater depth.
- Background concentrations – background soil quality, up gradient groundwater quality, site groundwater quality.
- Known and potential sources of contamination.
- Chemicals of concern/interest – mobility, toxicity and volatility (background and emissions from landfill).
- Human and ecological receptors.
- Potential exposure pathways.

- Identification of data gaps.
- Sampling and assessment – landfill gas and groundwater monitoring wells, location, methodology, parameters, aquifer properties and attenuation potential.

The CSM provides an understanding of the level of risk of groundwater becoming impacted by the landfill activity, and how these risks change as activities at the landfill site change. The CSM can inform how robust and meticulous the monitoring requirements need to be to confirm there is consistent and appropriate management of the site to prevent any impacts occurring. Appropriate design and operational measures should decrease the risks considerably and ease the burden on monitoring.

Climatic conditions

Assessment of climatic conditions includes rainfall, evaporation and wind conditions.

Surface water and drainage conditions

Assessment of surface water and drainage conditions includes topography, drainage, vegetative cover, flow, water quality, protected environmental values and users.

2.2.2 Suggested measures – assessment of impacts, management and control measures

Development of water management strategies for the protection of water will need to consider the following:

- site conditions
- water requirements for site operations including firefighting, dust control, irrigation, and construction of landfill cells and capping
- separation of stormwater and leachate
- safeguarding surface and groundwater from potential impacts associated with contaminated stormwater, sediment and leachate.

Leachate is water that comes into contact with the waste and is potentially contaminated by nutrients, metals, salts and other constituents present within the waste.

Groundwater and surface water can be contaminated by untreated leachate from landfill sites. Leachate has a potential to cause serious water pollution if not managed properly. Surface water may also be adversely affected by sediment or contaminants in uncontrolled stormwater flows.

Stormwater

Stormwater management strategies must consider the following:

- Management of onsite surface water, and control and monitoring of offsite stormwater discharge.
- Diversion of stormwater away from areas containing waste using drainage features and bunds.
- Erosion and sediment control along drainage lines, disturbed areas and soil stockpiles. This includes stormwater flow control, vegetation, detention ponds, minimising land disturbance, and other temporary and permanent erosion protection measures.

Management strategies and design criteria for storm events should consider potential receptors and the consequences of uncontrolled discharge. Typical design criteria include the 1-in-10 or 1-in-20 year recurrence interval storm event for design of drainage features and the 1-in-100 year recurrence interval storm event to assess the risk of major breakdown events such as failure of detention ponds, or flooding of the waste area of sensitive facilities or receptors.

Guidance on stormwater management is presented in *Stormwater pollution prevention code of practice for the building and construction industry* (EPA 1999) and *Stormwater pollution prevention code of practice for local, state and federal government* (EPA 1997) . Note that stormwater management is also an issue for closure and post-closure planning and management and is further discussed in section 4.

Leachate

Strategies to manage leachate will need to consider the following:

- Potential generation and composition of leachate during operation of active cells and after closure of landfill cells.
- Limiting infiltration through the final cover to a rate less than the infiltration through the landfill base. This will minimise the risk of a build-up of leachate in the waste and associated problems with saturation of the waste, leachate collection and treatment or breakout seepage through the landfill surface.
- Design and operation of the leachate containment and collection system in the landfill cells.
- Management, treatment and disposal of collected leachate.
- Safeguarding the protected environmental values of surface water and groundwater.
- Management strategies to prevent potential offensive odours.
- Health and safety, and minimising human contact with the leachate.

Assessment of the potential impact of leachate on groundwater needs to take into account the potential infiltration of leachate through the landfill base and the interaction with groundwater (based on the above assessment of the hydrogeological setting). The assessment will need to consider the potential concentration and mobility of contaminants in the leachate and safeguarding the protected environmental values of groundwater and surface water. At operating facilities, the assessment should also take into account the results of leachate and groundwater monitoring programs.

Consideration should also be given to cases during operation of active cells and after closure of landfill cells. Guidance for design of leachate containment, collection and treatment systems as part of a water management strategy is presented in section 4 and Appendix 4.

Landfill gas

Prior to establishing a landfill facility consideration should be given to the site's ability to control and manage potential odour emissions including landfill gas. It is recommended that large landfill facilities consider the type of landfill gas extraction system and access to suitable infrastructure to maximise the benefits from a landfill gas extraction system.

Guidance on landfill gas management and monitoring is presented in section 4.

Dust, odour and litter

Prior to establishing a landfill facility consideration should be given to the sites characteristics to mitigate potential nuisance impacts, including dust, odour and litter. It is recommended that landfill facilities detail what management and operational practices are proposed to minimise the generation of dust, odour and litter.

Guidance on nuisance, including dust, odour and litter is provided in section 5.

2.3 Landfill classification

Objective

To set a minimum standard for the design and construction of landfill facilities taking into consideration the hydrogeological settling, climate, waste disposal volumes and waste types, to protect the environment from harm.

Required outcomes

The required outcomes of a classification system for landfill facilities include:

- Assessment of risks systematically and proportionately to design and engineer a facility to minimise environmental impacts.
- Facilitate consistent regulatory outcomes in the design and construction of landfill facilities.
- Promote best practice landfill engineering and design.

Landfill facilities are required to be designed to minimise adverse impacts on the environment. The landfill design will need to consider the environmental setting, quantity and quality of waste to be disposed of, concerns of the host community, adjacent land use and economic and social factors.

2.3.1 Suggested measures

The landfill classification system reflects the EPA's expectations of the minimum containment requirements based on key risk factors associated with siting and from landfilling practices. The classification system includes a number of suggested measures which are a concession from best practice landfill design, where risks are lowered due to site-specific factors related to groundwater quality, separation, depth and type of waste disposed, rate of filing, geology and location. The classification system table (Appendix 1) is presented with suggested minimum measures from landfill having lowest risk to highest risk, reading from left to right along the table. The classification system is intended to provide consistency of minimum requirements across industry for the design, construction and operation of a landfill facility within South Australia.

The landfill classification system has been developed to provide a series of suggested measures for the design of leachate containment, collection and management together with capping requirements and performance outcomes.

The classification system, developed by the EPA, incorporates minimum standards for achieving satisfactory environmental and regulatory outcomes. Where proponents seek to implement an alternative design this guideline sets out a series of parameters that must be addressed to ensure performance outcomes are consistent and congruent with site-specific risks.

Classification determines the containment system minimum requirements and is based on the following risk factors:

- area serviced
- size (depth and disposal rate)
- location (hydrogeology, proximity to groundwater and beneficial use of groundwater)
- waste types received

Variation of the applicable classification and containment systems minimum requirements will require a site-specific risk assessment acceptable to the EPA.

3 Containment and control of emissions (including liner, leachate collection and capping)

Landfills must be designed, constructed and operated to manage leachate so as to minimise pollution and environmental harm. Landfills are designed as an integrated system that incorporate a base and side liner, leachate collection system and capping system which are further explained in this section.

Leachate is water that comes into contact with waste and is potentially contaminated by nutrients, metals, salts and other constituents. Ground and surface water can be contaminated by untreated leachate from the landfill site. Leachate has the potential to cause serious water pollution if not managed properly. Surface water may also be adversely affected by sediment or contaminants in uncontrolled stormwater flows.

Landfill containment and management systems can be constructed from compacted clay or a composite liner incorporating both compacted clay and geosynthetic materials. The classification of the landfill, based on Appendix 1 provides the basis from which to design and engineer a landfill to mitigate against environmental risks associated with its operation.

Landfill cells should be sized to provide enough airspace for waste disposal for a period not exceeding two years. Where landfill design and staging provide for more airspace, additional measures will be required to:

- minimise the exposure of the landfill liner to degradation from the elements and physical damage
- minimise the potential to generate leachate
- manage the risk of increased leachate volumes
- commence landfill gas collection prior to capping the landfill cell.

To meet the requirement of the general environmental duty as specified in section 9 of the Environment Protection (Water Quality) Policy 2015, landfill cell design and construction must address the criteria applicable to the relevant landfill classification (determined by reference to Appendix 1) set out in Appendices 2, 3, 4, 5 and 6 to section 3, and must implement the measures set out in those criteria subject only to the discretion of the EPA to approve an alternative measure in respect of a specific landfill cell proposal.

A landfill design must address in its design and construction documentation the standards, measures and requirements set out in Appendices 2, 3, 4, 5 and 6. An exemption to the requirement to address one or more standards, measures or requirements may be granted by the EPA at its discretion where compliance is deemed to be unnecessary. This is a mandatory provision for the purposes of clause 9(e) of the Environment Protection (Water Quality) Policy 2015 and s27(2)(d) of the EP Act.

3.1 Base and side liner

Objective

The objective of an engineered landfill containment system is to contain and manage leachate within the landfill to protect surface and groundwater environmental values by minimising pollution. The containment system must also be engineered to prevent landfill gas (LFG) migration and facilitate collection.

Required outcomes

The required outcomes of a landfill containment system include:

- Application of risk-based approach to landfill containment systems to minimise leachate seepage through the liner in accordance with the landfill classification system detailed in Appendix 1.
- Implement design measures consistent with the CSM.
- The design and implementation of a containment system that can be maintained and will continue to meet the objectives and required outcomes during the operating and post-closure phases of the landfill.
- Locate the base of the liner at the leachate sump above groundwater.
- Contain leachate within the landfill and leachate collection system prior to removal and disposal.
- Provide appropriate treatment and disposal of leachate.

The suggested measures for the design and construction of landfill liners is based on the classification of the landfill in accordance with Appendix 1. Variation of the applicable classification and containment system minimum requirements will require a site-specific risk assessment acceptable to the EPA.

Landfill liners may comprise compacted clay, geosynthetics, or a combination of compacted clay and geosynthetic materials. The base and side liner design should be designed to meet the performance criteria as relevant to the classification of the landfill.

3.1.1 Primary and secondary liners

Liner systems that incorporate mineral and/or geosynthetic elements are considered to be acceptable for use as a barrier layer in a landfill base and side liner. Suggested systems include:

- A compacted clay rich liner augmented by a geosynthetic clay liner.
- A composite liner comprising a geomembrane liner underlain by a compacted clay liner or a GCL – a suitable engineered subgrade is required under the GCL.
- A double composite liner comprising a primary geomembrane liner underlain by a GCL or a compacted clay liner and a secondary geomembrane liner underlain by a GCL or a compacted clay liner. A secondary leachate collection layer comprising a gravel drainage layer or a drainage geocomposite should be placed between the primary and secondary composite liners.

The design of geosynthetic base and side liner systems must be considered on a case-by-case basis. Acceptable geosynthetic liners include reinforced GCL, and reinforced and unreinforced geomembranes.

3.1.2 Acceptable compacted clay liners

The design and engineering considerations for the use of compacted clay in the base and side liner are presented in Appendix 2.

3.1.3 Acceptable geosynthetic liners and geosynthetic materials

The minimum requirements for the construction of the landfill base and side liner incorporating geosynthetics are specified in Appendix 3.

Acceptable materials for geosynthetic liners include:

- GCL manufactured from polyethylene, polypropylene or polyester geotextile, or geomembrane substrate and sodium bentonite filling for the GCL.
- High density polyethylene (HDPE) geomembrane.

Other materials may be considered for the base and side liner where the expected quality of the leachate is more predictable than landfill leachate from a mixed waste stream.

Geomembranes made from the following materials may be considered, depending on geotechnical, chemical and temperature considerations:

- linear low density polyethylene (LLDPE)
- bituminous geomembranes
- polypropylene
- PVC
- synthetic rubber
- ethylene alloy.

3.1.4 Acceptable liner protection systems

The design of geosynthetic protection layers must be considered on a case-by-case basis. An appropriately designed geomembrane protection layer consisting of non-woven, needle-punched geotextile, typically made of polyester or polypropylene (and may include inhibitors and/or carbon black for added UV resistance), is considered acceptable for protection from the stresses imposed by overlying materials. Sand layers may be used where they are of sufficient thickness and can be placed without damage to the underlying geosynthetics during installation or placement of subsequent layers.

Soil and drainage aggregate layers should be used to provide physical protection of geosynthetics and where confinement of GCL is required.

3.1.5 Acceptable protection and separation layers

An appropriately designed protection layer consisting of non-woven, needle punched geotextile, typically made of polyester or polypropylene (and may include inhibitors and/or carbon black added for UV resistance), is considered acceptable for limiting the effects of clogging, while at the same time limiting excessive migration of soil fines into the underlying drainage layer.

3.2 Leachate collection system

Objective

To design and operate a leachate collection system to minimise the hydraulic head on the lining system.

Required outcomes

The design of the leachate collection system must:

- Be demonstrated as capable of limiting leachate head over the liner to less than 300 mm on a daily basis under cases that include:
  - initial waste lift
  - operational
  - interim cover
  - final cover.
- Be resistant to chemical attack, and physical, chemical and biological clogging.
- Be able to withstand the weight of waste and the compaction equipment without crushing.
- Be able to be inspected and cleaned by readily available video inspection and pipe cleaning equipment.
- Be robust and designed to continue to function in the event of several components of the system failing.
- Ensure that the drainage layer, collection system and leachate sumps do not compromise liner integrity during installation and landfilling
- Ensure that leachate sumps do not compromise liner integrity under long-term down drag forces imposed on vertical risers or in the event of structural failure of the sump riser or base.
- The depth of leachate in each sump can be measured and removed.
- Leachate pump operation is automated and alarmed.

3.2.1 Acceptable primary leachate collection system

A leachate collection system typically comprises a high permeability drainage layer, perforated collection pipes, a sump where collected leachate is extracted from the landfill, and a geotextile layer separating the waste and drainage layer to prevent clogging of the drainage layer. Where a geomembrane liner is used it must be protected from the drainage layer. The floor must be sloped towards leachate collection pipes which in turn fall to the leachate collection sump.

The minimum requirements for the leachate collection system are provided in Appendix 4.

3.2.2 Acceptable drainage geocomposites

An appropriately designed geonet drainage geocomposite may be used as an alternative to the gravel drainage layer in secondary applications such as side wall leachate drainage systems, secondary leachate collection systems (leak detection systems) and groundwater drainage systems.

This alternative should not replace the primary gravel leachate collection layer on the base or floor of a landfill.

3.2.3 Acceptable modelling

Detailed water balance modelling considers precipitation, surface evapotranspiration, surface runoff, water storage in the soils and waste, leachate collection and infiltration through the landfill base. The modelling considers climatic conditions, landfill geometry, waste composition, the leachate collection system, final cover and surface vegetation. Water balance modelling to compare different options for leachate containments or final cover systems can be carried out using a recognised water balance model such as HELP originally published by the US Environmental Protection Agency and modified by Dr Klaus Berger at the University of Hamburg (current version: HELP 3.95D, Berger 2013) or an equivalent method. Water balance modelling must consider the uncertainties and limitations involved with the input data and the model. Modelling results should be compared to site records from leachate monitoring.

3.3 Capping

Objectives

The objectives of capping systems for landfill facilities are to:

- Provide a long-term and stable separation layer between the waste and the final surface that protects human health and the environment.
- Minimise the generation of leachate.
- Safeguard surface and groundwater in accordance with the Environment Protection (Water Quality) Policy 2015.
- Achieve performance equivalent to the measures specified in Appendix 1.

Required outcomes

The required outcomes of capping systems for landfill facilities are to:

- Design and install a landfill cap over the full extent of the landfilled waste.
- Limit seepage of water through the landfill cap to less than the anticipated seepage through the landfill base.
- Design and construct the cap to limit the opportunity for rainfall infiltration and the generation of leachate, and to safeguard surface and groundwater.
- Design and construct the cap to be compatible with the landfill gas management system and the principles of the guideline on landfill gas management.
- Install a capping system that is geotechnically stable and can be maintained and will continue to meet the objectives and required outcomes.

This section provides direction and consistency for design and construction of capping systems for landfills. Capping systems play an important role in closure and post-closure care of landfill cells. This includes isolating waste from the surrounding environment, supporting proposed post-closure land use and amenity, providing a sustainable surface requiring minimal maintenance while facilitating management of surface water, limiting leachate generation and surface emission of landfill gas.

Capping of landfill cells is ideally undertaken progressively during the operation of the cell unless additional measures are in place to:

- Minimise the exposure of the landfill liner to degradation from the elements and physical damage (e.g. by covering with a protection layer)
- Minimise the potential to generate leachate (e.g. by placement of a low permeability interim capping layer and diversion of surface waters).
- Manage the risk of increased leachate volumes (e.g. by increased capacity of leachate management and disposal systems).
- Commence landfill gas collection prior to capping the landfill cell.

Interim cover plays an important temporary role prior to placement of a final cap in minimising harm and should be placed within 30 days of temporary or permanent cessation of disposal within the landfill cell. Further information on interim cover is provided in section 5.

It is recommended that capping of landfill cells is completed within 12 months of cessation of disposal within the landfill cell.

Capping must achieve the relevant performance objectives specified in Appendix 1.

3.3.1 Suggested measures

The suggested measures for capping systems include:

- An engineered barrier layer overlaid by a protection layer and a growing medium with suitable vegetation. Options for the barrier layer include use of a compacted clay liner and/or use of geosynthetics.
- Phytocaps that control the drainage of precipitation into the buried waste through water balance mechanisms. Further guidance on phytocaps can be obtained in the *Guidelines for the assessment, design, construction and maintenance of phytocaps as final covers for landfills* (Waste *Management* Association of Australia 2010).
- Alternative capping systems that meet the performance requirements of the landfill classification as specified in Appendix 1.

Design of the capping system must consider the following:

- The final shape (landform).
- Capping the full footprint of waste landfill and extending the capping system laterally to link in with the surrounding ground.
- Accommodating infrastructure, loadings and surface runoff associated with post-closure uses of the site.
- Integration with other environmental protection measure that exist on site (eg base and side liner systems, landfill gas management system, leachate management systems).
- Guidance on assessment of the environmental setting and water management strategies to safeguard surface and ground waters.
- Promoting runoff of precipitation while controlling erosion.
- Capping all landfill cells (including those that do not include a base liner and leachate collection system) to minimise drainage of water through the cap. This will minimise the risk of generation and a build-up of leachate in the waste:
  - where the landfill base include a liner and leachate collection system
  - in unlined facilities that have a low permeability foundation.
- Limiting migration of landfill gas both on and offsite, with the associated risk of asphyxiation (death by gassing) of vegetation; limiting uncontrolled accumulation and concentration of landfill gas, with the associated risk of ignition; and limiting uncontrolled landfill gas emissions to the atmosphere.
- Construction materials (eg properties, quantity, management, handling, placement and construction quality assurance).
- Maintenance of the cap integrity and long term performance of the cap according to differential settlement (subsidence of the landform), vegetation, climatic conditions, changes in moisture content of the barrier system, etc.
- Landfill edge effects, protrusions (landfill gas extraction wells) and zones with thicker or younger waste that may undergo greater settlement than areas with older waste.
- Geotechnical slope stability – considerations include temporary and permanent slopes, drainage, lateral seepage on the underside of the liner system, interface strength parameters of lining systems and overall landfill stability.
- Subgrade conditions (prepared surface of the landfill and surrounding areas prior to installation of the cap) and site preparation to provide a sound and stable subgrade for cap construction.
- Access for maintenance and monitoring of the capping system.

The minimum requirements for capping systems are specified in Appendix 5.

3.4 Alternatives

Objective

To inform proponents of steps required for the proposal, evaluation and acceptance of variations or alternative landfill containment systems to maintain a consistent or better performance outcome.

