Environmental Guidelines

Solid waste landfills

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Structure and purpose of these guidelines

A landfill is an engineered, in-ground facility for the safe and secure disposal of society's wastes.

Landfills may produce the following pollution streams: leachate, stormwater runoff, landfill gas, offensive odour, dust, noise and litter. These pollutants can degrade the quality of surrounding surface water bodies, groundwater, soil and air. Landfilling activities have the potential to adversely affect local amenity, and they may also affect threatened species of flora and fauna, native vegetation and items of aboriginal heritage.

These guidelines provide guidance for the environmental management of landfills in NSW by specifying a series of 'Minimum Standards'. They involve a mix of design and construction techniques, effective site operations, monitoring and reporting protocols, and post-closure management.

The NSW Environment Protection Authority (EPA) will use these guidelines to assess applications for new or varied landfill licences under the *Protection of the Environment Operations Act 1997* and to assess issues that arise during the operational and post-closure periods of landfills.

The minimum standards in these guidelines apply to general solid waste and restricted solid waste landfills. There are some additional (higher) standards for restricted solid waste landfills, recognising the more highly contaminated nature of those wastes.

The minimum standards in these guidelines reflect the following broad goals for landfilling in NSW:

- landfills should be sited, designed, constructed and operated to cause minimum impacts to the environment, human health and amenity
- the waste mass should be stabilised, the site progressively rehabilitated, and the land returned to productive use as soon as practicable.
- wherever feasible, resources should be extracted from the waste and beneficially reused
- adequate data and other information should be available about any impacts from the site, and remedial strategies should be put in place when necessary
- all stakeholders should have confidence that appropriately qualified and experienced personnel are involved in the planning, design and construction of landfills to high standards.

These guidelines combine and replace the existing documents Environmental Guidelines: Solid Waste Landfills (NSW EPA, 1996) and the Draft Environmental Guidelines for Industrial Waste Landfilling (NSW EPA, 1998).

The Glossary contains detailed explanations and definitions of all technical and scientific terms used in these guidelines.

The legislative context in New South Wales

(a) The Protection of the Environment Operations Act 1997

The principal legislation governing waste management and landfill disposal of waste in NSW is the *Protection of the Environment Operations Act 1997*.

Most new landfills receiving waste from off-site must hold an environment protection licence issued by the EPA under the *Protection of the Environment Operations Act 1997*. There are some exceptions, mainly relating to sites receiving small quantities of building and demolition waste, virgin excavated natural material or waste tyres. Schedule 1 of the *Protection of the Environment Operations Act 1997* should be referred to for more information about these licensing thresholds. The EPA has published a Guide to Licensing under the *Protection of the Environment Operations Act 1997*.

All landfills must meet the requirements of the *Protection of the Environment Operations Act 1997* and the regulations made under that Act. The landfill occupier must not pollute waters in breach of section 120, cause air pollution in breach of sections 124, 125 or 126, or emit offensive odour in breach of section 129 of the Act.

The landfill occupier must notify the EPA of pollution incidents causing or threatening material harm to the environment within the meaning of section 148 of the *Protection of the Environment Operations Act 1997*.

Under Part 9.4 of the *Protection of the Environment Operations Act 1997*, the EPA can require licensees to provide and maintain a financial assurance to secure or guarantee funding for works required under a licence. Most landfill licences contain such a condition. The EPA may claim on a financial assurance under section 303 of the Act if a licensee fails to carry out any work or program required by or under the licence. The financial assurance must be maintained during the operation of the facility and during the post-closure period until the EPA is satisfied that the site is stable and not polluting.

The *Protection of the Environment Operations Act 1997* prescribes the waste classification system in NSW. The Act defines six waste classes:

- general solid waste (putrescible)
- general solid waste (non-putrescible)
- restricted solid waste
- special waste
- hazardous waste
- liquid waste.

The EPA's Waste Classification Guidelines (NSW EPA, 2014) provide further guidance on how to classify waste for disposal.

Landfill licences issued by the EPA list the types of waste that the landfill can receive. General solid waste and restricted solid waste can be disposed of in landfills licensed to receive those waste types. Restricted solid waste contains higher (up to four times) levels of contaminants than general solid waste; therefore, restricted solid waste landfills must be managed with more stringent environmental controls than those for general solid waste landfills.

Special wastes are clinical and related waste, asbestos waste and waste tyres. These wastes can be disposed of at a landfill under licence, provided that additional handling and operational measures are implemented.

Liquid and untreated hazardous wastes are not permitted to be landfilled in NSW. However, some hazardous wastes can be treated to remove or lock up (immobilise) contaminants. This may enable the waste to be reclassified as restricted or general solid waste, and only then disposed of in a landfill. Special EPA approval might be required to facilitate treatment and disposal.

These guidelines should also be read in conjunction with the regulations and policy on resource recovery orders and exemptions made under clauses 91 to 93 of the *Protection of the Environment Operations (Waste) Regulation 2014*. They enable the EPA to exempt waste applied to land from certain requirements under the waste regulatory framework and to exempt a land application site from the need to be licensed as a waste disposal facility (landfill). An order or exemption may be general or specific. General orders and exemptions, and guidance on how to apply for a specific order or exemption are published on the EPA's website.

(b) Other legislation

Most proposals for new or expanded landfills require development consent or approval under an Environmental Planning Instrument made under the *Environmental Planning and Assessment Act 1979*. This Act is administered by the NSW Department of Planning and Environment and local councils. The Department has published a guideline EIS Practice Guideline: Landfilling (Department of Urban Affairs and Planning, 1996)

The *Environmental Planning and Assessment Act 1979* sets out several project assessment processes, and the applicable process will depend on the scale of the project, the nature of the waste, and the location. The NSW Department of Planning and Environment and the relevant local council should be consulted for more information on the applicable assessment process in each case.

Regardless of the planning assessment process, these guidelines will form the basis of the EPA's input at the planning stage.

In addition, all landfill proposals must address the requirements of statutes protecting threatened and endangered species of fauna and flora, native vegetation and items of Aboriginal cultural heritage. Relevant statutes administered by the Office of Environment and Heritage are the *National Parks and Wildlife Act 1974*, the *Threatened Species Conservation Act 1995* and the *Native Vegetation Act* 2003.

Contaminated sites in NSW are regulated under the *Contaminated Land Management Act 1997*. Older, closed landfills are sometimes managed under this Act. The EPA has published risk assessment guidelines for this purpose. These contaminated sites guidelines apply to older, closed landfills that are not regulated by the EPA under the *Protection of the Environment Operations Act 1997*. Active or recently closed landfills are managed through the landfill licensing process under the *Protection of the Environment Operations Act 1997* and the minimum standards in these guidelines. For more information refer to Managing contaminated land in NSW at www.epa.nsw.gov.au/clm/management.htm.

Siting restrictions

Location is an important factor in determining the environmental risk posed by a landfill. Judicious location of a landfill is the single most effective environmental management tool.

Some of the minimum standards in these guidelines will be easier to achieve, and some design elements may even be omitted, by selecting a site where natural barriers (e.g. hydrogeological barriers) protect environmental quality and where the separation distances to sensitive receptors ensure that there will not be adverse impacts on existing and future development. The risk of leachate contamination increases where the site is in poor hydrogeological conditions, near sensitive water bodies such as wetlands, or near water sources used for drinking, irrigation, industrial use or stock watering.

These guidelines do not contain express buffer distances or locational requirements. However, there are a number of recognised environmentally sensitive and inappropriate areas for landfilling. The EPA supports the list of such locations set out in the NSW Department of Planning and Environment's EIS Practice Guideline: Landfilling, Table 1 (NSW Department of Urban Affairs and Planning, 1996).

In summary, the list of inappropriate areas for landfilling includes sites located as follows:

- within 250 metres (or other protection zone) of an area of significant environmental or conservation value identified under relevant legislation or environmental planning instruments, including national parks, historic and heritage areas, conservation areas, wilderness areas, wetlands, littoral rainforests, critical habitats, scenic areas, scientific areas and cultural areas
- within specially reserved drinking water catchments, such as special areas identified by the Sydney Catchment Authority, Sydney Water and local water supply authorities;
- within 250 metres of a residential zone or dwelling, school or hospital not associated with the facility;
- in or within 40 metres of a permanent or intermittent water body or in an area overlying an aquifer that contains drinking water quality groundwater that is vulnerable to pollution;
- within a karst region or with substrata that are prone to land slip or subsidence
- within a floodway that may be subject to washout during a major flood event (a 1-in-100-year event).

Inappropriate areas also include land identified in an environmental planning instrument as being of high Aboriginal cultural significance or high biodiversity significance.

In the case of large putrescible waste landfills (more than 50,000 tonnes of putrescible waste per year), buffers of at least 1000 metres should be provided where practicable to residential zones, schools and hospitals to protect the amenity of these land uses from odour, noise and other impacts.

Impact assessment requirements

Thorough planning and impact assessment is an important step in the establishment and operation of landfills with minimal environmental impact.

Each new landfill proposal must be supported by a comprehensive environmental impact assessment. This must demonstrate how the proposal will meet the minimum standards of these guidelines.

Applications to the EPA for a licence to construct and operate landfill development works (including new cells at existing sites) must address the general matters in the EPA's Guide to Licensing and must include the following specific details on the proposed landfill design and operation:

- details of the engineered features of the proposed landfill works, including (as relevant) the leachate barrier, leachate storage and disposal system, stormwater management works, water quality monitoring installations, landfill gas management and monitoring infrastructure, and final capping – this must include plans, specifications and engineering drawings
- a scaled plan diagram of the premises, depicting the boundary of the premises and footprint of landfill cells, the locations of residences and other sensitive receptors, and the locations of other relevant infrastructure such as sewer connections and urban stormwater systems

- projections of the types and quantities of wastes to be received, the classification of the wastes, the design capacity of the landfill or cell, and the expected life of the landfill/cell
- a filling plan that is consistent with any planning approval, showing the proposed layout of the cells, the type and amount of waste to be deposited in each cell, the projected rate of filling, and the location of any special burials (e.g. asbestos waste or clinical waste); an updated filling plan must be prepared before each new cell is started and must be submitted to the EPA as part of the approval process for the new cell
- details of any waste reprocessing to take place at the landfill, the nature of any resources to be recovered from wastes received at the landfill, and the locations and sizes of any proposed stockpiles
- enough information to demonstrate that the proposal will meet the required outcomes in these guidelines, with justification for any proposed alternatives to the acceptable measures described in these guidelines – this should be supported by a hydrogeological risk assessment, landfill gas risk assessment, air quality impact assessment, odour impact assessment, noise impact assessment, water balance calculations for leachate management, and proposed environmental monitoring programs
- confirmation that the application has been prepared by a suitably qualified and experienced person(s).

Approval must be sought from the EPA in writing before the construction of each new waste cell at an existing licensed landfill. Applications should be submitted to the EPA far enough in advance to allow for the approval process and construction of the new cell to be completed before the existing approved disposal capacity is exhausted.

Preparation of technical reports

Technical reports must be prepared and signed by appropriately qualified and experienced persons.

In the case of landfill design reports and Construction Quality Assurance documentation for major landfill works, this person should be an engineer such as a civil or geotechnical engineer with professional qualifications acceptable to Engineers Australia, or equivalent, with at least 5 years of experience in landfill design and construction, and currently practising competently in this field.

These requirements apply to design and construction associated with the leachate barrier, the leachate storage and disposal system, stormwater management works, water quality monitoring installations, landfill gas management and monitoring infrastructure and final capping.

Other types of required qualifications and experience for specialist assessments are noted throughout these guidelines.

From time to time the EPA may obtain independent reviews and audits of design and construction documentation. This is to make sure that a high and consistent standard of landfill design and construction is maintained in NSW.

Part B: Minimum standards for landfills

The following minimum standards apply to the design, construction and operation of landfills in New South Wales.

For each issue there is a set of required outcomes, followed by a description of acceptable measures for addressing the issue. These acceptable measures are well-established and reliable techniques for meeting the required outcomes.

Alternative approaches may be proposed if it can be demonstrated that the alternative can meet the required outcomes. Proposals for alternatives will need more careful justification and evidence, which may include site-specific risk assessment, evidence of successful use of the approach elsewhere, academic or industry research, recognised industry standards adopting the alternative approach, modelling and trials.

Clear reasons should be given for proposing an alternative in preference to the acceptable measure(s) in these guidelines.

For several issues, specific guidance is given on how to propose an alternative approach. This includes the leachate barrier system (Issue 1), covering of waste (Issue 8) and final capping and revegetation (Issue 9).

1. Leachate barrier system

Required outcomes

- The landfill must have a leachate barrier system to contain leachate and prevent the contamination of surface water and groundwater over the life of the landfill.
- Pollutants with the potential to degrade the quality of groundwater must not migrate through the strata to any point beyond the boundary of the premises or beyond 150 metres from the landfill footprint, whichever is smaller. If this occurs, additional engineered controls may be required to prevent further pollutant migration. It may also be necessary to remediate the existing pollution.

The following sections contain acceptable designs, specifications and operating practices for the leachate barrier system. Alternatives may be proposed: see section 1.10 for the procedure used when proposing an alternative.

1.1 Design of leachate barrier system

The base and walls of all solid waste landfill cells should be lined with a durable material of very low permeability to form a barrier between the waste and the groundwater, soil and substrata.

General solid waste landfills

This primary barrier system should include the following components, from bottom to top:

- a compacted sub-base 200 millimetres thick to provide a firm, stable, smooth surface of high bearing strength on which to install the liner
- a compacted clay liner at least 1000 millimetres thick, with an in situ hydraulic conductivity of less than 1×10^{-9} metres/second; for landfills receiving more than 20,000 tonnes of waste per year, the liner should include a geomembrane over the compacted

clay; the base liner should have gradients of greater than 1% longitudinally and 3% in transverse directions

- a leachate collection layer comprising a 300 millimetres thick gravel drainage layer including collection pipework, which slopes to a sump or other extraction point from which leachate can be conveyed from the cell; the pipes should be at least 150 millimetres in internal diameter, be placed on the floor at intervals of not more than 25 metres (running the length of the cell), and be laid at gradients of at least 1% longitudinally into the sump and 3% in transverse directions.

To achieve the required in situ hydraulic conductivity of less than 1 x 10^{-9} metres/second, the clay should have high plasticity and a suitable particle-size distribution, with no particles greater than 50 millimetres in any dimension. Source testing of the material should confirm these properties.

As an alternative to compacted clay, a geosynthetic clay liner may be used, provided it is used in composite with an overlying geomembrane liner.

A protection or cushion geotextile should be used to protect geomembranes from damage by construction equipment and overlying materials.

A separation geotextile should be placed above the drainage layer to reduce the ingress of fines from the overlying waste.

A geonet drainage geocomposite may be used as an alternative to the gravel drainage layer for wall drainage and leak detection layers.

A groundwater relief layer may also be needed below the leachate barrier where high groundwater levels could affect the stability and performance of the barrier. Where needed, the materials used in this system should be of the same quality as the materials used in the leachate drainage layer.

The elements of leachate barrier systems installed on slopes must have adequate slope stability. A slope stability analysis should demonstrate that there are adequate factors of safety for all potential failure mechanisms (e.g. veneer and global stability) at the proposed final landform and at interim stages during construction.

The outer perimeter at any elevation of all new landfill cells should be set back at least 15 metres from the boundary of the premises. This is to ensure that land is available for the installation of monitoring wells and plume-abatement measures (e.g. construction of barriers) if liquid or gaseous pollutants are found to be escaping off-site.

Restricted solid waste landfills

For restricted solid waste cells, the design of the leachate barrier system should be a dual barrier system addressing the following requirements:

- The leachate barrier system should consist of a primary barrier and a secondary barrier. The secondary barrier is installed below or outside the primary barrier. Its purpose is to detect and remove any leakage through the primary barrier.
- The primary barrier should contain a composite liner, comprising a lower geosynthetic clay liner and an upper geomembrane liner. The primary leachate collection layer above the liner should be a 300-millimetre-thick gravel layer containing collection pipework. Protection and separation geotextiles should be installed as for the design for general solid waste landfills. A geonet drainage geocomposite may be used as an alternative to the gravel drainage layer for wall drainage.
- The secondary barrier should contain either a single compacted clay liner 1000 millimetres thick with a saturated hydraulic conductivity less than 1 x 10^{-9} metres/second, or a composite geomembrane/geosynthetic clay liner. The secondary leachate collection layer

should be a gravel drainage layer or a drainage geocomposite with a minimum hydraulic transmissivity of 0.3 x 10^{-3} square metres/second.

- The leakage rate through the dual barrier system should be less than 1 litre/hectare/day of leachate for a maximum level of leachate of 300 millimetres over the upper liner.
- Material properties and specifications should be as for general solid waste landfills. In the case of restricted solid waste leachate barriers, materials should be used that will not be compromised by chemicals in the leachate.
- Restricted solid waste cells should have a base gradient of greater than 2% in the longitudinal direction and greater than 3% in transverse directions.
- Restricted solid waste cells should be wholly above the highest historically recorded groundwater table at all times. Alternatively, the cell can be sited partly or wholly above ground.

Restricted solid waste cells or monocells located within general solid waste emplacements should:

- be isolated from the rest of the landfill by a leachate and gas barrier of low permeability designed to the above standards
- be located at the edge of the landfill
- ideally not have other types of waste either above or below them.

1.2 Geomembranes (flexible membrane liners)

Geomembrane liners should:

- consist of a thin plastic film, minimum 2 millimetres 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 for, respectively, high density polyethylene geomembranes and linear low density geomembranes (Geosynthetic Research Institute, 2014a and 2014b).

1.3 Geosynthetic clay liners

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 5 x 10^{-11} metres/second
- be reinforced (i.e. 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, 2010)
- be made from bentonite that has been formulated for landfill applications; the bentonite should meet the specifications in Table 1.

Table 1: Minimum bentonite specification (Source: EPA Victoria, 2015 at page 102)

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

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

The hydraulic conductivity and swell of a geosynthetic clay liner can be affected by the presence of cations in liquids permeating through the liner. This is due to the process of cation exchange. In particular, sodium ions can be replaced by calcium and magnesium ions.

It has been shown that the effects depend on the overall concentrations of the cations (ionic strength) and on the ratio of monovalent to divalent cations. A parameter for assessing the effect is RMD, the ratio of the total molarity of monovalent cations to the square root of the total molarity of divalent cations.

When soil materials are installed adjacent to a geosynthetic clay liner, the liner may draw moisture from the soil before saturation. Such soils should have an appropriate RMD for the particular ionic strength that will not lead to an increase in the hydraulic conductivity or decrease in swell of the bentonite. This issue should be examined in accordance with the method in *Hydraulic conductivity and swell of nonprehydrated Geosynthetic Clay Liners permeated with multispecies inorganic solutions* (Kolstad et al., 2004) or in an equivalent method.

1.4 Gravel drainage layers

The gravel drainage material should:

- consist of hard, strong, durable and clean gravel that will maintain the required performance under the maximum loads likely to be imposed on it in service
- have a saturated hydraulic conductivity greater than 1 x 10^{-3} metres/second when tested in accordance with Australian Standard AS 1289.6.7.1 Determination of the Permeability of a Soil (constant head method)
- be relatively uniform in particle size, with a nominal particle size greater than 20 millimetres and a maximum particle size of 40 millimetres, and with not more than 10% of particles smaller than 20 millimetres in diameter and not more than 3% smaller than 0.075 millimetres

- be non-reactive in mildly acidic conditions and chemically resistant to the leachate in the landfill, with a calcium carbonate content of less than 8.5% by mass
- not have a shape and angularity that will damage the underlying geomembrane liner (the best type of gravel is rounded and smooth-surfaced)
- be installed in a continuous layer at least 300 millimetres thick across the entire base of the landfill cell, sloped with at least a 1% longitudinal gradient and 3% transverse gradient.

Source material should be tested to show that the gravel drainage material meets these requirements.

1.5 Collection pipework

The leachate collector pipes should:

- be flexible pipes (typically high density polyethylene) at least 150 millimetres in internal diameter (water balance and pipe flow calculations should confirm the pipe size needed to convey peak leachate flow rates)
- be perforated such that the size, frequency and layout of the perforations are sufficient to facilitate leachate inflow and extraction without clogging, prevent entry of drainage gravel, and maintain adequate pipe strength
- be strong enough to maintain performance under the maximum loads likely to be imposed in service, complying with the requirements of Australian Standard AS 2566.1-1998 Buried flexible pipelines – Structural design (Standards Australia, various dates)
- be joined by using techniques and materials recommended by the pipe manufacturer.

1.6 Protection geotextiles

The protection or cushion geotextile should:

- be a non-woven, needle-punched geotextile, typically made of polyester or polypropylene (with the exception of 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 joints of drainage geocomposites
- 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 GT12(a) and GRI Test Method GT12(b) (Geosynthetic Research Institute, 2012a and 2012b).

The grade (mass, strength, thickness) of the protection geotextile should be justified by the results of site-specific liner testing. This testing should incorporate the proposed liner and adjacent layers and apply the estimated confining pressures that will be experienced in service as a result of the overlying waste and equipment loadings.

Two published methods for examining the expected field performance of a geomembrane liner under gravel aggregate are: (1) LFE 2 – Cylinder Testing Geomembranes and their Protective Materials: A methodology for testing protector geotextiles for their performance in specific site conditions (UK Environment Agency, 2014); and (2) 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 material, protection geotextile and geomembrane liner. Measurements are taken of the deformations in the liner. Strains in the material are estimated from the deformation data and should be compared with the acceptable values for geomembrane strain listed in Table 2. Excessive strain can lead to environmental stress cracking in the liner over time. The testing should ensure that both short-term and long-term effects are taken into account.

Table 2: 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%

Source: EPA Victoria, 2015, page 75, adopting values from Peggs 2003.

1.7 Separation geotextiles

The separation geotextile should:

- be a non-woven, needle-punched geotextile, typically made of polyester or polypropylene (with the exception of inhibitors and/or carbon black added for UV resistance), formulated to meet landfill conditions and not containing recycled materials
- have appropriate filtration characteristics to limit the effects of clogging, while at the same time limiting excessive migration of soil fines into the underlying drainage layer
- allow flow of leachate into the underlying drainage layer without significant flow impedance
- have sufficient strength to resist installation damage
- have appropriate UV resistance properties based on the estimated exposure of the material before covering
- 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 GT13(a) and GRI Test Method GT13(b) (Geosynthetic Research Institute, 2012c and 2012d).

1.8 Drainage geocomposites

An appropriately designed geonet drainage geocomposite may be used as an alternative to the gravel drainage layer in secondary applications, such as sidewall 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.

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's 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.

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.

1.9 Leachate extraction and level-control system

The leachate extraction and level-control system should:

- include a collection sump and leachate riser(s) to facilitate extraction of leachate from the cell. The riser should be stable under the load of the surrounding waste mass and should be able to withstand stresses due to settling of the surrounding waste. The pipes should comply with the requirements of applicable Australian Standards for the pipe material, for example Australian Standard AS 4058:2007 Precast Concrete Pipes (pressure and non-pressure) (Standards Australia, 2007b).
- be installed in all cells, be able to control leachate levels within each cell, and be able to convey collected leachate out of the cell to surface storage or other infrastructure
- be able to keep the leachate level no greater than 300 millimetres above the upper surface of the base liner, or below some other level that is justified by the design, site conditions and leachate management measures (note: the flow of leachate through the liner is greater when leachate is allowed to accumulate within the cell, and higher leachate levels can also interfere with landfill gas controls)

- be able to continue to function effectively until the landfill is considered stable.

For restricted solid waste cells, there are some additional requirements. The leachate extraction and level-control system for restricted solid waste cells should:

- be automated and telemetered
- have an alarm system that is activated if the leachate level within the cell rises to more than 300 millimetres above the lowest point on the cell's floor or some other level justified by the design
- have interlocks or water level sensors to prevent leachate from being pumped out of the cell when the freeboard of any receiving dam is exceeded (additional storage or disposal capacity may be required when this occurs)
- in the case of sites disposing of more than 100,000 tonnes of waste per year, have an alarm system and pump interlocks on the leachate transfer pipework to prevent the pumping of leachate should the pipework rupture
- have a leachate riser connected to both the primary and secondary leachate collection layer and, for cells with a capacity of greater than 50,000 cubic metres of waste, have two leachate risers connected to the primary leachate collection layer.

