



Department of
Environment

BEST PRACTICE ENVIRONMENTAL MANAGEMENT

Draft

**SITING, DESIGN,
OPERATION
AND REHABILITATION
OF LANDFILLS**

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Level 8, Westralia Square
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AUSTRALIA

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FOREWORD

Landfills have served a key role in the management of solid wastes and are likely to continue to be an important component of the waste management system for at least the next 10 years. The implementation of the waste management hierarchy of waste avoidance, waste reduction, waste reuse, waste recycling and finally waste disposal has resulted in significant diversion of waste from landfill. This will continue, however, landfills will continue to underpin our waste management strategies until waste disposal is replaced by these measures. In the interest of intergenerational equity, today's landfills should not leave an environmental legacy for future generations to address. Furthermore, for as long as landfilling remains part of our waste management strategy, best practice measures must be adopted to ensure that landfills are managed acceptably.

The elimination or minimisation of adverse environmental effects from wastes in general, and landfills in particular, is being dealt with by Government on two fronts. The Waste Management Board has developed a Strategic Framework for Waste Management in Western Australia which will progressively set policy objectives for waste management in the State. In support of this, the Department of Environment, through the industry licensing process, is gradually refining and strengthening the regulatory framework for the operation of waste management facilities. This document represents part of that process.

Environmental impacts associated with the operation of a landfill site include adverse impacts on air quality through odour and dust, unsightly litter, increased traffic, potential adverse impacts on surface water and groundwater, and potential impacts from birds and vermin.

The first and most important consideration in the prevention of environmental impacts from landfill is selecting an appropriate landfill site. Once an appropriate site has been selected, it is critical for landfill operators to adopt best practice in:

- rigorous assessment of landfill design and its effect on the environment;
- construction quality and quality assurance;
- landfill management; and
- landfill rehabilitation.

The underlying philosophy of best practice environmental management is continual improvement. Waste management planners, landfill designers and operators are encouraged to adopt and implement this guideline as well as adopting the philosophy of continual improvement to ensure a high level of protection for the environment in keeping with community expectations.

This draft document is intended to apply to future Class III landfills, and where appropriate, upgrades to existing Class III landfills. In concert with a review of landfill standards and landfill policy in WA, it is proposed to further develop this document to apply to a Class I inert Landfills and Class II putrescible landfills. In the meantime, this document should be used as a guide for how the operation of such landfills might be improved to meet community expectations.

The DoE will be pleased to receive comments on this guideline from the waste management industry, industry and the public by 31 March 2006, and these will considered in the development of future editions. Comments should be directed to:

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Finally, acknowledgement is given to EPA Victoria for giving permission to use its Publication 788 of the same name as the major source of information in this document.

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1. INTRODUCTION

1.1 Background

Historically, landfills were commonly located on the fringe of urban development in quarries that provided the materials used in constructing our buildings and roads. As cities developed, the urban fringe moved beyond the landfills bringing residential and commercial development within close proximity of the landfill. This brought about a conflict in land uses, with landfills considered to be incompatible with these uses. This land use conflict has resulted in a ground swell of community concern about the need for landfills as well as their siting and design standards.

The Waste Management Board's Strategic Framework sets out a policy framework where landfilling of waste is the least preferred waste management option, and where it is expected that every opportunity will be taken to remove material from the waste stream through the management hierarchy – 'avoid, minimise, recycle, treat, dispose'. While this management hierarchy has been very successful in diverting waste from landfill, the policy framework recognises that landfills are likely to be required for at least the next few decades to manage wastes which are not yet able to be viably removed from the waste stream. In this context, the progressive implementation of more stringent regulation is aimed at ensuring that the landfills we do use are designed to minimise their risks to the environment.

An additional element to this policy framework is the implementation of best practice. Best Practice Environmental Management Guideline for Siting, Design, Operation and Rehabilitation of Landfills is a source document for best practice environmental management (BPEM) measures for landfills. It gives direction on the best practice siting, design, performance and rehabilitation standards for landfills commensurate with the risk they pose to the environment, and provides a guide for the measures required to meet legislative objectives. Finally, it provides a framework of environmental management objectives, required outcomes and suggested measures that may be used to achieve or surpass the objectives, encouraging innovative solutions rather than regulatory control.

In the context of the guideline, both the objectives and required outcomes are mandatory and reflect the minimum requirements of policy and community expectations. The suggested measures are the default means of achieving the required outcomes, and while strong arguments are required to implement alternatives, the suggested measures to achieve those outcomes are not mandatory.

1.2 Objectives of the guideline

This guideline aims to provide existing and future operators of landfills, planning authorities and regulating bodies with:

- information on the potential impact of landfills on the environment and how this is to be assessed;
- a clear statement of environmental performance objectives of each segment of the environment; and
- information on how to avoid or minimize environmental impacts, including suggested BPEM measures, to assist them to meet the objectives.