Required outcome

To allow reasonable alternatives subject to demonstrated equivalent or better performance outcomes to those stated in this guideline.

The measures (design, techniques and methods) contained in this guideline reflect widely accepted landfill practice. it is recognised that technology and best practice landfill design and construction can change as technology advances. Furthermore, the capacity to maintain consistent outcomes, while furthering innovation is critical to progressing waste management into the future. To address this, the EPA has developed a process to allow alternative approaches to landfill design, construction and operation.

3.4.1 Suggested measures

Step 1

The proponent should assess and describe the reason the variation or alternative is preferred. For example:

- substitution of materials, methods or techniques
- continual improvement
- application of best practice, technological change
- practical considerations arising from site-specific knowledge and conditions or risks
- reduced risk
- equivalent or better performance
- corrective action arising from a non-conformance
- cost or time saving or other net benefit.

Step 2

At this stage the proponent should conduct a preliminary assessment which considers:

- parameters necessary to assess performance of the alternative
- advantages and disadvantages of the proposal
- risks and consequences of adopting the alternative (compared with the guideline or existing approved approach)
- magnitude of cost and other resource savings
- magnitude (if quantitative) or list (if qualitative) of comparative benefits and/or outcomes
- variations necessary for statutory approvals (planning consents, licence conditions and environmental authorisations or exemptions)

On the basis of this assessment, the proponent should form a view as to the merit of pursuing the alternative prior to a formal approach to EPA.

Step 3

It is important to gain agreement with the EPA on performance parameters prior to commencement of alternative measures. Proponents should submit a preliminary assessment to the EPA together with a proposal for discussion and agreement prior to commencement.

The proposal should clearly define performance requirements and outcomes, and where these are not clear at this time, outline a process to enable an objective assessment.

A process to define performance requirements for any proposal will need to be completed before an assessment will be considered and agreement can be reached. A detailed timeline and proposal for an appropriately detailed risk assessment is expected in each case. It may also be necessary for the proponent to apply for a variation to an existing planning consent, and for the EPA to respond to a request for advice from the planning authority in relation to the variation. This process needs to be considered in the proponent's time and work schedule. The EPA will respond in writing to the proponent's proposal to:

- Indicate acceptance of the proposal scope as sufficient to enable an application to be made with sufficient detail to enable assessment

OR

- Provide feedback on areas where the proposal is considered deficient for further consideration by the proponent.

Step 4 (optional)

Peer review and possibly trials are likely to be required for new or innovative alternatives not currently accepted widely as best practice or considered transferable from evidence of successful application or use elsewhere. Where peer review is required, both the EPA and proponent must agree on the organisation(s) or person(s) undertaking the review and commercial arrangements.

With this acceptance, the proponent can commence the full scope of work necessary to produce an application to the EPA for consideration of the variation or alternative.

Following submission of the application, the EPA will assess the application against the performance requirements and outcomes described in the application. This assessment will provide information and advice for consideration by the EPA in forming its opinion on the application for a variation or alternative.

Implementation of any alterations or variations proposed may only proceed following:

- provision or amendment of the design report, specification and drawings (if appropriate)
- receipt of a formal approval by the EPA (and any other relevant authorities).

3.5 Design of containment systems

Objective

The objective of the design report is to ensure that the design is documented in a manner that facilitates communication of the design basis to stakeholders (ie landfill operator, contractors, regulators, site owners and future occupiers).

Required outcomes

- Preparation of a Basis of Design report by the responsible designer that accompanies the design drawings and technical specification for construction which sets out how the proposed landfill containment system design takes account of the minimum requirements of this guideline and considers site-specific risks.
- The licensee submits for approval by the EPA design documentation for the construction of a landfill containment system that sets out appropriate responsibilities and assumptions during construction, operation and closure of the landfill facility.

3.5.1 Suggested measures

Preparation of a design report that demonstrates consideration of this guidelines objectives, required outcomes and application of its minimum requirements including as appropriate those provided in:

- section 3 (this section)
- an approved variation provided by the EPA in accordance with section 3.4

- section 4
- Appendix 1
- Appendix 2
- Appendix 3 section 3.2
- Appendix 3 section 3.3
- Appendix 3 section 3.5
- Appendix 4

The designer must prepare the Basis of Design report to accompany the design drawing and specification. The report must contain:

- details to demonstrate that minimum requirements have been met
- design, construction and durability considerations
- the Safety in Design report
- design assumptions regarding operational, management, monitoring and treatment measures
- design decisions and any limitations these materials impose on landfill construction, operation and staging
- details of any approved variation provided by the EPA in accordance with section 3.4
- a declaration that the conditions of the environmental authorisation have been met by the design.

The installation of the containment system must be carried out in accordance with the requirements of the basis of design and be verified by an effective construction quality assurance (CQA) system (see section 3.6).

The approved Basis of Design report and CQA plan may only be varied in consultation with the EPA.

3.6 Construction quality assurance (CQA) plan

Objective

The objective of the CQA during construction of landfill facilities is to ensure that the materials, construction methods and completed works comply with the requirements of the construction drawings, technical specification and basis of design report.

Required outcomes

- Development and implementation of a CQA plan to ensure that the liner and leachate collection system meets the requirements of the specifications and drawings.
- Variations and design changes are assessed and accepted by the designer and EPA.
- The licensee submits to EPA for approval a CQA report containing a statement from an independent CQA engineer registered on the National Engineering Register stating that the installed liner and leachate collection system meet the requirements of the specification and drawings.

The development and implementation of a construction quality assurance (CQA) plan during construction and preparation of a CQA report following construction and prior to use of the constructed works provides a means of managing quality during construction and demonstrating to the project stakeholders (owners, contractors, consultants, regulator and general public) that the construction complies with the landfill design.

3.6.1 Suggested measures

Development and implementation of a CQA plan to ensure that:

- Stability of sub-base and liner are achieved.

- The materials and installation of compacted clay barriers meet the requirements of Appendix 2.
- The materials and installation of geosynthetic clay liners meet the requirements of Appendix 3.
- The materials and installation of geomembranes meet the requirements of Appendix 3.
- The materials and installation of geotextiles meet the requirements of Appendix 3.
- The materials and installation of drainage and leachate collection systems meet the requirements of Appendix 4.

Preparation of a CQA report by an independent CQA engineer that contains:

- details of the Basis of Design report, specification and drawings of work
- details of the works and monitoring devices installed including surveys, work-as-constructed drawings, and an updated site plan showing the location of the works
- records by the CQA engineer giving details of the works progress, the rate of liner or capping deployment, and any remedial actions that were taken
- a plan of prepared subgrade and clay barrier extent, geosynthetic panel deployment, and showing locations of defects, repairs and tests
- photographs of all aspects and stages of the construction
- details and results of all independent material testing, including data and certifications provided by manufacturers of supplied materials
- details showing that the CQA plan was followed
- an account of all variations from the approved design, specifications and CQA plan
- in the case of staged or cell wall construction, a schedule for submitting addenda to the CQA report as construction proceeds
- a declaration by the CQA engineer that there is sufficient information to demonstrate that the landfill works were constructed in accordance with the approved designs and specifications.

Guidance on the minimum CQA requirements for the CQA plan and CQA report are provided in Appendix 6.

4 Management, monitoring and treatment of emissions

Landfill facilities should be designed and operated to optimise the effective management of emissions including landfill gas, leachate and stormwater. Monitoring forms an important role in gaining an understanding and confidence in the site controls and risks, which in turn informs management and treatment options. A monitoring program should be developed to cover all emissions and place primary importance on monitoring to validate the effectiveness of existing controls, for example through monitoring leachate quality, leachate levels and surface water, rather than a monitoring program that validates impacts have occurred (groundwater monitoring). This section outlines strategies to manage, monitor and treat emissions in order to meet the general environmental duty.

For further information about evaluating air quality impacts (which could include air quality and/or odour modelling) and application of odour levels or ground level concentrations (GLCs) criteria refer to the EPA publication *Ambient Air Quality Assessment* (2016).

Where an alternative process is contemplated, the criteria outlines in section 3.4 must be considered.

4.1 Landfill gas

Objective

The objective of strategies for landfill gas and air quality is to manage potential hazards, adverse environmental impacts and potential loss of amenity from landfill gas, dust and odour during landfill operation and post closure.

Required outcomes

The required outcomes of landfill gas and air quality management include:

- Conduct a site-specific landfill gas risk assessment to identify appropriate measures for monitoring and managing landfill gas.
- Support and update the CSM as site activities change.
- Limit gas concentrations in monitoring bores at the boundary of the landfill facility or within structures located on or off site to less than 1% methane by volume or 1.5% carbon dioxide by volume.
- Prevent adverse impacts from on and offsite migration and emissions of landfill gas.
- Minimise greenhouse gas emissions.
- Manage potential hazards from asphyxiation or explosion in areas accessed by humans and in structures, equipment and other facilities.
- Prevent nuisance or offence from odorous emissions or dust.
- Manage airborne impurities, pathogens and toxins so that they do not pose an unacceptable health risk to the community.
- Monitor landfill gas migration and emissions and to mitigate emissions that pose risks to the community or facilities.
- Control air emissions to comply with the ground level concentrations and odour level criteria as specified in the Environment Protection (Air Quality) Policy 2016 (including hydrogen sulfide, nitrogen dioxide, sulfur dioxide, sulfuric acid).

Degradation of putrescible waste in a landfill generates methane, carbon dioxide and other trace gases that pose potential hazards to site safety, human health and the environment. Generation of landfill gas can continue for tens of years after placement of the waste and is intricately linked to leachate management.

Methane is explosive when it is present in the range of 5% (lower explosive limit) and 15% (upper explosive limit) by volume in air. Methane or carbon dioxide can also be an asphyxiate if present in excessive concentrations. Landfill gas poses a potential explosion or asphyxiation hazard by migrating from the waste (eg through the landfill surface, granular layers, man-made underground trenches, service conduits or similar) and accumulation in confined spaces. The conceptual site model, developed as part of the baseline environmental assessment, should identify site-specific pathways and receptors for landfill gas.

Methane and carbon dioxide are greenhouse gases. Methane has 21 times the effect of carbon dioxide on the greenhouse effect and related climate change. Management strategies include measures to promote oxidation of methane to water and carbon dioxide to provide a new reduction of greenhouse effects.

Methane and carbon dioxide are odourless however other components of landfill gas (including hydrogen sulfide and ammonia) can be very odorous and impact on amenity. Due to its potentially hazardous nature, landfill gas must be appropriately managed and monitored at landfill sites.

4.1.1 Suggested measures

Landfill gas risk assessment

Landfill facilities should undertake a landfill gas risk assessment to obtain a comprehensive understanding of site-specific risks to facilitate appropriate management strategies. The landfill gas risk assessment should include:

- Assessment of the quantity, rate and composition of the landfill gas generated at the site.
- Potential landfill gas emission pathways from the landfill waste.
- Potential risk/hazards presented by the landfill gas generated to all potential receptors both on and offsite.
- Proposed collection and combustion management strategies commensurate with risks.
- Proposed monitoring strategies for landfill gas commensurate with risks. Untreated emissions of landfill gas via vent pipes/trenches or similar infrastructure will not be permitted.

For further guidance on conducting a landfill gas risk assessment, see *Guidance on the management of landfill gas* (UK Environment Agency 2004).

Landfill gas collection and combustion

Landfill gas can be managed by either an active or passive gas collection system. Active systems use a vacuum to extract the landfill gas generated, whereas passive systems do not include a vacuum pump. The design of the landfill gas management system will, to a large extent, be based on the classification of the landfill and outcomes of the site-specific landfill gas risk assessment.

Where feasible, the EPA recommends active landfill gas collection systems and combustion, in combination with appropriate containment and leachate management as effective measures to achieve the objectives and required outcomes of this guideline. Similarly, gas recovery and utilisation for beneficial purposes is encouraged. Potential treatment technologies based on gas generation rates are suggested in Table 2.

Table 1 Potential landfill gas treatment technologies

Landfill gas generation rate	Potentially suitable landfill gas treatment technologies
>1,000 m^3/hr	• Combined heat and power generation • Substitute fuel • Power generation • Intermittent use and off-time flaring • High temperature flaring

Landfill gas generation rate	Potentially suitable landfill gas treatment technologies
>250 m^3/hr – <1,000 m^3/hr	• Power generation • Intermittent use and off-time flaring • High temperature flaring • Low calorific flaring
>100 m^3/hr – <250 m^3/hr	• Power generation • High temperature flaring • Low calorific flaring • Other oxidation technology and discharge (eg passive flares, biofilters, biocover)
<100 m^3/hr	Other oxidation technology and discharge (eg passive flares, biofilters, biocover)

Design and operation of the collection and combustion system will need to consider the following:

- Optimisation of the quality and quantity of gas collected.
- Operating hours and a backup/contingency plan for periods of maintenance or other down time.
- Extraction wells including the layout, orientation (vertical and/or horizontal), design, area of influence, flow control mechanisms and monitoring points. Wells must not penetrate or impact on the integrity of base or side liner systems. The integrity of the landfill capping system must also be maintained.
- Monitoring wells and points may need to be installed at different levels, depending on site-specific conditions to ensure that high-level concentration areas are detected.
- The collection system between the extraction wells and combustion system, including pipework, vacuum source, flow control facilities, monitoring and condensate management.
- Protection and maintenance of the integrity, operation and durability of system components. Considerations include corrosive gas, landfill leachate, condensate, vandalism, stresses from surcharge loads and settlement of the waste.
- The risk of air intrusion and potential explosion and fire hazards.
- Control of air emissions from the combustion system to comply with the *Environment Protection (Air Quality) Policy 2016* and reduce volatile organic compound emissions by 98%. Design of the flare systems will need to consider retention time, temperature, ignition control and flame arresters.

4.2 Leachate storage and disposal

Objective

To design an appropriate storage, treatment and disposal system for the management of leachate generated at landfill facilities to protect surface and groundwater.

Required outcomes

The required outcomes for leachate storage, treatment and disposal include:

- Leachate lagoons must be designed and constructed so that leachate in the lagoon does not intersect any underlying seasonal water table.
- Lagoons must be designed and constructed so as not to be prone to inundation or damage from flood waters.
- Lagoons must be designed and constructed to ensure that the contents of the lagoon do not overflow into waters or onto land in a place from which they are reasonably likely to enter any waters.
- Lagoons must be constructed with an appropriate liner which achieves the same level of protection as the landfill lining system.
- Lagoons must be designed and constructed to include an appropriate method of leak detection.
- Untreated leachate must not be disposed of or allowed to escape to surface or storm water or to land, used for dust suppression or used to supply the water needs of any process conducted at the landfill facility including composting.
- Appropriate disposal of leachate residue.

Lagoons (or ponds) have been used extensively in the past to collect and store (prior to reuse or discharge) or dispose of wastewater via evaporation. Leachate collected as part of the landfill containment system is required to be managed through appropriately designed storage, treatment and or disposal options, either on site or offsite. This section will detail how leachate is to be managed following extraction from the liner containment system.

4.2.1 Suggested measures

The leachate lagoon liner should be designed and constructed to the same standard as the landfill containment system. The design of the leachate lagoon should consider safety, fencing, exposure to environmental factors (leachate composition, sun and wind and wave action), operational factors such as access and egress for inspections, desludging and redundancy of operation for liner replacement or repair.

A leakage detection or interception layer below the leachate lagoon liner draining to a sump which is regularly monitored is recommended. The system should also be designed to relieve build-up of gasses and prevent formation of whales within geomembrane-lined leachate ponds.

The capacity of the lagoon should be such that, in addition to the stored leachate arising from an average year's net inflow and discharge, it can deal with rainfall runoff without overflowing. The EPA recommends a minimum 600-mm freeboard to prevent overflow arising from normal rainfall events and wind-driven waves.

The peak design flow of the leachate system should be based on a 1-in-20 year storm event over one lift of waste across the operating cell floor, and also include any runoff batters and adjacent areas contributing to the cell.

The required leachate pond size should be determined by an appropriate water balance model that takes account of:

- Contributions from all landfill cells in their condition at the time of construction.
- Local meteorological conditions (seasonal rainfall, evaporation).
- Leachate disposal practice (ie sewer, tankering offsite to a licensed facility or evaporation but excluding recirculation).

The EPA recommends stormwater inflows from other areas be minimised by raising lagoon embankments and diverting clean stormwater around the lagoon. The design considerations and minimum requirements for leachate collection and disposal systems are contained in Appendix 4.

Stored leachate should be disposed by either:

- discharge to sewer under the appropriate licence from SA Water

OR

- tanking offsite to a licence waste treatment facility

OR

- evaporation.

The EPA does not recommend irrigation and reinjection of leachate back into the landfill cell as a primary means of disposal or volume reduction to meet the recommended minimum requirement for leachate collection systems. Where an appropriately designed system to return leachate to the landfill cell is proposed for any reason, it should only occur with the explicit approval of the EPA.

4.3 Surface water

Objective

To design and operate a landfill facility to minimise contamination of surface water.

Required outcomes

Landfill operators are required to undertake all reasonable and practicable measures to prevent:

- entry of stormwater runoff into the landfill cell
- flooding of landfill activities
- contamination of surface waters from leachate and or contaminating stormwater by landfill operational activities.

Landfill facilities should be designed to minimise the contamination of surface water from activities conducted at the site and implement design controls to prevent waste (including leachate) coming into contact with surface waters. This minimises the potential generation of contaminated wastewater which is then required to be managed as leachate.

4.3.1 Suggested measures

Site design should provide the following minimum levels of protection:

- Design of stormwater systems and major drainage to control, treat or contain runoff from operating areas for 1-in-20 year ARI event.
- Consideration of 1-in-100 year ARI events to ensure no catastrophic failures such as:
  - flooding of the landfill cell
  - erosion or failure of capped areas of the landfill that results in release of waste
  - failure of dams, ponds or major stormwater infrastructure
  - failure of leachate control systems, leachate ponds or loss of containment.

In addition, consideration should be given to suitably sized cell footprints/internal temporary barriers to divert stormwater away from waste. Where surface water bodies are located within a defined proximity to landfill activities a monitoring program should be implemented to demonstrate that the activities undertaken at the landfill are not impacting surface water.

4.4 Monitoring

Objective

To design and implement a site-specific monitoring program that incorporates surface water, stormwater, leachate, groundwater and air emissions to support the CSM and safeguard the receiving environment from harm.

Required outcomes

The required outcomes of monitoring at landfill facilities include:

- Support the CSM developed for the site, systematically review risks and appropriately update design and management strategies as required.
- Provide confidence in the design, operation and management procedures at the site.
- To promote preventative monitoring of systems to allow for intervention prior to potential pollution.
- Characterisation of the quality and quantity of leachate generated at the site.
- Specification of indicator parameters for leachate, stormwater and groundwater monitoring that are based on the CSM developed for the site.
- Limit gas concentrations in monitoring bores at the boundary of the landfill facility or within structures located on or offsite to less than 1% methane by volume or 1.5% carbon dioxide by volume.

Landfill facilities should develop and implement a site-specific monitoring program to support the CSM and allow for modifications in design, management and operation of the facility as site activities and risks change. Monitoring of system performance (including landfill gas, leachate quality and levels) is of critical importance to allow for timely intervention to prevent and minimise impacts to the receiving environment.

Monitoring of the receiving environment (including surface, groundwater and air emissions) needs to be defined and justified by the risks identified in the CSM. Groundwater monitoring supports the overall monitoring program for the site and provides confidence over time that design and operational measures are effective, provides peace of mind for groundwater users down the hydraulic gradient and can potentially identify where harm may have occurred.