1.10 Justification of alternative leachate barriers

Alternatives may be proposed to the designs, specifications and methods in this section. The proposal should address the following requirements:

- The alternative proposal must be able to achieve the required outcomes for a leachate barrier and be compatible with achievement of the required outcomes for all other environmental issues.
- The proposal should be prepared by a suitably qualified and experienced person. This person should give an opinion that the alternative design can meet the required outcomes for a leachate barrier and is compatible with the achievement of all other required outcomes. This opinion should take into account the results of the hydrogeological investigation.
- Clear reasons should be given for proposing an alternative in preference to the acceptable measure(s) in these guidelines.
- The proposal must fully describe the properties and predicted performance of the alternative leachate barrier. For each barrier layer, this includes but is not limited to thickness, hydraulic properties, strength, resistance to degradation, long-term behaviour, compatibility with adjoining layers, compatibility with the site's leachate, slope stability where relevant, and construction methods. Performance predictions should be supported by all necessary test results, calculations and modelling.
- A hydrogeological investigation must characterise the surrounding soil and groundwater and must identify any risks to water bodies and other sensitive receptors in the locality. The assessment should be done in accordance with a recognised guideline for hydrogeological assessments.
- In some cases, the EPA may require a peer review of the proposal by a suitably qualified and experienced person. Examples of these situations are when the proposal involves a major departure from the acceptable design measure(s) in this section or when the landfill is located near sensitive receptors.
- In some lower risk circumstances, the EPA may approve the omission of an engineered leachate barrier and controls, either wholly or partly. An extensive investigation should show that the hydraulic conductivity of the in situ material is less than 1×10^{-9}

metres/second to depths of at least 10 metres at all elevations around the landfill. It should also show that there are no imperfections that may compromise the effectiveness of the natural material as a barrier. These lower risk situations include:

- landfills in rock with discontinuous fractures
- small, low-risk rural landfills: the waste is general solid waste only, the capacity is less than 20,000 tonnes of waste per year, average annual rainfall is less than 600 millimetres, there is no risk to surface water or groundwater, and the landfill is not located within 1000 metres of dwellings and other structures.

Even where these circumstances apply, there should be a minimum level of site-preparation work. The top surface of the landfill floor and side walls should be reworked to at least 300 millimetres to remove any fissures, fractures or desiccated soil.

1.11 Landfilling on closed cells

Proposals are sometimes made to build a new landfill cell wholly or partly (i.e. on a side slope) over an existing closed landfill.

Proposals to install a lined cell over an existing cell should address the following requirements:

- The proposed cell should be a self-contained landfill cell that is able to operate separately from the old cell on which it is placed. The new cell should not compromise ongoing collection and management of leachate and gas from the old cell. The new cell should have a leachate barrier system in accordance with these guidelines.
- The leachate barrier should not be damaged by settlement of the waste in the old cell. The design should include a settlement and liner deformation analysis demonstrating that the effects of waste settlement—both general and localised—can be managed. The analysis should demonstrate that the strains induced in the liner by the predicted settlement will be within the allowable ranges for the liner materials, and that there will be no grade reversal of drainage elements that could interfere with the collection and conveyance of leachate.
- There should be a stiff foundation or bridging layer below the leachate barrier to protect it from deformations due to settlement of the underlying waste. This layer should be at least 500 millimetres thick. It should comprise clean, well-graded, coarse engineered fill and should have geogrid reinforcement.
- The liner system should have adequate slope stability and should not compromise the stability of existing slopes. A slope stability analysis should demonstrate that there are adequate safety factors for all relevant potential failure mechanisms, both at the proposed final landform and at interim stages during construction.
- The settlement and slope stability analysis should be conducted by a suitably qualified and experienced person.
- If the old cell is generating landfill gas, gas collection and extraction infrastructure should be installed below the leachate barrier to collect and vent the gas. This is to protect the new cell's liner from gas uplift pressure and prevent uncontrolled lateral migration of landfill gas.
- The environmental monitoring program for the new cell should be able to differentiate impacts occurring from the new cell and those from the old cell so that any necessary remedial actions can be appropriately targeted. The monitoring program should also include monitoring of the settlement behaviour of the new cell's lining system.

2. Leachate storage and disposal

Required outcomes

- Collected leachate must be stored in appropriately sized dams or tanks and disposed of so as not to cause environmental harm.
- There must be sufficient leachate disposal capacity to prevent the build-up of leachate and an increase in the risks of water pollution and offensive odours.
- Untreated leachate must not be disposed of to off-site water or land, used for dust suppression, or used to supply the water needs of any process conducted at the landfill, such as composting.

The following sections contain acceptable designs, methods and operating practices for leachate storage and disposal.

2.1 Leachate storage

The design, construction and operation of the leachate storage dam should meet the following requirements:

- The dam must have sufficient leachate storage volume, as determined by using a water balance methodology in accordance with section 2.3 below.
- The dam must have a freeboard that can accept rainfall directly on the dam from a 24-hour rainfall event with a 1-in-25-year average recurrence interval without overflowing. The dam must have a visible marker to indicate the bottom depth of the required freeboard. If the freeboard is exceeded, the occupier must re-establish and maintain the required freeboard. If the dam is in danger of overflowing, an option may be to inject some leachate back into the cells and to stop leachate extraction from the cells.
- The dam liner must be designed and constructed to a standard similar to that of the landfill cell liner (see section 1.1).
- Leachate storage dams should not be constructed over previously landfilled areas, except in exceptional circumstances. Such proposals must clearly demonstrate the long-term geotechnical stability of the proposed dam.
- If above-ground tanks are used, the tanks and associated connection points must be surrounded by a bund with a capacity of at least 110% of the tanks.

2.2 Leachate treatment and disposal

Stored leachate should be dealt with by one or more of the following strategies: discharging to sewer under a discharge agreement with the local water authority, tankering off-site to a licensed treatment facility, evaporation, irrigation, or reinjection back into the waste.

Off-site discharge into waters is generally not permitted, because leachate invariably contains a wide range of pollutants that potentially pose a risk of nontrivial harm to human health or the environment.

On-site treatment of leachate broadens the range of management options. Several of the options discussed below require some degree of leachate treatment. Treatment options range from simple structures such as reed beds, constructed wetlands and aerated ponds, to treatment plants such as sequencing batch reactors and processes involving filtration and reverse osmosis.

Sewer discharge

Leachate can be discharged to sewer only under a sewer discharge agreement with the local water authority. These agreements often limit the concentrations of pollutants (e.g. ammonia, biochemical oxygen demand, total dissolved solids and barium), and typically leachate must be pre-treated to meet the discharge criteria. This option is usually not available for leachate from restricted solid waste cells because of the range of contaminants present in the leachate.

Off-site transport

Leachate may be transported off-site in a tanker to a treatment or disposal facility that can lawfully receive it. Some pre-treatment may be required, depending on the acceptance requirements of the receiving facility.

In the case of leachate from restricted solid waste cells, off-site transport is typically the only feasible option, because the level of contaminants in the leachate precludes most of the other options discussed here.

Evaporation

In climates where evaporation exceeds precipitation, a leachate dam with a large surface area and shallow depth will enhance leachate losses through evaporation. In some drier areas, evaporation from the leachate storage dam will be considerable, enabling the system to operate essentially as a closed system for most of the time.

However, in many climates this is only a partial solution (particularly during the winter months) and will need to be augmented by other disposal options.

Adverse odour impacts are a possibility with this approach, given the size of such dams and the volume of leachate in storage. Surface aerators may need to be installed to keep the leachate oxygenated or ‘fresh’ (i.e. to stop it becoming anaerobic and creating odour impacts).

Irrigation

In some cases, leachate may be able to be sustainably irrigated over suitable land areas at the landfill or off-site.

The EPA will take the following guiding principles into account when assessing irrigation proposals:

- Irrigation should be managed in accordance with Environmental Guidelines: Use of Effluent by Irrigation (NSW DEC, 2004b).
- Irrigation over rehabilitated landfill is usually preferable to irrigation on greenfield land.
- The irrigation application rate must not exceed the capacity of the land to absorb the nutrient, salt, organic and hydraulic loadings supplied by the leachate. It must not compromise any future use of the land or productivity of the soil. The application rate must minimise runoff. All runoff from the irrigation area should be collected and managed as leachate. Irrigation rates should be based on water balance modelling that demonstrates that a water deficit will be maintained and percolation and runoff will be minimised.
- Irrigation must not pose a threat to human or animal health through contact with the leachate or with crops and pasture irrigated with leachate. It should not be used in agriculture, and it should be done only at sites with restricted public access and low levels of human contact. It should not cause spray drift of leachate. Signs should be prominently displayed to inform the public that leachate irrigation is taking place.
- Leachate quality criteria for irrigation are to be determined on a case-by-case basis. Leachate should be characterised in terms of the pollutants present and their

concentrations. Characterisation parameters typically include pH, biochemical oxygen demand, ammonia and electrical conductivity. Depending on the landfill type, other parameters, such as thermotolerant coliform levels, may also need to be included. Treatment may be required in some situations, namely at:

  - sites that are adjacent to surface waters
  - sites in a neighbourhood that could be affected by offensive odour
  - sites where some new use of the land has started (e.g. for playing fields)
  - greenfield sites.

- Before irrigation starts, there should be sufficient operating data to characterise leachate quality and to demonstrate its suitability for irrigation.
- Occupiers must have contingency measures in place, should irrigation become unviable for any reason. This must include one or more of the other options discussed in this section.
- Leachate from cells containing restricted solid waste should not be used for irrigation, because such leachate will generally not meet the quality requirements in recognised irrigation guidelines.

Reinjection

Under some circumstances, untreated leachate may be injected back into the waste, provided that it is at a sustainable rate and the risk of adverse impacts can be managed.

Typically, reinjection is small-scale, temporary and ancillary to other disposal methods. It is used to manage peak flows and for seasonal flow-balancing purposes where storage capacity elsewhere in the leachate management system is temporarily unavailable. Reinjection will generally not provide a solution for all the leachate generated.

Reinjection may also be on a larger and more permanent scale, such as where the landfill is intended to operate as a so-called bioreactor. In these systems, leachate and often water from other sources (e.g. collected stormwater) is recirculated through the waste mass in a controlled manner to bring the waste up to an optimum moisture content (usually the water-holding or field capacity of the waste) for enhanced anaerobic biodegradation of organic materials in the waste.

The bioreactor approach is said to offer the following benefits compared with conventional dry tomb landfills:

- waste stabilisation is accelerated
- generation of landfill gas starts and finishes earlier
- energy recovery from gas is viable at an earlier stage
- leachate strength diminishes earlier
- long-term maintenance and monitoring needs are reduced
- new uses of the site can start earlier.

The EPA will use the following guiding principles to assess reinjection proposals:

- Reinjection should be done at a sustainable rate, enabling the waste to absorb the leachate. There should be sufficient storage volume within the waste and the leachate management system to contain the reintroduced leachate. Proposals should be supported by water balance modelling demonstrating sufficient storage capacity.
- Reinjection should be used only where the cell is lined and has an engineered leachate extraction and level-control system.

- Reinjection should not create excessive leachate levels over cell liners, leading to greater leakage rates to groundwater. Leachate in excess of the waste's field or holding capacity should be continuously withdrawn from the cell to ensure that the depth of leachate over the liner does not exceed 300 millimetres or some other maximum level justified in the design of the cell. The leachate level should at all times be below the lined capacity of the cell.
- The reinjection points should be properly designed, constructed and operated. Reinjection should be done in a controlled manner below the surface of the waste by using engineered trenching, wells and piping to distribute the leachate evenly throughout the waste. The reinjection points should not become sources of oxygen ingress to the cell or odour emission from the cell. Reinjection points should be away from leachate and gas extraction points to prevent 'short-circuiting'.
- Spray irrigation over the active landfill surface may not be as effective in distributing the leachate throughout the waste mass. It may also pose risks of increased odour impacts, surface runoff, and spray drift. These issues should be assessed in each case where spray irrigation is proposed as an alternative approach to sub-surface reinjection.
- Reinjection must not have the following impacts:
  - increased adverse odour impacts
  - increased fugitive gas emissions due to interference with landfill gas controls
  - seepage of leachate from above-ground batters or embankments
  - structural instability due to increased moisture levels and perched water tables
  - spray drift or runoff.
- Reinjection should not be used in certain situations. It should not be used in cells containing restricted solid waste. Leachate should not be reinjected into waste that is above the natural ground surface or over a liner built on an older waste cell. In these situations, increased moisture levels in the waste can increase the risk of seepage and structural instability.
- There must be contingency measures for dealing with exceedance of reinjection capacity or the need to discontinue reinjection for any reason. Similarly, leachate reinjection is not available during the initial stages of a landfill's life, when insufficient waste has been landfilled to absorb substantial quantities of leachate. The occupier must have sufficient options for leachate management during these periods.
- Leachate level and volume should be monitored regularly (see section 4).

Bioreactors

Full-scale bioreactor systems should address the above general requirements for reinjection, plus the following additional requirements:

- An engineered water distribution system should be installed within the waste. This system should be able to deliver water evenly throughout the entire waste mass so that the optimum moisture content for enhanced degradation can be achieved.

  Typically, the distribution system consists of horizontal drains spaced at 20 to 60 metres horizontally and 6 to 10 metres vertically. The drains comprise perforated pipes 100 to 150 millimetres in diameter laid in rock-filled trenches about 1 x 1 metres in cross-section (see Benson et al., 2007, p. 16 for more details of common practice).

  Such a system is needed to overcome difficulties in fully wetting the waste to its field capacity. These difficulties occur because of heterogeneity of the waste, problems with achieving an even moisture distribution throughout the waste mass, and the presence of dead zones and preferential vertical flow paths through the waste directly to the leachate collection layer ('short circuiting').

- An active landfill gas extraction and treatment or utilisation system should be progressively installed and operated, starting as soon as possible early in the landfilling phase and continuing during the post-closure period. Generally, water should not be added to the waste until the active gas extraction system is operating.
- Large bioreactor cells (with a waste capacity of greater than 100,000 tonnes/year) should be designed with a secondary leachate collection (leak detection) layer.
- Capping of bioreactor cells should minimise rainwater infiltration in accordance with the requirements of these guidelines (see section 9). Uncontrolled rainwater percolation into the waste is not a satisfactory method of bioreactor operation. If the quantity of leachate available for recirculation is insufficient to keep biological activity at the desired level, other water sources can be used (e.g. collected stormwater) and added to the cell via the purpose-designed leachate recirculation infrastructure.
- In addition to routine environmental monitoring (groundwater, surface water, gas, odour, dust, noise etc., as outlined in sections 4 to 6), there should be a bioreactor monitoring program. This program should assess whether the bioreactor has been successful in enhancing waste biodegradation and in achieving the other benefits claimed for this approach. All bioreactor performance data should be compared with appropriately benchmarked data on conventional landfilling. This program should include data gathering to measure or demonstrate the following:
    - gas production and composition
    - leachate strength
    - continued performance of the leachate collection system (i.e. the system is not impaired by clogging)
    - the moisture and volatile solids content of the waste
    - temperature
    - water inputs and outputs
    - waste settlement
    - slope stability.
- The bioreactor cell must contain mostly putrescible waste. The bioreactor approach is not suitable for landfill cells containing only non-putrescible waste.

2.3 Conducting a water balance

Leachate management proposals should be supported by water balance calculations that provide robust estimates of the required leachate storage capacity. A water balance should be conducted when a new landfill or cell is proposed, or when there is a proposal for a major change to leachate storage and disposal at the landfill.

The water balance model should be prepared in accordance with the following principles:

- The model should account for all predicted leachate inputs and outputs from the leachate management system. The required leachate dam(s) storage volume is the rainfall infiltration into the waste that becomes leachate (rainfall depth x surface area), plus groundwater inflow (if any), plus rainfall onto the leachate dam, <u>less</u> evaporation from the leachate dam, leachate disposed of by sewer, tankering off-site, irrigation or other means.
- The model should be run by using monthly time intervals, and it should estimate the changes in the cumulative volume with each month. The maximum cumulative volume may not be reached until many months into the landfill's operation. The size of the leachate storage dam should be based on this maximum cumulative monthly volume.

- The leachate dam(s) should also have a small amount of additional freeboard to accept the direct rainfall on the dam from a 1-in-25-year average recurrence interval 24-hour rainfall event for the location without overflowing.
- The amount of rainfall that infiltrates to become leachate (rather than surface runoff or evapotranspiration) should be estimated by inputting climate, soil, waste type and landfill-design data into a simulation program such as the Hydrologic Evaluation of Landfill Performance (HELP) model originally published by the United States 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.
- This simulation should be conducted for all cells at the landfill, including capped cells, cells with intermediate cover, and the active cell. The infiltration percentage varies with the characteristics of the cell cap or covering.
- For smaller sites, default rainfall infiltration percentages can be used as an alternative to running a simulation such as the HELP model. Conservative infiltration percentages should be used, for example, 10% to 20% for final capping, 50% for intermediate covering (90% when below the surrounding natural ground level), and 100% for an active area with daily covering. Proponents may propose daily covering materials and practices that will reduce rainfall infiltration, thereby justifying lower infiltration percentages.
- The volumes of leachate can be minimised by reducing the size of the active tipping face, surrounding the active face with bunding or contour drains to divert stormwater, and promptly applying intermediate cover and final capping to finished cells.
- The model can also make allowance for absorption by the waste of some of the rainfall and, if applicable, recirculated leachate. Recently placed waste in the active cell can be assumed to have an absorptive capacity of 7% on a volumetric basis (this is the default value in the HELP model).
- The rainfall volumes assumed in the modelling should be conservative. For example, the model could regularly incorporate rainfall volumes from historically wetter years (such as the 90th percentile wet year) in the locality, rather than from the historical average rainfall year.
- The Australian Government's Bureau of Meteorology may be consulted for rainfall, evaporation and other climate data needed to enter into the model. It is desirable to choose a weather station that has at least 50 years of data and is close to the site. The evaporation from the leachate dam should be estimated by using a pan coefficient of 70%. Thus the volumetric output from the leachate dam can be estimated as (0.7 x monthly evaporation rate x surface area of the dam).
- For operating sites, actual site data, if available, can be used in water balance modelling and storage capacity calculations.
- The water balance should be validated or updated from time to time by using site operational data. This is to test the accuracy of the assumptions in the original modelling and to assess whether the leachate management infrastructure will be adequate to continue to meet the requirements of these guidelines.

3. Stormwater management

Required outcomes

- Controls must be implemented to minimise erosion and reduce the sediment load (suspended solids) of stormwater discharged from the site.

The following sections contain acceptable measures for managing stormwater.

3.1 Erosion control

The volume of sediment-laden stormwater runoff should be minimised by implementing the following erosion controls (for further guidance see Managing Urban Stormwater: Soils and Construction Volume 2B Waste Landfills (NSW DECC, 2008a)):

- **Minimise the area of exposed soils.** The occupier should minimise the amount of cleared and exposed (unvegetated) areas that can generate suspended solids when water runs over the areas.
- **Stabilise exposed areas.** Exposed areas should be stabilised as soon as possible. All completed areas of the landfill should be progressively revegetated. Note that stormwater runoff from rehabilitated areas where approximately 70% of the groundcover has been re-established is considered to be 'clean' runoff and may not need further treatment. Other stabilisation measures include the use of batter blankets, mulching, geocellular containment systems and geobinders.
- **Reduce erosive effect of stormwater.** Concentrated stormwater flows should be managed by using diversions, armouring channels with rock or rubble to provide scour protection, check dams, batter drains, grade control structures and flumes, outlet dissipation structures, and revetments and retaining walls.
- **Protect stockpiles.** Stockpiles should be located away from concentrated stormwater flow. They should be protected by up-slope diversion banks, be stabilised with vegetative cover, mulches or matting products, and be provided with sediment control fencing.
- **Manage unsealed roads.** Unsealed access tracks are widely used at landfills. Detailed guidance on erosion and sediment control for access tracks is provided in Managing Urban Stormwater: Soils and Construction Volume 2C Unsealed Roads (NSW DECC, 2008b).
- **Site exit controls.** Site exit points should have appropriate controls such as shaker ramps, rock aprons and wheel wash systems to prevent off-site transport of suspended solids.
- **Maintenance.** All structures for erosion control must be maintained. They must be inspected regularly and after any significant rainfall (more than 10 millimetres in a day), and they must be repaired as necessary.

3.2 Sediment control

The occupier should ensure that all sediment-laden stormwater runoff passes through appropriate sediment control structures. Sediment controls include vegetative buffers, silt fences, fibre rolls, turbidity or silt curtains, and sediment basins.

The occupier should maximise the diversion of sediment-laden stormwater runoff to sediment basins.

Where required, sediment basins should be designed, constructed and operated in accordance with the following guidance:

- **Sediment basin design criteria.** The sediment basin(s) should be designed, constructed, operated and maintained in accordance with Managing Urban Stormwater: Soils and Construction Volume 1 (NSW Department of Housing, 2004).

  The sediment basin should be designed to capture and treat all sediment-laden runoff during a 90th-percentile 5-day rainfall event. It should be sized with a settling volume such that the suspended solids settle out to a concentration of less than 50 milligrams/litre before the treated stormwater is discharged. The required capacity of a sediment basin is normally the sum of the required settling volume, the sediment storage volume and the capacity required for storage of the water for on-site reuse. The sediment storage zone is the bottom part of a sediment basin where settled sediment is allowed to accumulate.

  All sediment basins should have a marker indicating the position of the upper level of the sediment storage zone. The water level should be drawn down to a level just above the sediment storage zone within 5 days of the end of any significant rainfall to restore the basin's capacity to contain runoff from the next rainfall event.

  These design requirements are based on the requirements specified for soils characterised as Type D (dispersive soils) in Managing Urban Stormwater: Soils and Construction Volume 1 (NSW Department of Housing, 2004). Smaller sediment basins than calculated may be acceptable if the soils at the site are non-dispersive and it is clear that dispersive soils will not be placed at the premises in future.

- **Disposal of treated stormwater.** The water emptied from the dam may be reused on site or discharged off-site if it is of appropriate quality. Examples of potential on-site uses of stormwater are dust suppression, moisture content control for compaction of clay liners and covers, irrigation of revegetation areas, and fire-fighting.

  Significant reuse of captured stormwater should have regard to the guidelines Managing Urban Stormwater: Harvesting and Reuse (NSW DEC, 2006c)—in particular, the stormwater quality criteria for public health risk management. Table 6.4 of those guidelines specifies limits for turbidity, *Escherichia coli* and pH for various reuse applications.

  Where concentrations of pollutants other than sediment are elevated in stormwater, the polluted water must be transferred to the leachate system.

- **Flocculation.** Sometimes captured stormwater may have to be treated with flocculants to help settle the suspended solids. Landfills often have dispersive clay soils, either won locally or imported for lining. The stormwater runoff from such soils typically contains high concentrations of very fine sediment that will not settle, even after extended retention in a sediment basin. Manual or automated techniques are available for adding flocculating agents. Flocculants must be carefully dosed and applied to ensure that no residual toxic product is discharged to waters. Before using flocculants, licensees should liaise with the EPA about managing the potential risks to waters from any discharge.

- **Construction issues.** Sediment basins and associated drainage should be installed and commissioned before the start of any clearing or grubbing works within the catchment area of the sediment basin. Sediment basins should not be placed over landfilled areas, unless the basin is lined to have a leakage rate less than that of the engineered landfill barrier.

- **Maintenance.** Sediment basins must be maintained. They must be inspected regularly and after any significant rainfall (more than 10 millimetres in a day), and they must be repaired as necessary. Sediment basins must be regularly cleaned out to ensure that they retain their design capacity.

- **Turbidity.** Total suspended solids measurement is a less reliable method of assessing the quality of stormwater containing very fine suspended colloidal materials (particles with diameters <1 microns), such as sodic clays and fine organic matter. Turbidity may be considered as an alternative indicator of water quality if the pollution is colloidal and the primary impact of the discharge is discolouration of the receiving water.

Turbidity is the cloudiness of a water sample due to light deflection by the suspended particles. In the standard test method, turbidity is measured by passing light though the sample and measuring the amount deflected by the particles by using an instrument called a nephelometer. The units of measurement from a calibrated instrument are nephelometric turbidity units (NTU).

To use turbidity as a valid measure, a statistical correlation should be developed between NTU and total suspended particulates. The correlation is unique for each situation. The assessment should be done on a case-by-case basis.

4. Water quality monitoring

Required outcomes

A water quality monitoring program must be implemented. It must:

- characterise the quality and quantity of wastewater (leachate and stormwater) generated at the site
- detect any pollution of off-site surface water and groundwater
- ensure that appropriate notification, investigation and remedial procedures are followed when monitoring indicates that pollution may have occurred
- ensure that appropriate sampling and analysis methods are used in accordance with Approved Methods for the Sampling and Analysis of Water Pollutants in NSW (NSW DEC, 2004a) and other recognised guidelines for matters not covered by the Approved Methods.

The charge balance error for the major cations and anions should be ±5% for all analysed samples.

The following sections contain acceptable water quality monitoring programs for leachate, stormwater, ambient surface water and groundwater.

4.1 Leachate monitoring

A leachate monitoring program should be established to provide data on the composition, height levels and volumes of leachate produced by each landfill cell, and to record details about any irregular discharges or overflows of leachate from the site.

In addition, for restricted solid waste landfills the monitoring program should detect any leakage through the leachate barrier system.

The leachate monitoring program should address the following requirements:

- **Routine composition monitoring.** Leachate should be sampled from the collection sump(s) and from surface storage dams to characterise leachate composition and strength.

  The indicator parameters and frequency of sampling will depend on the risk profile of the site, the stage of the landfill's life, and the volume of waste landfilled. Table 3 contains an appropriate program for an active high risk site and/or a large landfill (greater than 100,000 tonnes/year).

  Additional indicator parameters may be needed where there are wastes with known contaminants (e.g. wastes that are subject to an immobilisation approval).
- **Leachate level monitoring**. The leachate level should be monitored quarterly in the main leachate sump or riser in each cell to demonstrate that leachate is not

accumulating to unacceptable levels above the liner. Where leachate is reinjected, the frequency of monitoring should be at least weekly.