This guideline is intended to be used as a default position for landfill siting, design, operation and rehabilitation, and existing landfill operators should, as far as possible, implement the relevant best practice measures, described as suggested measures, contained within this guideline. Where a landfill operator believes that, for a particular section of the guideline, alternative means can achieve the objectives and required outcomes specified in all sections, then a risk based assessment will be required to support this conclusion. Alternatively, where

DoE or EPA believes that additional requirements are needed to protect the environment, then this will also be supported by a risk based assessment and tighter constraints imposed.

1.3 The guideline's audience

The target audience for this guideline is:

- Regional Waste Management Groups, particularly in the screening and ranking of potential landfill sites;
- Planning authorities, particularly in the preservation of planning attributes, such as buffer distances, of designated future landfills.
- Landfill operators in all elements of the guideline, but particularly in the design, operation and aftercare of landfills.
- The broader community so that a wider understanding can be reached of the standards that they can demand of landfills in Western Australia.
- Regulators, understanding what the expected standards are and to give some guidance to how to achieve these standards.

2. WASTE MANAGEMENT FRAMEWORK

2.1 Waste management hierarchy

When making decisions regarding the management of all wastes, including municipal and industrial wastes, the following hierarchy must be followed at all times:

- (a) avoidance;
- (b) minimisation;
- (c) recycling;
- (d) treatment;
- (e) disposal.

This hierarchy is expressed in the Waste Management Board's Strategic Direction document and cuts across all aspects of waste management, regardless of source.

Accordingly, where a generator has exhausted all possibilities for waste avoidance and reduction, then the alternatives for reuse, recycling and reclamation should be investigated. The landfill operator can assist in this process by providing facilities for the sorting of waste. Disposal to landfill should only be considered as a last resort when options further up the hierarchy are not available.

2.2 Statutory framework

All landfill operations must comply with the Environment Protection Act 1986 (EP Act), its Regulations and relevant environmental protection policies (EPPs).

The following types of landfills are defined in the Environment Protection Regulations 1997 and are subject to the works approval provisions of the EP Act:

- Category 63 (Class I) – Inert landfills
- Category 64 (Class II, III) – putrescible landfills
- Category 65 (Class IV) – secure landfills
- Category 66 (Class V) – intractable landfill

This guideline only deals with Class III landfills.

A works approval must be obtained before a landfill can be constructed or significantly modified. Operating Class III landfills are also subject to licensing. The licence conditions set the performance objectives of the operating landfill, define operating parameters and commonly require monitoring to check on environmental performance.

The legislation that is particularly relevant is described below.

2.2.1 Environmental Protection Act 1986

The principle legislative vehicle for pollution control in Western Australia is the Environmental Protection (EP) Act 1986.

The EP Act regulates the discharge or emission of waste to water, land or air by a system of works approvals and licences. The acceptable environmental quality standards and conditions for discharging waste and identification of beneficial uses of the environment are specified in relevant environment protection policies (EPPs).

2.2.2 Environment Protection Policies

Environment Protection Policies (EPPs) set out policies of the Government to manage the environment. These policies establish the environmental quality that must be attained and maintained to protect designated beneficial uses (i.e. amenity, health, ecosystem protection). Policies typically set quantitative, ambient, environmental (e.g. air, water, soil) objectives, and specify measures that must be implemented to minimise the risk of activities causing the policy's ambient standards to be exceeded.

Activities that result in environmental quality objectives being exceeded or cause pollution may be subject to enforcement action.

2.3 Best Practice Framework

This document is intended to provide guidance for how landfill operators can meet the environment protection objectives of the regulatory framework. This is achieved by establishing a hierarchy of objectives, required outcomes and suggested measures for each section of the document. The objectives and required outcomes are derived directly from legislation and must be achieved. The suggested measures are suggestions for how to achieve the objectives and required outcomes.

Where a landfill operator believes that alternative means to the suggested measures can be used to achieve the objectives and required outcomes, then the operator will need to provide an explanation that demonstrates this to the satisfaction of the DoE.

Alternatively, in the event that the suggested measures contained in this document are not likely to achieve the objectives and required outcomes then the DoE may require alternative measures to those suggested, which the DoE will support with an assessment of why the alternative measures are required. This is most likely to occur where a landfill is located or proposed in a particularly sensitive environment.

3. CLASSIFICATION OF LANDFILLS

This BPEM applies to Class III municipal waste landfills, considered to be a waste disposal facility at which solid, non-hazardous waste from municipal and/or industrial sources is permanently deposited on or in the ground. This BPEM does not cover facilities with for:

- inert waste only
- hazardous wastes only
- temporary storage of waste
- uncontaminated soils.