The Environment Protection (Water Quality) Policy 2015 sets out clear obligations for the prevention of pollution to waters, including surface and groundwater by taking all reasonable and practicable measures to prevent environmental harm when undertaking activities that pollute or might pollute waters. In relation to landfill facilities it is expected that facilities are designed and constructed to prevent the contamination of surface and groundwater. Monitoring of groundwater and leachate is a mechanism through which design assumptions can be validated, and where required, ameliorated in a timely manner to prevent pollution to waters.

The Environment Protection (Air Quality) Policy 2016 sets out the legislative basis for air quality regulation and management in the state including emissions generated at landfill facilities. Such facilities must take into consideration the ground level concentrations as specified in Schedule 2 and Schedule 3 of the Air Quality Policy.

The following publications provide additional guidance for meeting requirements of the Air Quality Policy relating to environmental authorisations and developments, or meeting the general environmental duty:

- *Evaluation distances for effective air quality and noise management* (EPA 2019)
- *Ambient air quality assessment* (EPA 2016)
- *Emission testing methodology for air pollution* (EPA 2013)

4.4.1 Suggested measures

The EPA acknowledges that for small sites reduced monitoring requirements may be justified based on the site-specific risk assessment.

Leachate

The monitoring of leachate levels in the landfill liner is critical to the timely identification of potential impacts to groundwater. As such, monitoring leachate levels in the sump or riser in each cell is an important management strategy for the prevention of pollution of groundwater. It also allows for timely management intervention where leachate levels exceeds the maximum permitted level in the liner.

Leachate monitoring should include routine sampling of composition, leachate level and leachate flow/volume rates. Suggested parameters for leachate monitoring are included in Appendix 7.

Landfill gas monitoring

An appropriate landfill gas monitoring program will be required to be developed for landfill facilities based on the site-specific landfill gas risk assessment to support the required outcomes of landfill gas management.

The number and location of landfill gas monitoring locations should be site specific and incorporate surface, subsurface and enclosed structure monitoring. The monitoring program should be capable of identifying on and offsite risks associated with landfill gas to facilitate the timely implementation of corrective actions.

Suggested investigation levels are provided in Appendix 7.

Stormwater

A monitoring program should be established capable of detecting excess sediment loads in stormwater together with the contamination of stormwater with leachate. The stormwater management plan should be reviewed and updated as the landfill evolves to ensure stormwater is appropriately managed to prevent the offsite release of total suspended sediments (TSS).

The monitoring program should include sampling at defined locations incorporating:

- total suspended sediments
- indicators of leachate contamination.

Surface water

Surface water monitoring should include monitoring points upstream and downstream to identify any impacts the landfill operation may be having on surface waters and equally, eliminate impacts to surface waters that are not a result of the landfill operation.

Suggested indicator parameters for stormwater are provided in Appendix 7.

Groundwater

A groundwater monitoring program should be developed in accordance with the outcomes of the conceptual site model (CSM). The program should be designed to assess potential impacts arising from the operation of the landfill facility based on background (or existing) groundwater quality. Monitoring is a mechanism in which to validate the effectiveness of design and operational practices at the landfill facility in addition to potential pollution impacts.

The program should include groundwater level and quality monitoring.

Groundwater wells should be located:

- Immediately down gradient of the leachate source but no closer than 10 metres from the edge of a landfill area.
- Further down gradient to identify impacts outside the landfill.
- Up hydraulic gradient for monitoring of the quality of groundwater flowing into the site.
- Across the groundwater flow gradient to capture changes in groundwater flow direction.

The number of groundwater wells required in a landfill is a function of:

- The size of the area filled with waste.
- Number and complexity of landfill cells.

- Complexity of the hydrogeology.
- Expected rate of movement of pollutants through the groundwater.

Suggested measures for monitoring of leachate, surface and groundwater is presented in Appendix 7.

5 Landfill operation

Objective

To implement best practice management and operation at landfill facilities to prevent offsite nuisance impacts and minimise the potential for environmental harm.

Required outcomes

The required outcomes from the operation of landfill facilities include:

- Minimise offsite nuisance impacts including odour, dust, fire, litter and noise from the day-to-day management and operation of the landfill facility.
- Dispose of waste into suitably engineered landfill cells in a planned and methodical way to minimise the active disposal face within a landfill cell.

The location, design and construction of a landfill facility must be supported by the day-to-day activities that are undertaken at the facility, and the operational and management practices implemented to minimise environmental nuisance and or harm.

Where an alternative process is contemplated, the criteria outlined in section 3.4 must be considered.

5.1 Amenity

5.1.1 Odour

Landfill facilities can cause offsite odour impacts if they are not appropriately planned, operated and managed. Potential odour sources at landfill facilities include waste types, disposal methods, leachate collection and landfill gas. Landfill facilities should consider best practices to minimise the potential for offsite odour impacts including:

- minimising the active disposal face, and applying daily and interim cover as per the requirements of this guideline
- managing leachate collection systems to prevent malodours and anaerobic conditions, which may require active management of leachate lagoons
- appropriately covering waste in accordance with the requirements of this guideline
- actively manage landfill gas to prevent offsite odour impacts.

5.1.2 Dust

Landfill facilities have the capacity to generate offsite dust nuisance from a variety of sources including construction and earth works, traffic movements, stockpiles, expansive areas of exposed soils and unsealed roads. Landfill facilities should implement management strategies to minimise the generation of dust including:

- seal internal roads and reduce vehicle speeds within landfill facilities
- install a wheel wash for vehicles on the site
- revegetate exposed soils as soon as practicable and stabilise stockpiles through the use of dust suppression agents
- modify activities during periods of high wind
- cover loads.

5.1.3 Fire

Landfill fires can cause significant impacts on air quality through the uncontrolled release of odour and smoke. There are two main types of fires that may occur at landfill facilities:

- Subterranean fire – a fire that burns within the waste mass. There may be no visual sign of the fire within the waste mass, however the smell of smoke, presence of carbon monoxide and collapse of the landfill may indicate that there is a subterranean fire at the landfill facility. Once started, subterranean fires are extremely difficult to extinguish, so management practices to prevent the fire are critically important. Remove all ignition sources and ensure waste disposed within the landfill cell is not smouldering at the point of receipt.

- Surface fire – a visible fire on the surface of the landfill facility but not within the waste disposal cell including bushfires, building fires or stockpile fires.

Management strategies to prevent fires within landfill facilities include:

- access to fire water of suitable pressure and volume at any point within the landfill facility
- installation of sprinklers within buildings
- appropriate storage of flammable materials
- appropriate stockpile controls
- fencing and appropriate security measures
- installation of firefighting equipment
- prohibition of disposal of flammable and highly reactive waste
- procedures to identify incoming loads that are smouldering and prohibited wastes, and the development of contingency plans to detail how such waste will be managed if received on site
- appropriate site signage and training for all personnel and visitors that access the site.

Landfill facilities should obtain the appropriate approvals from the Metropolitan Fire Service or Country Fire Service in relation to fire prevention and management strategies.

5.1.4 Litter

Landfill facilities have the potential to generate offsite litter nuisance, especially from lightweight plastics, during transportation, receipt and disposal. Landfill facilities should implement appropriate management practices as required to minimise the generation of litter including:

- covering disposed waste on a daily basis
- using litter nets
- perimeter fencing to contain litter and prevent the offsite escape of litter
- minimising the waste disposal face
- covering incoming loads and vehicle movements within the landfill facility
- implementing a management strategy to collect litter on a daily basis.

5.1.5 Noise

Landfill facilities must be designed and operated to ensure the activities comply with the indicative noise levels as specified in the *Environment Protection (Noise) Policy 2007.* Offsite nuisance from noise (including vibration) can be caused by earthworks, machinery and vehicles, reverse beepers, crushing, grinding and shredding activities, pumps and aerators, generators and engines. Landfill facilities should implement appropriate management practices to minimise the generation of offsite noise impacts including:

- design operational areas, especially noise generating activities, to be a maximum distance to sensitive receivers
- schedule activities that generate noise during daylight hours
- keep equipment well maintained
- place noisy machinery and equipment within an enclosed structure.

5.2 Waste disposal and placement

The design of the landfill cell should consider the method of waste disposal and placement so as to maximise operational efficiencies. All landfill designs will be based on assumptions on how the site will dispose of waste and it is therefore important to include this consideration during the design, to prevent overfilling of waste cells. Waste disposal and placement should be managed to support the following outcomes:

- minimise the active disposal face
- minimise the generation of litter
- control food sources and the generation of nuisance birds and vermin
- maximise the ability to compact waste
- minimise the amount of daily cover required
- minimise the gradient of the disposal face to maximise stability of the waste and machinery
- preserve the integrity of the engineered containment and control systems.

5.3 Onsite resource recovery activities

Landfill facilities may also incorporate onsite resource recovery and treatment facilities to maximise the resource recovery of waste prior to disposal. Such facilities present additional challenges and risks that are required to be appropriately managed.

Where resource recovery and or treatment facilities are co-located at landfill facilities the EPA will require the development of appropriate management plans to address:

- identification, tracking and recording/reporting requirements for all incoming wastes
- details of waste movements within the site
- detailed, scaled map of the site incorporating all waste management, storage, treatment and disposal activities (current, proposed and future) including internal roads and other site infrastructure and buildings
- details of resource recovery activities including waste volumes, type and stockpiling/handling within the landfill facility in accordance with existing published standards where applicable
- details of equipment and infrastructure associated with the resource recovery and treatment activities
- development of mass balance reporting systems
- appropriate identification and separation of resource recovery and treatment activities from landfilling activities.

5.4 Covering of waste (daily and interim cover)

Objective

Landfill facilities must apply an approved daily and interim cover to minimise the generation of nuisance impacts and prevent environmental harm resulting from the disposal of waste. The amount of cover must be commensurate with the risks.

Required outcomes

Landfill facilities are required to apply a daily cover at the end of each day's operation and an interim cover where no additional waste is disposed for 30 days or more to assist in the prevention and control of environmental nuisance, including:

- prevention of wind-blown litter.
- deterrence of scavenging by birds and rodents.
- control odour and uncontrolled landfill gas emissions.
- control dust nuisance.
- control fire risk.
- improved visual appearance.
- minimising infiltration of rain (for interim cover).

5.4.1 Daily cover

A minimum of 150 mm of daily cover that meets the physical and chemical criteria of Waste Fill, as defined in the *Environmental Regulations 2009* is required to be applied at landfill facilities at the end of each day's operation. Daily cover should be applied in a manner that does not cause environmental harm including:

- create or contribute to the generation of odour and dust
- encourage nuisance from flies, birds and other rodents
- cause ponding or perched leachate build up within the landfill cell
- interfere with the gas collection and extraction system
- capable of self-combustion.

Landfill facilities that include an engineered liner and leachate collection system can use waste soil that meets the chemical criteria for Intermediate Waste as specified in the guideline *Current criteria for the classification and disposal of waste* (EPA 2009).

Daily cover may be removed at the commencement of the next day's operation to improve operational efficiencies at the landfill facility.

5.4.2 Interim cover

A minimum of 300 mm of interim cover is required to be placed over waste disposed within a landfill cell where no additional waste will be placed for 30 days or more. Such cover serves as an interim cap prior to placement of a final cap, or where operational issues preclude ongoing daily disposal for a period of time. Interim cover is required to meet the same objectives as daily cover and in addition should reduce the infiltration of rainfall to help prevent the generation of leachate and landfill gas.

Landfill facilities that include an engineered liner and leachate collection system can use waste soil that meets the chemical criteria for Intermediate Waste as specified in the guideline *Current criteria for the classification and disposal of waste* (EPA 2009).

Where interim cover has been placed and landfill activities recommence after a period of time, it is recommended that the interim cover is scraped back or punctured prior to waste placement to prevent leachate perching.

Where interim cover is placed for a period exceeding six months, a temporary capping system may need to be put in place.

5.4.3 Alternative daily and interim cover

To facilitate the use of alternative cover materials at landfill facilities the EPA will require licensees to develop a proposal that details the physical and chemical properties of the alternative cover together with information on how it will achieve the same or better performance outcomes, taking into consideration seasonal variation.

The following information should be included in a written submission to the EPA:

- Physical and chemical properties of the cover material.
- Source and supply of cover material.
- Performance criteria:
  - biodegradability
  - odour
  - particle size
  - flammability and combustibility
  - permeability of the proposed cover
  - stockpiling and storage of the cover material including location and stockpile dimensions for cover materials
  - how the cover material will be applied including volumes
  - conversion ratio (m^3/tonne) of the cover.

The EPA may require a trial period to demonstrate the performance of the alternative cover material. The trial must record observations and monitoring for dust, odour, litter and vermin.

Alternative cover must not contain asbestos, food waste, animal waste, biodegradable waste, grease trap waste, liquid waste or other prohibited landfill waste.

Landfill facilities should develop a cover management plan to detail how daily and interim cover will be managed at the landfill facility. A cover management plan should specify:

- physical and chemical properties of the daily and interim cover(s)
- volume of cover required to be used on a daily basis
- m^3/tonne conversion ratio of the cover
- procedures detailing how cover material will be applied
- stockpile requirements (including location, dimensions and maximum volume) for cover material
- periodic review of performance of cover material (including seasonal variations).

5.4.4 Special waste

Asbestos presents a significant risk to human health through its inappropriate handling and disposal. Appropriately wrapped friable and non-friable asbestos waste should be buried in a separate, dedicated monocell and clearly labelled as an asbestos disposal area. The exception is the receipt of contaminated waste soils that contain asbestos together with elevated contaminants. The appropriate disposal route (treatment, monocell or engineered lined cell) will depend on the nature of contaminants, and the environmental and health risks presented.

Additional requirements are necessary to protect against environmental and health risks associated with the handling and disposal of asbestos, regardless of whether disposal is into a monocell or lined cell, including:

- placement in the waste disposal cell to minimise traffic movement over asbestos
- immediate covering with 150 mm of approved cover
- not dispose of asbestos within one metre of any final surface level at the facility.

In addition to the above requirements, additional cover may be required if asbestos waste and/or its packaging are visible at the close of each business day's operation.

5.5 Landfill environment management plan

A landfill environment management plan (LEMP) should be prepared for landfill facilities to document management and operational practices that will be implemented and reviewed from time to time, to specify how the facility will meet its environmental obligations. A LEMP provides the framework for management and mitigation of environmental impacts during construction, operation and closure of the landfill facility.

A LEMP is a working, living document that must be reviewed on a regular basis as management and operational practices change at the facility. It may be drawn up as part of the development application process, for existing sites that already hold an environmental authorisation, or as a condition of licence. The LEMP will be superseded by a closure plan once the landfill facility ceases to dispose of waste.

The LEMP is a tool to assist landfill facilities in meeting their environmental obligations as outlined in this guideline and should include:

- Legislative requirements and summary of standards and guidelines that have been referenced in the development of the LEMP.
- Location including zoning, ownership details, buffer distances and surrounding land-use activities.
- Summary of site conditions including climate, topography, geology, hydrogeology, groundwater and surface water.
- Site layout plan identifying infrastructure key to the management of environmental risks.
- Hours of operation and security provisions.
- Nature of operation and capacity including waste types, filling plan (including rates, methodology), lifespan and related onsite activities (including any resource recovery activities).
- Management structure including clearly defined roles and responsibilities of personnel.
- Technical process and design – concept design for landfill site to outline the performance criteria for liner and leachate management system, interface between cells (as appropriate), capping and final landform, landfill gas management and stormwater management.
- Operational aspects:
  - waste types, volumes and management requirements
  - record keeping
  - training
  - waste management procedure – operational filling process including compaction methods, management of specific wastes and retrieval of unauthorised wastes
  - waste minimisation practices on site – including diversion and recycling/separation activities, stockpile dimensions and heights and environmental controls
  - site materials and equipment and machinery
  - traffic control including entry and exit points, and all internal roads
  - environmental controls including litter, dust, mud, odour, noise, vermin, birds and weeds
  - emergency response procedures.
- Monitoring programs and reporting:

- groundwater, surface water, leachate and landfill gas
- air quality, noise and nuisance
- internal audits
- requirements for recording and reporting monitoring outcomes.

LEMPs will be subject to ongoing review and update as site practices change. The EPA recommends that LEMPs are reviewed on an annual basis as part of the site's quality management process. The LEMP is a controlled document and all updates and revisions must form part of a quality control process.

6 Closure and post closure

Objectives

The objectives of closure plans for landfill facilities are to:

- Provide long-term protection of human health and the environment.
- Minimise the generation and uncontrolled emissions of leachate and landfill gas, which may have adverse impacts on human health or the environment.
- Promote responsible land management and ensure that site closure and post-closure management are compatible with an appropriate post-closure use of the site.
- Manage hazards and amenity issues.
- Promote progressive closure of landfill cells within operating landfill sites.
- Limit the risk of post-closure maintenance and monitoring beyond the timelines included in this guideline.
- Improve systems for monitoring, review and maintenance during post-closure management.
- Maintain environmental protection measures and monitoring systems until it is demonstrated that the landfill no longer presents a risk to human health or the environment.

Required outcomes

The required outcomes of closure and post-closure plans for landfill facilities are to:

- Prepare a conceptual post-closure plan – as part of the design and approval process for new landfills and new landfill cells.
- Prepare a closure plan for future landfill cells at all facilities; current landfill cells that do not have a closure plan approved by the EPA; or closed sites where the EPA considers that the closure or post-closure management is, or is likely to be, inadequate to guard against pollution.
- Review and update the closure and post-closure plan at every landfill at intervals of not greater than two years. The review must consider the results of monitoring and changes in site conditions, environmental management measures and regulatory requirements.
- Design and install a capping system in accordance with the measures outlined in section 3. This must provide a stable cover over the waste, safeguard the protected environmental values of surface water and groundwater, and prevent and manage potential hazards associated with landfill gas.
- Manage landfill gas in accordance with the measures outlined in section 4.
- Implement the plans including a program of inspections, monitoring, review and continuous improvement.
- Plan and implement a program of post-closure management until it is demonstrated that the landfill no longer presents a risk to the environment or human health.
- Provide a certified statement of completion.

Planning for the closure and post-closure management of landfill facilities is essential to ensure the effective management of environmental risks which may persist for a significant period after waste disposal has ceased. A closure plan is required to be prepared during the operational phase of a landfill facility in order to document management and operational practices to be implemented in order to ensure environmental obligations are met during and following the closure of a landfill facility.

Closure plans will be prepared during the operational life of the landfill facility to prepare the site for closure and following closure, post-closure requirements. There are important distinctions in the closure and post-closure phase of a landfill which are explained below:

- Closure of a landfill cell – landfill facilities will ordinarily construct a series of landfill cells throughout their life, which should be capped within 12 months of cessation of disposal of waste within the cell. Capping of a cell will be undertaken in accordance with conditions of licence for the landfill facility consistent with the requirements for its classification (refer to Appendix 1).
- Closure of a landfill facility – a process that is undertaken when no further waste disposal is proposed at the site. Various infrastructure may be decommissioned and a closure plan will detail how the site will be managed, consistent with the proposed future land use.
- Post closure – relates to a period where a site has ceased disposing of waste, capping of all disposal cells has been completed to the satisfaction of the EPA, and ongoing monitoring and maintenance of the site is required for a defined period (ordinarily 25 years).

  Where landfill facilities have ceased disposal, capped their landfill cells and implemented an approved closure plan, the EPA will consider surrender of the environmental authorisation following the submission of a certified statement of completion from the landfill operator. The exception to this is where ongoing groundwater monitoring and landfill gas monitoring and/or extraction are required as a result of the scale of previous landfilling that has occurred at the site. The EPA will ordinarily continue to oversee these monitoring obligations via conditions of licence.