Levels should be taken after they have been allowed to stabilise; this may require several days without pumping.

It is also a good idea to construct additional monitoring points (additional risers or monitoring wells) away from the main collection sump. This provides information on conditions across the waste mass, away from the extraction point.

- **Leachate volume monitoring.** Data on the volumes of leachate being generated and removed from a landfill cell should be obtained from continuous-pumping or flow records. The volume data may be needed for several purposes:
  - to assess the performance of a final capping layer in limiting rainfall infiltration
  - to validate predictive water balances for the site
  - to help with process control in the case of a bioreactor landfill.

Table 3: Indicator parameters for leachate monitoring

Pollutant	**Units of measure**	**Frequency**	**Sampling method**
Electrical conductivity	µS/cm	Quarterly	Probe
pH	pH units	Quarterly	Probe
Standing water level in all leachate risers	m AHD	Quarterly	In situ and when not depressed by leachate extraction
Volume	m^3	Continuous	From flow meters 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, chemical oxygen demand)	mg/L	Annually	Grab sample
Ammonia and nutrients (nitrate, nitrite, and phosphorus)	mg/L	Annually	Grab sample
Metals (aluminium, arsenic, barium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, zinc)	mg/L	Annually	Grab sample
Organic contaminants: • phenols • petroleum hydrocarbons • monoaromatic hydrocarbons (in particular benzene, toluene, ethylbenzene and xylene) • organochlorine and organophosphate pesticides • polycyclic aromatic hydrocarbons.	mg/L	Annually	Grab sample

Note: AHD = Australian Height Datum.

- **Leachate discharges or overflows.** Leachate discharges include overflows from leachate dams and discharges from other locations (e.g. batter seeps and leaks from transfer pipes/pumps). These discharges should be sampled as soon as practicable from just beyond the overflow level of the dam or at the exit point of the leak, as applicable.

  The occupier should keep records and notify the EPA of any irregular leachate discharges or overflows from the site; these notifications should include an estimate of the volume of leachate discharged.

  Under the *Protection of the Environment Operations Act 1997*, the occupier must notify the EPA immediately upon becoming aware of incidents causing or threatening material harm to the environment.

  If a discharge occurs, the occupier should take immediate remedial action to contain the pollution and return any affected land, water and/or sediments to their original condition. Monitoring should verify that the remediation has achieved its aims. The occupier should also investigate the cause of the discharge or overflow and take action to prevent a recurrence of the incident. This could include measures such as redesign of the leachate storage and disposal system, installation of telemetry, and/or repair of batters (in the case of significant seeps).
- **Requirements for off-site disposal or irrigation of leachate.** Where leachate is discharged to sewer, the leachate monitoring program must address the requirements of the local water authority. Similarly, if an environment protection licence authorises the off-site disposal of treated leachate to land or water, the licence will specify monitoring requirements that must be complied with.

  Where leachate irrigation is used, regular monitoring (weekly or monthly) should be done in accordance with guidelines on effluent irrigation, e.g. Environmental Guidelines: Use of Effluent by Irrigation (NSW DEC, 2004b).
- **Additional requirements of leachate monitoring programs for restricted solid waste landfills.** For restricted solid waste landfills or cells, the occupier should monitor daily the leachate inflow rates from the secondary leachate collection system (leak detection layer) in order to detect any malfunction of the upper (primary) liner.

  Two types of leakage rates will act as triggers for further action: an action leakage rate and a rapid and large leakage rate.

  The action leakage rate is a low-level leakage rate that indicates the presence of a small hole or defect in the top liner.

  A rapid and large leakage rate is a high-level trigger that indicates a serious malfunction of system components in the dual liner and therefore warrants immediate action. It is the maximum design leakage rate that the secondary leachate barrier system can accept. Site-specific leakage rates should be developed on the basis of the design of the secondary drainage system.

  The occupier must have a remedial action program for responding to exceedances of these triggers.

4.2 Stormwater monitoring

A stormwater monitoring program should be established to detect excess sediment loads in stormwater leaving the site and/or cross-contamination of stormwater with landfill leachate.

The stormwater monitoring program should address the following requirements:

- **Sampling from sediment dam(s).** The contents of sediment basins should be monitored regularly (e.g. quarterly) to demonstrate that:
  - the size and design of the dam are facilitating the required settling-out of suspended solids from the stormwater
  - stormwater is not being cross-contaminated with leachate from the site.

- **Discharges from sediment basins**. Manually pumped or drained discharges should be sampled before release to off-site water to ensure that discharge criteria are met. Uncontrolled overflows should be sampled where practicable. The occupier should record the details of uncontrolled overflows, including time, duration and estimated volume, as well as the rainfall event preceding each overflow. An excessive number of uncontrolled overflows may indicate that the sediment basin is not adequately designed and sized and/or is not being properly managed (e.g. adequate freeboards are not maintained).
- **Analytes.** The pollutants to be monitored should include total suspended solids (or related measures such as turbidity) and indicators of leachate contamination (e.g. ammonia, total organic carbon and conductivity).
- **Stormwater reuse schemes.** For stormwater reused at the site, monitoring guidance can be obtained from the guidelines Managing Urban Stormwater: Harvesting and Reuse (NSW DEC, 2006c), Table 7.2 (Interim guidance on treated stormwater quality monitoring for public health) and Table 7.3 (Interim guidance on treated stormwater quality monitoring for irrigation).

4.3 Ambient surface water monitoring

An ambient surface water monitoring program should be established to detect pollution of off-site surface water bodies by leachate or by sediment-laden stormwater from the landfill.

If the landfill is near surface water bodies, there should be a program of upstream and downstream water quality monitoring to identify or rule out any degradation of receiving water quality by the landfill.

For each potentially affected surface water body, there should be at least one monitoring point downstream of the landfill (for flowing or perennial waters such as rivers and creeks) or near the landfill (for still waters such as lakes and dams).

There should also be one monitoring point upstream of the landfill (for flowing waters) or distant from the landfill (for still waters) to establish the background, or unimpacted, surface water quality in the locality.

Ambient water quality monitoring can be restricted to a reduced suite of typical indicators of landfill leachate and environmental impact. Table 4 lists suggested indicator parameters for ambient surface water monitoring in the case of a general solid waste landfill. The monitoring should be done at a regular frequency, depending on the proximity and sensitivity of the surface water body.

Table 4: Indicator parameters for ambient surface water monitoring

Pollutant	Unit of measure	Sampling method
pH		Probe
Dissolved oxygen	mg/L	Probe
Electrical conductivity	µS/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)	cfu/100 mL	Grab sample
Total dissolved solids	mg/L	Grab sample
Potassium	mg/L	Grab sample

Note: cfu = colony forming unit

4.4 Groundwater monitoring

A groundwater monitoring program should be established and the results regularly assessed to detect any pollution of groundwater by leachate.

Groundwater monitoring network

The design, number and location of groundwater monitoring wells should be sufficient to enable the detection of any pollution of soil and groundwater by the landfill by means of regular representative sampling of groundwater from the network. The network should be maintained and repaired as necessary.

The requirements for establishing a groundwater monitoring network include the following:

- The number and distribution of groundwater wells in the network will depend on a hydrogeological risk assessment of the site and surrounding groundwater regime. This investigation should be done as part of the environmental assessment for new landfills and major extensions to existing landfills. Relevant factors include the size of the landfill, type and depth of waste, groundwater and geological characteristics, historical use of the site, and proximity of sensitive receptors (e.g. sensitive wetlands, users of groundwater).
- There should be enough wells to establish the background or hydraulically up-gradient groundwater quality at the site and to establish the hydraulic characteristics of each aquifer (e.g. hydraulic gradients, groundwater flow rates and pathways). When it is not possible to locate hydraulically up-gradient wells, samples should be taken before landfilling at down-gradient compliance-point wells to establish background groundwater characteristics.
- The slotted or screened sections of the wells should align with the aquifer characteristics identified during the site investigation. If only one thin aquifer (less than 5 metres thick) is identified, single fully-slotted wells are sufficient. If there are multiple aquifers or an aquifer greater than 5 metres thick, the monitoring wells should be a nest of wells slotted over different intervals, a multi-port well, or an appropriate combination of both. Wells that monitor different aquifers should be as close to one another as practicable so that comparisons can be made.

  If the waste mass is above the groundwater level, the screened section of the well should extend through the upper 5 to 10 metres of the saturated aquifer, or into at least the first water-bearing zone in the case of fractured aquifers.

  If the waste mass extends below the groundwater level, the screened section of the well should monitor a profile from at least 5 to 10 metres below the base of the waste to the top of the aquifer or the waste mass.

  Groundwater monitoring wells should be designed, constructed and maintained in accordance with Minimum Construction Requirements For Water Bores In Australia, Third Edition 2012 (National Uniform Drillers Licensing Committee, 2012), or equivalent recognised guidelines. In summary, each well should have minimum internal diameter of 50 millimetres, be made of suitable strength pipe materials, have gravel-packed slotted sections comprising material that will not affect the sample's accuracy, have cement or bentonite seals between the slotted sections, be sealed and secured at ground level, and be constructed to prevent entry of surface water and other material.
- In some cases, when there is no evidence of groundwater, suction lysimeters should be installed to monitor the unsaturated zone beneath the landfill and at suitable locations surrounding the landfill liner. A suction lysimeter is used to extract pore water when groundwater is absent. It will indicate the presence and character of any leachate in the geological formation. The need for use of this technique will depend on hydrogeological risk assessment and the locations of any sensitive receptors.

- The groundwater monitoring wells should be adequately maintained and, where necessary, repaired or decommissioned in accordance with the procedures in Minimum Construction Requirements for Water Bores in Australia, Third Edition 2012 (National Uniform Drillers Licensing Committee, 2012). The performance of the wells can be affected by the deposition of clay or silt particles, chemical precipitates and/or bacterial deposits, which can accumulate in the well and block the screen. The monitoring program should include measurement and recording of well depth to monitor solids accumulation, as well as monitoring of any changes to well yield over time.

  Any remedial measures required will depend on the likely cause of the clogging. Typical measures include pumping, surging or air lifting. Disinfectants may be used for bacterial control, acids for removal of chemical precipitates, and dispersing agents to remove clay build-up. Specialty cleaning compounds are available for these purposes.

- There should be adequate documentation of the groundwater monitoring network, including the location, depth and screened sections of all wells in the network. Drilling and construction of groundwater monitoring installations should be included in the Construction Quality Assurance program for the site: see section 11.

Groundwater sampling and analysis

Sampling and analysis methodologies must ensure that the data obtained is representative of the groundwater quality.

The groundwater monitoring program should address the following requirements:

- Sampling should be in accordance with recognised published guidelines such as Groundwater Sampling Guidelines (EPA Victoria, 2000), Handbook Ground Water Volume II: Methodology (United States Environmental Protection Agency, July 1991), and Guidance on Monitoring of Landfill Leachate, Groundwater and Surface Water (UK Environment Agency, 2003).
- Measurements should be taken to establish the standing water level with an accuracy of ±5 millimetres. Groundwater level measurements are essential to determine the groundwater flow regime.
- The sampling technique should ensure that the samples are representative of the groundwater chemistry being investigated. In the traditional approach, wells should be purged before sampling to remove stagnant water that has remained in the well between monitoring rounds. This water may be unrepresentative. There are several approaches to purging, such as bailing and purging three fixed well volumes and/or low-flow pumping until field parameters are stabilised. (Relevant parameters include pH, electrical conductivity and temperature.) Evidence of stabilisation would be when three successive readings of stability parameters, taken several minutes apart, either agree or vary by only a small percentage. Note that if volatile organics are an issue, the flow rate needs to be reduced to reduce the loss of volatile components.
- Another option is passive sampling, in which the sampling device is installed within the well and it is assumed that the sample can be collected without the water mixing with the stagnant water. Samples are obtained without disturbing the stagnant water, and no purging is required. Such passive methods must be demonstrated to give results similar to those of traditional sampling involving purging.
- Whichever sampling approach is adopted, it must be applied consistently across the site and over time. If the method is changed, there should be a cross-over investigation to demonstrate equivalent results.
- For most analytes, the samples should not generally be field-filtered to remove suspended solids. Filtration can affect the representativeness of the data obtained. Ideally, the purging and sampling techniques should prevent the introduction of

particulates into the sample so that there is no need to filter it. Where excessive turbidity cannot be avoided, filtration should be done in accordance with recognised guidelines such as those cited above.

Note that the bioavailability, mobility and toxicity of metals are generally greater in the dissolved state. Use of total, unfiltered concentrations in metals analysis is therefore a conservative risk assessment approach to groundwater assessments (see ANZECC 2000, section 3.4.3).

Whichever approach to filtration is taken, details should be reported with the analytical data.

- Groundwater monitoring wells should be sampled by a suitably trained person.
- Monitoring frequency should be quarterly or as otherwise specified in the environment protection licence. The frequency may be relaxed if justified by data assessment; for example, where a landfill cell has been capped and revegetated for at least 5 years and the data show statistically constant low leachate pollutant concentrations after they have been collected for at least 5 consecutive years.
- Table 5 lists suggested indicator parameters for a groundwater monitoring program. The program may be varied depending on the risk profile of the site and the particular composition of deposited wastes. The need to consider specific metals and organic contaminants may be suggested by the special character of the waste landfilled at the site; for example, restricted solid waste cells and mono cells containing soils with known contaminants.

Table 5: Indicator parameters for groundwater monitoring

Pollutant	Unit of measure	Frequency	Sampling method
pH, redox potential and temperature		Quarterly	Probe, field analysis
Standing water level	m AHD	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, zinc)	mg/L	Annually	Grab sample
Organic contaminants: • phenols • petroleum hydrocarbons • monoaromatic hydrocarbons (in particular benzene, toluene, ethylbenzene and xylene) • organochlorine and organophosphate pesticides • polycyclic aromatic hydrocarbons.	mg/L	Annually	Grab sample

Note: AHD = Australian Height Datum.

Reporting and assessment of groundwater monitoring results

Groundwater monitoring data must be regularly assessed for trends in contaminant levels and any impacts on groundwater quality.

A groundwater assessment report should be prepared at least once every 5 years or if the groundwater monitoring program detects a possible failure of the leachate containment system. The assessment should be conducted by an appropriately qualified and experienced expert in groundwater contamination assessment. This report should include the following:

- **Description of groundwater monitoring network.** The report should describe the groundwater network, including:
    - well locations and well distance from the waste and the site boundary
    - well depths
    - geological strata encountered
    - groundwater levels
    - the location of the slotted/screened intervals (relative to the waste depth, leachate levels and groundwater levels).

  Supporting diagrams should be included in the report.
- **Background groundwater quality.** The report should outline the background or baseline groundwater quality at the site, as indicated by the results for up-gradient or unimpacted wells and by any historical data for the site. At least 1 year of baseline monitoring data should be obtained.
- **Hydrogeology.** The report should identify the groundwater level behaviour, the groundwater flow regime, the inferred direction of groundwater flow, the hydraulic conductivity of the strata, the potential for leachate migration, potential contaminant pathways, attenuation mechanisms, and predicted time frames for any future contaminant transport processes.
- **Receptors.** The report should identify all potential receptor environments and users of the groundwater. Sensitive environments include groundwater that is used for drinking and stock watering, and sensitive wetlands and water bodies into which the groundwater discharges. The NSW Office of Water should be consulted on the sensitivity of groundwater use in the area.
- **Quality control.** The report should confirm that the appropriate quality control procedures were applied to the sampling and analysis program.
- **Assessment criteria.** The report should contain assessment criteria and trigger values for evaluating the monitoring results. These criteria should be derived having regard to:
    - the background or baseline groundwater quality at the site
    - typical values of the analytes in unimpacted water in similar hydrogeological settings in the locality
    - recommended limit, trigger and investigation values in recognised water quality guidelines.

  Useful indicator parameters for landfill leachate from municipal solid waste typically include ammonia, total dissolved solids, potassium and total organic carbon. Other indicators may be chosen for specific sites with wastes of known chemical contamination.

  For further details on a wide range of analytes, see the National Environment Protection (Assessment of Site Contamination) Measure (National Environment Protection Council, 1999), Schedule B1, Table 1C Groundwater Investigation Levels. This table summarises trigger values from ANZECC 2000, Chapter 3: Aquatic ecosystems, and limits in the National Water Quality Management Strategy's Australian Drinking Water Guidelines (National Health and Medical Research Council and the Natural Resource Management Ministerial Council, 2011, updated 2014).

- **Assessment of the data.** The report should identify any elevated levels or upward trends in analyte values that may indicate leachate pollution of the groundwater. Basic trend analysis tools such as time series plots for key indicator parameters can help with the assessment. These plots provide a graphical display of changes in concentrations of the analytes in each well over time. In many cases, additional statistical tools and tests should be used to assess the data, particularly at complex sites with multiple pollution sources. For further guidance on these issues see Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance (USEPA, 2009).

  The report should assess the need for further action and should contain recommendations for conducting the ongoing groundwater monitoring program, including the need for any adjustments to the program and/or other response actions.

  Remedial action may be required if leachate pollution of groundwater is detected at the site boundary or 150 metres from the landfill's footprint. This may include the installation of additional wells to further investigate these levels, to ascertain the extent of any off-site migration of pollutants, or to confirm natural attenuation of any plumes.

  In serious cases, active management of the groundwater pollution may be required. Measures include additional source controls (e.g. leachate interception trenches, additional barriers, improvements to final capping), plume containment, groundwater clean-up (pumping and treating affected groundwater), notifications to relevant stakeholders, and restrictions on groundwater use in the affected area.

  For further guidance see Guidelines for the Assessment and Management of Groundwater Contamination (NSW DEC, 2007b).

  Note that under the *Protection of the Environment Operations Act 1997*, the occupier must notify the EPA immediately upon becoming aware of incidents causing or threatening material harm to the environment.

5. Landfill gas management and monitoring

Required outcomes

Landfill gas management practices must be adopted to:

- minimise emissions of untreated landfill gas to air and through sub-surface strata and services
- minimise greenhouse gas emissions (methane, the major bulk component of landfill gas, is 20 to 25 times more potent than carbon dioxide)
- minimise emissions of offensive odour
- minimise the explosive risk to humans from gas build-up in confined spaces
- ensure that, wherever feasible, landfill gas is sustainably utilised for energy recovery
- minimise emissions of air pollutants from the combustion of landfill gas in flaring or electricity-generating equipment.

A landfill gas monitoring program must be established to demonstrate the achievement of these outcomes.

Appropriate response action must be taken if the trigger or limit values specified in these guidelines are exceeded.

The following sections contain acceptable measures for managing and monitoring landfill gas.

5.1 Landfill gas control

Landfill gas control can be achieved by installing infrastructure to contain, collect and treat landfill gas.

The extent of gas controls will depend on a landfill gas risk assessment for the site. A landfill gas risk assessment should be done initially and should then be updated as gas monitoring data is obtained.

The landfill gas risk assessment should address all potential sources, pathways and receptors for landfill gas migration. The source assessment should consider the types of wastes, the size of the landfill, the gas generating potential, monitoring results, gas volumes and flow rates, and odour modelling and surveys. Potential pathways include through the ground, service pipes, basements and atmosphere. All sensitive receptors at on- and off-site locations should be considered—in particular, all buildings within 250 metres of the deposited waste.

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

The system of landfill gas controls should address the following requirements. The actual system will depend on the landfill gas risk assessment in each case. Not all of the following measures will be needed at every site:

- Landfill gas should be contained by installing low-permeability engineered barriers on cell floors and walls and in final capping, as discussed elsewhere in these guidelines (See section 1: Leachate barrier system, and section 9: Final capping and revegetation).
- Landfill gas should be collected by installing a network of wells, drainage layers, pipework, and an extraction system within the waste. Such a system should be installed in all putrescible waste cells and in other cells producing significant quantities of landfill gas.

  The gas extraction system may be an active (forced) or passive gas extraction system. In active extraction systems, gas is removed under vacuum and pumped for energy recovery or treated in a flare. In passive gas drainage systems, gas transfer is caused by atmospheric pressure differentials. The gas may be vented to a microbiological gas treatment system (see section 5.6) or to a passive flare.

  The various treatment options oxidise the methane and destroy non-methane organic compounds in the gas.

  Active systems tend to be used at sites with high gas volumes, whereas passive systems tend to be used at smaller sites. However, a thorough analysis of risks and generation rates should be conducted in every case. Wherever feasible, an active system with energy recovery should be used. Passive venting to atmosphere of untreated gas should be avoided.
- Landfill gas controls should be installed progressively during the life of the landfill and post-closure period. Gas collection, extraction and treatment should start as soon as practicable after the completion of each cell. In some cases this should start while the cell is still receiving waste (e.g. bioreactor cells; see section 2.2). Gas collection efficiency is encouraged by adopting a progressive capping strategy (see section 9.1).
- Landfill gas collection and extraction infrastructure should be designed and installed to withstand the forces created by the weight and settlement of waste in the landfill.
- Gas drainage layers should comprise aggregates consisting of hard, strong, durable and clean gravel with a saturated hydraulic conductivity to water of greater than 1×10^{-4} metres/second and with the particle size, chemical reactivity and shape properties specified for gravel drainage aggregate in section 1.4 of these guidelines. Each layer

should be covered on its upper surface with a separation geotextile to intercept fines. Suitable recycled materials may be used for gas drainage.

- The gas management system should be designed and operated to minimise the ingress of atmospheric gases to the landfill.
- The leachate management system should be operated in such a way that the leachate does not rise to a level that inhibits gas entry to the gas collection system.
- Where there is evidence of gas migration, additional controls (e.g. bentonite or cement slurry barrier walls, or venting trenches) should be constructed between the waste cell and receptors to intercept and collect migrating gas. The potential for lateral gas movement can increase after the landfill is capped, because escape of gas through the surface then becomes more difficult.

5.2 Landfill gas surface emissions monitoring

A surface gas monitoring program should be established to detect any emissions through the cover/capping material and fugitive emissions from any gas extraction system present.

The threshold level for further investigation and corrective action is 500 parts per million (volume/volume) of methane at any point on the landfill surface for intermediate and finally-capped areas.

The landfill gas surface emissions monitoring program should be conducted in the following way:

- Methane should be tested in the atmosphere 5 centimetres above the landfill surface in areas with intermediate or final cover/capping. Testing should be conducted in a grid pattern across the landfill surface at 25-metre spacings. Depressions in the cover material, or surface fissures away from the sampling grid, should also be investigated. The monitoring should be performed on calm days (winds below 10 kilometres/hour) and preferably during periods of relatively low and stable atmospheric pressure (e.g. less than 101.3 kPa).
- Surface gas emissions monitoring should be done on a monthly frequency, or as varied by the EPA on the basis of site assessment or monitoring results indicating that landfill gas does not pose an environmental risk.
- The landfill gas monitoring device should be capable of detecting methane gas in sufficiently low concentrations to ensure confidence in the results. For surface gas monitoring, this level is 20 parts per million. The device should be properly zeroed and calibrated according to the manufacturer’s instructions before any measurements are made. A flame ionisation detector is usually used for this purpose.

If methane is detected at levels above 500 parts per million, investigation and corrective actions can include:

- repair or replacement of the cover material
- flux (emissions) monitoring to quantify emission rates and help identify the extent of gas loss (surface scans give a concentration, not a flow rate)
- installation of sub-surface monitoring wells (if not already installed) to gauge the extent of any lateral migration of gas
- adjustment or installation of landfill gas controls to extract and treat gas.

5.3 Landfill gas sub-surface monitoring

For most putrescible waste landfills and for large and/or high-risk non-putrescible waste landfills, the occupier should establish a sub-surface landfill gas monitoring program to demonstrate that landfill gas is not migrating off-site. The need for, and the extent of, this program should be guided by a landfill gas risk assessment for the site in each case.

The threshold levels for further investigation and corrective action are detection of methane at concentrations above 1% (volume/volume) and carbon dioxide at concentrations of 1.5% (volume/volume) above established natural background levels.