As is detailed in Table 1, landfills are classified according to the wastes accepted by the landfill. This guideline deals with four types of waste: putrescible, inert, industrial waste or contaminated soils that meet relevant waste acceptance criteria; and fill material.

The classification of a landfill is the most stringent based on the wastes received or proposed to be received at the landfill. This classification is then used throughout this BPEM to determine the design, construction, operation and maintenance of the landfill necessary to protect the beneficial uses of the environment.

Table 1 Classification of landfills

Landfill class	Common name	Waste types permitted for disposal
Class I (Prescribed Premises Category 63)	Inert Landfill	<ul style="list-style-type: none"> • Clean Fill • Type 1 Inert Waste • Contaminated solid wastes meeting waste acceptance criteria specified for Class I landfills (possibly with specific licence conditions) • Type 2 Inert Waste (with specific licence conditions) • Type 3 Inert Waste (subject to DEP approval) • Type 1 Special Waste
Class II (Prescribed Premises Category 64 or 89)	Putrescible Landfill	<ul style="list-style-type: none"> • Clean Fill • Type 1 Inert Waste • Putrescible Wastes • Contaminated solid waste meeting waste acceptance criteria specified for Class II landfills (possibly with specific licence conditions) • Type 2 Inert Wastes (with specific licence conditions) • Type 1 and Type 2 Special Wastes (for registered sites as approved under the Controlled Waste Regulations)
Class III (Prescribed Premises Category 64)	Putrescible Landfill	<ul style="list-style-type: none"> • Clean Fill • Type 1 Inert Waste; • Putrescible Wastes; • Contaminated solid waste meeting waste acceptance criteria specified for Class II or Class III landfills (possibly with specific licence conditions) • Type 2 Inert Wastes (with specific licence conditions) • Type 1 and Type 2 Special Wastes
Class IV (Prescribed Premises Category 65)	Secure Landfill	<ul style="list-style-type: none"> • Clean Fill • Type 1 Inert Waste; • Contaminated solid waste meeting criteria specified for Class II, Class III or Class IV landfills (possibly with specific licence conditions) • Type 2 Inert Wastes (with specific licence conditions) • Type 1 and Type 2 Special Wastes
Class V (Prescribed Premises Category 66)	Intractable Landfill	<ul style="list-style-type: none"> • Intractable and other wastes in accordance with the approvals for the site.

4. BEST PRACTICE SITING CONSIDERATIONS

The appropriate siting of a landfill is the primary environmental control, so a preliminary investigation of all possible landfill sites should be conducted to identify those sites with the best potential to be developed for landfilling.

The objective of this section is to establish the means and criteria for identifying and ranking those sites that are the most appropriate for future landfills, because these are the ones that require the fewest engineering and management controls to meet the objectives of all relevant environment objectives.

An investigation of the sites that have the best potential for landfilling is conducted in two steps:

- a broad approach to identify all potential sites for new facilities from a broader group of all possible sites; and
- ranking of the potential sites in terms of their preference for use as a landfill.

The investigation is conducted by a proponent, and will result in a ranking of preferred waste disposal sites within and adjacent to the area to be served by the landfill. This ranking should be used in the development of planning strategies for region, and the development of new landfills should be in accordance with this ranking.

4.1 Screening for potential landfill sites

Screening for potential landfill sites starts with a list of all possible sites. As a minimum, this should include all extractive industry sites in the region, but may also include undeveloped sites which may be suitable for trench-and-fill or mound landfills (see section 4.1.2).

The hierarchy of aspects to be considered when screening for potential landfill sites is:

1. Community needs
2. Landfill type
3. Buffer distances
4. Groundwater
5. Surface water
6. Flora and fauna
7. Infrastructure
8. Geology
9. Land ownership

These are discussed in detail below.

Once a list of potential landfill sites has been derived from a list of all possible landfill sites, this list should be ranked to indicate the preferred order of development of potential sites as landfills.

4.1.1 Community needs

A landfill should not be located where it is not needed for the disposal of a community's waste. Generally, local government is responsible for providing a framework for the orderly development of waste management facilities for both the public and private sectors, and ensuring that a reliable system of waste management, including landfill airspace, is maintained within a region.

It is important to liaise with the community very early in the planning stage, as this enables early identification of the issues that are important to the local community and environment, and as a result, has a significant result on the siting, design and operation of the landfill. It also unlocks the significant amount of local knowledge contained by the community, enabling insights into how better environmental outcomes may be achieved. Full community engagement is expected of any project that may impact upon the community.

One of the key aspects that a community may expect to be addressed is the visual impact of the operation. The clever use of natural screening to reduce the visual intrusiveness of landfill operations is one way of ensuring that the landfill fits in with the general community. This should be considered at a very early stage, and where necessary, particular care should be used to construct bunds for visual screening, noise barriers and landscaping.