Where an alternative process is contemplated, the criteria in section 3.4 must be considered.

6.1 Suggested measures for closure plans

6.1.1 Plan preparation and approval

The plan should be prepared in accordance with the principles of continuous improvement outlined in *AS/NZS ISO 14001:1996 Environmental management systems–specification with guidance for use,* including the cycle of policy, planning, implementation, checking, corrective action and management review.

Plans will require EPA approval before implementation and should be reviewed by the licensee at least every two years. Planning for closure should consider landfill operational issues which include, but are not limited to landfill cell development, waste placement and compaction, earthworks materials, and measures to manage waters and landfill gas. Progressive closure of landfill cells should be carried out within 12 months of the completion of waste disposal in each cell, unless otherwise approved by the EPA.

The plan should include programs for implementation, quality assurance and reporting to the EPA. Landfill operators should make funding provision during landfill operation to cover costs for closure and post-closure management.

Post closure

The proposed post-closure use of the site should be outlined in the closure plan and consider:

- landfill location
- surrounding land uses
- consultation with the local community
- relevant regulatory and planning authorities strategic plans for acceptable land use
- post-closure management measures and infrastructure, eg for management of water issues and landfill gas
- issues related to land use and contamination.

Common types of post-closure use include:

- rehabilitation of sites with vegetation, with controlled access and limited public access
- public open space
- ongoing use for waste management, eg as a waste transfer station, materials resource recovery facility or for processing of green waste.

The EPA discourages the construction of water features over the waste site as part of landfill closure due to the risk of differential settlement, potential water leakage and leachate generation. Specialised engineering measures must be included if buildings, roads, water features or utilities are proposed, and must consider the risk of differential settlement, ground support and hazards associated with landfill gas.

Final shape (land form)

The final landfill shape should be compatible with the surrounding topography and land use, and consider the post-closure use of the site, stormwater and erosion control, suitability, the capping system, development approval and planning regulations.

The plan should nominate the final height prior to settlement and proposed surface grades or contours. The final contours should consider settlement as the waste decomposes, compresses and consolidates. Steep slopes should be battered with an overall gradient being a maximum of one vertical and three horizontal, unless an engineering design has been approved to control the long-term stability on steeper batter slopes.

6.2 Certified statement of completion

Prior to the EPA approving the surrender of an environmental licence, a certified statement of completion should be developed by a suitably qualified consultant which provides sufficient evidence from the landfill operator to confirm that the site has stabilised and no longer presents a risk of harm to the environment.

The certified statement of completion should demonstrate:

- The landfill facility has an approved closure plan, and all closure and post-closure works have been implemented to the satisfaction of the EPA.
- Gas concentration levels in all perimeter wells have fallen to less than 1% methane by volume and less than 1.5% carbon dioxide by volume for a period of 12 months.
- Groundwater monitoring demonstrates that the risk of pollution to groundwater has stabilised or is decreasing.
- Landfill capping has stabilised with no evidence of erosion, dead vegetation, ponding of surface water, differential settlement or slope instability.
- The site no longer poses an adverse amenity risk including odour, dust, noise, litter, fire and vermin.

7 References

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ASTM International 2016, *ASTM D6767 Standard Test Method for Pore Size Characteristics of Geotextiles by Capillary Flow Test.*

ASTM International 2016, *ASTM D1621 Standard Test Method for Compressive Properties of Rigid Cellular Plastics.*

ASTM International 2015, *ASTM D6496 Standard Test Method for Determining Average Bonding Peel Strength Between Top and Bottom Layers of Needle–Punched Geosynthetic Clay Liners.*

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Standards Australia, *AS 3706.3 Geotextiles–Methods of test–Determination of tearing strength–Trapezoidal method 2010,* New South Wales

Standards Australia, *AS 3706.4 Geotextiles–Methods of test–Determination of burst strength–California bearing ratio (CBR)–plunger method 2012,* Standards Australia, New South Wales

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Standards Australia, *AS 1726 Geotechnical site investigations*, New South Wales

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Waste Management Association of Australian 2011, *Guidelines for the Assessment, Design, Construction and Maintenance of Phytocaps as Final Covers for Landfills, WMAA*

Legislation and environmental protection policies (SA)

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Environment Protection Act 1993

Environment Protection (Waste to Resource) Policy 2010

Environment Protection (Water Quality) Policy 2015

Environment Protection (Air Quality) Policy 2016

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Natural Resources Management Act 2004

Modelling programs

Environment Agency United Kingdom, *GasSim*

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United States Environmental Protection Agency, *Hydrologic Evaluation of Landfill Performance (HELP)*

Appendix 1 Landfill classification

CRITERIA		CLASSIFICATION				
		Asbestos disposal cell	**Small**	**Medium**	**Large**	**Restricted (including treated low level contaminated waste or LLCW)**
Intended use or service area		A disposal cell intended for regional or single project disposal sites for asbestos wastes	Very small landfills in remote, low rainfall areas servicing local community only where there is a low risk to groundwater	Landfills servicing local community only	Regional landfills accepting municipal, commercial and industrial wastes	Regional or special purpose landfills accepting treated high level contaminated waste
Size	Filling rate	–[2]	<5,000 tpa	<20,000 tpa	–	–
	Average Depth	<10 m	<10 m	<30 m	–	–
Location	Geology	Geotechnically suitable	• Geotechnically suitable • Founded in natural low permeability clay soils	Geotechnically suitable	Geotechnically suitable	Geotechnically suitable
	Groundwater separation[3]	>2 m groundwater separation	>2 m groundwater separation	>2 m groundwater separation	>2 m groundwater separation	>2 m groundwater separation

2 '–' means no general limitation. Site-specific conditions, design and operational limitations will apply.

3 An attenuation zone whose thickness is measured from the base of the constructed liner to the closest aquifer or unconfined groundwater surface which is significant as either a groundwater resource or migration pathway. The location of the closest aquifer is interpreted to be the highest piezometric surface unless demonstrated otherwise to the satisfaction of the EPA.

CRITERIA		CLASSIFICATION				
		Asbestos disposal cell	**Small**	**Medium**	**Large**	**Restricted (including treated low level contaminated waste or LLCW)**
	Groundwater total dissolved solids[4]	>3,000 mg/L total dissolved solids	>13,000 mg/L total dissolved solids	>13,000 mg/L total dissolved solids	>3,000 mg/L total dissolved solids	>13,000 mg/L total dissolved solids
	Groundwater beneficial use[5]	No extraction or beneficial use of groundwater	No extraction or beneficial use of groundwater	No extraction or beneficial use of groundwater	Groundwater extraction or beneficial use of groundwater	No extraction or beneficial use of groundwater
Waste acceptance restriction (to be effected by conditions of licence)	Inclusions	Asbestos	• Municipal solid waste[6] • Construction and demolition waste	• Municipal solid waste • Construction and demolition waste • Commercial and industrial waste	• Municipal solid waste • Construction and demolition waste • Commercial and industrial waste • Contaminated soils[7] that meet LLCW criteria without immobilisation	• Waste that has been immobilised to meet LLCW • Waste that meet LLCW criteria • Co-disposal of other wastes as permitted by licence

4 These criteria are taken from the *Environment Protection (Water Quality) Policy 2015*.

5 Receiving groundwater has a beneficial use (groundwater dependent: ecosystem, potable, recreational, agricultural or industrial use).

6 Small quantities of commercial and industrial waste may be accepted only where they arise from local activities directly servicing the local community.

7 Existing large sites may continue to use 1-m thick CCL primary liner where they meet the siting requirements for medium landfills, but are not permitted to accept contaminated soils meeting LLCW criteria.

CRITERIA		CLASSIFICATION				
		Asbestos disposal cell	**Small**	**Medium**	**Large**	**Restricted (including treated low level contaminated waste or LLCW)**
	Exclusion	All other waste including municipal solid waste, construction and demolition waste, commercial and industrial waste, listed waste	All other waste including commercial and industrial, listed waste	All other waste that exceeds Intermediate criteria	All other waste that exceeds Intermediate criteria	All other waste that exceeds LLCW criteria Restrictions on co-disposal of other wastes by license
Containment system[8]	Liner type	Reworked in-situ soils	Reworked in-situ soils	$1x10^{-9}$ CCL	Composite	Double composite
	Liner profile[9]	Site soils reworked and compacted (300 mm)	Site soils reworked and compacted (300 mm)	• Separation geotextile • 300 mm drainage • 600 mm CCL[10]	• Separation geotextile • 300 mm drainage • Geomembrane • 1 metre CCL ($1x10^{-9}$)	• Separation geotextile • 300 mm drainage • Geomembrane • 600 mm CCL ($1x10^{-9}$) • Drainage • Geomembrane • 600 mm CCL ($1x10^{-9}$) • Low permeability attenuation layer ($1x10^{-7}$)

8 An alternative containment system for a landfill classification may be proposed for approval by EPA where it can be demonstrated to provide equivalent performance to the minimum requirement specified.

9 Primary items only. Not all require reinforcement, filter and protection layers listed.

10 GCL may be used as an alternative to CCL but must be underlain by an attenuation layer of low permeability.

CRITERIA		**CLASSIFICATION**				
		Asbestos disposal cell	**Small**	**Medium**	**Large**	**Restricted (including treated low level contaminated waste or LLCW)**
	Leachate management	–	–	Leachate collection limiting head on liner to <0.3 m plus a disposal system	Leachate collection limiting head on liner to <0.3 m plus a disposal system	Leachate collection limiting head on liner to <0.3 m plus a disposal system
	Design seepage rate[11]	N/A	N/A	N/A	10 litres/ha/day	1 litre/ha/day
	Cap	• Appropriate vegetation • Topsoil • 1 m subsoil[12]	• Appropriate vegetation • Topsoil • 600 mm well-graded subsoil[13]	• Appropriate vegetation • Topsoil • 1.5 m total thickness[14] • Drainage<liner seepage	• Approved vegetation • Topsoil • 1.5 m total thickness • Drainage<liner seepage	• Approved vegetation • Topsoil • 1.5 m total thickness • Drainage<liner seepage

11 Intended as best practice benchmark for rational design and for the evaluation of the contaminant containment equivalence of alternative proposals and cap design infiltration rates. To be taken as a daily maximum for liner design and a long-term average for capping design.

12 Total thickness may include a verified interim cover layer forming part of an approved final cover design.

13 As above.

14 Total thickness (including topsoil) above a geocomposite barrier element, or total thickness of a conventional design or phytocover design (including an interim cover layer of verified thickness and forming part of an approved final cover design).

Appendix 2 Minimum requirements for compacted clay liners

Consideration related to clay liners

The inclusion of clay materials in base and side liner must take into account the following:

- Appropriate design of the system to provide the required level of environmental protection.
- General construction considerations.
- Suitability, consistency and availability of materials, particularly where these are from an unproven burrow source.

Design considerations

The design of a clay liner must include the following considerations:

- Seepage through the liner is a primary design consideration and is related to materials selected, thickness, seepage management, installation control and geometry of the base and side liner. Measures to reduce seepage include:
  - a composite liner (better than a single liner)
  - low permeability of the underlying layers
  - a thicker liner (better than a thinner liner)
  - a low hydraulic head over the liner.
- There must be effective bonding between successive layers that includes kneading between layers, and scarification and moisture conditioning between successive layers. The maximum layer thickness and number of layers is intended to promote uniformity within each layer and reduce the probability that preferential flow paths may align and adversely impact on the hydraulic conductivity of the overall liner. The appropriate layer thickness also depends on the degree of uniformity of moisture conditioning and compaction that can be achieved by the construction equipment.
- Provision must be made to tie in future sections of soil liner into an existing liner, including safe and practical access, the necessary limitations to the filling plan and protection of the liner in the tie-in zone from construction activities, erosion and control of LFG and leachate emissions.
- Tie-in lateral extension should be made over 3–6 m into the existing liner in a stair-stepped manner following the individual layers of the existing liner. Materials forming the existing liner must be scarified over a minimum horizontal distance of 1 m to maximise bonding and have a minimum horizontal overlap of 1 m between successive layers to have confidence that a preferential pathway for leachate flow is not being created.
- Maintenance of the integrity of successive layers and the completed liner. This includes prevention of disturbance, erosion and desiccation cracking.
- Traffic over clay liners during installation should generally be limited. The risks and impact of construction activities must be considered in the design to limit defects in the liner which would result in increased seepage through the system.
- Special details such as construction joins, staging of works, edge effects around the perimeter of cells and the join detail of the side liner to the cap should be considered.
- Static loads and the geometry of the leachate collection sump structure can affect the underlying clay liner system. Settlement of the waste can cause downward forces on sump riser pipes which can be transferred to liner components.
- Joining future extensions usually requires exposing existing liners. Exposing clay liners without damage requires careful consideration, including recognition of the potential presence of leachate over the existing liner system.
- Minimum horizontal overlap of 1 m between successive layers to have confidence that a preferential pathway is not being created.

The hydraulic conductivity of a clay liner depends on the material properties and the method of construction. The following sections provide technical guidance for assessment of material properties and the methods of construction.

Material properties

Assessment of material properties typically includes a program of site investigation and laboratory testing by a NATA-accredited laboratory. Site investigation typically includes a program of soil sampling, inspection, logging and laboratory testing by a geotechnical professional in accordance with *AS1726 Geotechnical Site Investigations*. The program typically includes sampling in surface exposures, test pits and/or boreholes. Considerations must include the following:

- **Particle size distribution (AS1289 3.6.1)**

  Typically, the maximum particle size should be about one-third the thickness of each layer prior to compaction (for example a maximum particle size of 66 mm for a 200-mm thick layer). Typically, there should be more than 90% passing the 19-mm sieve, 70% passing the 2.36-mm sieve and more than 30% passing the 0.075-mm sieve (fine-grained material).

- **Atterberg Limits (AS1289 3.1.1, 3.2.1, 3.3.1, 3.4.1)**

  These tests measure soil plasticity and provide an indication of the plasticity, sensitivity to moisture conditioning and the susceptibility to undergo desiccation cracking with reductions in moisture content. Clays with a low plasticity index (liquid limit less than 50%) are generally more sensitive to moisture conditioning and less susceptible to desiccation cracking compared with clays with a high plasticity index (liquid limit greater than 50%). Generally, clay soils for low permeability liner construction would have a plasticity index of greater than 10%. If a higher calcium carbonate content is suggested for the liner material, the durability and long-term performance of the material needs to be assessed and justified in the design on a site-by-site basis.

- **Dispersion (AS1289 3.8.1)**

  Clay soils should have a low susceptibility to undergo dispersion.

- **Calcium carbonate content**

  Clay soils should have a calcium carbonate content of less than 15%.

- **Permeability (hydraulic conductivity)**

  Samples for laboratory permeability testing in accordance with AS1289 6.7.3 must be remoulded in layers to a uniform density and moisture condition. Testing should consider the dry density and moisture condition during sample preparation, the composition of water available on site for moisture conditioning during earthworks and the composition of the leachate, leachate head and vertical surcharge loads to ensure that the test method is applied to obtain a representative result.

  Standard compaction testing (AS1289 5.1.1) must be performed on the sample prior to permeability testing to assess the relationship between dry density and moisture content. This includes the maximum dry density and the optimum moisture content for standard compactive effort.

  A separate compaction test must be carried out for each permeability test sample. The permeability test method should consider the particle size distribution of the proposed materials. In some cases, it may not be practicable to obtain or prepare representative samples for laboratory testing, and testing on a field trial pad may be preferred.

Pre-qualification testing guidance is provided in Appendix 6 – Minimum construction quality assurance requirements

Construction methodology

Conventional compaction criterion

The hydraulic conductivity (permeability) of clay is typically minimised if the clay is moisture conditioned and compacted at a moisture content that is greater than the optimum moisture content in standard compactive effort (AS1289 5.1.1). The optimum moisture content (OMC) is the moisture condition where the dry density of the soil is maximised for a given compactive effort.

Specification of acceptable envelopes of density ratio and moisture condition during compaction (AS1289 5.1.1 or AS1289 5.7.1) have been effectively used as performance criteria for quality control during liner construction. Acceptable envelopes should be assessed by testing as part of the design process (see the section above on material properties). Typically, construction of low permeability clay liners include the following:

- Uniform moisture conditioning to between 0 and +3% of the OMC in standard compactive effort (AS1289 5.1.1).
- Uniform compaction in layers of less than 200 mm compacted thickness using a sheepsfoot roller to achieve a dry density ratio of greater than 95% relative to standard compactive effort (AS1289 5.1.1).
- Effective bonding between layers.

Construction quality assurance guidance is provided in Appendix 6 – Minimum construction quality assurance requirements.

Line of optimums method

The method defines combinations of water content and dry unit weight corresponding to hydraulic conductivities meeting a design criterion (eg 1×10^{-9} m/s), and generally results in an acceptable zone falling wet of the line of optimums. The line of optimums is defined as a line or curve connecting MDD/OM points from compaction curves created at different compactive energies for given soil. This zone must be established for the actual materials and methods used in construction.

For this method, the most important aspects of quality control testing are material control and compaction control.

Material control is typically conducted to ensure that the properties of the soil do not differ substantially from those anticipated during design. Tests to determine these properties should be conducted at least once per 1,000 m^3 of soil placed unless lower frequencies may be justified where extensive experience exists with the soil or a statistical process control technique is used to monitor the construction process. In all cases, continual visual oversight should be provided during construction. Curing times are likely to be required where water content is varied more than 3% from stockpiled or borrowed soils.

Compaction control is typically conducted to ensure that the compaction water content and dry unit weight fall within the acceptable zone and is the most important aspect of quality control testing. If significant changes in the soil occur during construction, an updated compaction criterion needs to be developed. Water content and dry unit weight should be measured on each lift at a rate of at least 12 measurements per 10,000 m^2 (approximately 1 test/125 m^3).

Typically, specification of construction of low permeability clay liners using the line of optimums method developed for a site-specific material will include:

- Methods of material and compaction control, including continuing evaluation to ensure the line of optimum is applicable to the soils being used. If the criteria are not satisfied, then the region should be re-worked until satisfactory compaction has been achieved. Reworking might include reconstructing the entire area under consideration, or reworking those areas where combinations of water content and dry unit weight fell dry of the line of optimums (where sufficient data exists to justify this).
- Trial pad/large-scale hydraulic conductivity assessment.
- Maximum moisture content to provide adequate shear strength.
- Soil processing to ensure a clod size <50 mm prior to compaction or water addition.
- Blending soil in stages so that change in water content change is <3% during each stage, and curing requirements if larger changes are made.
- Loose lift thickness should not be more than 200 mm.
- Minimum total liner thickness of 0.9 m.
- Compaction using a sheepsfoot roller with a foot length greater than 150 mm.

Appendix 3 Minimum requirements for geosynthetic materials in liners

General considerations related to geosynthetic materials

The inclusion of geosynthetic materials in base and side liners and covers must take into account the following:

- Appropriate design of the system, to provide the required level of environmental protection.
- General construction considerations for using specialist materials.
- Durability of the materials.