The following is general guidance for the establishment and conduct of a sub-surface gas monitoring program:

- A network of sub-surface gas monitoring wells should be installed around the perimeter of the waste cells (not in or near the waste).
- The design of the network should recognise that gas will generally find the pathway of least resistance. Lateral movement should be less through low-permeability strata such as clay, and potentially greatest through permeable strata dominated by fissures or fractures providing a pathway. High soil moisture content can impede gas migration. Capping will impede vertical (upward) movement and tend to promote lateral movement. Gas can also find a conduit in underground services such as pipes.
- The wells should be spaced at sufficiently small intervals to detect any off-site migration to potential receptors. The required spacing and design of the wells will depend upon a landfill gas risk assessment addressing the source, potential gas migration pathways and potential receptors. Typically, numerous wells are required where there is a large putrescible waste landfill near residential areas. On the other hand, only a few gas wells may be needed for small sites remote from any structure where people may reside or work. For further guidance on well spacing see Guidance on the Management of Landfill Gas (UK Environment Agency, 2004), Table 8.1: Guidance on typical off-site monitoring borehole spacing.
- The wells should be deep enough to cover all potential unsaturated pathways for gas from the waste. The wells should extend to the minimum reported groundwater level, the greatest depth of the waste, or 10 metres below underground utilities or manholes within 50 metres of the landfill.
- If the risk assessment identifies distinct sub-surface layers that may act as conduits for landfill gas, the wells should be either multi-port wells that are able to monitor the distinct layers separately, or separate wells for each distinct layer.
- The wells should have individual slotted probes with bentonite seals between monitoring zones. The monitoring zones should be back-filled with pea gravel to facilitate gas movement. The well should have a seal at the top and a valve to connect to the gas monitoring probe. For further guidance on well construction see Guidance on the Management of Landfill Gas (UK Environment Agency, 2004), section 7: Gas control measures.
- If groundwater monitoring wells are to be used to monitor landfill gas, any gas present must be able to enter the wells. Groundwater wells typically have a short screened section located in the saturated zone only (in an unconfined aquifer). Any gas present may not be able to enter the well and may therefore not be measured. To detect gas migration, the screened interval should be above the saturated zone.
- The well's contents should be sampled and analysed before it is diluted by air.
- The landfill gas monitoring device should be capable of detecting methane gas in sufficiently low concentrations to ensure confidence in the results. The device should be

properly zeroed and calibrated according to the manufacturer's instructions before any measurements are made. Instruments are available that can detect methane, carbon dioxide, oxygen, carbon monoxide and hydrogen sulfide. In addition to methane monitoring, carbon dioxide monitoring is recommended to help identify potential gas flow pathways from the waste (under some conditions, some of the methane generated can be oxidised to carbon dioxide).

- Monitoring should be conducted at a quarterly frequency or some other frequency justified by a site-specific landfill gas risk assessment. The frequency should be revised as required on the basis of the results and changing site characteristics. For example, if methane is not detected in the perimeter wells after a sufficient period the frequency of monitoring may be reduced. Monitoring frequency may need to be increased if new receptors are introduced adjacent to the site (e.g. housing developments). In new cells, to establish a baseline, monitoring should begin before filling starts.

If methane is detected at concentrations above 1% (volume/volume), the occupier must notify the EPA promptly. Within 14 days of this notification, the occupier must submit a plan to the EPA for further investigation and/or remediation of the elevated gas levels. Depending on the circumstances, this plan may include one or more of the following measures:

- an increase in monitoring frequency and/or the installation of additional monitoring wells
- volumetric/gas flow determinations to assess the significance of gas generation rates and the potential scale of off-site gas migration
- gas accumulation monitoring in enclosed structures located nearby
- a revised landfill gas risk assessment, addressing the source, potential gas migration pathways and potential receptors
- notifications to potentially affected persons
- installation of landfill gas controls at the source and/or receptors.

5.4 Gas accumulation monitoring in enclosed structures

A landfill gas accumulation monitoring program should be implemented to demonstrate that gas is not accumulating at dangerous levels in enclosed spaces on or near the landfill.

Landfill gas is primarily made up of methane and carbon dioxide and must not accumulate in buildings. Methane is explosive in the range of 5% to 15% (volume/volume), and landfill gas can be an asphyxiant in enclosed spaces.

The threshold level for further investigation and corrective action is detection of methane at concentrations above 1% (volume/volume).

The gas accumulation monitoring program should consist of monthly methane monitoring in all buildings and other enclosed structures within 250 metres of deposited waste or leachate storage, or at frequencies and locations justified by a site-specific landfill gas risk assessment that is regularly reviewed and updated.

If methane is detected at concentrations above 1% (volume/volume), the occupier must notify the EPA within 24 h. Within 14 days of this notification, the occupier must submit a plan to the EPA for further investigation and/or remediation of the elevated gas levels. Depending on the circumstances, this plan may include:

- daily testing of the building or enclosed structure until ventilation or other measures have been put in place to eliminate the methane build-up
- installation or adjustment of source and receptor landfill gas controls (see sections 5.1 and 5.7)

- further sub-surface monitoring to delineate any potential migration of landfill gas (see section 5.3).

The landfill gas monitoring device should be capable of detecting methane gas in sufficiently low concentrations to ensure confidence in the results. The device should be properly zeroed and calibrated according to the manufacturer's instructions before any measurements are made.

5.5 Emissions from combustion of landfill gas

Extracted landfill gas should be used for energy recovery (electricity generation) or should be treated by flaring.

The key air pollutants of concern from the combustion of landfill gas include oxides of nitrogen and sulfur, and uncombusted volatile organic compounds.

The design and operation of landfill gas combustion plants must address the following requirements:

- Flares for treating landfill gas must be enclosed and at ground level. They must meet the operating requirements in the *Protection of the Environment Operations (Clean Air) Regulation 2010*, namely gas residence time >0.6 seconds, combustion temperature >760°C, destruction efficiency >98%, and flame present at all times while air impurities are required to be treated. Regular monitoring is required of temperature (in °C) and volumetric flow rate (in cubic metres/second).

Emissions from any internal reciprocating combustion engine fuelled on landfill gas must not exceed the concentration limits in the *Protection of the Environment Operations (Clean Air) Regulation 2010* (see Table 6).

Table 6: Gas treatment discharge limits

Pollutant[1]	**Standard of concentration (mg/m^3)[2]**
Hydrogen sulfide (H_2S)	5
Nitrogen dioxide (NO_2) or nitric oxide (NO) or both, as NO_2 equivalent	450 (internal reciprocating combustion engine), 350 (flare)
Sulfuric acid mist (H_2SO_4) or sulfur trioxide (SO_3) or both, as SO_3 equivalent	100
Volatile organic compounds as n-propane equivalent	40

Notes: 1. A complete list of standards of concentration for scheduled premises in NSW is provided in the Protection of the Environment Operations (Clean Air) Regulation 2010 (www.legislation.nsw.gov.au).
2. Reference conditions are: dry, 273.2K, 101.3 kPa, 3% O_2.

- For any proposed energy recovery facility, an air quality impact assessment should be conducted. This assessment should demonstrate that emissions from the facility will not cause exceedances of the EPA's ground level concentration impact assessment criteria. These criteria are specified in Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW DEC, 2005) and are reproduced in Table 7. A dispersion modelling study should be done to predict the ground level concentrations of pollutants for comparison with the impact assessment criteria.
- The discharge point(s) from any landfill gas combustion source should be designed to promote good dispersion (i.e. by means of such factors as stack height, diameter and discharge velocity) and ensure that the ground level concentration criteria are not exceeded. Further information about the design of discharge points can be obtained from Local Government Air Quality Toolkit, Module 3: Guidelines for Managing Air

Pollution, Part 1: Air pollution control techniques (chapter 3): www.epa.nsw.gov.au/air/lgaqt.htm (NSW DECC, 2007).

- Any liquid condensed from the landfill gas should be handled in the same manner as leachate. Because of the low pH and the potential odour it should not be spray-irrigated.
- In energy recovery facilities, the landfill gas supply line and gas engine exhausts should be regularly monitored for dry gas density (milligrams/cubic metre), moisture content (%), molecular weight of stack gases (grams per gram mole), oxygen content (%), temperature (degrees Celsius), volumetric flow rate (cubic metres/second), velocity (metres/second), carbon dioxide (%), volatile organic compounds (mg/m^3) and (in the exhausts only) nitrogen oxides (milligrams/cubic metre), sulfuric acid mist and sulfur trioxide (as SO_3) (milligrams/cubic metre), carbon monoxide (milligrams/cubic metre), sulfur dioxide (milligrams/cubic metre) and hydrogen sulfide (milligrams/cubic metre).
- Air pollutants should be sampled and analysed in accordance with the methods specified in the EPA's Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales (NSW DEC, 2007a) at www.environment.nsw.gov.au/resources/air/07001amsaap.pdf.

Table 7: Ground-level concentration criteria

Pollutant[1]	**Design ground-level concentration criteria ($\mu g/m^3$)**	**Averaging time**
Hydrogen sulfide[2]	1.38 for populations > 2000 2.07 for populations ~ 500 2.76 for populations ~ 125 3.45 for populations ~ 30 4.14 for populations ~ 10 4.83 for single residence	Nose-response time average
Nitrogen dioxide	246 62	1 h Annual
Sulfur dioxide	712 570 228 60	10 min 1 h 24 h Annual
Sulfuric acid	18	1 h

Notes: 1. For a complete list of the EPA's air quality impact assessment criteria refer to the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW.

2. The hydrogen sulfide ground level concentration criteria must be applied at the nearest existing or likely future off-site sensitive receptor.

5.6 Microbiological gas treatment systems

Microbiological treatment is an alternative to thermal oxidation in some situations.

In these systems, the gas is passed through a biofilter, biocover or biowindow containing a material that can biologically oxidise the methane in the gas to carbon dioxide. If these systems are properly designed and constructed, the rate of methane oxidation can be much greater than the limited level of microbial methane oxidation that occurs naturally in typical landfill cover soils.

Suitable sites for such systems include sites with low or declining gas volumes (generation rates typically less than 100 cubic metres/hour) where a thermal oxidation system is not feasible or has ceased to be feasible. They can be used as part of the final capping profile, and/or as temporary gas controls to aid intermediate covering.

Microbiological treatment systems can also be used at sites with higher gas generation rates in parallel with conventional gas extraction and thermal treatment systems to treat residual emissions from those systems.

Proposals to use microbiological gas treatment should be prepared in accordance with *Handbook for the Design, Construction, Operation, Monitoring and Maintenance of a Passive Landfill Gas Drainage and Biofiltration System* (NSW DECCW, 2010), available at www.epa.nsw.gov.au/resources/warr/10141Biofiltration.pdf. Proposals should address the following requirements:

Types of microbiological gas systems

The design of the proposed system must be compatible with the approved landfill final capping for the site and with the requirements for final capping contained in these guidelines.

The three main types of systems are:

- biofilters
- biocovers
- biowindows.

Biofilters are small, fixed-bed filters constructed within the final landfill capping. They contain a layer of methane oxidation material (usually a compost). A layer of aggregate material should be installed below the biofilter media to facilitate gas distribution over the full surface area of the filter and to facilitate drainage of excess water from the biofilter media.

Biofilters must be connected to a gas collection system to route gas to the biofilter. The gas drainage system should incorporate a way of monitoring the composition and flow rate of gas to the filter; this is needed to assess the effectiveness of the biofilter in reducing methane flux.

The design should assess whether incorporating a biofilter in the final capping may lead to a significant increase in rainfall infiltration and leachate generation rates at the site. Rainfall infiltration can be minimised by measures such as placing a roof over the biofilter or otherwise covering it.

Following installation of a biofilter, the final capping should be reconstructed as previously approved, or otherwise in accordance with the EPA's requirements.

Biocovers are laid over the entire waste surface and typically consist of a methane oxidation layer (usually a compost) 0.8 to 1.5 metres thick, under which is a gas distribution layer 0.3 to 0.5 metres thick and comprising coarse material such as gravel.

A biocover is composed of relatively permeable material and is not an alternative to a low-permeability final cap (see section 9 of these guidelines). If a biocover is used in final capping, it should be underlain by a low permeability barrier layer and there should be a means of routing gas by pipework through the barrier layer and into the biocover.

Because of this difficulty, biocovers for gas control may be better suited for use in intermediate covering situations rather than in final capping.

Biowindows are hybrids of the above two approaches. They are small areas of methane oxidation material constructed at discrete locations within the final cap through which landfill gas is passively vented. They differ from biocovers in that they do not cover the entire waste surface. They differ from biofilters in that they are not in a support structure and they are not connected to a gas drainage system.

Methane oxidation material

The methane oxidation material should comprise a mature, well-decomposed compost that can sustain the growth of methanotrophic bacteria and promote a level of methane oxidation substantially higher than can be achieved by conventional landfill cover soils. The methanotrophic bacteria use oxygen to convert the methane to energy, carbon dioxide, water and cell material.

The material should meet the requirements in section 6.5 of Handbook for the Design, Construction, Operation, Monitoring and Maintenance of a Passive Landfill Gas Drainage and Biofiltration System (NSW DECC, 2010). The compost must be free of foreign materials.

Performance and monitoring

All surfaces above the landfill must meet the general requirements in section 5.2 of these guidelines for surface concentrations of methane.

Data must also be obtained on the performance of the microbiological treatment system in destroying methane. The performance of biofilters or biocovers is usually measured by the percentage of methane oxidised.

In the case of biofilters, 90% oxidation may be achievable, depending on the design. As the landfill gas loading rate increases, the percentage methane oxidation decreases for a given sized biofilter.

The performance of a biofiltration system should be regularly monitored to obtain data to demonstrate the effectiveness of the technique in oxidising methane in landfill gas. At a minimum, quarterly monitoring should be done for:

- composition and flow of landfill gas from the passive drainage system to the biofilter, including the landfill gas loading rate in litres/square metres/hour and the methane loading rate in grams/square metres/hour
- emissions/flux from the surface of the biofilter (methane and carbon dioxide)
- methane oxidation achieved as a percentage of the methane loading of the biofilter
- the moisture content of the upper layers of the material and the depth of the drainage water in the bottom layers (including the gas distribution layer).

Regular visual inspections should be made to assess the condition, moisture content and degree of settlement of the biofilter media. In arid climates, the biofilter media may readily dry out.

Additional monitoring may be required whenever the results of monitoring and visual inspections indicate a failure to meet design goals or a deterioration in the condition of the methane oxidation material. This may include full-profile monitoring of the layer and sampling and analysis of the material (e.g. microbiological analysis and examination of the material for evidence of clogging).

Biocover proposals should include monitoring programs addressing the same parameters as biofilter monitoring. However, monitoring the effectiveness of a biocover layer is more complex than monitoring a biofilter because of the variability of fluxes over a wide surface area and because there is no dedicated incoming gas collection line in which to conduct inflow monitoring. Therefore, the monitoring program may need to include monitoring to establish reference influx values (e.g. by flux measurements on adjacent control areas before biocover application).

Microbiological treatment systems must be appropriately maintained. This is likely to include periodic adjustment of moisture content and reworking or replacement of the methane oxidation material, as required by the results of the monitoring program.

5.7 Gas control measures at the receptor

Gas control measures at the receptor must sometimes be considered if gas migration has reached, or may reach, buildings near the landfill.

Migrating gas can accumulate in enclosed spaces in nearby buildings, basements, manholes, tunnels and service ducts. Any buildings built within 250 metres of deposited waste must be designed not to accumulate landfill gas.

Several options are available for gas control at the receptor (not all of these measures are possible when trying to retrofit an existing structure):

- removal of the gas-generating source (if practicable and the volumes are small)
- gas-proof membranes beneath the building or enclosed space, and around underground services such as stormwater and sewer pipes, which can act as conduits for gas
- venting systems beneath the building or other void space, passive or fan-assisted
- vertical barriers to control gas migration from the source or to prevent migration to the receptor site
- vertical venting trenches and wells, with passive or active extraction and venting to atmosphere
- sub-slab depressurisation systems (using fans or blowers) with venting to atmosphere
- building and sub-slab over-pressurisation systems to stop gas migrating into the building
- monitoring systems and alarms
- safe work procedures to manage risks that may be present in confined spaces such as manholes, tunnels and service ducts.

6. Amenity issues: odour, dust, noise, litter and fire control

Required outcomes

The landfill must not adversely affect amenity in the locality, in particular:

- offensive odour impacts must not occur at off-site locations
- emission of nuisance dust and other particulate matter beyond the landfill boundaries must be minimised
- excessive noise must not be generated by activities at the site
- local amenity must not be degraded by litter from the landfill or by mud or litter attached to vehicles leaving the landfill
- the risk of fire at the site must be minimised and the site must be adequately prepared in the event of fire.

The following sections contain acceptable measures for controlling amenity impacts.

6.1 Odour control

Offensive odour impacts at off-site locations can be minimised by a combination of upfront planning and operating practices.

Odour impact assessment for new landfills

Proposals for new landfills or expansions of existing landfills should be supported by an odour impact assessment. This should demonstrate that the proposal is unlikely to result in adverse air quality impacts.

The assessment should be prepared in accordance with the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW DEC, 2005) and Assessment and Management of Odour from Stationary Sources in New South Wales: Technical Framework and Technical Notes (NSW DEC, 2006b).

The assessment should demonstrate that predicted off-site odours from the new or expanded landfill will not exceed the impact assessment criteria given in the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW DEC, 2005). These criteria range from 2 odour units (99th percentile for Level 2 assessments) for schools, hospitals and urban areas with populations of 2000 or greater, up to 7 odour units (99th percentile for Level 2 assessments) for a single rural residence. The criteria should be applied at the nearest existing or likely future off-site sensitive receptor.

The emission rates to be entered into the model may be obtained from emission factors in the literature or from direct measurement. For an existing site, emission rates measured from existing operations may be used in the modelling. Such source sampling and analysis should be done in accordance with methods for sampling using an emission isolation flux chamber and analysis by dynamic olfactometry, as specified in Approved Methods for the Sampling and Analysis of Air Pollutants in NSW (NSW DEC, 2007a).

The most odorous sources at a landfill typically include the active tipping face, the leachate sump and riser, and leachate storage and treatment facilities.

During the planning stage of projects, applicants should consider the use of sufficient distance between the landfill and sensitive receptors (such as residential zones) to minimise the requirement for other more stringent odour controls.

Operating practices for odour control

To minimise the emission of offensive odour, the occupier should:

- Apply daily and intermediate cover to the waste in accordance with the requirements of section 8: Covering of waste.
- Keep the active tipping face as small as practicable. Ideally, the area of the tipping face should be no more than 600 square metres (i.e. 30 x 20 metres) where health and safety considerations allow: see Landfill Operational Guidelines, 2nd Edition (ISWA Working Group on Landfill, 2010), p. 68.
- Attend to the delivery of highly biodegradable and odorous wastes. The occupier should require such wastes to be delivered in a covered, enclosed or treated form and should ensure that they are immediately buried with adequate cover.
- Adopt the techniques for landfill gas management outlined in section 5 of these guidelines.
- Control odour from leachate sources by
    - using air tight fittings on leachate risers and pipework
    - treating leachate stored in ponds (e.g. by mechanical aeration)

  - reducing leachate seeps from the landfill
  - (if relevant) stopping leachate reinjection into the waste if it interferes with the gas management system and leads to odour problems.
- Modify activities appropriately when the wind is blowing towards sensitive receptors.

Handling odour complaints

The occupier should have a system in place for dealing with odour complaints and other odour-related issues. When an odour complaint is received, the following details should be recorded and maintained, at a minimum:

- date and time of complaint
- contact details of the complainant
- nature of the complaint, including odour characteristics, perceived duration and frequency, and perceived source or conditions giving rise to the complaint
- activities happening at the time of the complaint
- weather conditions (i.e. wind, rainfall, temperature) at time of complaint
- names of staff on duty
- action taken to investigate and resolve the complaint, including any remedial control measures to reduce odour emissions. At landfills receiving many odour complaints over a significant period of time, the investigation should include measurement of surface emission rates by using the methods in Approved Methods for the Sampling and Analysis of Air Pollutants in NSW (NSW DEC, 2007a). This data should be compared with the emission factors used in the initial impact assessment modelling and with any published emission rates for the type and location of the landfill.

In addition to these reactive measures, the occupier should implement a program of regular field odour surveys around the site boundary. These surveys should be undertaken during worst-case weather conditions—for example, in the morning during calm conditions (when there is poor dispersion), in the middle of a hot day, and when prevailing winds are blowing in the direction of sensitive receptors.

Personnel conducting field odour surveys should be trained and calibrated for odour assessment in accordance with the requirements for olfactory testing in Australian Standard AS 4323.3:2001 Stationary Source Emissions – Determination of odour concentration by dynamic olfactometry (Standards Australia, 2001).

To help manage odour complaints and to obtain data for updating the odour dispersion modelling, new or expanded landfills should have meteorological equipment sited and operated in accordance with the requirements in Australian Standard AS 3580.14-2011 Methods for Sampling and Analysis of Ambient Air – Part 14: Meteorological monitoring for ambient air quality monitoring applications (Standards Australia, 2011).

6.2 Dust control

Emission of nuisance dust and other particulate matter beyond the landfill boundaries can be minimised by a combination of upfront planning and operating practices.

Air quality impact assessment for new landfills

Proposals for new landfills or expansions of existing landfills should be supported by an air quality impact assessment. This should demonstrate that the proposal is unlikely to result in adverse air quality impacts.

The assessment should be prepared in accordance with the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW DEC, 2005).

The assessment should demonstrate that cumulative off-site levels of deposited dust, particulate matter as PM_{10}, and total suspended particulates will comply with the impact assessment criteria given in Table 7.1 of Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales. These criteria are:

- deposited dust: a maximum increase in deposited dust level of 2 grams/square metre/month, and a maximum total deposited dust level of 4 grams/square metre/month
- PM_{10} : 30 micrograms/cubic metre for an annual averaging period, and 50 micrograms/cubic metre for a 24-hour averaging period
- total suspended particulates: 90 micrograms/cubic metre for an annual averaging period.

The criteria should be applied at the nearest existing or likely future off-site sensitive receptor.

Operating practices for dust control

To minimise the emission of dust from the landfill, the occupier should:

- minimise the area of exposed soils
- stabilise exposed areas (e.g. through revegetation) and stockpiles of dusty materials as soon as practicable
- revegetate completed areas as soon as practicable
- use sealed or gravel roads, particularly from the public roadway to the gatehouse or waste reception section of the landfill
- reduce drop heights, where applicable
- spray water for dust suppression, particularly over exposed surfaces, at key material transfer points, and on unsealed haul roads to minimise wheel-generated dust
- appropriately modify excavation works and operations on dry, windy days or when the wind is blowing towards sensitive receptors
- enforce speed limits to minimise wheel-generated dust
- cover loads of dusty material transported by road in open-topped trucks
- minimise dirt tracked from the site to external roads; measures include visual inspection of trucks leaving the site, use of wheel-wash and shaker grids, and construction of sealed haul roads
- install wind barriers and enclosures (where practicable) to deflect wind from erodible areas and to minimise exposure of falling dusty materials to winds.

Dust sampling and measurement

The impact assessment criteria given above for dust deposition and suspended particulates are not typically used as limit conditions in landfill licences. However, in some cases, ambient particle monitoring at off-site receptors should be undertaken as part of a reactive dust management strategy.

Monitoring methods can include the use of dust deposition gauges, high-volume air samplers, beta attenuation monitors, and tapered element oscillating microbalance. These should be established and operated in accordance with the requirements in Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales (NSW DEC, 2007a).

All monitoring locations should conform to the requirements of Australian Standard AS 3580.1.1:2007 Methods for Sampling and Analysis of Ambient Air – Guide to siting air monitoring equipment (Standards Australia, 2007a) subject to site constraints.

6.3 Noise control

Noise levels at sensitive receptors can be minimised by a combination of upfront planning and operating practices.

Noise impact assessment for new landfills

Proposals for new landfills or expansions of existing landfills should be supported by a noise impact assessment. The proponent should consider the potential for operational noise impacts, road noise impacts and vibration impacts from the landfill.

The noise impact assessment should be prepared in accordance with the following EPA guidelines: the NSW Industrial Noise Policy (NSW EPA, 2000), the NSW Road Noise Policy (NSW DECCW, 2011), and Assessing Vibration: A Technical Guide (NSW DEC, 2006a). These can be found at www.epa.nsw.gov.au/noise/index.htm. The assessment should demonstrate that the proposal is unlikely to result in adverse noise and vibration effects in the surrounding community.

(a) Operational noise impact assessment

The proponent should compare the predicted noise levels at the most sensitive receivers with the target noise levels specified in the NSW Industrial Noise Policy (NSW EPA, 2000). This should be done for day, evening and night-time conditions.

Typical noise sources at landfills include:

- trucks and earthmoving machinery
- material dumping and scraping activities
- reversing alarms
- pumps and aerators such as leachate pond equipment, which, unlike other noise sources, may need to be run through the night
- crushing, grinding and separating activities
- sawing, grinding, shredding or mulching activities
- engines and generator modules associated with energy recovery infrastructure.

The proponent should use the methodologies in section 6 of the NSW Industrial Noise Policy (NSW EPA, 2000) to predict the off-site noise that will be produced by these sources.

The target noise levels, called project-specific noise levels, are based on protecting the existing noise character of the neighbourhood. They are the lower of the intrusiveness criterion (the measured background noise level + 5 dB) and the amenity criterion. To determine amenity criteria, the NSW Industrial Noise Policy (NSW EPA, 2000) sets out acceptable ambient noise levels for different types of receivers, such as residences in urban and rural areas and schools and hospitals.

If the predicted noise level exceeds the project-specific noise levels, mitigation measures should be proposed that will enable the project-specific noise levels to be satisfied.

In some instances, noise limits may be specified in environment protection licences. These limits will be based on achievable noise levels predicted by the noise impact assessment. These limits will usually apply only under typical meteorological conditions at the site and not under extreme conditions of wind speed greater than 3 metres/second or strong (G Stability

Class) temperature inversions; see section 5 of the NSW Industrial Noise Policy (NSW EPA, 2000) for more information.

During planning, applicants are encouraged to consider the use of an appropriate separation distance or buffer zone to minimise adverse noise impacts on sensitive receivers.

(b) Road noise impact assessment

The proponent should predict the off-site noise that will be produced by the additional road traffic on the surrounding road network as a result of the landfill development. The proponent should compare the predicted noise levels at the most sensitive receivers with the target noise levels and relative increase criteria specified in the NSW Road Noise Policy (NSW DECCW, 2011) sections 2.3 and 2.4. This should be done for day and night-time conditions.