Best practice measures for community consultation include:

- recognising that local knowledge may provide useful insights leading to better environmental outcomes
- being readily contactable and flexible in dealing with community concerns
- listening to all community concerns and ensuring a considered response is provided to all concerns raised.

Further information on successful consultative programs can be obtained from DoE's Interim Industry Guide to Community Involvement document.

4.1.2 Landfill type

When screening for potential landfill sites, an important aspect is the type of landfill to be developed. The four basic types of landfills and the hierarchy of their preference for use is discussed below:

1. the area method where an existing hole such as a former quarry is filled;
2. the trench-and-fill method where a hole is dug and back filled with waste using the excavated material as cover;
3. the mound method where most of the landfill is located above the natural ground level; and
4. the valley or change of topography fill method where a natural depression is filled.

The most appropriate landfill type for a region will be determined based on local conditions as identified in the environmental assessment, however the preferred types are the area method and the trench-and-fill method.

The area method is preferred because it achieves an additional outcome of rehabilitating an existing hole. It is also generally easier to manage litter and leachate (contaminated water that has percolated through or drained from a landfill) from the site.

Trench-and-fill landfills are a good landfill type where there are no suitably located holes, or where the trench-and-fill alternative achieves better environmental outcomes. They also enable the operator to determine exactly how the hole is to be configured on the ground, thus enabling the best possible design of the landfill.

Mound landfills are to be avoided because their exposed nature requires significant litter controls, as well as presenting a significant visual impact on the landscape. Further difficulties attached to these landfills are leachate seeps from the side of the landfill and the potential for the landfill cap to slip.

Valley fill landfills are to be avoided as they have inherent environmental problems such as unstable slopes, water infiltration and leachate seepage. Due to the open nature of these landfills and shallow placement of waste, they consume a greater amount of soil for cover and capping than an equivalent volume landfill in a disused quarry.

Furthermore, because a valley fill landfill is by definition located in a drainage line, extensive management is required to control stormwater ingress into the landfill, potential planes of geotechnical weakness from leachate flows within the landfill, and leachate seeping from the landfill. This type of landfill should be limited to select solid inert wastes that are part of an engineered solution for an erosion problem.

4.1.3 Buffer distances

To protect sensitive land uses from any impacts resulting from normal and upset landfill operating conditions, such as offensive odours, noise, litter and dust, an adequate separation (buffer) distance should be maintained between the landfill and sensitive land uses. Sensitive land uses include houses, schools, hospitals, airports and market gardens.

Buffer areas are not an alternative to providing appropriate management practices, but provide for contingencies that may arise with typical management practices. Where this buffer is not available, management practices need to be significantly improved to provide the same level of protection to sensitive land uses. While buffers have traditionally been used to protect residential amenity, the buffer for a landfill may also protect different segments of the environment such as water courses or different sensitive uses such as airports.

Table 2 identifies the minimum buffer distances recommended by the EPA to protect the environment and to prevent any amenity reduction in sensitive areas. Buffer distances are measured from the activities capable of causing a nuisance to the nearest sensitive land use.

Table 2 Recommended buffer distances

Type of landfill	Recommended buffer distances
Class 1	150 metres from residential development.
Class II or III	500 metres from residential development.
	150 metres from single dwelling.
Class IV	Case by case.
Class V	Case by case.

These buffer distances are based on the buffer distances contained within the EPA Guidance for the Assessment of Environmental Factors Draft Guidance Statement No. 3, Separation Distances Between Industrial and Sensitive Land Uses.

Subject to an evaluation demonstrating that the environment will be protected and the amenity of the sensitive areas will not be adversely affected, lesser buffer distances may be applied subject to a risk assessment that considers design and operational measures. As part of a risk management approach, additional design or operational measures will be required to ameliorate the risks associated with a reduction of the buffer distances identified in the table.

Land within buffer areas may be used for purposes that are not adversely affected by landfilling. It is preferred that this land is owned or at least under the control of the landfill operator.

Planning overlays should include the buffer area to ensure that it is maintained through the life of the landfill. Contingency plans should also be developed to show how the landfill could be developed and operated to ensure that the amenity of the affected land would still be preserved. For landfills with an anticipated lifespan exceeding 10 years, an analysis should be conducted of the anticipated changes in the zoning or land use of the surrounding area during the life of the facility.

4.1.4 Groundwater

Pollution of groundwater by leachate is very difficult to remediate, and accordingly, landfills should be sited in areas where impacts on beneficial uses of groundwater are minimised. In particular, landfills should not be located:

- in areas of potable groundwater, groundwater recharge areas or in areas identified by the DoE as a Groundwater Supply Area; or
- below the regional watertable.