General design considerations

The design of geosynthetic liners and surrounding materials must include the following considerations:

- Materials placed over geosynthetic liners can be unstable. Generally, the interface friction of geosynthetic liners is very low, resulting in a preferential sliding plane. The interface friction of textured geomembranes is generally higher and may require complex stability analysis. Stability issues may exist at side liner and at the edge of landfill cells, where interim or permanent waste slopes may be constructed. Where appropriate, laboratory testing of geosynthetics in conjunction with the proposed construction materials should be considered to determine the interface friction over the likely confining stress range.
- Stresses and strains resulting from imposed loads on the liner system are applied to the geosynthetics both from waste placed over the liner and from construction loads. The design must consider the total load applied from the full thickness of the waste and landfill cap. The impact of point loads from the gravel of the leachate collection layer must be considered when assessing the cushioning required to protect geosynthetic liners. Imposed loads may also result from settlement and movement of the waste adjacent to a side liner of the landfill. Settlement of the subgrade soils (underlying the liner system) may also occur, resulting from the imposed load of the overlying waste, which may be significant. Consideration should be given to both static and seismic conditions.
- The requirements to maintain the integrity, strength and stability of seams and constructing joints.
- Safety in design and construction.
- Once covered with waste, the liner system cannot be accessed for repair and maintenance without significant cost and impact on operations.
- Seepage through the liner is a primary design consideration and is related to materials selected, thickness, seepage management, installation control and geometry of the base and side liner. Measures to reduce seepage include:
  - a composite liner (better than a single liner)
  - low permeability of the underlying layers
  - a thicker liner (better than a thinner liner)
  - a low hydraulic head over the liner.
- Chemicals and temperature have impacts on the liner system as part of the leachate collection system or from landfill gas. Temperatures in excess of 40^0C commonly occur in large landfill facilities due to decomposition of the waste.
- Traffic over geosynthetic liners during installation should generally be avoided. The risks and impact of construction activities must be considered in the design to limit defects in the liner which would result in increased seepage through the system, and be communicated on the basis of design report and specification.
- Special details such as joins and other materials, staging of works, anchorage, edge effects around the perimeter of cells and the join detail of the side liner to the cap should be considered. Penetrations are difficult to install and require special attention to design and construction to achieve a good seal, and should be avoided where possible.

- Static loads and the geometry of the leachate collection sump structure can affect the underlying geosynthetic liner system. Settlement of the waste can cause downward forces on sump riser pipes which can be transferred to liner components.
- Joining future extensions usually requires exposing existing geosynthetics. Exposing geosynthetics without damage requires careful consideration, including recognition of the potential presence of leachate over the existing liner system.
- Demonstration of equivalence of the lining system should take into consideration issues such as flow rate and concentration gradients with respect to time, related to the point of compliance for the site.

General construction considerations

The construction of the geosynthetic liner, and the underlying and overlying materials must be carried out in accordance with an effective quality control and quality assurance program. Poor installation can neutralise the potential benefits of a geosynthetic liner system.

Construction must at least consider the following points:

- Good subgrade preparation to provide a sound and stable base for liner construction.
- The quality of the geosynthetic liner delivered to the site.
- The quality of joins.
- The risk of damage during handling, storage and installation, taking into account weather conditions, eg wind, rainfall and temperature.
- Provision of intimate contact between the geosynthetic and underlying materials where appropriate, including prevention of wrinkles in the geosynthetic.
- Stormwater management during construction, as geosynthetics placement requires relatively dry condition – particular consideration is required for lining leachate collection sumps located at the lowest point of a base liner.
- Appropriate access and practical requirements to enable placement of a geosynthetic side liner and joining of geosynthetics on slopes.
- Controls and measures to address safe methods of work and risks during construction.
- The risk of subsequent damage from other construction activities, such as placement of materials over the geosynthetic liner.
- Stormwater management on side slopes to prevent infiltration under the liner system.
- Presence or risk of groundwater or hydrostatic pressures under the liner system.

General durability consideration

Durability issues are related to the environment of the geosynthetic liner. The durability considerations of geosynthetics of GCLs, geomembranes, geotextiles and geocomposites are different.

Geomembrane considerations must include:

- chemical resistance to leachate
- oxidation and stress cracking over the entire life of the landfill (including the operating and post-closure periods)
- temperature around the liner and its impact on effective life
- protection from surface water and wind before covering.

GCL considerations must include:

- risk of degradation of reinforcement fibres
- chemical effects of leachate on textile materials

- filtration characteristics to limit the effects of clogging
- strength to resist installation damage
- UV resistance for the period of exposure before covering (ie same day for GCL)
- protection from surface water and wind before covering.

Geocomposite considerations include:

- risk of degradation of reinforcement fibres
- chemical effect of leachate on geotextile and core materials
- oxidation and stress cracking of the core material over the entire life of the landfill (including the operating and post-closure periods)
- clogging of the geotextile and core
- internal shear strength and interface friction with adjacent layers
- long-term flow capacity under operational and post closure loads
- protection from surface water and wind before covering.

Due to reliance placed on structural and lining performance of geosynthetics in critical applications over long periods of time, the risks associated with failures and the lack of data regarding the impact of using post-consumer resins and materials in their manufacture on performance, current recognised minimum specifications exclude their use in manufacture and limit the proportion of reworked materials within the manufacturing facility. Peer reviewed, evidence based, scientific justification is required to support variation of these specifications for critical lining, protection and drainage applications.

General minimum requirements for design

The geosynthetic liner system for the base and side liner must be designed by a person with demonstrated understating of and experience in the design and installation of the proposed geosynthetics, and in the geotechnical considerations related to lining the base of landfills.

The designer must prepare a specification and drawings that address the minimum requirements of this guideline. Variations and design changes during construction (including acceptance of any work or materials considered to be non-confirming in the opinion of the CQA engineer) must be assessed and accepted by the designer and EPA in accordance with the requirements of Appendix 6.

The designer must prepare a Basis of Design report to accompany the design drawing and specification that contains:

- Design, construction and durability considerations.
- Details to demonstrate that minimum requirements have been met.
- Design decisions and any limitations these or materials impose on landfill construction, operation and staging.
- Design assumptions regarding the management of construction and operational hazards.
- A statement confirming that the minimum requirements of the guideline and environmental authorisation have been met by the design.

The installation of the geosynthetic liner must be carried out in accordance with an effective construction quality assurance (CQA) system, as developed in consultation with the EPA before commencement of construction. The approved CQA plan may only be varied in consultation with the EPA.

Minimum requirements for geomembrane

Geomembrane properties

Geomembrane liners must:

- Consist of a thin plastic film, minimum 2-mm thick, manufactured from high density polyethylene or other material demonstrated to offer equivalent performance, strength and durability.
- Be strong enough to ensure adequate tear resistance, puncture resistance, and resistance to installation damage.
- Be able to resist degradation caused by factors such as chemical attack, temperature, oxidation and stress cracking over the entire life of the landfill (including the operating and post-closure periods).
- Meet or exceed the requirements for manufacture and performance contained in the relevant specifications published by the Geosynthetic Research Institute (Folsom, PA, USA) from time to time, or in equivalent recognised industry standard specifications; see GRI Test Method GM 13 and GRI Test Method GM 17 respectively, for high density polyethylene geomembrane and linear low density geomembranes (Geosynthetic Research Institute 2015 and 2016). These minimum properties are intended to provide a guide to minimum expectation of good practice for the materials only. The designer must address the minimum requirements for survivability during installation and service. The design of the liner system may require additional parameters or improved values compared with these specifications, to provide the required design performance of the liner system.
- Independent Quality Assurance (IQA) testing frequencies of the materials should be related to the area being lined for the project and the parameter being tested. Minimum recommended testing frequencies are provided in Tables 2, 3 and 4.

Table 2 IQA testing requirements for HDPE geomembranes

Property	Standard	Frequency
Thickness	ASTM D5199 (smooth) ASTM D5994 (textured)	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Asperity height (textured)	ASTM D7466	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Density	ASTM D1505 or ASTM D792	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Tensile properties (yield and break stress, yield and break elongation)	ASTM D6693	1 test per 5,000m2, including the first and last rolls (based on production order). Minimum of two tests.
Puncture resistance	ASTM D4833	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Tear resistance	ASTM D1004	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Caron black content	ASTM D1603 or ASTM D4218	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.

Property	Standard	Frequency
Carbon black dispersion	ASTM D5596	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Stress crack resistance	ASTM D5397	1 test per 10,000 m^2, or resin type or manufacturing run (whichever results in the number of tests), including the first and last rolls (based on production order). Minimum of two tests.
Standard oxidative induction time and High pressure oxidative induction time	ASTM D3895 ASTM D5885	1 test per 10,000 m^2, or resin type or manufacturing run (whichever results in the greatest number of tests), including the first and last roll (based on production order). Minimum of two tests.

Table 3 IQA testing requirements for LLDPE geomembranes

Property	Standard	Frequency
Thickness	ASTM D5199 (smooth) ASTM D5994 (textured)	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Asperity height (textured)	ASTM D7466	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Density	ASTM D1505 or ASTM D792	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Tensile properties (break stress and elongation)	ASTM D6693	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Puncture resistance	ASTM D4833	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Tear resistance	ASTM D1004	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Carbon black content	ASTM D1603 or ASTM D4218	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Carbon black dispersion	ASTM D5596	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.

Property	Standard	Frequency
Axi-symmetric break resistance strain	ASTM D5397	1 test per 10,000 m^2, or resin type or manufacturing run (whichever results in the greatest number of tests), including the first and last rolls (based on production order). Minimum of two tests.
Standard oxidative induction time High pressure oxidative induction time	ASTM D3895 ASTM D5885	1 test per 10,000 m^2, or resin type or manufacturing run (whichever results in the greatest number of tests), including the first and last rolls (based on production order). Minimum of two tests.

Table 4 IQA weld testing for HDPE and LLDPE geomembranes

Item	Property	Standard	Frequency
Start-up weld	Welding equipment	–	Checked daily at start of works, and whenever the welding equipment is shut off for more than 1 hour, and also after significant changes in weather conditions
	Weld conditions	–	Test weld strips, minimum 1.5 m continuous seam, required whenever personnel or equipment are changes and/or wide temperature fluctuations are experienced
Destructive weld testing	Onsite; tensiometer in peel and shear	ASTM D6392	Every weld
	Offsite; weld seam strength in peel and shear	ASTM D6392	HDPE – every 150 m if fusion weld; every 120 m if extrusion weld LLDPE – every 300 m if fusion weld; every 150 m if extrusion weld
Non-destructive weld testing		Air pressure test, ASTM D5820 Vacuum box test, ASTM 5641	All seams over full length

(Source: EPA Victoria 2015, pp 89–90)

Guidance on the minimum acceptable criteria and evaluation of destructive tests are provided in GRI Test Method GM 19a for thermally bonded homogenous polyolefin geomembranes (Geosynthetic Research Institute 2017)

Geomembrane design

The following minimum requirements must be satisfied:

- The design of the geosynthetics liner should endeavour to keep the geosynthetic barrier material unstressed wherever possible. The function of the liner is to limit seepage, and it should not be subject to significant tensile stresses.
- The geosynthetic barrier should be protected from damage or strains that might result in stress cracking from adjacent materials, installation and in-service load conditions, and leachate sump loads.
- Geosynthetic materials should be installed and covered as soon as is necessary to protect the materials from processes that may result in deterioration from their design performance.
- Penetrations for inlet and outlet pipes or other penetrations through the liner should be avoided where possible. Penetrations must be designed and constructed so that the liner integrity is maintained and the liner material unstressed.
- The design of the liner needs to consider the various potential stresses imposed on the geomembrane by the in-service configuration and conditions. It is necessary to include the calculations of the physical stresses due to:
  - strains imposed at the anchor trench
  - strains imposed over long, steep side slopes
  - differential settlement of the subgrade foundation soils, if any
  - point loading by angular or rough stones, and leachate collection infrastructure.
- The design needs to consider (with justification) the chemical compatibility of the geomembrane liner and the leachate, in particular for the case of a LLCW cell, the ability of the liner to retain adequate strength and performance after exposure to leachate.
- The design needs to consider the effect of thermal stresses on the liner during installation and construction, and effect of temperature during operation (effect of waste temperatures). It is important to describe how the effect of waste temperature on service life and the thermal stresses have been taken into account and any limits this places on operation of the landfill.
- The design must take account of installation and construction stresses, and state the limits the design places on the use of equipment and traffic during installation. In particular the stresses resulting from application of the protection layer placed between the liner and the leachate collection system. Describe how these stresses have been taken into account.
- In the case of installations with sloping sides (including bunds and other lined features), it needs to be demonstrated that there is adequate friction between the various components of the liner system to prevent slippage or sloughing on the slopes of the installation. In particular, the following must be assessed:
  - The ability of the geomembrane to support its own weight on the side slopes.
  - The ability of the geomembrane to withstand down drag during and after waste placement.
  - The suitability of the anchorage configuration for the geomembrane (prior to and after waste placement).
  - The ability to maintain a stable state when a granular drainage layer is placed on top of the geomembrane.
  - The ability to maintain a stable configuration when other geosynthetic components such as geotextiles or geocomposites are placed on top of the geomembrane.
  - The ability to maintain a stable configuration when installed on top of a compacted clay liner or a geosynthetic clay liner.
- Provide clear detail for each configuration of the liner profile showing its location, extent and all layers and geosynthetic elements.

Geomembrane installation

Installation and seaming of the geomembranes must be undertaken by geomembrane installers with extensive experience in seaming the same type of geomembrane being installed and using the same seaming procedure to be used on site. They must hold a current independent certification for seaming and installation to a recognised industry standard (national or international) and must provide experience records prior to any installation.

The *Guidelines for Installation of HDPE and LLDPE Geomembrane Installation Specification* (International Association of Geosynthetic Installers 2015) provides an example of minimum acceptable qualifications and experience.

Installation specifications should include details regarding:

- Subgrade condition (including cracking and other irregularities) and suitability. The geomembrane needs to be placed flat on a well compact, smooth and firm foundation material. The surface shall be free of any sharp objects, stones, debris, water, sudden changes in grade, and desiccation cracks. The geomembrane should not be installed until inspection of the finished surface has been undertaken and deemed suitable by the CQA engineer.
- Procedures to be adopted to prevent desiccation of any underlying compacted clay liner or shrinkage of any underlying GCL (both before and subsequent to the placement of the geomembrane).
- Geosynthetic labelling.
- Methods of protecting the geomembrane during shipping, storage, handling and installation. Installation of a geomembrane can result in scratching or scoring which can affect the geomembrane's performance and initiate stress cracking. The method used to unroll and deploy the panels should not score, scratch or crimp the geomembrane.
- Methods of dealing with:
  - thermal effect on geomembrane surfaces on rolls
  - spotting of deployed geomembranes
  - thermal expansion and contraction
  - wind effects and ballasting to prevent uplift.
- Panel deployment layout plan, panel identification, method of placement, seam orientation, seam preparation, seaming methods and seaming temperature constraints which include the following requirements:
  - The geomembrane sheets should be installed such that the panels are continuous down side walls/slopes and across the base. The arrangement of the geomembrane sheets should be according to a predetermined plan to minimise the amount of welding needed.
  - All panels should be overlapped onto adjacent sheets by a minimum of 125 mm and orientated so that the lap is in the down sloping direction and across the flat base. All welds should run down a slope or be on the flat base.
  - The weld surfaces should be clean immediately prior to welding. The weld area should be free of moisture, dust, dirt, debris, markings and foreign material.
  - Welding of all main joints between adjacent geomembrane panels (primary welds) should be conducted using hot-wedge welding, producing two parallel seams with an air channel in between (dual-track fusion welding). The hot wedge welding shall be conducted out using the split head wedge fusion weld method which will fuse the upper and lower overlapped geomembrane sheets.
  - Extrusion welding is used primarily for detailed work and repair work (secondary weld) or where approved in areas that would be inaccessible to the dual track fusion weld (such as around structures, pipes and other penetrations). The extruded granulate for surface extrusion welding should be manufactured from the same resin type used in the manufacture of the geomembrane. All physical properties shall be identical to those possessed by the geomembrane raw material. The manufacturer should provide certified test data with each batch of welding granulate.

- In the case of extrusion fillet welding, oxidation by products need to be removed from the surface to be welded by grinding/buffing. Grind marks should not be deeper than 10% of the geomembrane thickness. Welding should be performed shortly after grinding so that surface oxide formation does not reform.
- All geomembrane panels subject to hot wedge welding shall be overlapped by a minimum of 125 mm and a minimum of 75 mm for extrusion welding to allow for proper construction quality assurance testing.
- All primary welds used to connect panel ends to sheets shall form T-joins (tees). These T-connections must have a distance of at least 0.5 m. The welding seams of the geomembrane cannot cross (no cruciform connections).
- On slopes, the seams shall to a large extent run parallel to the line of maximum slope.
- Patching geomembrane panels using transverse joints on slopes is not permitted. The connecting seam between geomembranes on the slope and the base should be located in the base at a distance of at least 1.0 m from the slope toe.
- Procedures to deal with damages and defects. The entire surface area of each and every roll shall be inspected by the CQA engineer, prior to works commencing. The geomembrane surface inspection may occur during unrolling/installation to ensure that there are no tears, punctures, abrasions, indentations, cracks, thin spots or other faults in the material. If damages are identified, they will need to be repaired according to the specifications put in place for the site.

- Criteria, testing and action on test failure which include the following requirements:
  - Rejection criteria of the geomembrane sheets and details of actions to be taken if geomembrane fails a conformance test.
  - Details of actions to take after cutting of each destructive test sample from the production seam.
  - Details of actions to take in the event of a defective weld, including retesting procedures.
  - Details of criteria and actions in the event of damage during welding.
  - Rejection criteria of the laid geomembrane if test results indicated failure.
  - Details of actions to take in case of defects and/or damages to the surface of the laid geomembrane are identified (by any means) and corrective measures.
  - Details of actions to take if geomembranes have been damaged due to shifting by wind.
  - Weather and temperature conditions during geomembrane deployment and seaming.
  - Details of actions to take to minimise geomembrane wrinkles and bridging.
  - Verification process of the geomembrane installation around areas of protrusions and penetrations is made according to specifications.
- Geomembranes installed on slopes are required to be fixed in anchor trenches. This is done to secure the geomembrane and prevent it from sloughing or slipping down the inside side slopes during construction or service.
- Details of actions to take to protect the geomembrane following installation.
- Methods of placement of the protective layer and/or leachate collection layer.
- Methods of dealing with or managing wrinkles (waves) which includes the following requirements:
  - The geomembrane should be installed without undergoing substantial buckling or wrinkling which result in tensioning/bridging at changes of grade or depressions due to thermal effects or otherwise.
  - Particular care shall be taken during installation of the geomembrane to ensure that the surface of the geomembrane after installation is substantially free from buckles, wrinkles, ripples, creases and folds, and is flat and conforms to the underlying surface before the cover material is placed above it.

- At the time the geomembrane is covered with soil (eg drainage gravel), the growth or movement of wrinkles must be minimised. Any remaining wrinkles must be sufficiently small that they are flattened without creasing, and not 'locked' or preserved within the placed drainage layer.
- Removal of wrinkles by cutting out and patching where necessary.

Minimum requirements for GCL

GCL properties

Geosynthetic clay liners used as alternatives to compacted clay should:

- Consist of a thin layer of bentonite 'sandwiched' between layers of geotextiles with a hydraulic conductivity less than $5x10^{-11}$ m/sec.
- Be reinforced (ie the geotextile layers are bonded by needle punching or stitching to enhance the internal shear strength of the geosynthetic clay liner compared with that of unreinforced products).
- Have adequate strength, flexibility and durability to maintain performance over the entire life of the landfill (including the operating and post-closure periods).
- Meet or exceed the requirements for manufacture and performance contained in the relevant specifications published by the Geosynthetic Research Institute (Folsom, PA, USA) from time to time, or in equivalent recognised industry standard specifications; see GRI-GCL3 (Geosynthetic Research Institute 2016).
- Be made from bentonite that has been formulated for landfill applications; the bentonite should meet the specifications in Table 6.
- Where additives such as polymers and pH modifiers are added by a manufacturer to bentonite to improve their performance, the manufacturer must provide details of the additives and demonstrate their nature, suitability and long term durability in the application.