In some cases, principal haulage routes will be identified whereby heavy vehicles will use local roads. If so, the noise criteria of the haulage route should match that for arterial or sub-arterial roads.

When the predicted noise level exceeds the road noise criteria in the NSW Road Noise Policy (NSW DECCW, 2011), mitigation measures should be proposed that will enable the criteria to be satisfied.

(c) Vibration impact assessment

The proponent should predict the off-site vibration levels that will be produced by operation of the landfill development.

The proponent should compare the predicted continuous and impulsive vibration levels at the most sensitive receivers with the maximum weighted root mean square acceleration values specified in Assessing Vibration: A Technical Guide (NSW DEC, 2006a), Table 2.2.

The proponent should also compare the predicted intermittent vibration levels at the most sensitive receivers with the maximum vibration dose values specified in Assessing Vibration: A Technical Guide (NSW DEC, 2006a), Table 2.4.

All vibration assessments should be done for day and night-time periods.

When the predicted vibration levels exceed the criteria, mitigation measures should be proposed that will enable the criteria to be satisfied.

Examples of sources of continuous vibration are machinery, continuous construction activity, and steady road traffic.

Examples of impulsive vibration are infrequent activities that create up to three distinct vibration events in an assessment period, such as occasional dropping of heavy equipment and occasional loading and unloading.

Intermittent vibration can include interrupted continuous and repeated impulsive vibration sources. Its feature is that it varies significantly in magnitude.

(d) Blasting

Occasionally blasting will be done at the site for the purposes of construction or quarrying. Impacts from blasting include the pressure wave sound (blast overpressure) transmitted through the air (measured as a noise level in decibels) and ground vibration (measured in particle velocity in millimetres/second).

Blasting overpressure and ground vibration should be assessed in accordance with the criteria in Technical Basis for Guidelines to Minimise Annoyance due to Blasting Overpressure and Ground Vibration (Australia and New Zealand Environment Council, 1990): www.epa.nsw.gov.au/resources/noise/ANZECBlasting.pdf.

Noise control measures

To minimise noise the occupier should:

- schedule noisy activities and vehicle movements to minimise noise impacts
- keep equipment well maintained
- use enclosures for noise sources
- silence exhausts
- dampen or line metal trays or bins
- design speed humps and vibration grids in a way that minimises noise generation
- minimise vehicle movements that activate reversing beepers, or adopt an alternative safe system of work that does not use tonal movement alarms
- use noise mounds and barriers to control noise transmission
- design the site to maximise the distance from critical noise sources to the most sensitive receivers
- in serious cases, consider controlling noise at the receiver (e.g. by insulating buildings, double-glazing windows, or acquiring the affected property).

Noise monitoring

To assess performance, noise monitoring should be conducted:

- within 3 months of starting operations
- at the three nearest affected residents every 12 months (as a minimum) over a full, representative 'worst case' working day
- at various discrete stages of the development when different noise outputs were predicted during the assessment process
- in response to complaints.

The methodology to be used is specified in section 11 of the NSW Industrial Noise Policy (NSW EPA, 2000).

6.4 Litter and debris control

Litter control

To minimise litter impacts on local amenity, the occupier should:

- apply daily cover to the waste and continuously compact the waste
- install litter fences and inspect and clear litter from all fencing daily, or as required
- retrieve all litter that leaves the site as soon as practicable
- ensure that sedimentation dams have trash filters to prevent litter being washed or pumped into watercourses.

Cleaning of vehicles

Vehicles using landfills will inadvertently collect mud and litter on their wheels as they go to and from the active face. These materials can adversely affect local amenity and stormwater runoff.

The occupier should provide cleaning equipment for customers to remove mud and litter from vehicles before they leave the site. This may include wheel-washing facilities, hand-held pressure-washing hoses, drive-through immersion bunds and vibration grids.

The occupier should display entry and exit signs advising customers that they are responsible for making sure that remnants of their load or material stuck to the underside of the vehicle or the wheels do not litter public roads. These signs should advise transporters that they can be fined for any litter on public roads.

6.5 Fire prevention

The following fire-prevention and fire-fighting practices should be followed:

- Signs should clearly inform the general public that flammable liquids are not permitted on the site, and there should be an emergency contacts list at the site entrance.
- Stockpiles of approved amounts of combustibles for recycling and composting (such as tyres, wood or vegetation) should be divided into small piles or windrows so that any burning material can be isolated from additional fuel. Tyre stockpiles should not exceed 50 tonnes at any one time and should be located in a clearly defined area away from the tipping face.
- All sealed or contaminated drums should be banned from the landfill unless they are delivered as a specific consignment, the contents of which are clearly identified and suitable for acceptance.
- All fuels or flammable solvents for operational use should be stored in an appropriately ventilated and secure store located on unfilled land. All flammable liquids should be stored within a bund that has a capacity of 110% of the volume of the flammable liquids so that any release of raw or burning fuel will not cause a fire in the filled waste or affect stormwater.
- Flammable solid wastes must not be stockpiled at the premises in excess of the quantity limits imposed on the licence.
- Fire breaks should be constructed and maintained around all filled areas, stockpiles of combustibles, gas extraction equipment and site buildings.
- Fire-fighting equipment should be installed at the site, including at flammable waste storage areas.
- All fire-fighting equipment should be clearly signposted and access to it must be available at all times.
- All fire-fighting equipment should be maintained according to a regular schedule (at a minimum, weekly visual checks for damage and 3-monthly test operation of the equipment).
- Landfill staff should be trained in all of the above fire-prevention and fire-fighting techniques.

7. Waste acceptance and site security procedures

Required outcomes

- Only authorised wastes must be received at the site.
- Any unauthorised wastes delivered to the site must be appropriately managed and disposed of lawfully.
- Statutory record-keeping and reporting requirements must be complied with.

- The premises must be secure, and unauthorised entry must be prevented.

The following are acceptable standards of operation to meet these outcomes (note that some of these requirements are mandatory in NSW under the Protection of the Environment Operations (Waste) Regulation 2014):

- **Signs.** The site entry point should have prominent signs clearly indicating authorised and non-authorised wastes.
- **Inspection of loads.** The occupier should implement a program of inspection and analysis of incoming waste loads. This should include routine tip face observations and a regular program for closer examination of selected loads away from the tip face. This may include sampling and chemical analysis of waste loads. The sampled wastes should not be landfilled until validated.
- **Supervision of tipping face**. The occupier should supervise tipping activities at the tipping face to prevent deposit of non-authorised wastes.
- **Generator documentation.** The occupier should verify that the waste received for disposal has been assessed and classified by the generator or owner of the waste in accordance with the EPA's Waste Classification Guidelines (NSW EPA, 2014). If the landfill has approval for the disposal of restricted solid wastes, or wastes subject to immobilisation approvals, or wastes covered by chemical control orders, the occupier should verify that all such waste has appropriate documentation before it is accepted at the site.
- **Special wastes.** The occupier must make sure that all regulatory requirements relating to the acceptance of special wastes are complied with before disposing of such wastes. The Protection of the Environment Operations (Waste) Regulation 2014 specifies requirements for asbestos waste and clinical waste.
- **Waste tracking.** The occupier must make sure that any requirements of the waste tracking system in NSW are complied with. The types of waste that must be tracked are listed in Schedule 1 of the Protection of the Environment Operations (Waste) Regulation 2014. Information about waste tracking is available from the EPA's website.
- **Record-keeping.** The occupier should keep records of all inspections for at least 6 years.
- **Hazardous waste.** The EPA should be notified if any unauthorised hazardous wastes are found on-site.
- **Staff training.** Staff should be trained to recognise, handle and isolate hazardous or other non-authorised wastes so that decisions can be made about their proper management.
- **Waste storage areas.** The landfill should have designated storage areas with appropriate environmental controls to securely store all non-authorised wastes, or to further assess incoming loads, until they can be lawfully disposed of or treated at another facility.
- **Emergency incident waste.** Emergency incident waste may be temporarily stored at the premises until it has been assessed and classified in accordance with the EPA's Waste Classification Guidelines (NSW EPA, 2014). It should be stored in a separate area of the site, kept separate from other wastes received at the site, and be readily retrievable once the waste classification results have been obtained. The waste must not be landfilled if it is classified as non-authorised waste under the licence.
- **Off-site transfer.** Any waste dispatched from the site must be sent to a facility that is licensed to receive it or is otherwise lawfully able to receive it in accordance with the *Protection of the Environment Operations Act 1997*. If it is trackable waste, the occupier

must comply with the waste-tracking requirements in the Protection of the Environment Operations (Waste) Regulation 2014.

- **Tyres.** Whole tyres present problems in landfills because they cannot be compacted and may move to the surface over time, creating stability problems. Therefore, a tyre should not be disposed of in a landfill unless the tyre:
    - has a diameter of 1.2 metres or more, and/or
    - has been shredded into pieces measuring no more than 250 millimetres in any direction or has had its walls removed, and/or
    - was delivered to the premises as part of a domestic load containing no more than five tyres, with each tyre having a diameter of less than 1.2 metres.
- **Restricted solid waste cells.** Restricted solid waste cells should not receive any general solid waste (putrescible). This is to:
    - avoid undesirable chemical and physical interactions with the putrescible waste and its leachate
    - minimise the quantity of leachate generated
    - minimise the generation of landfill gas, because gas may purge any volatile chemical contaminants from the restricted solid waste
    - preserve the capacity of these more highly engineered and managed landfills
    - make it easier to locate all placements of restricted solid waste for future reference.

  For each incoming load of restricted solid waste, the occupier should keep accurate records of the quantity, composition, source and disposal location at the site. This makes it easier to retrieve the waste in future, if required.
- **Verification of virgin excavated natural material.** If the landfill licence permits the disposal of virgin excavated natural material below the water table without engineered controls, there should be a procedure for virgin excavated natural material verification. It should contain:
    - pre-acceptance validation procedures to collect information about the waste and its origin (such as a description of the waste, site history, and any contaminated site investigations)
    - acceptance verification procedures to confirm these details
    - inspection and audit of deliveries to evaluate the effectiveness of these procedures. Whenever waste that is not virgin excavated natural material is delivered, the occupier should audit all further loads from that source before the waste is accepted, until the results demonstrate that the waste can properly be classified as virgin excavated natural material.
- **Potential acid sulfate soil verification.** If the landfill permits disposal of potential acid sulfate soil below the water table, the occupier should implement the validation and disposal procedures set out in the EPA's Waste Classification Guidelines Part 4: Acid Sulfate Soil (NSW EPA, 2014). In summary, the verification procedures include:
    - soil should meet the definition of virgin excavated natural material (apart from the sulfidic content)
    - soil must be disposed of within 8 hours of receipt
    - soil must be placed at least 2 metres below the lowest historical water table level

  - soil must be kept wet at all times
  - the pH of the leachate should not fall below 6
  - the occupier should obtain and retain documentation about each delivery of potential acid sulfate soil, signed by a certified practising soil scientist
  - the occupier should test each load to confirm it has not turned acidic.

- **Reporting and payment of waste contribution**. Certain licensed landfills must pay a waste contribution to the NSW State Government under section 88 of the *Protection of the Environment Operations Act 1997*. For these sites, Regulations made under the Act prescribe record-keeping, reporting and payment requirements. These requirements include monthly reporting of waste data to the EPA, installation of a weighbridge, and reporting of 6-monthly volumetric surveys documenting how the land has been filled. Rebates of these payments are available for the use of waste in approved operational purposes at the site. To ensure compliance, occupiers must refer to the specific legislative provisions, guidance material, and reporting forms available on the EPA's web site.

  The Regulations require those landfills that are not required to pay the waste contribution to report annually to the EPA about waste types and quantities received.

- **Site security**. All landfills should have a physical barrier around the perimeter of the site (e.g. an 1.8-metre-high wire mesh fence with lockable security gates). For general solid waste landfills in rural areas that receive less than 25,000 tonnes of waste per year, it may be sufficient to install this system around the active tipping area and flammable storage areas only, and to rely on perimeter stock fences around the site boundaries. The site fence should have signs to identify the site, warn off trespassers and advise of an emergency telephone number.

  Unauthorised entry should be prevented to areas used for storage of non-authorised wastes or storage of flammable materials, as well as to all unattended areas of the site.

  At restricted solid waste landfills the security system should also include a video monitoring system.

8. Covering of waste

Required outcomes

- Landfilled waste must be covered regularly during operations with a suitable material to minimise odour, dust, litter, the presence of scavengers and vermin, the risk of fire, rainwater infiltration into the waste (and therefore the amount of leachate generated) and the emission of landfill gas.

The following sections contain acceptable measures for covering waste.

8.1 Daily cover

Daily cover should be applied to the waste each day before the close of business.

The daily cover material should be virgin excavated natural material in the form of soil. A minimum cover depth of 150 millimetres is required.

The main functions of daily cover are to minimise adverse amenity impacts such as odour, dust, litter, the presence of scavengers and vermin, and the risk of fire. It is also desirable that the daily cover material limits rainfall infiltration into the waste (and therefore the amount of leachate generated) and the emission of landfill gas.

At all times, at least 2 weeks' cover material should be available at the landfill. If this material cannot be won on-site, a stockpile of daily cover material should be maintained adjacent to the tip face.

The amount of exposed waste should be kept to a minimum at all times. Additional effort may be required for loads containing large amounts of highly biodegradable wastes, in order to minimise vermin attraction and adverse odour impacts.

To facilitate leachate and gas movement and prevent the creation of perched watertables, the occupier should puncture or remove previously applied cover before further filling, or demonstrate that perched watertables will not form.

8.2 Intermediate cover

Intermediate cover is a more substantial cover than daily cover. It is used to close off a cell that will not receive additional lifts of waste for some time or will not be finally capped for some time.

Any waste-filled areas that have not been landfilled for more than 90 days should have an intermediate soil cover meeting the following requirements:

- the cover layer should be a minimum 300 millimetres layer of virgin excavated natural material in the form of a fine-grained, largely cohesive soil
- soil should have a saturated hydraulic conductivity of less than 1×10^{-5} metres/second
- the cover layer should restrict the rainfall infiltration rate into the waste to 20% of the total rainfall
- the methane concentration in surface gas monitored above the intermediate cover should be less than 500 parts per million.

8.3 Alternative daily cover materials

Occupiers may propose alternative daily cover materials, provided that they can achieve the required outcomes for cover.

Alternatives proposed to date in New South Wales include inert waste materials (e.g. crushed building waste and glass), waste-derived organic materials, and specialty manufactured covers (e.g. plastic sheets, tarps, foams and fabricated metal landfill lids).

Occupiers must obtain the EPA's approval to use an alternative daily cover. The proposal should describe the alternative and provide evidence that it can meet the required outcomes for daily cover.

If it is a waste-derived material, there should be a specification describing the fraction of each component, particle size distribution, and limits for foreign matter. The waste classification of the material should be general solid waste (non-putrescible). The proposal should include a program for monitoring compliance with the specification.

For factory-manufactured alternatives, the proposal should describe the components and the procedures for applying, installing and operating the alternative cover.

In some cases, the EPA may require a trial of the alternative daily cover before approving it for ongoing use. The trial should demonstrate that the alternative daily cover can perform satisfactorily and meet the required outcomes.

The trial should include regular observations of amenity indicators, including levels of odour, dust and litter and the presence of scavengers and vermin. The trial should demonstrate that use of the alternative daily cover does not increase these impacts. Odour monitoring during the trial should include regular observations at the site boundary and at sensitive receptors.

In some cases at high risk sites, the trial should include odour emissions monitoring from the surface of the landfill. Emission rates should be compared with concurrent emission rates from an area of waste that is covered with the standard soil cover.

Ideally the trial should last for several seasons. For some types of waste-derived materials, the degradability of the material may be an issue. For example, organic alternatives can dry out in hot or windy conditions.

Records should be kept during the trial and a report should be prepared on completion. If the trial is satisfactory, the EPA may approve ongoing use of the alternative daily cover.

Alternative daily cover specification: particulate waste materials

Some alternative daily cover materials have been widely used and therefore do not need to be further trialled. An example is the following specification for an alternative daily cover consisting of particulate waste materials mixed with soil:

- The alternative daily cover must consist of crushed concrete and/or crushed bricks and/or crushed clay tiles and/or crushed glass fines from domestic or commercial recycling collections, mixed with soil. The amount of soil in the mixture must be at least 25% (by mass).
- The alternative daily cover material must not contain contaminants at concentrations above those specified for General Solid Waste (Non-putrescible) in Tables 1 and 2 of the Waste Classification Guidelines, Part 1: Classifying Waste (NSW EPA, 2014).
- The alternative daily cover material must not contain asbestos, food waste, animal waste, grease trap waste, biosolids, rubber, plastic, bitumen, asphalt, paper, cloth, paint, wood, other vegetable matter, plaster or metal.
- The maximum permissible dimension of particles is 50 millimetres, and 50% by mass of the material must comprise particles less than 1 millimetre in diameter. Note: To meet these requirements, it is likely that the alternative daily cover will require processing into a fine particle size.
- Rainwater that comes into contact with the alternative daily cover must be managed as landfill leachate.

8.4 Additional covering requirements for special wastes

Specific requirements for landfilling asbestos waste and clinical waste are contained in the Protection of the Environment Operations (Waste) Regulation 2014.

Under the regulation, asbestos waste must be covered with virgin excavated natural material or other material as approved in the environment protection licence. The depths of the required covering are:

- immediate covering with 150 millimetres of cover
- 500 millimetres of cover at the end of each day
- final cover of at least 1000 millimetres (in the case of bonded asbestos waste or asbestos-contaminated soils) or 3000 millimetres (in the case of friable asbestos material).

Ideally, asbestos waste should be buried in a separate, dedicated monocell and covered in accordance with the above requirements. Where this is not practicable and the asbestos waste is deposited in a cell with other wastes, the asbestos deposition area should be as small as possible and located away from areas used by customers bringing in other waste streams.

In all cases, dust generation must be minimised and the occupier must comply with all requirements of the NSW WorkCover Authority.

The Regulation also contains requirements for landfilling clinical and related waste at unlicensed sites. The waste must be buried, or be immediately contained, in a way that prevents the waste from coming into contact with any person or animal.

9. Final capping and revegetation

Required outcomes

All completed landfill cells must be capped and revegetated as soon as practicable after the final delivery of waste to the cell. The final capping must:

- reduce rainwater infiltration into the waste and thus minimise the generation of leachate (infiltration from the base of the final cap should be less than 5% of the annual rainfall)
- stabilise the surface of the completed part of the landfill
- reduce suspended sediment and contaminated runoff
- minimise the escape of untreated landfill gas
- minimise odour emissions, dust, litter, the presence of scavengers and vermin, and the risk of fire
- prepare the site for its future use; this includes protecting people, fauna and flora on or near the site from exposure to pollutants still contained in, or escaping from, the landfill.

During the post-closure period, the occupier must monitor the integrity and performance of the final cap.

The following sections contain acceptable designs and monitoring programs for final capping. Alternatives may be proposed—see section 9.3 for the procedure when proposing an alternative.

9.1 Final capping requirements

The final capping of general and restricted solid waste landfills should comprise, from bottom to top:

- a seal-bearing surface consisting of a properly designed and engineered layer of material at least 300 millimetres thick to support the sealing layer; the material should meet recognised specifications for engineered materials, such as QA Specification 3071: Selected Material for Formation (NSW Roads and Maritime Services, December 2011), as amended from time to time
- a sealing layer, comprising a compacted clay layer at least 600 millimetres thick, with an in situ saturated hydraulic conductivity of less than 1×10^{-9} metres/second
- a revegetation layer at least 1000 millimetres thick and comprising clean soils and vegetation with root systems that will not penetrate into lower layers; the upper 200 millimetres should be a topsoil layer, which can include compost to help with vegetation establishment and growth.

The revegetation layer should promote water removal by evapotranspiration and runoff; protect the sealing layer from desiccation and/or damage; and sustain microbial populations that oxidise a proportion of any methane passing up through the cap.

For all restricted solid waste landfills and for general solid waste (putrescible) landfills receiving more than 20,000 tonnes of waste per year, the sealing layer should include a geomembrane liner over the compacted clay. The geomembrane should meet the specifications in section 1.2. In capping, linear low-density polyethylene may be used instead of high-density polyethylene: it may be better able to withstand the differential settlement and strains experienced by landfill capping materials.

To achieve the required in situ hydraulic conductivity of less than 1 x 10^{-9} metres/second, the clay should have high plasticity and a suitable particle-size distribution, with no particles greater than 50 millimetres in any dimension. Source testing of the material should confirm these properties. A relationship should also be established between the material's density, moisture content and hydraulic conductivity, showing how it can meet the required in situ hydraulic conductivity.

A geosynthetic clay liner may be used as an alternative to compacted clay, provided it is used in composite with a geomembrane. It should meet the specifications in section 1.3 of these guidelines. The cover soils should be chemically compatible with the geosynthetic clay liner to prevent deterioration of the liner's performance as a result of cation exchange.

If required, the final capping should also incorporate the following drainage layers:

- a gas collection layer, installed below the sealing layer, to collect gas and convey it to treatment or to the atmosphere. This layer may be needed if landfill gas is being generated in significant quantities. If the gas is not relieved, it could be diverted laterally and off site by the cap, or it could exert upward pressure and disfigure the geomembrane in the cap.
- an infiltration drainage layer, installed above the sealing layer, to remove infiltrating water and drain it away from the landfill. This layer may be needed if high rainfall and unfavourable climatic conditions are likely to generate high rainfall infiltration rates. Water balance modelling can help determine whether an infiltration drainage layer is required; see section 2.3 of these guidelines. This layer should be included in all caps for restricted solid waste landfills.

The designer should determine whether these additional layers are required.

These drainage layers, if required, should be 300 millimetres thick and should consist of hard, strong, durable and clean gravel with a saturated hydraulic conductivity to water of greater than 1 x 10^{-4} metres/second. They should have the particle size, chemical reactivity and shape properties specified for gravel drainage aggregate in section 1.4 of these guidelines.

If a drainage layer is required, a separation geotextile should be placed over the upper surface to prevent the ingress of fines from overlying soil, which can clog the drainage layer. See section 1.7 of these guidelines for the requirements for separation geotextiles.

If a drainage layer is adjacent to a geomembrane liner, a protection geotextile should be installed to protect the liner from damage. See section 1.6 of these guidelines for the requirements for protection geotextiles.

Geonet drainage geocomposites may be used as alternative drainage materials. See section 1.8 of these guidelines for the requirements for geonet drainage geocomposites.

For final capping installed on steep slopes, the capping elements should be demonstrated to have adequate slope stability. A slope stability analysis should demonstrate that there are adequate factors of safety for all relevant potential failure mechanisms (e.g. veneer and global stability), both at the proposed final landform and at interim stages during construction.

Final capping incorporating geosynthetic elements should be adequately designed to accommodate any penetrations and protrusions (e.g. landfill gas controls and leachate risers).

To facilitate runoff and minimise ponding of water, the cap should have a gradient of greater than 5% to defined drainage points. However, to reduce the risk of erosion, steep caps (greater than 20%) should be avoided.

The final capping should not permit water pooling and should not contain constructed water features such as ornamental lakes or ponds on areas over the waste mass. These features may leak and infiltrate the cap if the pond lining is compromised by differential settlement of the waste and/or desiccation if the pond becomes dry.

A construction quality assurance program should be implemented during construction of the final capping; see section 11 of these guidelines.

Where practicable, final capping should be installed progressively throughout the active landfilling stage of the landfill and should not be left to the post-closure period. The occupier should start capping completed filling areas as soon as practicable after the completion of landfilling.

9.2 Monitoring the cap's integrity and performance

To assess the continued integrity and performance of the final capping, post-closure monitoring should include the following components:

- regular visual inspections for deterioration of the capping's condition, including erosion, cracking, dead or stressed vegetation, ponding, differential settlement, slope instability, and damage to any pipes, drains and other works installed on the final capping
- regular surveys for indications of differential settlement, using appropriate techniques such as topographic surveys and settlement plates
- repair and/or replacement of portions of the final capping found to be damaged
- monitoring of leachate and rainfall volumes
- measurement of landfill gas emissions.

9.3 Justification of alternative capping

Alternatives may be proposed to the designs and specifications in section 9.1. The proposal should address the following requirements:

- The alternative proposal must be able to achieve the required outcomes for final capping and be compatible with achievement of the required outcomes for all other environmental issues.
- The proposal should be prepared by a suitably qualified and experienced person. This person should give an opinion that the alternative design can meet the required outcomes for final capping and is compatible with achievement of all other required outcomes.
- Clear reasons should be given for proposing an alternative in preference to the acceptable measure(s) in these guidelines.
- The proposal must fully describe the properties and predicted performance of the alternative capping. For each alternative capping layer, this includes (but is not limited to) thickness, hydraulic properties, strength, resistance to degradation, long-term behaviour, compatibility with adjoining layers, slope stability (where relevant), and construction methods (including around penetrations and protrusions). Performance predictions should be supported by all necessary test results, calculations and modelling.
- The site's leachate management system must be able to manage leachate volumes at the site. Water balance modelling should be conducted in accordance with section 2.3 of these guidelines.
- Some alternative materials may require minimum depths of cover soils placed over them to reduce mechanical or other damage; this must be addressed in the alternative design.