The DoE administers a groundwater database containing information on boreholes throughout Western Australia. This database contains information on the location of boreholes, water levels and some chemical analysis information on groundwater quality. The data can be used to estimate the depth to and quality of groundwater, its general flow direction and utilisation; however these estimates must be verified by local field testing.

Landfills below the regional watertable are not generally considered to be best practice because landfilling below the regional watertable is to effectively place the landfill directly in the segment of the environment to be protected (groundwater). Therefore the risks of detrimental impacts on beneficial uses of groundwater are much higher. Where such a site must be landfilled, a groundwater extraction system should be installed to keep groundwater below the landfill, or the leachate level within the landfill should be managed to at least five metres below the watertable (as discussed in section 5.3.4). These systems are strongly discouraged because of the continual and effectively perpetual requirement to:

- Maintain and operate pumps;
- Manage an increased volume of groundwater or leachate; and
- Intensively monitor both groundwater and leachate quality and levels.

Any landfill that places waste below the watertable will require significantly greater engineering and management controls to ensure ongoing protection of groundwater.

Where the watertable is elevated, the region may need to consider a shallow landfill with the bulk of the waste above ground. Where the most appropriate site for a landfill is in a hole that extends below the watertable, the base of the landfill should be raised to above the watertable using a sub-base material that will attenuate contaminants. The sub-base material between the base of the liner and the watertable (that is, in the unsaturated zone) should be made of a natural or imported fine-grade soil with a cation exchange capacity of about 10 mEq/100g. This cation exchange capacity allows the sub-base to remove some contaminants from leachate seeping through the base of the liner, and further minimises the risk of groundwater pollution from the landfill. Recommended minimum thicknesses for this attenuation zone are tabulated in Table 3.

The most preferred site for a landfill is one that reduces the risk of groundwater pollution by providing a natural unsaturated attenuation layer beneath the liner for contaminants that may leach through the liner. This means that sites with naturally attenuating soils, such as sites in clayey areas, are preferred to those that do not have such soils, such as sites in sandy areas.

Table 3 Minimum separation of wastes from watertable

Waste accepted	Minimum thickness of attenuation zone
Putrescible waste (Class II or III landfill)	2 metres
Inert waste (Class I landfill)	1 metre
Fill material, potential waste acid sulfate soil or selected solid inert wastes*	Below watertable

* Selected inert wastes, or hard wastes, contain negligible plastic, steel and biodegradable material, including woody material.

4.1.5 Surface waters

Since leachate can be toxic to aquatic organisms and cause eutrophication of the waterways, it must be managed so that it cannot escape to surface waters. Accordingly, landfilling should not occur in:

- wetlands protected under Ramsar and JAMBA treaties;
- marine and coastal reserves;

- water supply catchments;
- land liable to flooding if determined to be so liable by the responsible drainage authority; and
- within 100 metres of surface waters.

Landfills should not be located in a 1-in-a-100 year watertable floodplain (that is, where there is a one per cent chance in any year that the site will flood) unless it can be demonstrated that the facility will be protected from flooding and erosion by flood waters.

Tipping areas for putrescible landfills should be located more than 100 metres from surface waters. A solid inert landfill may be located within 100 metres of surface waters if an assessment demonstrates there is no interaction between groundwater and the adjacent surface-waterbody that would potentially transport contaminants to the surface-waterbody, and also demonstrates that protective measures can ensure no transfer of waste or contamination to surface waters.

4.1.6 Flora and fauna protection

The development of landfills may impact on the flora and fauna of the local area. The potential impacts on flora and fauna are:

- clearing of vegetation;
- loss of habitat and displacement of fauna;
- loss of biodiversity by impacts on rare or endangered flora and fauna;
- potential for spreading plant diseases and noxious weeds;
- litter from the landfill detrimentally impacting on flora and fauna;
- creation of new habitats for scavenger and predatory species;
- erosion; and
- alteration of water courses.

Particular areas where landfilling should not occur are:

- critical habitats of taxa and communities of flora and fauna; and
- areas where landfilling is likely to have a significant impact on threatened species and ecological communities as identified in the Environment Protection and Biodiversity Conservation Act 1999, except with the approval of the Commonwealth Environment Minister.

A survey of the site and collection of comprehensive baseline environmental data are essential steps in the assessment of potential impacts from proposed landfilling operations. The nature and extent of this data should be site-specific, taking into account the size of the proposed operation and the risks posed to adjacent sensitive areas. This includes potential impacts from scavenger birds on aircraft safety and water supplies, as well as impacts from predatory animals, such as feral cats, on surrounding native fauna. An expert in the field should be consulted for an assessment of potential impacts from scavenger birds or predatory animals.