Table 5 also provides minimum properties for GCL geosynthetic lining materials intended to provide a guide related to survivability during installation and joining. The design of the liner system may require additional parameters of improved valued compared with these tables, to provide the design performance of the liner system.

Table 5 Minimum requirements for geosynthetic clay liner (GCL)

Property	Range or value
Montmorillonite content	>70 wt.%
Carbonate content*	2 wt.%
Bentonite form	Natural Na-bentonite or >80 wt.% sodium as activated bentonite
Particle size	Powdered (eg 80% passing 75-micron sieve) or Granulated (eg <1% passing 75-micron sieve)**
Cation exchange capacity	≥70 meq/100 g (or cmol/kg)
Free swell index	≥24 cm^3/2g

Note:

* Carbonate implies calcite, calcium carbonate or other soluble or partially soluble carbonate minerals.

** Provided for classification purposes; not a minimum requirement. The designer must specify appropriate installation and hydration requirements as appropriate.

(Adapted from SA EPA and Victorian EPA)

IQA testing frequencies of the materials should be related to the area being lined for the project and the parameter being tested and provided in Table 6.

Table 6 IQA testing requirements for geosynthetic clay liners

Property	Standard	Frequency
GCL (geosynthetic clay liner) mass per unit area	ASTM D5993	1 test per 2,500 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Bentonite mass per unit area	ASTM D5993	1 test per 1,250 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Peel strength	ASTM D6496	1 test per 1,250 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Tensile properties (machine directions)	ASTM D6768	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
CBR (California bearing ration) burst strength	AS 3706.4	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Fluid loss	ASTM D5891	1 test per 1,250 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Swell index	ASTM D5890	1 tests per 2,500 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Cation exchange capacity	Methylene blue method	1 test per 2,500 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Permeability	ASTM D5887 or ASTM D6766	1 test per 10,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Montmorillonite content and carbonate content	CSIRO X–ray diffraction	1 test per 10,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.

(Adapted from NSW EPA)

GCL design

The following minimum requirements must be satisfied:

- Preparation of an engineered subgrade capable of supporting the landfill without mechanical damage affecting the performance of the GCL.
- Justification of the equivalency of the GCL by comparison of contaminant transport to that of a CCL.
- Overlaps of the GCL panels must provide a similar seepage control performance as the rest of the GCL, and must be:
  - free of wrinkles
  - sealed with bentonite paste or powder
  - a minimum of 300 mm
  - 1,500 mm for transverse overlaps [occurring with grade slopes steeper than 1 vertical (V) and 5 horizontal (H)].
- Panels must be anchored to achieve stability required by the design.

- Particles in contact with the GCL must be less than 15 mm in any dimension, with protrusions limited to less than 10 mm (in both the subgrade and overlying layer).
- The design avoids or appropriately manages the risk of internal erosion and panel separation.
- The compatibility of the GCL is confirmed for applications where GCL is exposed to cations (eg Ca+) for Na+ exchange reactions (ie during hydration, from cover soils or leachate), and the design hydraulic conductivity is supported by testing.
- Adequate interface friction is present to ensure stability of the lining system and prevent individual component failure:
  - under the loads and conditions imposed by installation, construction, waste placement, waste settlement and post closure use
  - the presence of construction water, storm water and leachate.
- Design and material specification acceptable for exposure to UV, thermal gradients and wind loads during construction and in service.
- Specific details are provided for all:
  - anchorages
  - interfaces with adjacent liners and structures
  - temporary works
  - staged construction
  - changes in construction and ultimate design load cases
  - changes in subgrade.

GCL Installation

The installation specification should include details regarding the management of:

- Subgrade condition (including cracking and other irregularities) and suitability.
- Geosynthetic clay liner labelling.
- Methods of protecting the geosynthetic clay liner during shipping, storage and handling.
- Panel deployment layout plan, panel identification, method of deployment and placement, overlap orientation, overlap preparation and overlap methods.
- Procedures to be adopted to ensure hydration of the GCL.
- Procedures to be adopted to prevent premature hydration of the GCL.
- Procedures to be adopted to provide confinement to the GCL.
- Procedures to be adopted to prevent opening of the overlaps due to placement of overlaying layers of wet-dry cycle(s).
- Procedures to be adopted to control the effect of trafficking by vehicles to limits that satisfy manufacturer guidance and the design stress and strain.
- Methods of placement in a trench.
- Procedures to identify and deal with damage and defects.
- Procedures to deal with inclement weather.
- Methods of dealing with or managing wrinkles (waves).
- Methods of dealing with installation around protrusions and penetrations.

- Procedures to be adopted to prevent desiccation of geosynthetic clay liner and/or any underlying subgrade material.
- Procedures to be adopted to install a geomembrane on top of the GCL.

Minimum requirements for protection layers

Soil and drainage aggregate as protection layers

Soil and drainage aggregate may serve as protection and confinement layers during landfill construction and operation. The purpose of protection layers and their design limitations (eg construction traffic or load limitations during landfill operation) shall be set out in the basis of design report and where necessary the construction specifications.

Soil protection layers should be specified by the designer having regard to the potential for erosion, damage of adjacent geosynthetics due to particle size and veneer stability. The CQA plan should include measures to verify the thickness and adequacy of protection layers prior to trafficking by construction equipment and if necessary conduct field trials of proposed construction methods.

Protection geotextile properties

The protection or cushion geotextile should:

- Be a non-woven, needle-punched geotextile, typically made of polyester or polypropylene (and may include inhibitors and/or carbon black added for UV resistance), formulated to meet landfill conditions and not containing recycled materials
- Be of sufficient mass, strength and thickness to protect the underlying geomembrane from puncture and from excess stresses and strains due to indentations from overlying gravel particles or from the ribbing, edges and joins of drainage geocomposites
- Be free of contamination (eg needles from manufacture) which may damage the geomembrane
- Meet or exceed the requirements for manufacture and performance contained in the relevant specifications published by the Geosynthetic Research Institute (Folsom, PA, USA) from time to time, or in equivalent recognised industry standard specifications [see GRI Test Method GT12a and b (Geosynthetic Research Institute 2012a, 2012b).

IQA testing frequencies of the materials should be related to the area being lined for the project and the parameter being tested and are provided in Table 7.

Table 7 IQA testing requirements for protection

Property	Standard [1]	Frequency
Mass per unit area	AS 3706.1	1 test per 2,500 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Grab tensile strength	AS 3706.2b	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Trapezoidal tear strength	AS 3706.3	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
CBR (California bearing ration) burst strength	AS 3706.4	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.

[1] Relevant Australian Standards have been recommended. A designer may specify the use of alternative equivalent ASTM test methods which achieve the same intended outcome.

Protection geotextile design

Excessive strain can lead to environmental stress cracking in susceptible geomembranes over time. The testing should ensure that both short and long-term effects are taken into account.

The grade (mass, strength, thickness) of the protection geotextile should be justified by the results of site-specific liner testing since performance is affected by the type of geotextile, nature of drainage materials, stiffness of subgrade, loads imposed by the landfill and construction traffic.

Two published methods for examining the expected field performance of a geomembrane liner under gravel aggregate are:

- LFE 2, *Cylinder Testing Geomembranes and their Protection Materials: A methodology for testing protector geotextiles for their performance in specific site conditions* (UK Environment Agency 2014); and
- ASTM D5514/D5514M–14, *Standard Test Method for Large Scale Hydrostatic Puncture Testing of Geosynthetics* (ASTM International 2014).

In these tests, a representative load is applied under standard conditions to a sample comprising the proposed drainage materials, protection geotextile and geomembrane liner. Measurements are taken of the deformations in the liner. Strains in the material are estimated from the deformation data as an indirect measure of stress and should be compared with the acceptable values for geomembrane strain.

The German BAM requirements adopt a maximum strain limit of 3% and maximum local strain (eg at individual stone protrusions) of 0.25% (Seeger and Muller 1996 applied to results from the LFE cylinder test) to account for a range of effects including geomembrane bending.

Table 8 provides recommended maximum allowable strains, to limit stress to a subcritical value where stress cracking will not be a practicable problem (Peggs 2003), noting that in a confined situation the stress will be applied very slowly to the geomembrane as the adjacent soils move, and the geomembrane will be able to relax resulting quite rapidly in geomembrane stresses that are maybe 50% of the value implied by the deformation. These maximum allowable strains limits cannot be directly evaluated against the results of strain measurements obtained by testing (LFE 2 or ASTM D5514/D5514M) without modification to take account of the effects of creep in protection materials, geomembrane bending, uncertainty in the strain measurement technique and actual field conditions.

Table 8 Maximum allowable strains for various geomembrane materials

Geomembrane type	Maximum allowable strain
HDPE smooth	6%
HDPE randomly textured	4%
HDPE structured profile	6%
LLDPE density <0.935 g/cm^3	12%
LLDPE density >0.935 g/cm^3	10%
LLDPE randomly textured	8%
LLDPE structured profile	10%

(Adapted from Victorian EPA 2015 and values from Peggs 2003)

The designer should ensure that:

- Site-specific conditions are taken into account.
- Appropriate allowance is made for construction, service and after use conditions, and any uncertainty in assumptions made.
- Sampling and testing is representative of the materials, protection and site-specific service conditions selected.
- Measured strains are factored to account for creep in protection materials, geomembrane bending, uncertainty in the strain measurement technique and actual field conditions and evaluated against appropriate criteria.

Protection geotextile installation

The installation specification should include details regarding the management of:

- Geomembrane surface conditions (CQA completed and accepted, surface free of sharp objects, stone, debris, surface water and damage) and suitability prior to deployment.
- Panel deployment layout plan, panel identification, method of deployment and placement, overlap orientation, overlap preparation and overlap methods.
- Procedures to prevent damage to the geomembrane during deployment.
- Procedures to prevent damage to the geotextile during deployment and exposure prior to covering.
- Procedures to identify and deal with damage and defects.
- Methods of dealing with installation around protrusions and penetrations.

The CQA plan shall include measures to verify the thickness and adequacy of protection layers prior to trafficking by construction equipment and if necessary conduct field trials of proposed construction methods.

Minimum requirements for separation geotextiles

Separation geotextile properties

The protection or cushion geotextile should:

- Be a non-woven, needle-punched geotextile, typically made of polyester or polypropylene (and may include inhibitors and/or carbon black added for UV resistance), formulated to meet landfill conditions and not containing recycled materials.
- Be of sufficient mass, strength and thickness to resist damage from surrounding materials during placement of waste that would allow entry of the overlying materials to the drainage layer that results in clogging.
- Allow flow of leachate into the underlying drainage layer without significant flow impedance.
- Have appropriate chemical resistance to the site's leachate.
- Meet or exceed the requirements for manufacture and performance contained in the relevant specifications published by the Geosynthetic Research Institute (Folsom, PA, USA) from time to time, or in equivalent recognised industry standard specifications [see GRI Test Method GT12a and b (Geosynthetic Research Institute, 2012a, 2012b)].

IQA testing frequencies of the materials should be related to the area being lined for the project and the parameter being tested and are provided in Table 9.

Table 9 IQA testing requirements for separation geotextiles

Property	Standard	Frequency
Grab tensile strength	AS 3706.2b	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Trapezoidal tear strength	AS 3706.3	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
CBR (California bearing ration) burst strength	AS 3706.4	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Pore size	ASTM D6767	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Permittivity	AS 3706.9	1 test per 5000 m^2, including the first and last rolls (based on production order). Minimum of two tests.

Separation geotextile design

The geotextile should be designed to resist puncture during installation and covered with waste. Geotextile should not be wrapped around leachate collection pipes as this has been demonstrated to clog rapidly.

Separation geotextile installation

The installation specification should include details regarding the management of:

- Drainage layer surface condition (CQA completed and accepted, surface free of sharp objects, stone, debris, surface water and damage) and suitability prior to deployment.
- Panel deployment layout plan, panel identification, method of deployment and placement, overlap orientation, overlap preparation and overlap methods.
- Procedures to prevent damage to the geomembrane during deployment.
- Procedures to prevent damage to the geotextile during deployment and exposure prior to covering.
- Procedures to identify and deal with damage and defects.
- Method of dealing with installation around protrusions and penetrations.

Minimum requirements for drainage geocomposite

Drainage geocomposite properties

The geonet drainage geocomposite should be protected by an overlying padding or protection layer. This layer should have adequate thickness, particle size distribution, permeability, internal shear strength and interface friction with adjacent layers.

The geonet drainage geocomposite should:

- Have an internal geonet drainage core manufactured from high-density polyethylene (plus anti-oxidants) and consisting of layers of parallel ribs creating drainage channels through which liquid can flow.
- Have a geotextile fabric bonded to the upper surface of the geonet to prevent fines from entering the drainage channels, and a geotextile fabric bonded to the lower surface to prevent damage to adjacent geosynthetic layers from the ribbing, edges and ties of the geonet.

- Be able to resist degradation caused by factors such as chemical attack, temperature, oxidation and stress cracking over the entire life of the landfill (this includes chemical resistance of the geotextile fabric polymers to the site leachate).
- Have adequate internal shear strength and interface friction with adjacent layers.
- Have adequate long-term flow capacity for the calculated leachate flow rate at the site.

IQA testing frequencies of the materials should be related to the area being lined for the project and the parameter being tested and are provided in Table 10.

Table 10 IQA testing requirements for geonet drainage geocomposites

Property	Standard	Frequency
Drainage geocomposite core		
Thickness	AS3706.1	1 test per 1,250 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Compressive strength	ASTM D1621	1 test per 1,250 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Drainage geocomposite		
Tensile strength	AS 3706.2a	1 test per 5,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
In-plane flow rate	ASTM D4716	1 test per 1,250 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Geotextile		
Pore size	ASTM D6767	1 test per 10,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.
Permittivity	AS 3706.9	1 test per 10,000 m^2, including the first and last rolls (based on production order). Minimum of two tests.

Drainage geocomposite design

The allowable flow rate should be determined from a standard 100-hour test simulating field conditions (adjacent layers, waste loads and hydraulic gradient). This test will account for decreases in flow capacity due to intrusion of the geotextile into the geonet core.

The designer should then allow for factors that will further reduce the thickness and capacity of the drainage core under long-term field conditions. These factors include long-term creep deformation of the geonet, and chemical and biological clogging caused by leachate. In addition to these specific reduction factors, adequate general safety factors should be applied to account for overall design uncertainties.

Design measures should be adopted to prevent:

- Bentonite intrusion from GCL.
- Separation of adjacent panels and slope instability
- Development of hydrostatic pressure equivalent to greater than 300 mm head above the liner.
- Damage to the geocomposite due to the loads imposed by construction and operational plant.

- Damage due to UV exposure of the material before covering.
- Entry of surface runoff.
- Uncontrolled release of LFG.

The drainage geocomposite should:

- Have a minimum hydraulic transmissivity of 0.3×10^{-3} m^2/sec under design considerations
- Maintain a maximum leachate head of less than 300 mm above the liner.

Drainage geocomposite installation

The installation specification should include details regarding the management of:

- Underlying geosynthetic surface condition (CQA completed and accepted, and surface free of sharp objects, stone, debris, surface water and damage) and suitability prior to deployment.
- Panel deployment layout plan, panel identification, method of deployment and placement, overlap orientation, overlap preparation, and overlap methods.
- Procedures to prevent damage to the underlying geosynthetics during deployment.
- Procedures to prevent damage to the geotextile during deployment and exposure prior to covering.
- Procedures to prevent soil entering the geocomposite drainage channels.
- Procedures to identify and deal with damage and defects.
- Methods of dealing with installation around protrusions and penetrations.

Geosynthetic construction quality assurance

The designer must prepare a CQA plan to address the following minimum requirements for geosynthetic materials (ie geomembranes, geosynthetic clay liners, geotextiles, geonet drainage geocomposites and geogrids) in addition to the minimum requirements of the CQA plan (Appendix 6).

Manufacturing quality control

Manufacturing quality control details should be received from the manufacturer or supplier for all geosynthetic materials delivered to the site. This includes factory test results, certifications and material warranties. It also includes quality control details in relation to the raw materials (such as resins, bentonite, polymers and fibres) supplied to manufacture the geosynthetic materials. The source of geotextile polymers must be identified, and it must be confirmed that the polymer has previously been demonstrated as suitable for use on landfill sites.

The manufacturing quality control details should show that the geosynthetic materials satisfy the requirements of the relevant specifications published by the Geosynthetic Research Institute (Folsom, PA, USA) from time to time, or in equivalent recognised industry standard specifications.

Independent conformance testing

The following procedures should be implemented on receipt of geosynthetic construction materials at the site:

- There should be a program of construction quality assurance (CQA) that includes independent conformance testing to verify that the materials supplied to site comply with the required specifications. The minimum testing requirements are those set out in the relevant table for each geosynthetic component.
- Each roll of geosynthetic should be labelled to provide the following identifying data:
  - name of manufacturer and type
  - material thickness
  - roll number

- roll length
- roll weight
- roll width
- reference numbers to raw material batch and laboratory certified reports
- manufacturer's approved QA stamp and the technician's signature.

- All conformance tests must be reviewed, accepted and reported by the CQA engineer before deployment of the geosynthetic layer.
- The specified frequencies in the test schedule assume that all rolls are from a single continuous manufacturing run. If the rolls are from multiple runs, the frequencies should be applied to each run.
- Sampling and testing should be representative of the materials being sampled.
- Sampling should be done from rolls to be used in the works and should be overseen and witnessed by the CQA engineer (manufacturer, supplier or installer recovered samples are not acceptable).
- Delivery of samples to the laboratory should be organised by the CQA engineer, not the contractor, and a suitable chain or custody procedure should be implemented.
- All laboratory testing should be done by an independent, geosynthetics accredited laboratory.
- Results of testing should be sent directly from the laboratory to the CQA engineer.
- The CQA engineer should use his or her judgement as to whether independent conformance testing additional to the testing stipulated by the designer is required and in particular circumstances review the material for acceptance or at any other time.
- If a sample records a non-conforming test result, it may be retested. If it passes this retest, both results should be provided in the laboratory report. If the retest produces a non-conforming result, the contractor should remove and replace all rolls between the sampled roll and the nearest conforming rolls either side (on the basis of the production order of the rolls). The contractor may, by testing and verification of these intermediate rolls, reduce the range of rolls to be removed in this way. Such additional testing should be for the full range of specified tests, not just the test or property that yielded a non-conforming result. Any replacement material should undergo the specified independent conformance testing.
- If any geosynthetic material supplied to the site is of a product class, grade or category different from that in the approved designs and specifications, this is considered to be a major variation.
- In addition to laboratory testing, the surface area of every roll of materials delivered to the site should be visually inspected for obvious visual flaws, such as damaged portions, tears, punctures, cracks, clear variations in thickness or mass from the specified values, broken needles, and initial moisture content (in the case of geosynthetic clay liners). Geosynthetic clay liners should be delivered to the site in waterproof wrapping.