- In some cases, the EPA may require a peer review of the proposal by a suitably qualified and experienced person. Examples of these situations are when the proposal involves a major departure from the acceptable measure(s) in section 9.1, or when the landfill is located near sensitive receptors.
- If the alternative cap is a phytocap, the proposal must address the requirements in section 9.4.

9.4 Alternative caps: phytocaps

Phytocaps (also called evapotranspiration caps, water balance caps or store-and-release caps) do not use an impermeable sealing or barrier layer to resist water movement. Instead, these caps reduce rainwater percolation into the waste by storage and evapotranspiration processes. Water is stored in a deep soil layer during wetter periods and is removed during hotter, drier periods by evaporation from the soil surface and transpiration by plants in a diverse vegetation community.

The performance of phytocaps depends on the soils, vegetation and climate. These types of caps tend to perform better in arid and semi-arid climates than in humid climates. They are likely to struggle to limit percolation into the waste in climates where rainfall significantly exceeds evaporation and/or in climates where the annual distribution of rainfall is unfavourable to the water removal processes. Therefore, they may be unsuitable in such climates.

Phytocaps use a vegetation community containing deep-rooted species that can draw water from the full depth of the soil storage layer. This contrasts with the typical barrier cap, which uses shallow-rooting species so as not to penetrate the barrier layer. Phytocaps may be able to use locally available soils that do not have the engineering properties required for use in the sealing layer of a conventional barrier cap.

Design of phytocaps

Proposals to use a phytocap should address the following requirements:

- The proposal should be prepared in accordance with recognised guidelines, such as Guidelines for the Assessment, Design, Construction and Maintenance of Phytocaps as Final Covers for Landfills (Waste Management Association of Australia, 2011), or equivalent recognised guidelines. A useful text is Water Balance Covers for Waste Containment: Principles and Practice (Albright et al., 2010).
- The design should include numerical modelling of the anticipated cap performance in limiting rainfall percolation into the waste. The modelling should be conducted by using a recognised and proven unsaturated flow model, for example LEACHM (Leaching Estimation and Chemistry Model) or UNSAT-H (Unsaturated Soil Water and Heat Flow Model), or equivalent recognised models. The modelling should include a sensitivity analysis of critical input variables. The modeller should be experienced in using these water balance models.
- The modelling should demonstrate that the proposed phytocap design will transmit percolation at a rate not more than 5% of average annual rainfall for the locality. The design should also consider likely cap performance during wet years (i.e. 90th percentile wet years) and during the initial vegetation establishment stage.
- The modelling should use site-specific soil, vegetation and climate data. Climate data should be from the closest weather station with at least 50 years of rainfall and evaporation data, if one is available and suitable. The model inputs should be conservatively chosen, using sequences of the wettest years on record to model worst case scenarios.

- In addition to modelling, there should be soil placement and plant establishment trials showing that the proposed capping profile can achieve the performance predicted by the design. If necessary, data from the trials should be used to refine the design and calibrate the modelling.
- The trials should last for at least 3 years from when the vegetation is established to allow data collection during various weather patterns.
- Phytocap proposals will be considered by the EPA only for capping of general solid waste cells (not restricted solid waste). Ideally, the cell to be capped should have basal leachate collection and measurement capability in order to assess ongoing leachate generation rates.
- If landfill gas generation is a significant issue at the landfill, the design must also address landfill gas control in accordance with section 5 of these guidelines.
- The proposal should be prepared by appropriately qualified and experienced persons; this may include input from engineers, soil scientists, botanists and/or ecologists. Information on suitable plant species may also be obtained from native vegetation contractors with experience in selecting species for revegetation projects.
- The construction of phytocaps, like all types of caps, must be quality assured. See Construction Quality Assurance: phytocaps in section 11.1.

Soil selection

The soil profile of a phytocap, including the topsoil, should facilitate plant growth, store moisture during wetter periods, and prevent drainage through to the waste below. The soil specification should be selected in accordance with the following considerations:

- The soil(s) should be well structured and typically loamy in texture; support plant growth; have good water-holding capacity; have low salinity; have moderate to high organic content; and have a low to moderate hydraulic conductivity that will facilitate rainwater infiltration but not permit drainage through the cap (note: soils at the base of the cap may have a low hydraulic conductivity, similar to that of a barrier cap, to limit drainage to the waste).
- Samples of soil from the proposed soil-borrow area(s) should be analysed for the physical and chemical properties specified in Table 5.1 of the Guidelines for the Assessment, Design, Construction and Maintenance of Phytocaps as Final Covers for Landfills (Waste Management Association of Australia, 2011). Testing should be in accordance with methods published by Standards Australia or equivalent methods. This data should be used to characterise the soil, to demonstrate its suitability for use in a phytocap, and to enter in the predictive water balance modelling. Further guidance on soil testing may be obtained from Soil Physical Measurement and Interpretation for Land Evaluation (McKenzie et al., 2002).
- Phytocaps are typically not shallow caps. As a guide, the depth of the cap will typically need to be at least 1.5 metres thick to provide sufficient soil water storage to limit percolation. Adequate storage is particularly important in climates where plant growth is limited for long periods during the year (e.g. in alpine climates). The designer should also consider the rooting depth of plant species. The detailed design should justify the required depth based on the above factors and modelling.
- During construction of the cap, the soil should be placed at a density that does not affect the water storage capacity or impede root establishment and penetration. This density may differ from the target densities typical of barrier cap earthworks. An indicative placement density is 75% to 83% of maximum dry density, as measured by standard compaction. See further the discussion in Section 8.1 of Guidelines for the

Assessment, Design, Construction and Maintenance of Phytocaps as Final Covers for Landfills (Waste Management Association of Australia, 2011).

Vegetation selection

The primary mechanisms for moisture removal from a phytocap are evaporation from the soil surface and transpiration by plants. Therefore, vegetation coverage and sustainability are essential to the performance of a phytocap cover system.

The vegetation should be selected in accordance with the following considerations:

- The vegetation should contain species that will provide rapid and sustainable establishment, stabilise the surface, protect the cap from erosion, sustain high evapotranspiration rates, extend roots into all areas of the cap for moisture removal, ensure growth and coverage through all seasons, survive sub-optimal seasons (such as droughts), and be resilient (able to continue to meet the performance objectives despite extreme weather, fire, weeds, grazing and pests). No one species can meet all these requirements.
- A variety of vegetative species should be planted to make sure the goals for the cap are achieved. A combination of diverse species of grasses, shrubs and trees is usually required to minimise the risks posed by individual species failure and fires. Native species are usually preferable. The species should include both plants with high water use and species that are drought tolerant. In general, the wetter the climate, the greater the required content of plants with high transpiration rates (e.g. large-leafed trees).
- The proposed end-use of the site must be consistent with the vegetation community selected for the phytocap.

Monitoring a phytocap's integrity and performance

To assess the continued integrity and performance of a phytocap, post-closure monitoring should include the following:

- There should be regular inspections and surveys for the same things as specified for the standard barrier capping; see section 9.2.
- There should be a dedicated vegetation assessment program for bare spots, weeds and pests, dry soil and wilted plants, poor establishment, and succession. This program should be in accordance with Table 9.2 Vegetation Monitoring Schedule for Site Owners in the Guidelines for the Assessment, Design, Construction and Maintenance of Phytocaps as Final Covers for Landfills (Waste Management Association of Australia, 2011).
- There should be water flux monitoring to assess the performance of the phytocap in limiting the amount of rainfall that percolates into the waste to become leachate. If the cell does not have effective leachate collection and measurement infrastructure, the occupier should install a means for measuring or estimating percolation (e.g. by using lysimetry, or soil moisture sensors at various depths in the profile).
- A groundwater monitoring program should be implemented in accordance with section 4.4 of these guidelines.
- The observational and monitoring data should be assessed against the performance criteria and design expectations on an annual basis for the first 3 years, and then after 5 and 10 years. The occupier may reduce the observational and monitoring frequencies as evidence accumulates that the vegetation has successfully become established and the cap is performing as designed.

- Remedial action should be taken when the observations and monitoring indicate that the phytocap is not performing as designed. Remedial measures may include:
  - increasing the depth by topdressing
  - incorporating composts or other soil improvers into the topsoil
  - extra irrigation
  - planting additional species
  - controlling weeds and/or pests.

10. Closure

Required outcomes

- The landfill must continue to be non-polluting and not cause environmental harm after site closure.
- The occupier must prepare a closure plan, setting out a program for making sure that the site does not cause environmental harm after closure. The occupier must implement the approved closure plan.

The following sections contain acceptable measures for closure and post-closure maintenance of a landfill.

10.1 The closure plan

The landfill licence usually requires the licensee to submit a written closure plan to the EPA for approval no later than 12 months before the completion of a landfill's waste receipt operations.

The closure plan should:

- specify the steps taken or to be taken in closing and stabilising the landfill, and the time frame for doing so
- specify the detailed design, the materials to be used and the construction quality assurance plan for the final capping, in accordance with the requirements of sections 9 and 11 of these guidelines
- specify post-closure management and monitoring measures (sometimes called aftercare) for leachate, stormwater, landfill gas, odour, dust, litter and final cap integrity
- identify any proposed future use of the site
- be consistent with all applicable conditions of the development consent or other planning approvals that apply to the premises
- make sure that neighbouring residents are advised of the contact persons for discussing any problems (e.g. odour emissions); records of these complaints should be kept in the same way as during operation
- make sure that waste is not received for disposal at the site after landfill operations cease. Wastes intended for use during remediation of the premises should be documented and reported in the same way as for an operating facility; see section 7 of these guidelines.

The occupier must install the final capping in accordance with the approved closure plan. On completion of the final capping, the occupier must submit a Construction Quality Assurance

Report to the EPA containing the as-constructed details and addressing the Construction Quality Assurance matters specified in section 11.2 of these guidelines.

If the Construction Quality Assurance Report for the capping is satisfactory, the EPA may approve the surrender of the licence and issue a Surrender Notice under section 80 of the *Protection of the Environment Operations Act 1997.* This Notice may contain conditions requiring ongoing monitoring at the closed landfill and/or other conditions that the EPA considers appropriate having regard to the environmental issues at the site.

10.2 Certified statement of completion

When sufficient evidence can be provided that the landfill is stable and non-polluting, the occupier may seek to complete all obligations and retrieve any financial assurance by submitting a certified statement of completion to the EPA. This statement must certify that the closure plan has been implemented, remediation work has been completed, and further environmental management of the premises is not required. This stage may not be reached until 30 years after the site stops receiving waste.

The certified statement of completion should show that the following stabilisation criteria have been met:

- Gas concentration levels in all perimeter gas wells have fallen to less than 1% methane (volume/volume) and less than 1.5% carbon dioxide (volume/volume) above the established natural background for a period of 24 months.
- Analysis of the leachate composition indicates low levels of contamination posing no hazard to the environment, and surface water and groundwater monitoring indicates no water pollution. These matters should be addressed in accordance with the relevant published water quality guidelines.
- The landfill final capping has been assessed over some years and found to be in good condition and stable, with acceptable stormwater drainage and with no evidence of erosion, cracking, dead vegetation, ponding, differential settlement or slope instability.
- The level of suspended solids in rainwater running off the final capping should be less than 50 milligrams/litre.
- The methane concentration at the surface of the final capping should not exceed 500 parts per million at any point.
- The closed landfill no longer poses an adverse amenity risk. It does not generate offensive or excessive odour, dust, noise, litter and debris, present a fire risk, or attract scavengers and vermin.
- All other requirements of the Closure Plan and Surrender Notice have been completed and/or satisfied.

Once the EPA has approved the certified statement of completion, the last licensee can stop maintaining and monitoring the site and any financial assurance requirements will lapse.

10.3 Development on closed landfills

Development on or near closed landfills can be a problem, because it can take many years after closure for the waste to become physically, chemically and biologically stable. The landfill can produce leachate and gases for many years.

Therefore, development on or near closed landfills should be considered only if the following conditions are met:

- The landfill should meet the EPA's stabilisation criteria for reduction in leachate strength, stormwater contamination and gas levels (see section 10.2). The gas criteria are particularly important for developments that create enclosed spaces where gas can accumulate or migrate (e.g. buildings, basements, manholes, tunnels, service ducts, stormwater and sewer pipes). These criteria may be less critical in the case of open developments: sporting fields, golf courses and car parks are sometimes created over recently closed landfills.

- The development should not compromise the functioning of the environmental controls at the site. Any proposed encroachment into the landfill (e.g. footings, piling or utilities) should not compromise the integrity of the landfill capping, lining and gas collection systems. The development should not impede drainage of rainfall off the cap. Constructed water features such as ornamental ponds should be avoided on landfill caps (see section 9).
- The risk of gas accumulation in any enclosed spaces within the development should be appropriately managed through design measures such as venting systems, sub-floor systems, gas barrier systems and other measures for managing sub-surface gas migration. See section 5.7 of these guidelines for more details about available techniques.
- The former landfill must be structurally and geotechnically sound for the proposed development. Settlement and slope stability analyses should be conducted by a suitably qualified and experienced person. Buildings and utilities should be designed and constructed to withstand the effects of differential settlement.
- Periodic methane monitoring should be conducted in all buildings and underground utilities. Automatic methane sensors should be installed in buildings directly above landfilled areas.

11. Quality assurance

Required outcomes

- Quality assurance measures must be implemented to make sure that all critical features of the landfill are constructed according to the approved designs and specifications.
- Before major construction works, the occupier must prepare a Construction Quality Assurance Plan. This must set out the proposed testing, inspection and other verification procedures to be implemented during construction of the landfill works.
- Following construction, the occupier must prepare a Construction Quality Assurance Report on the quality assurance that was implemented to ensure that the works comply with the approved designs and specifications.
- In the case of a new landfill or cell, a satisfactory Construction Quality Assurance Report must be submitted to the EPA before the EPA can issue an approval to dispose of waste in the new landfill or cell.
- In the case of final capping works under a Closure Plan, a satisfactory Construction Quality Assurance Report must be submitted to the EPA before the EPA can approve the surrender of the licence.

The following sections contain acceptable content and procedures for Construction Quality Assurance Plans and Reports. Note that the testing programs and frequencies are considered to be minimum standards for a construction quality assurance program for landfill liner and capping materials. There is limited scope for offering alternatives containing reduced programs.

11.1 Construction Quality Assurance Plan

General requirements of the plan

The Construction Quality Assurance Plan should address the following requirements:

- **Purpose of plan**. The Plan should set out the proposed testing, inspection and verification procedures to demonstrate that materials and constructed features at the landfill comply with the approved designs and specifications.
- **Materials testing**. The Plan should specify the sampling locations, frequency of testing, test methods, laboratories, accreditations, applicable specifications and quality standards, data evaluation, acceptance and rejection criteria and contingency measures in the event of failure.
- **Responsible parties**. The Plan should describe the roles, responsibilities and qualifications/experience of the parties involved in delivering construction quality assurance. All parties should have qualifications and experience appropriate for their roles in the project.
- **Construction Quality Assurance engineer**. The licensee should engage a suitably qualified and experienced Construction Quality Assurance engineer to verify and report on all Construction Quality Assurance matters. The engineer should be independent of the construction contractor and should be either an independent consultant engaged by the Principal (the licensee) or by the construction Superintendent (if there is one).
- **Sub-contractors**. Sub-contractors who install geosynthetic materials should have qualifications, experience, and competence in the installation, seaming and/or joining of such materials. Drilling sub-contractors installing sub-surface monitoring devices should hold appropriate licences to do this work.
- **Hold and inspection points**. The Plan should specify the hold points and inspection points for the project. These points are typically the start and finish of key stages of the work that cannot later be rectified because they will no longer be accessible. At each hold point, the Construction Quality Assurance engineer should review all test results for the materials proposed to be used; the contractor's proposed work methods and quality control procedures; the proposed panel layouts for any geosynthetic elements; and each sub-contractor's credentials. When each stage has been completed, the engineer should review a work-as-executed survey of the completed work. At all of these points, work should stop and should not restart until the engineer has reviewed the documentation and given approval for the project to continue.

  The Construction Quality Assurance engineer should do on-site inspections of the work at all of these points and should be present when all samples are taken for the testing of construction materials.

  At a minimum, hold and inspection points should be established at the start and finish of the following stages during construction of the leachate barriers and final capping: trial pad activities, sub-base, bearing layers, each lift of clay liner or sealing layer, the finished top surface of the clay liner or sealing layer, drainage layers, all geosynthetic layers, protection layers, pipework, landfill gas controls, penetrations of liners by leachate and gas collection infrastructure, and monitoring installations.

  These are minimum requirements for hold points and inspections to facilitate a Construction Quality Assurance program. Ideally, a Construction Quality Assurance engineer should be present at the site full-time during the construction of major features such as the leachate barrier system and the final capping of completed cells.
- **Variations**. Response actions are required if there are variations to the approved designs and specifications and the Construction Quality Assurance Plan. If a major

variation arises, work should stop on the affected element and the licensee should notify the EPA in writing, seeking a licence variation. For minor variations, notification is not required; it is sufficient for the Construction Quality Assurance engineer to note the variation in the final Construction Quality Assurance Report and to confirm that the variation did not compromise achievement of the required outcomes in these guidelines. The engineer should use his or her judgment to determine whether a variation is a major one in terms of the requirements of these guidelines.

- **Staged construction**. If staged construction is proposed, this should be noted in the Construction Quality Assurance Plan. The most common example of this is where the walls of a new cell will be constructed progressively as the waste height rises. The licensee should submit an addendum to the Construction Quality Assurance Report upon completion of each new portion of the cell wall.

In addition to these general requirements, the following sub-sections contain acceptable procedures for particular types of construction materials used at landfills.

Construction Quality Assurance: clay liners

For clay liners and sub-grade material, the Construction Quality Assurance Plan should address the following requirements (in addition to the General requirements of the plan in section 11.1):

- The sub-grade (whether natural or a constructed sub-base) should provide a firm, stable, smooth surface of high bearing strength on which to install the liner. It should not compromise the performance of the liner by differential settlement.
- Construction and compaction of clay liners should be done in layers or ‘lifts’, each of a maximum loose thickness of 300 millimetres. Successive lifts should be of compatible material and should be bonded to minimise the risk of preferential flow paths developing through the liner.
- Before the construction, the contractor should establish the range of densities and moisture contents that will give the clay liner the required hydraulic conductivity. During construction, field testing for density and moisture content should be conducted in accordance with Table 8.1 (Type 1 earthworks) of Australian Standard AS 3798-2007, with a minimum of four tests per project (new cell, cap or dam, as applicable). The sampling should be overseen by the Construction Quality Assurance engineer. Note: Pre-construction source testing should also include particle size distribution and plasticity index.
- Direct hydraulic conductivity may also be conducted to confirm that the liner meets specifications. This test may be conducted in situ or at a laboratory. Laboratory testing is most common. It is done on small, undisturbed samples of the clay liner material, obtained with a core cutter. In situ testing typically uses a sealed double ring infiltrometer and should be run for several months to obtain results that are representative. The Construction Quality Assurance engineer may elect to do such testing based on visual inspections and other test results.
- A design may identify more stringent field testing requirements for clay liners on the basis of the site conditions and the design objectives.
- Testing should be conducted by an independent, NATA-accredited laboratory. The Construction Quality Assurance engineer should approve the chosen laboratory before the start of construction.
- Testing should use methods specified in Australian Standard AS1289 Methods of Testing Soils for Engineering Purposes (Standards Australia, various dates) or equivalent methods in other recognised quality standards.

- The Construction Quality Assurance engineer should assess whether field testing additional to that stipulated by the designer is required in particular circumstances during construction.
- Regular visual inspections should be made of the liner during the construction of each lift. Relevant properties include thickness; homogeneity; and the presence of impurities, poorly compacted material, sharp objects or dry or cracked areas.
- On completion, the clay liner should be surveyed to verify that it has been installed with the correct thickness and at the correct grades.
- Between the time when the clay liner is constructed and the time when materials are placed on top of it, clay liners should be protected from damage due to sunlight and erosion. The barrier properties of the clay liner can be irreversibly damaged by desiccation due to cracking, which often remains even after the liner is wetted again. Clay liners exposed for more than 7 days before placement of overlying materials should be covered and suitably moistened to protect them from drying out.

Construction Quality Assurance: gravel drainage layers

For gravel drainage layers, the Construction Quality Assurance Plan should address the following requirements (in addition to General requirements of the plan in section 11.1):

- For granular drainage materials, regular field testing of particle size distribution should be conducted during construction. There should be at least one test per 2500 tonnes of material placed and at least one test per source of drainage aggregate, with a minimum of three tests per project. The sampling should be overseen by the Construction Quality Assurance engineer. Note: Source testing before construction should confirm that the material can meet the hydraulic conductivity requirements and other properties specified in section 1.4 of these guidelines.
- A design may identify more stringent field-testing requirements for gravel drainage material on the basis of the site conditions and the design objectives.
- Testing should be conducted by an independent, NATA-accredited laboratory. The Construction Quality Assurance engineer should approve the chosen laboratory before construction starts.
- Testing of granular drainage materials should use methods specified in Australian Standard AS 1141 Methods for Sampling and Testing Aggregates and AS 1289 Method of testing soils for engineering purposes (Standards Australia, various dates) or equivalent methods in other recognised quality standards.
- The Construction Quality Assurance engineer should assess whether field testing additional to that stipulated by the designer is required in particular circumstances during construction.
- Granular drainage materials should be placed in a way that avoids damaging any underlying geosynthetic liner material.
- The contractor should minimise the entry of soil and rock particles into the drainage layer. These can increase the risk of clogging in the drainage layer. When waste is first placed over the layer, it should not damage or push up the separation geotextile layer and allow small particles into the drainage layer.
- Pipes should be laid on an even bed of material, be appropriately bedded and protected with surrounding material (at least 300 millimetres over the crown of the pipe), and be properly joined, aligned and spaced.
- All site personnel should avoid driving heavy machinery over the drainage layer following placement.

Construction Quality Assurance: geosynthetic materials

For geosynthetic materials (i.e. geomembranes, geosynthetic clay liners, geotextiles, geonet drainage geocomposites and geogrids), the Construction Quality Assurance Plan should address the following requirements (in addition to General requirements of the plan in section 11.1):

(a) 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, Pennsylvania, USA) from time to time, or in equivalent recognised industry standard specifications. Relevant specifications are listed in section 1 of these guidelines.

(b) 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 independent conformance testing to verify that the materials supplied comply with the required specifications. The minimum testing requirements are those set out in the test schedule at the end of this section of the guidelines (section 11.3).
- All conformance tests must be reviewed, accepted and reported by the Construction Quality Assurance 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 should be done from rolls to be used in the works and should be overseen by the Construction Quality Assurance engineer.
- Delivery of samples to the laboratory should be organised by the Construction Quality Assurance engineer, not the contractor, and a suitable chain of 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 Construction Quality Assurance engineer.
- The Construction Quality Assurance engineer should use his or her judgment as to whether independent conformance testing additional to the testing stipulated by the designer is required in particular circumstances during construction.
- 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 within the meaning of the General requirements of the plan in section 11.1.
- In addition to laboratory testing, the surface area of every roll of material 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 (in the case of geosynthetic clay liners) initial moisture content. Geosynthetic clay liners should be delivered to the site in waterproof wrapping.

(c) 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 Construction Quality Assurance 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 plan in section 11.1.
- A panel layout should be prepared before the installation of each geosynthetic layer; it should show the proposed arrangement 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 the 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 and joins should be regularly inspected and tested. 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 holes, 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 at the end of this section of the guidelines (section 11.3).
- 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 installed on slopes should be anchored in trenches located at least 1 metre back from the top edge of the slope. This secures the geosynthetic material and prevents ingress of surface runoff beneath the layers.
- Geosynthetic layers should be placed on smooth, firm, dry surfaces, and should 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. The rate of deployment of geosynthetic clay liners should be restricted 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 should otherwise 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.

(d) 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 – surveys at the two 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 a 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) 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 millimetres 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 see 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.

Construction Quality Assurance: composts

If composts or mulches are used in the revegetation layer of final capping, the Construction Quality Assurance Plan should address the following requirements (in addition to General requirements of the plan in section 11.1):

- Regular testing should be conducted by the manufacturer or supplier in accordance with Australian Standard AS 4454-2012 Composts, Soil Conditioners and Mulches (Standards Australia, 2012) or as specified by the EPA. Minimum test frequency should be at least one round of testing per 2500 tonnes placed, at least one per source and at least one per cell.
- Regular visual inspections should be made of such materials for obviously non-complying composts and foreign materials.

Construction Quality Assurance: phytocaps

If phytocaps are approved as the final capping, the Construction Quality Assurance Plan should address the following requirements (in addition to the General requirements of the plan in section 11.1):

- The Construction Quality Assurance engineer should verify that all soils and vegetation species are as specified in the approved design report. Any variation to the approved soil or vegetation specifications during construction may significantly affect the ability of the cap to store and remove water. This is considered to be a major variation within the meaning of the General requirements of the plan in section 11.1.
- The soil should not be over-compacted. The placement methods and density should be such that the soil has the hydraulic and water storage properties assumed in the design. Over-compaction can reduce water storage capacity and impede root establishment and penetration through the soil profile. To minimise this risk, the placement method used is different from that for a compacted clay barrier. The soil should be placed in thicker lifts (e.g. 450 millimetres), in a drier condition, and using lighter, less penetrative construction machinery than is typical for compacted clay.
- There should be a trial placement to establish the compactive effort that will achieve the required soil density and to establish relationships between the various soil properties; these data can then be used for field control purposes.
- The construction personnel should receive instructions on the appropriate placement methodology, including the need to avoid over-compaction.