4.1.7 Infrastructure

Local infrastructure must be able to sustain the operation of a landfill. Landfilling requires the transportation of waste. The capacity of the road network to cope safely, and with a minimum of disturbance to the local community, with any increased traffic load should be examined. The preferred transportation route should minimise the transport of waste through residential and other sensitive areas. This consideration may influence the placement of the entrance to the landfill.

A transportation study may reveal the need for additional road infrastructure, such as freeway interchanges, turning lanes or signals.

The availability of services such as reticulated water, sewerage and power will influence the facilities provided for staff at the landfill and perhaps indicate a need to provide additional services, such as water storage for fire-fighting purposes.

4.1.8 Geological setting

As the decomposition and stabilisation of waste may take many decades, landfills should be constructed in areas where the land on which the landfill will be placed is stable, thereby enabling the long-term integrity of the landfill cap and liner system to be assured.

One potential impact on this stability is earthquakes. While Australia is considered a seismically stable continent, it does not mean that no large-scale earthquakes will occur, only that they are infrequent. A reasonable degree of assurance of the long-term protection of the landfill from an earthquake is to avoid sites within 100 metres of a fault line displaced in the Holocene period. Maps that show the location of fault lines throughout Western Australia are available.

A further part of the assessment of the suitability of a potential site is the geotechnical stability of the ground on which the landfill will be placed. This land should be capable of supporting the landfill, with or without engineering assistance. The assessment should also extend to the site embankments and slopes. In an area that has been subject to subsurface mining, it must be demonstrated that the ground will not collapse.

Where a landfill is located within a karst region, characterised by sinkholes, caves and possibly large water springs, special attention must be given to the investigation of the stability of the area and the containment of leachate. In general, karst regions are inappropriate for siting landfills.

A further factor to consider is the mineralogy of the area in which the landfill is to be built. In particular, the shrink/swell characteristics of the landfill substrate should be assessed to minimise the potential for differential movement of the liner resulting from changes in the moisture content of the substrate. A further aspect to consider when assessing the local mineralogy is the suitability of the local material for liner construction.

4.1.9 Land ownership

Land ownership will influence the siting of landfills. Where it is proposed that a site be on State land, a landfill may not be established without the written consent of the Minister responsible for the relevant Act under which the land is managed.

Screening for potential landfill sites
Objective
To identify and rank those sites that require the fewest engineering and management controls to meet the objectives of all environment policies.
Required outcomes
<ul style="list-style-type: none"> • Use waste management planning to identify the sites within or adjacent to the region which are best suited for future landfilling. • Develop landfill sites in the sequence specified in the relevant waste management plan. • Ensure that sufficient buffer is available for the life of the landfill. • Consider the most appropriate landfill type to meet the requirements imposed by local conditions. • Ensure that the landfill is sited to protect surface waters, groundwater and flora & fauna.
Suggested measures
<ul style="list-style-type: none"> • Consider natural features which will reduce the visual impact of the landfill. • Commence the community consultation process early using the DoE's Interim Industry

Screening for potential landfill sites

Guide to Community Involvement document as a guide.

- Avoid valley fill landfills.
- Provide buffers in accordance with Table 2, or where these are unavailable, demonstrate the additional measures to be taken to safely enable a lesser buffer.
- Avoid locating a landfill in areas of potable groundwater, groundwater recharge areas or groundwater supply protection areas.
- Provide an unsaturated attenuation layer to the landfill liner.
- Avoid landfills below the regional watertable.
- Where the proposed landfill site extends below the watertable, backfill the site to above the watertable.
- Avoid locating a landfill in a wetland, marine and coastal reserve, water supply catchment, 1-in-100 year floodplain or within 100 metres of surface waters.
- Carry out a detailed existing condition survey of the flora and fauna on and around the site to identify potentially sensitive aspects.
- Ensure that the local infrastructure can sustain the operation of a landfill, and identify any infrastructure needs.
- Assess the geology to determine the stability of the land on which the landfill is proposed to be sited, including potential impacts of seismic activity, underground mining and karst terrain.

5. BEST PRACTICE DESIGN

Once a landfill has been sited, it must be designed to ensure that it is able to protect the environment. This section sets out the objectives and required outcomes of each element of a landfill design, as well as providing suggested measures for achieving these. Where the landfill designer believes that alternative measures can achieve the objectives and required outcomes, these should be supported by a risk assessment.

The design of a landfill facility will be influenced by the existing natural environment, adjacent land uses, available infrastructure, waste to be received and the need to provide integrated waste-management facilities supplying both disposal and recycling options. It must be based on a thorough understanding of the existing environment and address all of the site-specific circumstances of each site.