Installation procedures

The following procedures should be implemented during the installation of geosynthetic construction materials:

- Geosynthetic materials should be stored to protect them from weather and other damage until installation. In particular, geosynthetic clay rolls should be kept dry.
- Installation of a geosynthetic layer should not start until the CQA engineer has accepted the independent conformance test results for that material. Also, the engineer must have passed the underlying layer. These are typical hold points in the project schedule; see general requirements of the CQA plan in Appendix 6.
- A panel layout should be prepared before the installation of each geosynthetic layer; it should show the proposed arrangements of panels, including penetrations and connections.

- Panel overlaps, welds, jointing and seam orientation should be in accordance with good practice and the manufacturer's instructions for each type of material. In the case of geosynthetic clay liners, the bentonite used for overlaps, penetration sealing and repairs should meet the same specifications as the bentonite used in layers themselves. In the case of geomembranes, where extrusion welding is used, the extruded granulate should be manufactured from the same resin as the geomembrane itself.
- During the installation of geosynthetic materials, all welds, seams, bentonite mass at overlaps in GCL and joins should be regularly inspected and tested. Testing locations selected at random locations, selected by the CQA engineer, that achieve the minimum frequencies are required.
- Inspection of seams and welds should occur for evidence of defects or damage due to the seaming or welding processes or variability in these processes.
- For geomembranes there should be a program of regular weld testing. This should include non-destructive and destructive weld testing. Non-destructive testing is vacuum or air pressure testing performed over the length of the seam to detect any discontinuities or holds, but it does not assess weld strength. In destructive weld testing, a sample is cut out of the weld every 150 metres and tested for strength in a laboratory. The minimum testing requirements are those set out in the test schedule in the relevant section of this guideline.
- In the event of a failure of a geomembrane weld destructive test, repairs shall extend back to the last test passed.
- All repairs should be tested and recorded. Repairs should be done in accordance with good practice and with the manufacturer's instructions. They should use compatible materials taken from the quality controlled/quality assured geosynthetic rolls delivered to the project.
- Geosynthetic layers should be placed on smooth, firm, dry surfaces, and achieve intimate contact with the underlying layer. Wrinkles and folds should be minimised. If the underlying surface is compacted clay, the clay should be smooth, free of sharp objects, and free of rough areas that may prevent intimate contact between the geosynthetic liner and the clay.
- Geosynthetic layers should not be installed in wet weather or windy conditions and should not be left exposed for any length of time.
- All geosynthetic layers should be protected from ultraviolet light damage after installation. They should be covered as soon as practicable to prevent damage from ultraviolet light, rain, wind and other weather related damage.
- The rate of deployment of geomembranes should be restricted to the amount that can be welded on the same day, and to the amount that can be covered on the same day. For composite liners consisting of a geomembrane over a geosynthetic clay liner, the geomembrane should be deployed concurrently with the geosynthetic clay liner.
- All overlying layers should be placed in a way that prevents damage to underlying geosynthetic layers and does not entrap soil, stones or moisture that could damage or impair the performance of adjacent layers. Soil material placed over geosynthetic layers should be free of sharp or angular objects that could penetrate the geosynthetic material.
- In the case of geosynthetic clay liners, adjacent soil should not have high concentrations of calcium and be chemically compatible with the liner.
- Soil particles should not be allowed to enter the drainage channels of a geonet drainage geocomposite.
- Vehicular traffic should be avoided over installed geosynthetic layers. Foot traffic only should be allowed, except over hydrated geosynthetic clay liners. Site personnel should ensure that footwear and equipment used on geomembranes are free of sharp particles.

The daily log prepared by the CQA engineer monitoring the works should contain the following:

- weather and site conditions
- quality of subgrade
- description of any material received at the site, including quality control data provided by suppliers
- location of clay construction activities and progress

- conformance to panel layout design
- recording of installation activities consisting of panel placement, roll numbers, seam/weld locations, repairs and testing results for all works
- records (including photos) of the wrinkling in the geomembrane at the time that cover soil is placed over the geomembrane
- photographs of construction works and any items of specific interest. The captions of all photographs should contain the name of the project, the date on which the photograph was taken and the identity of the feature being photographed
- type of equipment used in each work test (eg handling equipment, welding equipment, onsite testing equipment)
- calibrations or recalibration of test equipment and weld equipment
- testing conducted and test methods used
- record of any material or workmanship that does not meet specified designs and corrective actions taken to remediate the problem
- details of site visits
- summaries of any meetings held and action taken
- signature of CQA engineer.

Electrical leak detection survey

An electrical leak detection survey (also called an electrical liner integrity survey) should be carried out on geomembrane liners before and after the overlying drainage material has been placed. Damage can occur both during installation of the geomembrane and during placement of the materials on top of it, and surveys at both stages can assess this.

Such surveys use the fact that most geomembrane materials are electrically non-conductive. Where there are no defects, electrical current cannot flow through the geomembrane. The various methods locate spots where, under an applied voltage, electrical current is able to flow through holes and other breaches in the geomembrane. There must be conductive material above and below the geomembrane. The power source is grounded to the underlying material. Water is typically added to the overlying material to provide a conductive medium that can carry current through holes to the conductive material below.

The survey area must be electrically isolated from surrounding ground and structures to prevent the formation of competing electrical pathways between the upper and lower conductive materials.

A compacted clay liner below a geomembrane usually has suitable conductivity. However, other types of sub-grade soils or geosynthetic clay liners below a geomembrane must have sufficient moisture content to be adequately conductive of electricity. In these cases, the methods will not work if the underlying material is too dry. Sometimes copper wiring must be installed to provide lower conductive pathway. This may need to be considered at the design stage.

The methods and instruments that can be used in each case depend on whether the geomembrane is covered or uncovered. Methods for surveying uncovered (bare) geomembrane is covered or uncovered. Methods for surveying uncovered (bare) geomembranes include the water puddle and water lance methods. Water is applied to the surface of the geomembrane to create an electrically conductive layer able to form a bridge through holes to the lower conductive material when a voltage is applied. There must be good contact between the geomembrane and underlying material, otherwise holes may be missed. An emerging method, not involving water, applies a high voltage above the geomembrane to create an electric arc where there are holes.

For covered geomembranes, a dipole method is used in which a positive electrode is placed in the cover material, the power source is connected to the material beneath the geomembrane, and measurements of voltage potential are taken with a dipole probe in a grid pattern across the surface. Waves or spikes in voltage potential indicate the presence of a hole through which current is leaking. As with other methods, the cover material may need to be suitably moistened.

The methods for testing covered geomembranes are less sensitive than the methods that can be used in uncovered situations. The dipole method will detect only larger holes (typically about 6.4 mm in diameter when the cover material is 0.6 metres deep). The test methods for uncovered geomembranes are typically sensitive to holes of about 1 millimetre diameter. Standard test methods prescribe applicable sensitivities and procedures for sensitivity testing and calibration.

For detailed guidance on these issues and on the various methods, refer to *ASTM D6747–15 Standard Guide for Selection of Techniques for Electrical Leak Location of Leaks in Geomembranes* (ASTM International 2015) and *Electrical Leak Location General Guide* (TRI Environmental Inc 2014) or equivalent standards.

Appendix 4 Minimum requirements for leachate collection and disposal system

Minimum requirements for Leachate Collection Systems

Drainage layer material properties

The following minimum requirements must be met by the primary leachate drainage layer:

- Drainage layer to be at least 300 mm thick with a hydraulic conductivity of not less than $1x10^{-3}$ m/s.
- Drainage layer extending over the entire base of the landfill.
- A drainage layer must be provided on side walls longer than 10 m or flatter than 1V in 3H.
- Leachate collection pipes must drain at a minimum grade of 1% to a sump. The minimum slope of the surface of the underlying liner is 2% towards drainage lines.
- The pipes must extend across the base and up the sides of the liner. Leachate drainage pipework must be accessible for inspection and flushing.
- Drainage layer aggregate:
  - clean, hard, durable, sound gravel
  - D85 of not less than 37 mm
  - D10 of not less than 19 mm
  - uniformity coefficient of less than 2.0
  - not more than 1% (by weight) of material may pass a 0.075-mm sieve (AS1289.1.1–2001)
  - not consist of limestone or calcareous material susceptible to attack or degradation
  - material that is free of clay, organic matter or other deleterious material and not subject to physical or chemical degradation by leachate
  - material that is not soluble in acid (test method AWWA B 100.96).

Leachate collection pipework design

The following minimum requirements must be met by the pipework used to collect and convey leachate within the drainage layer towards collection sumps:

- Pipe sizing must take into account potential leachate flow, strength, inspection and maintenance and the issues presented above. Pipes must be resistant to degradation by leachate and landfill gas and must be manufactured from HDPE or MDPE. The sizing of leachate pipes is based on leachate flow rates within the pipe and the diameter required for the passage of remote inspection and cleaning equipment. The minimum internal pipe diameter should be greater than 150 mm.
- Provision should be made for deployment and passage of remote inspection and cleaning equipment. This should include use of sufficiently large radius swept bends and fittings.
- Giroud's equation shall be used to derive the required spacing between subsurface drainage pipes to achieve maximum permissible head over the liner of 300 mm on a daily basis under cases that include:
  - initial waste lift
  - operational
  - interim cover
  - final cover.

- An appropriate lower permeability to account for clogging in service should be used for the longer-term design case.
- Pipe perforations should include 12-mm diameter holes. The hole locations should be alternated in pairs at 150 mm intervals along the pipe. Each alternate pair of holes should be located at 45° and 225° to the vertical axis (pair 1) and 135° and 315° to the vertical axis (pair 2).
- The leachate drainage system must be sealed to prevent release of LFG and air being drawn into the landfill if a landfill gas extraction system is operated.

Design considerations – leachate collection sumps

The design of a leachate collection sump must include the following considerations:

- Resistance to chemical attack, and physical, chemical and biological clogging.
- Loads due to the placement, compaction and settlement of waste without crushing.
- Ability to be inspected and cleaned by readily available video inspection and pipe cleaning equipment.
- Design for redundancy and robustness to allow continued function in the event of several components of the system failing.
- The drainage layer, collection system and leachate sumps do not compromise liner integrity during installation and landfilling.
- Leachate sumps must not compromise liner integrity under long-term down drag forces imposed on vertical risers or in the event of structural failure of the sump riser or base.
- Protection of the liner from impacts of the pump, its installation, operation and maintenance.
- The depth of leachate in each sump can be measured and removed.
- Leachate pump operation is automated and alarmed.

Leachate sumps must be designed to allow for the increased heads that are required to allow for the pumping and removal of leachate.

Where sumps are located such that they reduce the minimum required separation to groundwater, additional measures to improve the performance are required.

Design leachate quantities

The design of a leachate flow must consider:

- The design flow capacity of the leachate collection system pipework should be based on a 1-in-20 year storm event over one lift of waste across the operating cell floor, and also include any runoff from batters and adjacent areas contributing to the cell.
- The design flow capacity of the leachate collection system pumps should be based on a modelled peak leachate flowrate of the operating cell following placement of one lift of waste and also include any runoff from batters and adjacent areas contributing to the cell.
- The required leachate pond size shall be determined by an appropriate water balance model that takes account of:
  - contributions from all landfill cells in their condition at the time of construction
  - staging of leachate pond construction in advance of landfill cells to provide capacity at commencement of filling
  - local meteorological conditions (seasonal rainfall, evaporation)
  - 1-in-20 year storm event and a decile 10 wet year
  - leachate disposal practice (ie sewer, evaporation but excluding recirculation).
- The required leachate pond size shall be determined by an appropriate water balance model that takes account of:

   - contributions from all landfill cells in their condition at the time of construction, including where appropriate future cell contributions
   - local meteorological conditions (seasonal rainfall, evaporation)
   - leachate disposal practice (ie sewer, evaporation but excluding recirculation).
- Where leachate is disposed offsite by tankering to a licensed facility or to a sewer, adequate provision must be made for temporary storage of leachate during extreme weather, breakdown or operational delay.
- The EPA does not recommend irrigation and re-injection of leachate back into the landfill cell as a primary means of disposal or volume reduction or storage of leachate within the landfill under normal operating conditions. Where an appropriately designed system to store or return leachate to the landfill cell is proposed for any reason, it should only occur with the explicit approval of the EPA.

The EPA recommends stormwater inflows from other areas be minimised by raising lagoon embankments and diverting clean stormwater from the lagoon.

Leachate collection system installation

The installation specifications should include:

- Prequalification testing of drainage aggregate.
- Measures to install leachate drainage aggregate, sumps and pipeworks without damaging geosynthetics (refer to Appendix 3). A field trial should be conducted to verify construction techniques do not damage the geosynthetics (refer GRI–GS11 *Standard Guide for Constructing Test Pads to Assess Protection Materials Intended to Avoid Geomembrane Puncture 2012*).
- Methods of dealing with or managing wrinkles (waves) in the geosynthetics (refer to Appendix 3).
- Measures to provide the necessary isolation from surrounding soils and cells to allow liner integrity survey to be conducted.
- Measures to delineate haul roads of sufficient aggregate thickness for trafficking.
- Measures to minimise breakdown of aggregate during placement.
- Recovery of samples of placed aggregate to verify compliance with the grading specification has been achieved in-situ.
- Measures to prevent soil and debris entering the drainage pipework and aggregate layer.
- Supervision of sump installation and inspection of liner for damage.
- Inspection of leachate pipework, perforations, connections, including verification of removal of and end caps drill cuttings, debris and temporary bungs used during construction prior to covering.

Minimum requirements for leachate ponds

Leachate pond design considerations

Design of leachate ponds must:

- Be designed to achieve equivalent performance to the liner and generally of the same materials as used in the landfill cells. Since leachate ponds are operated under exposed conditions, subject to desludging, have larger hydrostatic heads and lower confining loads, may be inspected, repaired or replaced, their design, specification and installation will differ from the landfill liner.
- Where leachate is collected from cells without an engineered liner or are classified small, the liner must not be less than 600-mm clay or appropriate for the landfill classification.
- GCL should not be used as a primary liner and must be provided with sufficient confinement under empty pond conditions if used in a composite liner.

- Be protected from surface water and groundwater inflows.
- Have floors graded and provided with a gas relief system to prevent whales forming and reducing the pond capacity (*GSI White Paper #33 Underdrain Design for Geomembrane Lined Surface Impoundments to Avoid Whales/Hippos from Occurring 2015*).
- Have a minimum 600 mm freeboard
- Incorporate safety in design requirements.
- Be accessible in all weather conditions for removal of leachate by tanker.
- Use liner materials that are suitable for exposure to the leachate chemistry, temperature and UV conditions within the pond.
- Manage risks of liner disturbance by wind on the exposed liner.
- Enable 'de-mucking' of sediments/solids while protecting the integrity of the liner system. As well as safe access for pond maintenance or leachate treatment.
- Incorporate inlets, outlets and monitoring systems that preserve the integrity of the liner system and avoid submerged penetrations.
- Be designed to manage the risk of liner and subgrade deterioration from wave action on the side slopes.
- Provide safe ingress/egress and access for inspections, maintenance, monitoring and sampling.
- Provide a means of access control by fencing to manage risks to safety and damage.
- Manage risk associated with the presence of fauna and growth of weeds or other vegetation.

Leachate pond installation

The pond installation specifications must include:

- Measures to install leachate drainage aggregate, sumps and pipework without damaging underlying geosynthetics.
- Measures to provide the necessary isolation from surrounding soils and cells to allow liner integrity survey to be conducted.
- Measures to delineate haul roads of sufficient aggregate thickness for trafficking.

Appendix 5 Minimum requirements for capping systems

Minimum requirements for capping systems that include a compacted clay layer and overlying protection layer

Geotechnical considerations for design and construction of the capping system

- Considerations include subgrade conditions for cap construction, geotechnical slope stability and potential earthworks construction materials.
- Slope stability considerations include temporary and permanent slopes, interface strength parameters of lining systems, impact of soil moisture and lateral flow from infiltration reaching barrier layers and global landfill stability.
- Earthworks construction materials include those suitable for compacted clay liner, drainage layer, subsoil, growing medium and other fill, as appropriate. Further considerations and details for assessment of clay materials are presented in Appendix 2.

Site preparation to provide a sound and stable subgrade and promote surface drainage

- The subgrade should comprise a minimum thickness of 300 mm of cover soil over the waste. The subgrade surface should promote runoff of surface water during construction and be shaped similarly to the final landfill surface, subject to stability considerations.
- The prepared subgrade should be proof rolled to assess the presence of zones that may require subgrade improvement.
- Subgrade improvement may be required in the following areas:
  - if there is a risk of differential settlement that may have an adverse impact on the integrity or long-term performance of the cap
  - to provide a sound platform for subsequent cap construction.
- Subgrade improvement works should follow sound engineering principles and be carried out in accordance with a construction quality assurance plan. Improvement measures may include placement of course granular materials or use of geosynthetics to provide reinforcing.
- Use of fill placement to raise subgrade levels must consider the potential total and differential settlement.

Design and construction of an engineered clay barrier layer:

If a compacted clay liner is used, it must comprise:

- Minimum compacted total thickness of 600 mm of material with a minimum of three layers of 200 mm compacted thickness each.
- A hydraulic conductivity of less than 1 x 10^{-8} m/s or 1 x 10^{-9} m/s depending upon landfill classification.
- A design to limit seepage of water through the landfill cap to less than the seepage through the landfill base.
- A subsurface drainage system may be required to manage lateral flow intercepted by barrier layers.
- Construction by uniform moisture conditioning and uniform compaction using a sheepsfoot roller in layers with a maximum thickness of 200 mm. There must be effective bonding between successive layers that includes kneading between layers and scarification and moisture conditioning between successive layers. The specification of maximum layer thickness and the number of layers is intended to promote uniformity within each layer and reduce the probability that preferential flow paths may align and have an adverse impact on the hydraulic conductivity of the overall barrier layer. The appropriate layer thickness also depends on the degree of uniformity of moisture conditioning and compaction that can be achieved by the construction equipment. If staged construction of each layer is carried out, the joins between episodes of layer construction must be offset at a minimum horizontal distance of

3 m between successive layers. Further information on material properties and the method of construction for clay liners is presented in Appendix 2.

- Development and implementation of a CQA plan as a means of managing quality during construction and of reporting that the materials used, construction methods and completed works comply with the landfill design
- Maintenance of the integrity of successive layers and the completed compacted clay liner. This includes prevention of disturbance, rutting, erosion, softening and desiccation cracking

Penetrations through barrier layers in the cap are to be avoided if feasible. Where penetrations are required, they must be designed so that the barrier layer integrity is maintained and a pathway is not created for infiltration of water or escape of leachate or landfill gas.

Compacted clay barriers in caps are known to suffer from increased permeability due to desiccation cracking, differential settlement and vegetation. The designer should consider these risks on a site-specific basis in determining the suitability of a clay barrier over alternative systems incorporating phytocovers or geosynthetics.

Geosynthetic materials may be required as an alternative or supplement to a compacted clay liner depending on site specific circumstances.