- Highly compacted areas on the cap, such as haul roads and stockpile locations, should be decompacted by ripping or similar techniques when their service is complete.
- Weed control should be undertaken before planting to help the selected vegetation to establish.
- Sediment and erosion control measures should be installed to protect the seed or tubestock during establishment.
- Seeding and/or planting should be overseen by a qualified and experienced botanist or related scientist familiar with the local environment. The Construction Quality Assurance engineer should view records containing evidence of this competency.
- On completion, the cap should be surveyed to verify that it has been installed with the correct thickness and at the correct grades.

11.2 Construction Quality Assurance Report

The Construction Quality Assurance Report should contain:

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

The work-as-executed drawings, also called ‘as-built’ drawings, must be prepared from field surveys. They must be at a suitable scale and must provide elevations in Australian Height Datum. The work-as-executed drawings must clearly show all changes to the approved drawings.

In the case of the construction of new cells and associated infrastructure, the drawings should depict, where applicable:

- a plan view of the perimeter of the cell and finished surface contours of the cell floor and side slopes
- cross-sections of the basal features of the cell
- finished contours of the various layers within the leachate barrier
- the layout and reduced levels of any groundwater drainage infrastructure
- the alignments and grades of installed pipes and risers
- the leachate levels in the riser(s) that will trigger leachate extraction and the alarm system.

In the case of the installation of groundwater and landfill gas monitoring wells, the Construction Quality Assurance Report and drawings should show:

- the number of wells installed in the network, the drilling method, the material used in well construction, the procedures used for well development, and well security
- well construction and geological details, with all elevations recorded relative to the Australian Height Datum
- all other details needed to confirm that the wells were designed and constructed in accordance with these guidelines.

11.3 Schedule: Independent conformance testing for geosynthetic materials

For the test schedules in Tables 8 to 14 below, some general requirements apply, regardless of the type of geosynthetic material being tested:

1. Test results must be passed by the Construction Quality Assurance engineer before deployment of the geosynthetic material.
2. All testing must be performed on samples taken from the geosynthetic rolls to be used for the works, with all sampling overseen by the Construction Quality Assurance engineer.
3. All laboratory tests should be performed in a third-party, independent, accredited geosynthetics laboratory.
4. Delivery of samples to the laboratory should be organised by the Construction Quality Assurance engineer, not the contractor. A suitable chain of custody procedure should be implemented.
5. Test results should be sent directly from the laboratory to the Construction Quality Assurance engineer.
6. The specified frequencies assume that all rolls are from a single continuous manufacturing run. The frequencies should be applied to each continuous manufacturing run producing the rolls to be used in the project.
7. In the tables, ‘ASTM methods’ refers to standard test methods published by ASTM International (West Conshohocken, Pennsylvania, USA).

Table 8: Construction Quality Assurance testing requirements for HDPE geomembranes

Property	**Standard**	**Frequency**
Thickness	ASTM D5199 (smooth) ASTM D5994 (textured)	1 test per 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
Asperity height (textured)	ASTM D7466	1 test per 5000 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 5000 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 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
Puncture resistance	ASTM D4833	1 test per 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
Tear resistance	ASTM D1004	1 test per 5000 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 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
Carbon black dispersion	ASTM D5596	1 test per 5000 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 greatest 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 9: Construction Quality Assurance testing requirements for LLDPE geomembranes

Property	Standard	Frequency
Thickness	ASTM D5199 (smooth) ASTM D5994 (textured)	1 test per 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
Asperity height (textured)	ASTM D7466	1 test per 5000 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 5000 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 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
Puncture resistance	ASTM D4833	1 test per 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
Tear resistance	ASTM D1004	1 test per 5000 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 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
Carbon black dispersion	ASTM D5596	1 test per 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
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 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 rolls (based on production order): minimum of two tests

Table 10: Construction Quality Assurance testing requirements for geosynthetic clay liners

Property	Standard	Frequency
GCL (geosynthetic clay liner) mass per unit area	ASTM D5993	1 test per 2500 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 1250 m^2, including the first and last rolls (based on production order): minimum of two tests
Peel strength	ASTM D6496	1 test per 1250 m^2, including the first and last rolls (based on production order): minimum of two tests
Tensile properties (machine direction)	ASTM D6768	1 test per 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
CBR (California bearing ratio) burst strength	AS 3706.4	1 test per 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
Fluid loss	ASTM D5891	1 test per 1250 m^2, including the first and last rolls (based on production order): minimum of two tests
Swell index	ASTM D5890	1 test per 2500 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 2500 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

Table 11: Construction Quality Assurance testing requirements for protection geotextiles

Property	Standard	Frequency
Mass per unit area	AS 3706.1	1 test per 2500 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 5000 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 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
CBR (California bearing ratio) burst strength	AS 3706.4	1 test per 5000 m^2, including the first and last rolls (based on production order): minimum of two tests

Table 12: Construction Quality Assurance testing requirements for separation geotextiles

Property	Standard	Frequency
Grab tensile strength	AS 3706.2b	1 test per 5000 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 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
CBR (California bearing ratio) burst strength	AS 3706.4	1 test per 5000 m^2, including the first and last rolls (based on production order): minimum of two tests
Pore size	ASTM D6767	1 test per 5000 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

Table 13: Construction Quality Assurance testing requirements for geonet drainage geocomposites

Property	**Standard**	**Frequency**
Drainage geocomposite core		
Thickness	AS 3706.1	1 test per 1250 m^2, including the first and last rolls (based on production order): minimum of two tests
Compressive strength	ASTM D1621	1 test per 1250 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 5000 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 1250 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

Table 14: Construction Quality Assurance weld testing for HDPE and LLDPE geomembranes (Source: EPA Victoria, 2015, pages 89–90)

Item	Property	Standard	Frequency
Start-up test 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 changed and/or wide temperature fluctuations are experienced
Destructive weld testing	On-site; hand tensiometer in peel and shear	ASTM D6392	Every weld
	Off-site; 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

Glossary

90th percentile wet year: yearly rainfall that has been exceeded only in 10% of the years for which records are available for a particular locality.

90th percentile 5-day rainfall event: a 5-day rainfall event that has been exceeded only by 10% of historical 5-day rainfall events at the location. The event can be determined from the historical rainfall curves provided in Appendix L of Managing Urban Stormwater: Soils and Construction Volume 1 (NSW Department of Housing, 2004).

Absorptive capacity: of waste refers to the ability of waste to absorb additional water without the water draining. The theoretical maximum liner is the difference between the waste's inherent or as-placed moisture content and its field capacity.

Action leakage rate: a low-level leakage rate that indicates the presence of a small hole or defect in the liner above a leachate collection layer. In these guidelines, the concept relates to the secondary leachate detection layer used in the dual liner system required for restricted solid waste landfills.

Alkalinity: a measure of a water's ability to neutralise acids, that is, to keep the pH from changing. The main species contributing to alkalinity are bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). Alkalinity is expressed as an equivalent concentration of calcium carbonate.

All unpolluted natural waters have some alkalinity, which is beneficial. These levels rarely exceed 500 milligrams/litre. Alkalinity in landfill leachate can range from 1000 to 10,000 milligrams/litre calcium carbonate equivalent.

Ammonia (total): refers to the sum of unprotonated ammonia (NH_3) and the ammonium ion (NH_4+). Ammonia is usually a very strong indicator of landfill leachate. It is formed when organic wastes undergo decomposition in the oxygen-poor environment in landfills. It is present in landfill leachate in a typical range of 300 to 3000 milligrams/litre.

Ammonia is a plant nutrient, and elevated levels can cause blooms of algae and weeds in aquatic environments. ANZECC trigger values for ammonia as a nutrient in NSW surface waters range from 0.01 to 0.025 milligrams/litre. Ammonia is also potentially toxic to freshwater aquatic life and varies with the pH of the water. See ANZECC (2000), volume 2, Table 8.3.7.

Analytes: chemicals and other substances (e.g. in water), the concentrations of which must be determined by chemical analysis.

Aquifer: an underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, silt, or clay) from which groundwater can be usefully extracted by using a water well.

Average recurrence interval: the average recurrence interval (in years) for a particular intensity rainfall event, for example a '1 in 10 year average recurrence interval rainfall event of 24 hours duration' means the number of millimetres of rain that fall during 24 hours on average only once every 10 years.

Australian Height Datum: the mean sea level for 1966–68 was assigned the value of zero on the Australian Height Datum at 30 tide gauges around the coast of the Australian continent. All engineering drawings for the landfill must be annotated relative to this datum.

Background (characteristics): the characteristics of the water, soils and air at a site before they have been affected by the activities and polluting processes taking place at the landfill.

Batter seep or leak: the seepage or leakage of leachate from the landfill side slopes in situations where the waste is above the surface of the land and is retained on the sides by sloping earthen walls known as batters.

Biochemical oxygen demand (BOD): a measure of the amount of oxygen required by microorganisms to degrade organic matter present in a water sample under standard test conditions. The test is conducted over 5 days and the result is reported as BOD_5 in mg of oxygen consumed/litre of water.

BOD_5 is present at high levels in landfill leachate, typically greater than 1000 milligrams/litre during the active landfilling phase. Unimpacted or slightly disturbed surface waters typically have BOD_5 less than 20 milligrams/litre. High levels of biodegradable organic matter may very quickly deplete oxygen levels in receiving water bodies, affecting the respiration of aquatic species and causing amenity impacts.

See also **Dissolved oxygen**.

Biocover: a cover layer placed over waste and consisting of compost and a gas distribution layer with the purpose of microbiologically treating landfill gas emissions through the cover.

Biodegradable waste: organic waste that may be decomposed by the action of microorganisms. The products of this decomposition under the anaerobic conditions in landfills include methane, carbon dioxide and ammonia.

Biofilter: a filter filled with compost or other suitable organic material through which landfill gas, vented from waste, is passed to microbiologically treat the gas.

Bioreactor (landfill): a type of landfill in which leachate and water from other sources are recirculated through the waste to accelerate the decomposition of organic materials to methane and humus. The short-term generation of landfill gas may be increased, often enabling it to be used for energy recovery. The waste may be biodegraded and stabilised quicker, reducing the post-closure care and maintenance period.

Biosolids: the organic products that result from sewage treatment processes (sometimes referred to as sewage sludge).

cfu: colony-forming units; see **Thermotolerant coliforms**.

Capping: see: **Final capping.**

Cation exchange capacity: the capacity of the soil to hold and exchange cations. It is usually expressed as milliequivalents free of hydrogen per 100 grams (meq/100g) or centimoles of positive charge per kilogram of soil (cmol/kg).

Cell: a discrete unit of a landfill that is physically separated from other waste emplacements at the site.

Charge balance error: occurs when the results of an analysis of the concentrations of anions and cations in water do not balance, indicating that the solution is not electrically neutral and suggesting that the results of the analysis are not correct.

Chemical oxygen demand: a measure of the oxidation of organic compounds to carbon dioxide, as determined by using oxidising chemical reagents under standard test conditions. The test takes several hours and measures the amount of oxygen consumed per litre of water. The test measures both biodegradable and non-biodegradable organic matter and is usually higher than biochemical oxygen demand. The ratio of biochemical oxygen demand to chemical oxygen demand usually decreases over the life of a landfill as waste degradation proceeds.

Clogging: the blocking-up of leachate drainage layers as a result of deposition of solids, growth of biomass and the formation of inorganic precipitates. Clogging can reduce the hydraulic conductivity of the layer, potentially having adverse consequences such as leachate mounding, leachate seeps and/or increased rates of leachate leakage through the base liner. The risk of clogging can be reduced by increasing the particle size, hydraulic conductivity and layer slope of the drainage material and by increasing the number of collection pipes.

Cohesive soil: a soil able to hold together by itself and be moulded or shaped without breaking apart (this property is called plasticity). Cohesive soils usually contain significant amounts of silt and/or clay.

Composite liner: a landfill barrier and sealing layer that is composed of more than one liner material (e.g. a geosynthetic clay liner covered with a geomembrane liner).

Compost: reprocessed organic waste meeting Australian Standard AS 4454-2012 Composts, Soil Conditioners and Mulches.

Construction quality assurance plan: a plan required for the construction of all features of a landfill to ensure that they are constructed according to the approved designs and specifications.

Daily cover: material applied on the tipping face of the landfill upon close of business each day to reduce environmental and amenity impacts.

Decomposition: the breakdown of organic waste materials by microorganisms.

Deposited dust: particulate matter that is deposited from the atmosphere, measured as the surface concentration of deposited dust settling from the air over a time period of 1 month (in units of grams/square metre/month).

Dispersive soils: clayey and fine silty soils that are structurally unstable in water and readily split into their constituent fine particles. Runoff from such soils is typically highly turbid. The fine particles can stay in suspension for very long periods, mainly because of negative electrical charges on their surfaces that cause them to repel each other.

Dissolved oxygen: is necessary for supporting life in water, and its level is an important indicator of water quality. Levels of dissolved oxygen in water can be reduced by the presence of organic material that exerts an oxygen demand. Wastewater with high organic loads, such as landfill leachate, can significantly decrease dissolved oxygen levels in receiving water bodies.

Low dissolved oxygen levels can adversely affect aquatic organisms and can cause the release of nutrients and toxicants from sediments. Concentrations below 5 milligrams/litre can be stressful to many species of freshwater fish. See ANZECC (2000) Chapter 3 Aquatic ecosystems, section 3.3 Physical and chemical stressors.

Electrical conductivity: or salinity of water (units: µS/cm or dS/m) measures the water's ability to transmit an electric current and is an indicator of the concentration of ions formed from water soluble salts that are dissolved in the water. Good quality water has a relatively low concentration of dissolved salts and hence a relatively low electrical conductivity. Ionic species contributing to the conductivity of landfill leachate include sodium, calcium, magnesium, potassium, chlorides, sulfates and carbonates.

Electrical conductivity is only an approximate measure of dissolved solids, because only ions contribute to conductivity; non-ionized organic molecules and other dissolved substances are not measured. The following relationship has been developed to convert from electrical conductivity to total dissolved solids concentration: total dissolved solids (milligrams/litre) = electrical conductivity (deciSeimens/metre) x a factor ranging from 550 to 900. The precise conversion factor depends on the particular constituents of the water (see Environmental Guidelines: Use of Effluent by Irrigation (NSW DEC, 2004b), p. 27).

Testing is usually done in the field with a hand-held conductivity meter. Because it does not require laboratory analysis, electrical conductivity is more convenient than total dissolved solids for obtaining routine measures of dissolved substances in water.

Environment protection licence: a licence issued under the *Protection of the Environment Operations Act 1997* (NSW) to conduct any of the scheduled activities listed in Schedule 1 of the Act. Most new landfills must be licensed, with minor exceptions depending on the scale of the landfill and the type of waste received.

EPA: New South Wales Environment Protection Authority.

Evapotranspiration: the process whereby water held in soil layers, such as landfill capping, is lost by evaporation and transpiration from vegetation established in the layer. The extent of evapotranspiration depends on the climate, the depth of the layer, the soil properties, the type of vegetation and the depth of root penetration.

Field capacity: a measure of the capacity of a material such as soil or waste to absorb water. At field capacity, any further water added to the material will drain by gravity. Field capacity is given as a percentage; it is defined as the ratio of the volume of water that can be absorbed by the material to the total volume of the material before drainage by gravity occurs.

Final capping: the covering that is applied to the waste to rehabilitate the landfill once it has reached its maximum height. Final capping in a traditional barrier cap usually comprises several layers, depending on the design (from bottom to top): a seal-bearing surface, a gas drainage layer, a sealing layer, an infiltration drainage layer, and a revegetation layer.

Flammable waste: readily combustible wastes and wastes that may cause fire through friction.

Flare: a burner used for the combustion of landfill gas, including the conversion of methane to carbon dioxide and the destruction of the majority of non-methane volatile organic compounds present in the gas.

Flexible membrane liner: see **Geomembrane**.

Free swell index: a measure of the potential of a soil to swell upon addition of water; determined by using a standard test method.

General solid waste: any waste that is classified or assessed as general solid waste in accordance with the Waste Classification Guidelines (NSW EPA, 2014). The definition further breaks the waste up into putrescible and non-putrescible components.

General solid waste landfill: a landfill licensed under the *Protection of the Environment Operations Act 1997* for disposal of wastes classified as general solid waste.

Geomembrane: a synthetic landfill liner comprising a thin plastic film (minimum 2 millimetres thick), usually manufactured from high-density polyethylene or linear low-density polyethylene or other polyolefins. Sometimes called a **Flexible membrane liner.**

Geonet drainage geocomposite: a factory-manufactured drainage material that can be used instead of gravel for drainage in some situations. It consists of a plastic internal drainage core, with geotextiles bonded to one or both surfaces. The internal drainage core (the geonet) is typically manufactured from high-density polyethylene and consists of parallel ribs in layers creating drainage channels through which fluids can flow. The geotextile on the upper surface is designed to prevent fines from entering the drainage channels. The geotextile on the bottom surface is designed to prevent damage to underlying geosynthetic layers.

Geosynthetic clay liner: a manufactured liner consisting of a thin layer of bentonite ‘sandwiched’ between layers of geotextiles.

Geosynthetic material: factory-manufactured engineering material containing polymers and other materials. The main categories of geosynthetic materials in these guidelines are geomembrane liners (also called flexible membrane liners), geosynthetic clay liners, geonet drainage geocomposites and geotextiles.

Geotextile: a non-woven, needle-punched geotextile (typically polypropylene) installed in landfill barrier systems. A protection (or cushion) geotextile is installed adjacent to a geomembrane liner to protect it from damage. A separation geotextile is installed above a drainage layer to reduce the ingress of fine particles from the overlying waste or soil.

Greenhouse gas: any gas whose presence in the atmosphere contributes to global warming. Methane and carbon dioxide are the main greenhouse gases emitted from landfills.

Hazardous waste: any waste that is classified as hazardous in accordance with the Waste Classification Guidelines (NSW EPA, 2014). Hazardous waste cannot be disposed of to landfill unless it is treated to remove or immobilise the contaminants.

High-density polyethylene: a polymeric material used in the manufacture of geomembrane liners, geonet drainage geocomposites and pipes used in landfilling.

Hydraulic conductivity: a measure of the ease with which a liquid can move through a substance (in units of cubic metres/square metre/second, or simply expressed as metres/second). It depends on the material's permeability, the liquid flowing through it and the degree of saturation. Saturated hydraulic conductivity to water is a measure of water flow through saturated media; it must be relatively high for leachate drainage layers (greater than 1×10^{-3} metres/second for gravel) and relatively low for leachate barriers (less than 1×10^{-9} metres/second for clay).

Hydraulic transmissivity: a measure of how much water can move through a layer of material (either an engineered layer or natural aquifer). It is related to hydraulic conductivity by the relationship hydraulic transmissivity = hydraulic conductivity of material x layer thickness (in units of $m^3/s/m$, or simply expressed as m^2/s).

Immobilisation approval (immobilised contaminants): an approval issued by the EPA under the Protection of the Environment Operations (Waste) Regulation 2014. An immobilisation approval enables a waste to be reclassified as a less harmful type of waste because the contaminants are locked up (immobilised) in the waste and will not be released into the landfill leachate at levels of concern. The approval may be a 'general approval' or a 'specific approval'. The mechanisms of immobilisation are natural immobilisation, chemical fixation, microencapsulation, and macroencapsulation.

There is a list of general immobilisation approvals on the EPA's website.

Indicator parameters: measurable properties of water, air and soil used to detect pollution. For example, in these guidelines, indicator parameters for leachate pollution of waters include the concentration of ammonia, total dissolved solids or electrical conductivity, and total organic carbon.

Infiltration drainage layer: a layer in the final capping of a landfill to collect any stormwater that has infiltrated through the revegetation layer.

Intermediate cover: a cover of soil at least 300 millimetres deep that must be applied to surfaces of the landfill that will be exposed for more than 90 days.

Landfill gas: gaseous emissions from the anaerobic decomposition of organic waste materials placed in a landfill. About 90% of landfill gas is methane and carbon dioxide, in roughly equal amounts depending on the phase of the waste decomposition and other factors, such as oxygen levels. These are sometimes called bulk landfill gases.

Landfill gas also contains water vapour and small amounts of various volatile organic compounds, aldehydes, organosulfurs (including mercaptans), hydrogen sulfide and ammonia. These are sometimes called trace landfill gases.

Landfill gas can be generated over a long time. Modelling suggests that about 30% of total landfill gas generation can occur before landfill closure; 50% occurs during the first 30 years after closure and the remaining 20% occurs 30 to 100 years after closure (Landfill Gas Emissions Model (LandGEM) Version 3.02, USEPA, 2005).

Landfill gas can be flammable or explosive when mixed with air at methane concentrations of 5% to 15% (on a volume per volume basis). It can be an asphyxiant when allowed to accumulate in enclosed spaces. It is typically highly odorous owing to the presence of trace gases. (Methane and carbon dioxide are odourless.) It can kill vegetation in the vicinity by displacing oxygen in the soil. It is a greenhouse gas: methane is 21 to 25 times more potent than carbon dioxide as a greenhouse gas.

Leachate: the liquid that passes through, or is released by, waste. It arises from the inherent moisture content of the waste and from rainwater (and sometimes groundwater) percolating through or contacting the waste mass. Leachate may contain high levels of dissolved solids, ammonia, organic matter, and sometimes metals and other pollutants. These levels are typically well above background levels for undisturbed or slightly disturbed groundwater and surface water systems. The levels are also well above national quality guidelines for drinking water and other beneficial reuses of water.

Leachate drainage layer: a highly permeable layer above the leachate barrier for draining leachate that has percolated down through the waste.

Leachate riser: a vertical pipe through which leachate is pumped from a drainage sump into surface leachate dams or tanks.

Linear low-density polyethylene: a polymeric material sometimes used in the manufacture of a landfill final capping material.

Liner: a low-permeability layer installed on the floor and walls of a landfill as part of a leachate barrier system to minimise the escape of leachate (and also gas, if present). Typical liner materials are compacted clay liners and factory-manufactured geosynthetic liners. Liners are also installed in final caps at landfills to limit rainfall infiltration. In caps they are usually referred to as sealing layers.

Lysimeter: a device to collect and measure the quantity of water in the pore spaces of soils.

Metals: a suite of potentially toxic metals and metalloids that may be present in landfill leachate. They are generally present at low concentrations in leachates from general solid waste landfills; in such leachates their levels are often not markedly higher than background concentrations in the groundwater. This is thought to be the result of immobilisation processes within the waste. A monitoring program should establish the levels of metals in the leachate and groundwater.

Methane: a colourless, odourless gas that is generated under anaerobic conditions in most landfills containing degradable organic carbon.

Monitoring: the regular and systematic accumulation of data to characterise pollution streams (e.g. leachate; sediment-laden stormwater; landfill gas; products of combustion of landfill gas; odour; dust; and noise) and the receiving environments (surface water, groundwater, soil, and air).

Monocell: part of a landfill cell isolated from the rest of the cell by means of a leachate or gas barrier of low permeability for the disposal of one specific waste type.

Monofill: a landfill unit isolated for the disposal of one specific waste type.

NATA: National Association of Testing Authorities.

Nutrients: consist primarily of nitrogen and phosphorus. These are generally at elevated levels in landfill leachate. Excessive levels of nutrients in water bodies are generally associated with excessive plant growth (eutrophication and algae) and aquatic species toxicity.

There are several forms of nitrogen. Total nitrogen is a combination of organic nitrogen, ammonia nitrogen, nitrate and nitrite. The nitrogen is derived from organic matter, fertilisers, cleaning and polishing agents, and other products within the waste.

Background levels of total nitrogen range from 0.1 to 0.2 milligrams/litre in small, near-pristine mountain streams to over 10 milligrams/litre in heavily polluted rivers. Total phosphorus concentrations in natural water bodies can vary from less than 0.01 milligrams/litre in small, near-pristine mountain streams to over 1 milligrams/litre in heavily polluted rivers (ANZECC, 2000, section 8.2 Physical and chemical stressors).

See also **Ammonia**.

Occupier: the person who has the management or control of the landfill.

Offensive odour: defined in section 129 of the *Protection of the Environment Operations Act 1997*. Essentially it is an odour of a character, duration or time of occurrence that could harm, or unreasonably interfere with the comfort of, a neighbouring resident.

Odours are commonly generated at landfills receiving organic waste because of decomposition of these wastes under anaerobic conditions. The primary odorous compounds are mercaptans, hydrogen sulfide and various complex organic compounds.

Odour production rates from landfills are highly variable, depending on the type of waste, its moisture content, the extent of its decomposition, the type and extent of cover material, whether or not landfill gas collection is installed, the terrain, the temperature, and the wind conditions.

Off-site: means not occurring on the premises licensed as a landfill site under the *Protection of the Environment Operations Act 1997*.