The DoE will require this section of the guideline to be implemented for all new landfills as a minimum. The Environmental Impact Assessment (EIA) process may impose stricter conditions. The DoE will further require existing landfills to implement the guidelines for all new cells.

5.1 Environmental assessment

To gain a thorough understanding of the existing environment at the site in order to develop a sound landfill design, an environmental assessment of the site is required. This assessment must examine the impact of the landfill on the air, groundwater, surface water and noise environments, and should be based on at least two to three years of data. This data may need to be constructed through a combination of recent, targeted data sets with existing, less targeted sets.

If, following an environmental assessment, the site is identified as unsuitable for a landfill, then the proposal should not proceed any further.

An environmental assessment should contain:

- Meteorological data, including monthly rainfall, monthly evaporation, seasonal wind strength and direction;
- Hydrogeological assessment, which includes:
 - local and regional geology;
 - spatial distribution of groundwater (local and regional if watertable is artificially depressed);
 - depth to groundwater (current and after any rebound if the watertable is artificially depressed) and watertable elevation (mAHD);
 - groundwater gradient and flow direction;
 - description of groundwater interaction with local surface waters;
 - aquifer physical properties:
 - permeability;
 - aquifer thickness;
 - saturated thickness; and
 - porosity
 - aquifer chemical properties:
 - mineralogy; and
 - cation exchange and sorption capacity;
 - groundwater quality (local and regional if aquifer is likely to have been impacted on by previous activities);
 - beneficial uses of groundwater to be protected;
 - groundwater use in the surrounding area;
 - predicted extent and degree of impacts on groundwater quality during and after the landfill operation;
 - verification that beneficial uses are not adversely impacted at the site, or at the boundary of an attenuation zone if one is designated by the DoE;
- Water Management, including:
 - water balance for the site and estimated volume of leachate to be generated;
 - leachate collection, storage facilities, treatment and disposal;
 - stormwater diversion banks and/or cut-off drains and storage dams;
 - fire-fighting equipment and water supply; and
 - wheel washes; and
- Landfill gas and odour control, including:
 - availability of cover material onsite;
 - anticipated volume and rate of landfill gas generation;
 - potential users of landfill gas;
 - impacts of landfill gas on greenhouse gas emissions; and
 - risk posed by migration of gas.

Environmental Assessment
Objective
To gain a thorough understanding of the environment where the landfill is to be sited in order to design the landfill to minimise impacts on the environment.
Required outcomes
<ul style="list-style-type: none"> • Conduct a hydrogeological assessment to assess the potential for impacts on local groundwater quality. • Investigate water management requirements. • Investigate landfill gas and odour control options.

5.2 Site layout

The landfill and associated facilities should be designed to:

- minimise potential environmental impacts;
- minimise health and safety risks for landfill operators and the public;
- encourage recycling; and
- make the most efficient use of resources onsite.

Best practice is to fill the landfill site as a series of independent tipping areas, each taking less than two years to fill, after which they are immediately rehabilitated. In the case of a large area fill landfill, this will require the establishment of independent cells. In the case of trench-and-fill landfills, each trench should be sized to ensure that it is filled within two years. Larger excavations for trench-and-fill landfills must be filled on a cellular basis.

Where an area fill or large trench-and-fill excavation is to be filled as a series of cells, prudent location of these cells may help to:

- stabilise a batter or embankment;
- screen the landfill operation from view;
- reduce groundwater flow into the site;
- shed clean stormwater into the stormwater system;
- reduce the need to relocate facilities such as leachate dams;
- minimise the need to constantly construct roads within the site; and
- avoid active landfilling near areas being developed for residential purposes.

For a trench-and-fill landfill, the trenches should be:

- aligned perpendicular to the prevailing wind to reduce litter; and
- use excavated soil to create windbreaks.

The proper balance between all these factors encourages recycling, makes the most efficient use of resources and minimises amenity reducing factors.

A transfer station with recycling and drop-off areas should be provided so that the public has no need to unload vehicles at the tipping area, thus minimising safety risks to the public. In turn, this means that less supervision of the tipping area is required and that waste sorting is also encouraged. Transfer stations should be designed according to guidelines such as the Guide to Best Practice at Transfer Stations, published by EcoRecycle Victoria.

The gradient of internal haul roads, the external road network and availability of services will influence the positioning of the transfer station, recycling facilities, site office, weighbridge, gatehouse, staff facilities, plant maintenance or storage area and the vehicle wash.

Best practice for a Class III and Class I landfill is to have a gatehouse at the entrance to the site or at a point that cannot be bypassed when travelling to the landfill. The gatehouse is the first line of active measures to vet the incoming waste stream to detect nonconforming wastes and divert materials to the recycling area. There should be facilities such as a viewing platform, elevated mirrors or video camera which allows the gatehouse attendant to readily scrutinise the incoming waste load.