Design and construction of a protective layer and growing medium

The protective layer and growing medium must comprise:

- A minimum thickness of 100 mm of topsoil comprising silty sand, sandy silt, clayey sand or sandy clay with organic matter (naturally occurring, mulch or compost).
- A subsoil layer to provide protection for the underlying barrier layer (from cracking or disturbance), enable moisture storage and release, and assist with sustaining plant roots.
- The thickness of subsoil must be based on the landfill classification.
- Consideration for the cap design must include:
  - Shaping the surface to comply with the final landform.
  - The sustainability of the system for supporting vegetation.
  - Local climatic conditions and soil profile.
  - Use of vegetation compatible with surrounding land uses, habitat and climate.
  - Planting of indigenous species.
  - The rooting depth of the vegetation, such that it does not extend into and damage the integrity of the barrier layer. This typically means limiting vegetation to grasses and small shrubs with rooting depths not more than the topsoil and subsoil thickness, and adding thicker covers of soil for areas of trees and small shrubs.
  - Prevention of introduction of weeds, plant pathogens and pests.
  - Stormwater and erosion control.
  - The water-holding capacity and drainage of the subsoils and topsoil.
  - The stability of the soils covering a lower permeability engineered barrier layer with a potential perched water table.
  - Protection from disturbance, or use of sufficient thickness of subsoil for disturbance, by burrowing animals.
  - Use of nutrients and organic matter to promote plant growth.
  - Durability of the cap components and surface.
  - Maintenance and ongoing management of the growing medium and vegetation.
  - Use of a gas distribution layer and thick organic layer to maximum oxidation of methane.

– A program of CQA.

Minimum requirements for capping systems that include a geosynthetic barrier layer

Liner systems that incorporate geosynthetics and are considered to be acceptable for use as a barrier layer in a landfill cap include:

- A geosynthetic clay liner (GCL) that may need to be underlain by a compacted clay liner or engineered layer

OR

- A geomembrane liner underlain by a GCL or a compacted clay liner

AND

- A design to limit seepage of water through the landfill cap to less than the seepage through the landfill base.

The geosynthetic cap liner system must be considered on a case-by-case basis. However, reinforced GCL and reinforced and unreinforced geomembranes are generally considered as appropriate geosynthetic liners for inclusion in a cap. Acceptable materials for geosynthetic liners include:

- GCL manufactured from polyethylene, polypropylene or polyester geotextile or geomembrane substrate and either sodium bentonite or calcium bentonite filling
- Linear Low Density Polyethylene (LLDPE)
- PVC geomembrane
- synthetic rubber geomembrane
- ethylene alloy geomembrane.
- Subsurface drainage must be considered carefully. Risks may be managed at some sites by careful design of slopes and choice of cap soils and vegetation. Subsoil drainage may comprise a series of subsurface interception strip drains. Some sites may require a blanket subsurface drainage system comprising a geosynthetic drainage layer or use of pipes lain in a 200-mm thickness of free-draining granular material.
- Design of subsurface drainage measures will need to consider the cap soil types, vegetation, climatic conditions, surface slopes (grade and length), geotechnical stability, stormwater control systems, post-closure use and activities (for example irrigation, access and maintenance) and control of the drainage water. Build up of moisture within poorly drained cap soils can have an impact on geotechnical stability, vegetation growth and trafficability and may increase infiltration through the liner and subsequent leachate generation.
- Design of the cushion geotextile protection of geomembranes differ from base lining systems and must consider the nature and weight of overlying materials plus loads due to post closure use.

Minimum requirements for geosynthetic materials

These are provided in Appendix 3.

Minimum requirements for alternative capping systems

This section includes suggested measures for assessment of alternative capping systems that do not include an engineered barrier layer, where the design is based on water storage and release principles. These might include evaporative type caps or use of a capillary barrier system.

The proponent must demonstrate an equivalent or better performance of the proposed alternative system compared with capping systems that include an engineered barrier layer. These systems do not have a long track record, so the emphasis is on demonstrated performance of the proposed system.

Considerations must include:

- the objectives and required outcomes of this guideline

- infiltration of water through the cap
- modelling of moisture movement in unsaturated soils
- the risk and potential consequences of extended dry weather or high intensity rainfall on performance
- plant life cycle effects on the system, eg roots of dead shrubs
- the durability of the cap components and surface
- landfill gas management and potential effects on vegetation
- use of earthworks materials
- an action plan to select, plant, manage and maintain vegetation and the growing medium.

A field trial to monitor and measure the performance of the proposed system must be undertaken for a minimum of three years and must consider representative climatic conditions for the site. The field trial should be carried out at the site, use the proposed materials and vegetation for the final cap and represent the different topographic conditions of the proposed cap. A shorter time period can be considered by the EPA if the applicant can demonstrate that trial results from comparable sites can be transferred in some circumstances.

Equivalence of an alternative cap system shall be demonstrated in terms of:

- long-term average seepage of water through the landfill cap is less than the seepage rate through the landfill base liner over the same period
- infiltration into the underlying waste
- accommodation of effects resulting from settlement of underlying waste
- erosion control
- robustness of the cap to moderate variations in management of the system.

Appendix 6 Minimum construction quality assurance requirements

CQA plan

The following are general minimum requirements for the CQA plan. Further requirements specific to the materials, methods and systems forming part of the works will also be required as determined by the designer together with the minimum requirements of this guideline (refer to Appendices 2–5)

The CQA plan must be approved by the EPA before commencement of construction works

Roles, responsibilities and communication lines

The CQA plan should be prepared by the designer.

The plan should define clear roles, responsibilities and communication lines for implementation of the plan and for contact with the EPA.

A specific person or organisation must be responsible for the overall implementation of the plan.

The CQA report must be prepared by a CQA engineer who is independent of the contractor and principal, suitably experienced and competent, and registered on the National Engineering Register.

Documentation

The CQA plan must contain or append:

- The Basis of Design report (including Safety in Design report).
- Specification and drawings of the work.
- A schedule of all required certification, testing, hold points, inspections, submittals and approvals nominating the responsible and approving parties.

The CQA plan must ensure that evidence of the satisfactory completion of the works is achieved and that a CQA report can be prepared that includes:

- Details of the works and monitoring implemented, including surveys, work-as-constructed drawings, and an updated site plan showing the location of the works.
- Records by the CQA engineer giving details of the works progress, the rate of liner or capping deployment, testing undertaken and any defects and associated remedial actions that were taken.
- A set of plans showing the prepared subgrade and clay barrier extent, geosynthetic panel deployment, and showing locations of defects, repairs and tests.
- Photographs of all aspects and stages of the construction.
- Details and results of all independent material testing, including data and certifications provided by manufacturers of supplied materials.
- Details showing that the CQA plan was followed.
- An account of all variations from the approved design, specifications and CQA plan.
- In the case of staged cell or cell wall construction, a schedule for submitting addenda to the CQA report as construction proceeds.
- A declaration by the CQA engineer that there is sufficient information to demonstrate that the landfill works were constructed in accordance with the approved designs and specifications.

EPA contact

The plan must include notification to the EPA to provide the opportunity for the Authority to monitor and inspect elements of the construction. Notification is required at least two weeks prior to commencement of the key elements of the works, including set out, subgrade preparation and construction of the liner and leachate collection systems.

The EPA must be notified if there are any changes to site conditions compared with those designed and approved. Similarly EPA notification in advance is required for proposed changes to agreements between the EPA and the landfill stakeholders.

Set-out and survey control

Set-out and survey control of the works should include the elevation reference benchmark and system (Australian Height Datum – AHD), layout plan, base elevation, grades, layer thickness, total thickness of elements and the as-built details.

It will also need to consider details at the interface between cells and where the leachate drainage layer enters the leachate sump.

As-constructed survey must capture:

- Location, levels and grading of the liner and drainage system elements to verify construction in accordance with the specification and CQA plan.
- Location, levels and grading of pipework, inspection points and sumps.
- The edge of the liner or works required for interface with future construction.
- Set out of the limits of the completed works.

Prequalification of materials

Evidence of QA testing to demonstrate compliance with the design and specification requirements should be provided for all materials and products used in construction. The following information should be reviewed for compliance with the design and specification requirements:

- Representative supplier QA/MQA test results **prior** to sourcing procurement.
- QA and manufacturing quality assurance (MQA) test results for the supplied material.
- IQA test results for the supplied material **prior** to acceptance for construction.

This review should be conducted by the design engineer or CQA engineer and documented in the CQA report. The basis for acceptance and the response to any failure or deviation from the specified requirements (re-testing, remediation or rejection) by the CQA engineer must be provided. No test results are to be omitted from the CQA report.

Subgrade preparation and clay liner construction

CQA of the subgrade preparation and clay liner construction shall include inspection and testing by an independent geotechnical inspection testing authority (GITA) to provide Level 1 Inspection and Testing as outlined in clause 8.2 of *Australian Standard AS3798–2007 Guidelines on earthworks for commercial and residential developments*.

This includes inspection and testing of materials and the moisture conditioning and compaction process to assess the acceptability and uniformity of materials and workmanship and maintenance of the integrity of completed portions of the works.

Testing includes compliance testing of materials (eg particle size distribution and Atterberg Limits), field density testing (AS1289.5.8.1) and reference compaction testing (AS 1289.5.1.1 or AS12895.7.1). AS 3798 provides guidance on the frequency of field density and compaction testing. The test locations and frequency should take into account the size and geometry of the works and if certain aspects require specific density and reference compaction testing should be carried out at a frequency not exceeding those of Table 8.1 of AS3798-2007.

Proof-rolling of the prepared subgrade should be conducted to assess the presence of weak or compressible zones that may require improvement. Inspection should be conducted of the method of bonding between layers of the clay liner.

This should take into consideration surface and moisture conditions at the interface between layers. Items for potential corrective action include, but are not limited to, non-uniformity, non-complying materials (for example, inclusions of oversized material or organic matter), moisture condition or compaction outside the specified criteria, inadequate bonding between layers and non-complying geometry or thickness.

The GITA should progressively provide feedback to the project stakeholders, including the EPA, on the results of the inspection and testing program. On completion of the inspection and testing program, the GITA should provide a report of the program of inspection and testing and a statement of the compliance of the clay liner construction with the project documentation.

Testing should be conducted to assess whether the hydraulic conductivity of the completed liner complies with the design. This can be done by laboratory testing of undisturbed samples of the liner in accordance with AS1289.6.7.3–2016 or by field testing. The minimum testing requirements are dependent on the scale of the construction works. For example, for typical cell size of 100 m by 100 m, a minimum of three tests per cell is required. The sample size and test method should consider the particle size distribution of the materials tested.

Minimum CQA requirements are set out in Appendix 2.

Geosynthetic materials

CQA of supply and installation of geosynthetic materials will need to consider the following:

- Requirement for full time supervision of the installation of geosynthetic materials.
- Material properties and manufacturing quality assurance.
- Inspection of materials when delivered to the site.
- Storage and handling procedures.
- Preparation of the ground surface prior to installation, to minimise the risk of damage to the geosynthetic. This may include, but not be limited to, geometry, smoothness, the presence of sharp objects, density and moisture condition.
- The presence of defects.
- Set out of panels.
- Anchoring points.
- The connection between panels or elements.
- Connection of areas that have undergone sampling or repair with the main works.
- The interface with underlying or overlying materials.
- Methods to protect the integrity of completed portions of the works.

Consideration may need to be given to any additional quality assurance guidelines of the geosynthetic manufacturer.

Minimum CQA requirements are set out in Appendix 3 Section 3.3.

Leachate collection system and sump

CQA of the leachate drainage layer and sump as part of the leachate collection system will need to consider the following:

- Grades to and along drainage lines.
- The manufacture, type, delivery, storage, handling, layout, bedding, connection and integrity of leachate collection pipes.
- The sump geometry and connection to the leachate drainage layer.
- The thickness of granular drainage materials.

- The particle size distribution, composition and placement of granular drainage materials to comply with the design requirements for durability and hydraulic conductivity.
- The integrity of the underlying liner system.

Minimum CQA requirements are set out in Appendix 6.

Variations

Variations that occur to the specific materials, methods and design of the works must be assessed as major or minor in accordance with the following table by the designer.

Table 11 Minor and major variation criteria

Aspect	Minor variation criteria	Major variation criteria
Potential environmental risk from the variation	Unchanged or reduced	Increased. An environmental risk assessment of the variation has not been conducted.
Size or capacity of landfill cell	<10% change or no change	Change of 10% or more
Construction material	Proposed construction material has been shown to provide better environmental protection that that originally proposed	Proposed construction material does not provide better environmental protection that that originally proposed
Construction method	The change does not involve a modification of the approved design, technical specification or CQA plan	The change involves a modification of the approved design, technical specifications or CQA plan
Technical specification	The change in specification is consistent with the Landfill guideline minimum requirements or licence conditions MQA and/or IQA inspection and testing which: • are within specification or test method acceptance criteria, and • do not reduce performance, and • the independent CQA engineer considers conforming and suitable for use.	The change in specification is contrary to the landfill guideline minimum requirements or licence conditions MQA and/or IQA inspection and testing which: • are outside specification or test method acceptance criteria, and • do not reduce performance, and • the independent CQA engineer considers conforming and suitable for use.
Leachate collection, treatment or disposal		A change of method of leachate collection, treatment or disposal
Material performance standards		A reduction in material performance standards
Design change	Variation of the liner slope, where additional measures are provided for leachate collection. Placement of temporary stormwater diversion bunds within the cell to minimise the operational/tipping area to reduce or manage stormwater flows	• Variation to the liner slope where additional measures are not proposed • Divide the cell into two or more sub-cells • Change the location of the leachate collection sump

Aspect	Minor variation criteria	Major variation criteria
		• Barrier system change
Design change/construction process/procedure change		To address any rectification work to the liners, undertake and replacement work for the liner system
Construction change		To address unforeseen circumstances, site circumstance change
Other		A change falling outside the scope of this table

(Adapted from VIC EPA 1323.3)

In the event of a minor variation, the following actions form part of the CQA plan and must be recorded in the CQA report:

- EPA notification of change assessment and proposed change is required.
- A written design variation record must be provided by the designer addressing any change to the basis of design, as an amendment to the basis of design report.
- The site owner must provide written acceptance of the design change.

In the event of a major variation, the following actions form part of the CQA plan and must be recorded in the CQA report:

- Referral to the EPA for revised written approval is required.
- Documentation necessary to satisfy the approval of the revised design must be provided to the EPA including a written design variation record must be provided by the designer, addressing any change to the basis of design, as an amendment to the basis of design report.
- A written design variation approval must be provided to the EPA.

CQA report

A CQA report must be prepared that demonstrates to the EPA and other project stakeholders that the construction complies with the requirements of the landfill design. The CQA report must demonstrate that the minimum requirements for the CQA plan and CQA report are provided in Appendix 6 and the relevant specific guidance in Appendices 2–5.

The CQA report must contain:

- Details of the works and monitoring implemented, including surveys, work-as-constructed drawings, and an updated site plan showing the location of the works.
- Records by the CQA engineer giving details of the works progress, the rate of liner or capping deployment, testing undertaken, and any defects and associated remedial actions that were taken.
- A set of plans showing the prepared subgrade and clay barrier extent, geosynthetic panel deployment and showing locations of defects, repairs and tests.
- Photographs of all aspects and stages of the construction.
- Details and results of all independent material testing, including data and certification provided by manufacturers of supplied materials.
- Details showing that the CQA plan was followed.
- An account of all variations from the approved design, specifications and CQA plan.
- Review and if necessary update the basis of design (including safety in design report) to account for variations or changes encountered during construction.

- In the case of staged cell or cell wall construction, a schedule for submitting addenda to the CQA report as construction proceeds.
- A declaration by the CQA engineer that:
  - Variations that occurred during construction that have been assessed as minor are detailed in the report (copies of assessment attached).
  - Variations that occurred during construction that have been assessed as major have been approved by EPA as a major variation (copies of variation approval attached).
  - The CQA plan was complied with and demonstrated that, in the opinion of the CQA engineer, the landfill works were constructed in accordance with the approved designs and specifications.

The CQA Report must be submitted and approved by the EPA prior to the placement of waste or use of the works pursuant to the licence.

Appendix 7 Suggested parameters for leachate, surface water, groundwater and landfill gas monitoring at landfill facilities

Landfill facilities should implement a site-specific monitoring program to support the CSM and allow for changes in design, management and operation of the facility as activities evolve.

Table 12 Indicator parameters for leachate monitoring

Pollutant	Units of measure	Frequency	Sampling method
EC	uS/cm	Quarterly	Probe
pH	pH units	Quarterly	Probe
Standing water level in all leachate risers	mAHD	Quarterly	In situ
Volume	m^3	Continuous	From flow metres or pumping records of the amount of leachate transferred from cell
Total dissolved solids	mg/L	Annually	Grab sample
Total suspended solids	mg/L	Annually	Grab sample
Major cations and anions (calcium, magnesium, potassium, sodium, chloride, fluoride and sulfate)	mg/L	Annually	Grab sample
Alkalinity (bicarbonate and carbonate)	mg/L	Annually	Grab sample
Dissolved organic matter (total organic carbon, biochemical oxygen demand and chemical oxygen demand)	mg/L	Annually	Grab sample
Ammonia and nutrients (nitrate, nitrite and phosphorous)	mg/L	Annually	Grab sample
Metals (aluminium, arsenic, barium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel and zinc)	mg/L	Annually	Grab sample
Organic contaminants: • phenols • petroleum hydrocarbons • monoaromatic hydrocarbons (in particular benzene, toluene, ethylbenzene and xylene) • organochlorine and organophosphate pesticides • oolycyclic aromatic hydrocarbons	mg/L	Annually	Grab sample
PFOS and PFOA	To be developed in response to national requirements		

Table 13 Indicator parameters for surface water monitoring

Pollutant	Unit of measure	Sampling method
pH	–	Probe
Dissolved oxygen	mg/L	Probe
Electrical conductivity	uS/cm	Probe
Total suspended solids	mg/L	Grab sample
Nitrogen – ammonia	mg/L	Grab sample
Total organic carbon	mg/L	Grab sample
Thermotolerant coliforms (only when downstream waters are used for stock water, drinking water or recreational uses)	mg/L	Grab sample
Total dissolved solids	mg/L	Grab sample
Potassium	mg/L	Grab sample
PFOS and PFOA	To be developed in response to national requirements	

Table 14 Indicator parameters for groundwater monitoring

Pollutant	Unit of measure	Frequency	Sampling method
pH, redox potential and temperature	–	Quarterly	Probe, field analysis
Standing water level	mAHD	Quarterly	In situ
Total dissolved solids	mg/L	Quarterly	Grab sample
Major cations and anions (calcium, magnesium, potassium, sodium, chloride, fluoride and sulfate)	mg/L	Quarterly	Grab sample
Alkalinity (bicarbonate and carbonate)	mg/L	Quarterly	Grab sample
Total organic carbon	mg/L	Quarterly	Grab sample
Ammonia and nutrients (nitrate, nitrite and phosphorus)	mg/L	Quarterly	Grab sample
Metals (aluminium, arsenic, barium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel and zinc)	mg/L	Annually	Grab sample

Pollutant	Unit of measure	Frequency	Sampling method
Organic contaminants: • phenols • petroleum hydrocarbons • monoaromatic hydrocarbons (in particular benzene, toluene, ethylbenzene and xylene) • organochlorine and organophosphate pesticides • polycyclic aromatic hydrocarbons • phthalate esters (leachable plasticizers)	mg/L	Annually	Grab sample

Table 15 Landfill gas threshold levels for further investigation

Location	Parameter	Threshold level	Frequency
Surface emissions on landfill surface (excluding operational cell)	Methane	500 parts per million (volume/volume)	Monthly
Subsurface monitoring	Methane	1% (volume/volume) above natural background levels	Quarterly
Subsurface monitoring	Carbon dioxide	1.5% (volume/volume) above natural background levels	Quarterly
Enclosed structure within 250 m of waste disposal	Methane	1% (volume/volume)	Monthly
Enclosed structure within 250 m of waste disposal	Carbon dioxide	1.5% (volume/volume)	Monthly

The EPA must be contacted within 24 hours where monitoring exceeds the threshold levels identified above to discuss an appropriate action plan.