Organic contaminants: includes monoaromatic hydrocarbons (benzene, toluene, ethylbenzene and xylene), phenols, petroleum hydrocarbons, organochlorine and organophosphate pesticides, and polycyclic aromatic hydrocarbons. Leachate from modern general solid waste landfills typically has very low or undetectable concentrations of these contaminants. They are more likely to be present if the site has restricted solid waste cells and monocells catering for more contaminated waste streams from industrial and other non-residential sources.

Oxidation and reduction: the gaining and losing of oxygen, hydrogen and/or electrons by the reactants in a chemical reaction. In these guidelines, the most common example is oxidation of methane in landfill gas to carbon dioxide, either thermally or biologically (note that when the gas is combusted, carbon monoxide can be another oxidation product of incomplete combustion).

Pan coefficient: a coefficient used to modify evaporation data obtained from the Australian Government's Bureau of Meteorology. It reflects differences between the dam under consideration (e.g. a large leachate dam) and the small, standardised pans used by the Bureau for gathering evaporation data. For example, in these guidelines it should be assumed when doing water balance predictions that the evaporation from a leachate dam is 70% of the monthly pan evaporation rate obtained from the Bureau of Meteorology or another source of measured evaporation rates.

Percolation: the passage of water through a particular layer in the landfill (e.g. the flow of rainwater infiltration through a cap down into the waste).

Permeability: a property of a material such as soil or rock that is a measure of the ability of that material to allow fluids to pass through it.

Petroleum hydrocarbons: a large family of several hundred chemical compounds derived from crude oil. They consist of only carbon and hydrogen atoms, to be distinguished from oils and fats of animal and vegetable origin, which contain oxygen and other atoms.

pH: a logarithmic scale that is based on the logarithm of the hydrogen ion concentration and is used to measure the acidity, alkalinity or neutrality of water. The range is from 0 to 14: 0 to 7 is acidic, 7 is neutral and 7 to 14 is alkaline.

Phenols: aromatic compounds containing a hydroxyl group and used in household disinfectants and other products. In unpolluted waters, the concentration of phenols is typically less than 0.02 milligrams/kilogram. Phenols can be present in leachate at greater than 0.2 milligrams/kilogram and can be toxic to aquatic microorganisms at a concentration of 0.32 milligrams/litre (ANZECC 2000, section 3 Aquatic ecosystems).

Plume: the extent of the water body (groundwater or surface water) that is affected by pollution emanating from a point source.

PM_{10}: fine dust particles up to 10 microns (µm), typically measured in units of micrograms/cubic metre for annual and 24-hour averaging periods.

ppm: parts per million, used in these guidelines to express gas concentrations. For example, methane at 500 ppm volume/volume is equal to a 0.05% methane concentration by volume.

Pore water: water that is retained in the pores of soil or rock and that will not percolate further. Porosity is a measure of the void spaces in a material such as soil. It is measured as a fraction of the volume of the material (units: volume/volume) and is expressed as a value between 0 and 1.

Primary leachate collection layer: the upper or inner leachate collection layer in a double-lined landfill such as a restricted solid waste landfill. The primary leachate collection layer is above the upper liner in the double liner system and is used to collect the leachate for extraction and treatment or disposal.

Protection geotextile: see **Geotextile**.

Putrescible waste: a type of waste that is characterised by materials that readily decay under standard conditions, emit offensive odours, and attract vermin or other vectors (such as flies, birds and rodents). It includes household waste containing putrescible organics, and food and animal waste. See the Waste Classification Guidelines (NSW EPA, 2014) for more details.

Redox potential: the tendency of a solution to gain or lose electrons, measured in volts. The ability of an organism to carry out oxidation-reduction reactions depends on the oxidation-reduction state of the environment, or its redox potential. Strictly aerobic microorganisms can be active only at positive redox potential values, whereas strict anaerobes can be active only at negative redox potential values.

Reinjection: the process of returning leachate to the landfill from which it has been abstracted.

Restricted solid waste: waste that is classified as restricted solid waste in accordance with the Waste Classification Guidelines (NSW EPA, 2014). Restricted solid waste contains higher (up to four times) levels of contaminants than general solid waste.

Restricted solid waste cell: a cell located at a general solid waste landfill that is licensed to accept restricted solid waste. The cell must be isolated from the rest of the landfill by means of a leachate or gas barrier of low permeability.

Restricted solid waste landfill: a landfill licensed under the *Protection of the Environment Operations Act 1997* for disposal of wastes classified as restricted solid waste. A reference in these guidelines to a restricted solid waste landfill includes a reference to cells, monocells and monofills licensed for the disposal of restricted solid waste.

Revegetation: the planting and growing of vegetation in the final capping and other disturbed areas of the landfill to stabilise the soil against erosion and promote evapotranspiration of rainfall.

Runoff: the portion of water falling on an area (either precipitation or irrigation water) that drains from the area as surface flow.

Saturated hydraulic conductivity: see **Hydraulic conductivity.**

Screened section or interval: the interval in a sub-surface monitoring well where liquids and/or gases are allowed to enter the well for sampling.

Secondary leachate collection layer: the lower or outer leachate collection layer in a double-lined landfill. It is installed below the primary liner system and it is used for the detection of any leaks in that system.

Sensitive receptors: environments that could be affected by pollution from the landfill. Typically this includes locations close to the landfill where people work or reside, such as a dwellings, schools, hospitals, offices or public recreational areas. It can also include water bodies such as groundwater resources, drinking water catchments and sensitive wetlands.

Separation geotextile: see **Geotextile**.

Settlement: the lowering of waste levels in a landfill as a result of consolidation and biodegradation processes over time. Differential settlement is where this process occurs unevenly across a waste mass. It is a particular problem for the integrity of final capping. The amount of settlement depends on the waste composition, quantity, age, degree of compaction and loading placed on the waste. Typically it is greater where the waste is largely putrescible and at the centre of a landfill where the waste depth is usually greater. Regular compaction can reduce post-closure settlement.

Standing water level: the upper level of water in an undisturbed monitoring well with no pumping taking place.

Stormwater runoff: rainfall runoff from the overall area of a landfill that picks up high sediment loads when it runs over disturbed areas, earthworks, exposed soils and stockpiles. Poorly managed stormwater runoff can contain high levels of total suspended solids, which can adversely affect receiving water bodies. See **Total suspended solids**.

In addition to generating sediment loads, poorly-controlled stormwater can contact waste and generate additional volumes of leachate.

Stratum (strata): a distinct layer of rock or soil, distinguishable from neighbouring layers.

Surface water: water that is located in the rivers, creeks, lakes, billabongs, wetlands and dams surrounding a landfill and that could potentially be affected by discharges of contaminated water from the landfill.

Tipping face: the area of the landfill where waste is disposed of during daily operations.

Thermotolerant coliforms: coliform bacteria that are found in the intestinal tracts of humans and other warm-blooded animals and can be used as indicators of faecal contamination. They consist chiefly of *Escherichia coli.* These bacteria are rarely present in unpolluted water. The presence of microbiological contaminants in leachate is generally not a major issue, but it should be considered in two main situations: (1) where the landfill is adjacent to water bodies with downstream water users (human consumption, livestock, recreational use), and (2) where leachate is to be irrigated.

An upper limit of l000 colony forming units/100 millilitres is typically specified in Australian guidelines for wastewaters to be used in irrigation and other beneficial reuse schemes. The limit depends on the sensitivity of the likely human contact.

Total dissolved solids: the combined content of all inorganic and organic substances dissolved in water. It consists mainly of inorganic salts, but also contains small amounts of dissolved solid organic matter, clay particles and other colloidal matter. It is measured by evaporating a sample that has been filtered to remove all the suspended solids.

Landfill leachate contains high concentrations of total dissolved solids, typically in the range of 1000 to 10,000 milligrams/litre. NSW freshwater rivers and lakes generally have dissolved solids at less than 1000 milligrams/litre, although some have naturally high salinity levels. Highly saline water may adversely affect aquatic organisms in fresh water. It may be unsuitable for irrigation and drinking (by humans if greater than 500 to 1000 milligrams/litre and by livestock if greater than 3000 milligrams/litre).

See also **Electrical conductivity**, which is a related measure.

Total organic carbon: the amount of carbon in organic compounds in a sample (milligrams/litre in a liquid sample), as distinct from the carbon in inorganic compounds, such as carbonates.

The test procedure is simpler and quicker than the 5-day test used to determine the biochemical oxygen demand of a water sample. However, unlike BOD_5, total organic carbon does not precisely measure the readily biodegradable organic matter in a sample, i.e. the content of organic matter that creates an oxygen demand in receiving waters. Total organic carbon measures some organic materials that do not exert an oxygen demand in water.

Total organic carbon can be used for routine analysis of water quality, but BOD_5 should be used when characterising leachate for irrigation, off-site or sewer discharge schemes. Discharge and irrigation quality standards in NSW commonly use BOD_5.

Total organic carbon is present in landfill leachate at high levels (typically greater than 1000 milligrams/litre) during the active landfilling phase. Unimpacted or slightly disturbed surface waters typically have total organic carbon levels less than 20 milligrams/litre.

Total suspended particulates: particulate matter suspended in the air and typically measured in units of $\mu g/m^3$ for an annual averaging period. Typical sources of dust and fine particulate matter at landfills include unsealed roads, earthworks, waste-handling operations, composting, concrete waste reprocessing, and vehicle exhaust emissions.

Total suspended solids: the combined content (in milligrams/litre) of all solid substances suspended in water that can be removed by filtration. At a landfill, both leachate and stormwater runoff often have high levels of suspended solids, typically in the range of 200 to 1000 milligrams/litre.

Typical levels in eastern Australian rivers are from 10 to 50 milligrams/litre, depending on catchment characteristics.

High levels of total suspended solids can give receiving watercourses a turbid appearance and can affect aquatic ecosystems (see ANZECC 2000, volume 2, section 8.2.1.3).

Trigger value or trigger level: the value of an indicator parameter such as a chemical contaminant or a gas concentration above which (or sometimes below which) prescribed action must be taken.

Unsaturated zone: extends from the top of the ground surface to the water table. Water in this zone is retained by a combination of adhesion and capillary action and is termed soil moisture.

Virgin excavated natural material: material defined in the *Protection of the Environment Operations Act 1997* as virgin excavated material (as amended from time to time), which at the time of publication of these guidelines means natural material (such as clay, gravel, sand, soil or rock fines):

(a) that has been excavated or quarried from areas that are not contaminated with manufactured chemicals, or with process residues, as a result of industrial, commercial, mining or agricultural activities, and

(b) that does not contain any sufidic ores or soils or any other waste,

and includes excavated natural material that meets such criteria for virgin excavated natural material as may be approved for the time being pursuant to an EPA gazettal notice.

Volatile organic compounds: organic chemical compounds, human-made and naturally occurring, that have high enough vapour pressures under normal conditions to significantly vaporise and enter the atmosphere. They are components of landfill gases in small quantities and include some potentially toxic organic compounds.

Volatile solids content of waste: the amount of total solids in the waste lost when the waste is heated at 550°C in the presence of excess air.

Waste: means material defined in the *Protection of the Environment Operations Act 1997* as waste (as amended from time to time). For the latest meaning of waste under this Act, see www.legislation.nsw.gov.au.

Waste Classification Guidelines: the document titled Waste Classification Guidelines (NSW EPA, 2014) published by the EPA as revised and in force from time to time.

Water balance: a set of simulations and calculations used to estimate the volume of leachate that will be generated and the required size of leachate storage infrastructure at landfills.

References

Albright, William H., Benson, Craig H., and Waugh, W. J. 2010, *Water Balance Covers for Waste Containment: Principles and Practice.* ASCE Press, Reston, VA.

American Public Health Association 2012, *Standard Methods for the Examination of Water and Waste Water*, 22nd edition. American Public Health Association, Washington, DC

ANZECC 1990, *Technical Basis for Guidelines to Minimise Annoyance due to Blasting Overpressure and Ground Vibration.* Australia and New Zealand Environment and Conservation Council, Canberra. www.epa.nsw.gov.au/resources/noise/ANZECBlasting.pdf

ANZECC 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000.* Australia and New Zealand Environment and Conservation Council (Canberra) and Agriculture and Resource Management Council of Australia and New Zealand. www.environment.gov.au/water/publications/quality/australian-and-new-zealand-guidelines-fresh-marine-water-quality-volume-1

ASTM International, ASTM D5514/D5514M-14 2014, *Standard Test Method for Large Scale Hydrostatic Puncture Testing of Geosynthetics.* ASTM International, Conshohocken, PA. www.astm.org/Standards/D5514.htm

ASTM International, ASTM D6747-15 2015, *Standard Guide for Selection of Techniques for Electrical Leak Location of Leaks in Geomembranes.* ASTM International, Conshohocken, PA. www.astm.org/Standards/D6747.htm

Benson, C.H., Barlaz, M.A., Lane, D.T., and Rawe, J.M. 2007, Practice review of five bioreactor/recirculation landfills, *Waste Management* 27, 13–29.

Berger, K. 2013, *The Hydrologic Evaluation of Landfill Performance (HELP) Model, Current version HELP 3.95D,* Institute of Soil Science, University of Hamburg. https://www.geo.uni-hamburg.de/en/bodenkunde/service/help-model.html

EPA Victoria 2000, *Groundwater Sampling Guidelines*. EPA Victoria, Southbank. www.epa.vic.gov.au/our-work/publications/publication/2000/april/699

EPA Victoria 2006, *Hydrogeological Assessment (Groundwater Quality) Guidelines*. EPA Victoria, Southbank. www.epa.vic.gov.au/our-work/publications/publication/2006/september/668

EPA Victoria 2015, *Best Practice Environmental Management, Siting, Design, Operation and Rehabilitation of Landfills.* EPA Victoria, Southbank. www.epa.vic.gov.au/our-work/publications/publication/2014/october/788-2

Geosynthetic Research Institute 2010, *GRI-GCL3 Standard Specification for Test Methods, Required Properties, and Testing Frequencies of Geosynthetic Clay Liners (GCLs)*, Revision 2: July 26, 2010. Geosynthetic Research Institute, Folsom, PA. www.geosynthetic-institute.org/specs.htm

Geosynthetic Research Institute 2012a, *GRI Test Method GT12(a) – ASTM Version Standard Specification for Test Methods and Properties for Nonwoven Geotextiles Used as Protection (or Cushioning) Materials*, Revision 1: December 18, 2012. Geosynthetic Research Institute, Folsom, PA. www.geosynthetic-institute.org/specs.htm

Geosynthetic Research Institute 2012b, *GRI Test Method GT12(b) – ISO Version Standard Specification for Test Methods and Properties for Nonwoven Geotextiles Used as Protection (or Cushioning) Materials*, Revision 1: December 18, 2012. Geosynthetic Research Institute, Folsom, PA. www.geosynthetic-institute.org/specs.htm

Geosynthetic Research Institute 2012c, *GRI Test Method GT13(a) – ASTM Version Standard Specification for Test Methods and Properties for Geotextiles Used as Separation*

Between Subgrade Soil and Aggregate, Revision 3: December 19, 2012. Geosynthetic Research Institute, Folsom, PA. www.geosynthetic-institute.org/specs.htm

Geosynthetic Research Institute 2012d, *GRI Test Method GT13(b) – ISO Version Standard Specification for Test Methods and Properties for Geotextiles Used as Separation Between Subgrade Soil and Aggregate*, Revision 1: December 19, 2012. Geosynthetic Research Institute, Folsom, PA. www.geosynthetic-institute.org/specs.htm

Geosynthetic Research Institute 2014a, *GRI Test Method GM13 Standard Specification for Test Methods, Test Properties and Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes*, Revision 12: November 14, 2014. Geosynthetic Research Institute, Folsom, PA. www.geosynthetic-institute.org/specs.htm

Geosynthetic Research Institute 2014b, *GRI Test Method GM17 Standard Specification for Test Methods, Test Properties and Testing Frequency for Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes*, Revision 10: November 14, 2014. Geosynthetic Research Institute, Folsom, PA. www.geosynthetic-institute.org/specs.htm

ISWA Working Group on Landfill 2010, *Landfill Operational Guidelines,* 2nd Edition. International Solid Waste Association, Vienna.

Kolstad, D.C., Benson, C.H., and Edil, T.D. 2004, Hydraulic conductivity and swell of nonprehydrated Geosynthetic Clay Liners permeated with multispecies inorganic solutions, *Journal of Geotechnical and Geoenvironmental Engineering*, 130(12), 1236–1249.

McKenzie N., Coughlan K., and Cresswell H. 2002, *Soil Physical Measurement and Interpretation for Land Evaluation*. CSIRO Publishing, Clayton, Victoria

National Uniform Drillers Licensing Committee 2012, *Minimum Construction Requirements For Water Bores In Australia*, Third Edition. Australian Drilling Industry Training Committee Ltd, Lane Cove, NSW. www.adia.com.au/resources/waterwell-sector/water-bore-construction/

National Health and Medical Research Council and the Natural Resource Management Ministerial Council 2011 (updated 2014), *Australian Drinking Water Guidelines 6*. Version 3. National Water Quality Management Strategy, Canberra. www.nhmrc.gov.au/guidelines-publications/eh52

National Environment Protection Council 1999, *National Environment Protection (Assessment of Site Contamination) Measure*. www.comlaw.gov.au/Details/F2013C00288

NSW DEC 2004a *Approved Methods for the Sampling and Analysis of Water Pollutants in NSW.* NSW Department of Environment and Conservation, Sydney. www.environment.nsw.gov.au/resources/water/approvedmethods-water.pdf

NSW DEC 2004b, *Environmental Guidelines: Use of Effluent by Irrigation*. NSW Department of Environment and Conservation, Sydney. www.environment.nsw.gov.au/resources/water/effguide.pdf

NSW DEC 2005, *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales*. NSW Department of Environment and Conservation, Sydney. www.environment.nsw.gov.au/resources/air/ammodelling05361.pdf

NSW DEC 2006a, *Assessing Vibration: A Technical Guide*. NSW Department of Environment and Conservation, Sydney. www.epa.nsw.gov.au/noise/index.htm.

NSW DEC 2006b, *Assessment and Management of Odour from Stationary Sources in New South Wales*. NSW Department of Environment and Conservation, Sydney. www.epa.nsw.gov.au/resources/air/20060440framework.pdf

NSW DEC 2006c, *Managing Urban Stormwater: Harvesting and Reuse*. NSW Department of Environment and Conservation, Sydney. www.environment.nsw.gov.au/resources/stormwater/managestormwatera06137.pdf

NSW DEC 2006d, *Using the ANZECC Guidelines and Water Quality Objectives in New South Wales*. NSW Department of Environment and Conservation, Sydney. www.environment.nsw.gov.au/water/usinganzeccandwqos.htm

NSW DEC 2007a, *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales*. NSW Department of Environment and Conservation, Sydney. www.epa.nsw.gov.au/licensing/wateranalysisMethods.htm

NSW DEC 2007b, *Guidelines for the Assessment and Management of Groundwater Contamination*. NSW Department of Environment and Conservation, Sydney. www.epa.nsw.gov.au/resources/clm/groundwaterguidelines07144.pdf

NSW DECC 2007, Local government air quality toolkit (available only on the web). NSW Department of Environment and Climate Change, Sydney. www.epa.nsw.gov.au/air/lgaqt.htm.

NSW DECC 2008a, *Managing Urban Stormwater: Soils and Construction Volume 2B Waste Landfills*. NSW Department of Environment and Climate Change, Sydney. www.environment.nsw.gov.au/resources/stormwater/08188soilsconststorm2b.pdf

NSW DECC 2008b, *Managing Urban Stormwater: Soils and Construction Volume 2C Unsealed Roads*. NSW Department of Environment and Climate Change, Sydney. www.environment.nsw.gov.au/resources/stormwater/0802soilsconststorm2c.pdf

NSW DECC 2009, *Guide to Licensing Under the Protection of the Environment Operations Act 1997.* NSW Department of Environment and Climate Change, Sydney. www.epa.nsw.gov.au/licensing/licenceguide.htm

NSW DECCW 2010, *Handbook for the Design, Construction, Operation, Monitoring and Maintenance of a Passive Landfill Gas Drainage and Biofiltration System.* NSW Department of Environment, Climate Change and Water, Sydney. www.epa.nsw.gov.au/resources/warr/10141Biofiltration.pdf

NSW DECCW 2011, *NSW Road Noise Policy*. NSW Department of Environment, Climate Change and Water, Sydney. www.epa.nsw.gov.au/resources/noise/2011236nswroadnoisepolicy.pdf

NSW Department of Housing 2004, *Managing Urban Stormwater: Soils and Construction Volume 1*. NSW Department of Housing, Sydney. www.environment.nsw.gov.au/stormwater/publications.htm

NSW Department of Urban Affairs and Planning 1996, *EIS Practice Guideline: Landfilling*. NSW Department of Urban Affairs and Planning, Sydney. www.planning.nsw.gov.au/rdaguidelines/documents/Section_E_Landfilling.pdf

NSW EPA 1996, *Environmental Guidelines: Solid Waste Landfills.* NSW Environment Protection Authority, Sydney. www.environment.nsw.gov.au/resources/waste/envguidlns/solidlandfill.pdf

NSW EPA 1998, *Draft Environmental Guidelines for Industrial Waste Landfilling.* NSW Environment Protection Authority, Sydney. www.epa.nsw.gov.au/resources/waste/envguidlns/industrialfill.pdf

NSW EPA 2000, *New South Wales Industrial Noise Policy*. NSW Environment Protection Authority, Sydney. www.epa.nsw.gov.au/noise/index.htm

NSW EPA 2014, *Waste Classification Guidelines.* NSW Environment Protection Authority, Sydney. www.epa.nsw.gov.au/wasteregulation/classify-guidelines.htm

NSW Roads and Maritime Services 2011, *QA Specification 3071 Selected Material for Formation*. NSW Roads and Maritime Services, North Sydney. www.rms.nsw.gov.au/business-industry/partners-suppliers/specifications/materials.html

Peggs I.D. 2003, Geomembrane liner durability: Contributing factors and the status quo, *Proceedings of the First UK National Geosynthetics Symposium*, Nottingham, UK, pp. 1–26.

Standards Australia (various dates) *Australian Standard AS 1141 Methods for sampling and testing aggregates*. Standards Australia, Sydney.

Standards Australia (various dates), *Australian Standard AS 1289 Methods of testing soils for engineering purposes*. Standards Australia, Sydney.

Standards Australia (various dates), *Australian Standard AS 2566 Buried flexible pipelines*. Standards Australia, Sydney.

Standards Australia 2001, *Australian Standard AS 4323.3:2001 Stationary source emissions –Determination of odour concentration by dynamic olfactometry*. Standards Australia, Sydney.

Standards Australia 2007a, *Australian Standard AS 3580.1.1:2007 Methods for sampling and analysis of ambient air – Guide to siting air monitoring equipment.* Standards Australia, Sydney.

Standards Australia 2007b, *Australian Standard AS 4058:2007 Precast concrete pipes (pressure and non-pressure)*. Standards Australia, Sydney.

Standards Australia 2007c, *Australian Standard AS 3798: 2007 Guidelines on earthworks for commercial and residential developments*. Standards Australia, Sydney.

Standards Australia 2011, *Australian Standard AS 3580.14-2011 Methods for sampling and analysis of ambient air – Part 14: Meteorological monitoring for ambient air quality monitoring applications*. Standards Australia, Sydney.

Standards Australia 2012, *Australian Standard AS 4454:2012 Composts, soil conditioners and mulches*. Standards Australia, Sydney.

TRI Environmental Inc. 2014, *Electrical Leak Location General Guide*. www.linersurvey.net/wp-content/uploads/2013/01/LINER-INTEGRITY-SURVEY-GUIDE.pdf

UK Environment Agency 2003, *Guidance on Monitoring of Landfill Leachate, Groundwater and Surface Water*. Environment Agency, Bristol, UK. www.gov.uk/government/uploads/system/uploads/attachment_data/file/321602/LFTGN02.pdf

UK Environment Agency 2004, *Guidance on the Management of Landfill Gas*. Environment Agency, Bristol, UK. www.gov.uk/government/publications/management-of-landfill-gas-lftgn-03

UK Environment Agency 2014, *LFE 2 – Cylinder testing geomembranes and their protective materials: A methodology for testing protector geotextiles for their performance in specific site conditions*. Environment Agency, Bristol, UK. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/321491/LFE2_cylinder_testing_geomembranes_and_their_protective_materials.pdf

USEPA 1991, *Handbook Ground Water Volume II: Methodology*. United States Environmental Protection Agency, Washington DC.

USEPA 2005, *Landfill Gas Emissions Model (LandGEM) Version 3.02*. United States Environmental Protection Agency, Washington DC. www.epa.gov/ttncatc1/dir1/landgem-v302-guide.pdf

USEPA 2009, *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance.* Office of Resource Conservation and Recovery Program Implementation and Information Division, United States Environmental Protection Agency, Washington DC. www.epa.gov/wastes/hazard/correctiveaction/resources/guidance/sitechar/gwstats/

Waste Management Association of Australia 2011, *Guidelines for the Assessment, Design, Construction and Maintenance of Phytocaps as Final Covers for Landfills*. www.wmaa.asn.au/scripts/cgiip.exe/WService=WMAA/ccms.r?pageid=10118