A weighbridge is commonly installed at major landfill sites to facilitate accurate record keeping for the purposes of invoicing clients, landfill levy documentation and monitoring waste disposal rates.

Site Layout
Objectives
To ensure that the site layout minimises environmental and health and safety risks, encourages recycling and makes the most efficient use of onsite resources.
Required outcomes:
<ul style="list-style-type: none"> • Site layout and filling sequence planned to ensure that landfill centres are open for the minimum period of time and site operations are optimised. • Minimisation of public access to the tipping face and, where appropriate, assurance that waste received at the landfill can be vetted and recycled.
Suggested measures:
<ul style="list-style-type: none"> • Each independent tipping area to be sized so that it can be filled within two years for subsequent rehabilitation. • Class III and Class I landfills to install and operate a gatehouse, weighbridge and waste transfer station for the public. • Position site facilities to take into account haul-road gradients, the external road network and the availability of services. • Consolidate all waste prior to deposition at the landfill. • Design the gatehouse to facilitate the vetting of the incoming waste stream.

5.3 Liner and leachate collection system

The primary function of a landfill liner system is to protect groundwater from impacts of leachate. This is achieved by the landfill liner slowing the vertical seepage of leachate to allow its collection and removal by the leachate collection system. The liner may also attenuate contaminants in leachate seeping through the liner to the point where the leachate that makes contact with the aquifer beneath the landfill has minimal detrimental impact on groundwater. A further function of the liner is to retard the lateral movement of landfill gas from the landfill and the infiltration of groundwater.

The design objective of the liner and leachate collection system is to protect the beneficial uses of all groundwater, including that directly beneath the landfill.

Table 4 shows indicative best practice landfill liner performance standards, which would generally provide a high level of protection to the environment; 'Groundwater impacts from liner designs' (see Appendix 2) indicates basic modelled impacts on groundwater from the various seepage rates that may seep through the liner. Liners comprise up to five components:

- sub-base;
- clay layer;
- geomembrane and protection layer;
- drainage layer/leachate collection system;
- geotextile.

In designing a landfill liner, the landfill designer must ensure that the liner system is geotechnically stable between components and as a total system.

Table 4 : Landfill liner performance standards and indicative liner design

Landfill type	Liner performance	Indicative liner designs
Class III	Uses best available technology to control seepage to an amount not exceeding 10 L/ha/day.	<p>The diagram shows a cross-section of a landfill liner. At the top, there are two layers: 'Geomembrane' and 'Geotextiles'. Below these is a 'Drainage layer'. Underneath the drainage layer is a thick layer of 'Low permeability clay'. At the bottom is the 'Sub base'. Arrows point from the labels 'Geomembrane' and 'Geotextiles' to their respective layers, and from 'Drainage layer' to its layer.</p>
		<p>The diagram shows a cross-section of a landfill liner. At the top is a 'Drainage layer'. Below it is a thick layer of 'Low permeability clay'. At the bottom is the 'Sub base'.</p>
Class II	Uses commonly available technology to control seepage to an amount not exceeding 1,000 L/ha/day.	<p>The diagram shows a cross-section of a landfill liner. At the top is a 'Drainage layer'. Below it is a thick layer of 'Low permeability clay'. At the bottom is the 'Sub base'.</p>

5.3.1 Sub-base

The integrity of the landfill liner and leachate collection system is fundamentally reliant upon the integrity of the sub-base that lies beneath. The sub-base must be well-consolidated, with minimal settlement, in order to supply a firm platform for the compaction of the clay layer, to protect the geomembrane from excessive strains and to ensure that the drainage system drains effectively throughout the life of the landfill. The sub-base should also offer the capacity to further attenuate contaminants seeping through the liner.

Where the sub-base is undisturbed material (rock or soil) at the base of a quarry, it is likely to be well-consolidated. Where the sub-base has been installed prior to the liner and leachate collection system, it needs to be installed in such a manner that it is geotechnically stable. One method of providing this stability is to install and compact the sub-base in thin layers.

Using solid inert waste or slimes (washings from sand-mining operations) for a sub-base is not best practice because of the inherent problems in constructing a stable liner on such a sub-base. These problems, which include the very high moisture content and the acid-generating properties of many slimes, result in a sub-base that is difficult to travel across, much less compact a liner upon.

These problems may be resolved by drying the slimes to the point where the material is stiff enough to compact upon. In drying slimes, any potential for acid generation must be addressed.

If solid inert waste is used, it should be limited to crushed and compacted hard waste (rock, bricks and concrete with no timber, plastic or steel). This will ensure that the sub-base is sufficiently stiff to build a liner on.

All plans for the construction of a sub-base must be verified and approved by a geotechnical engineer. To provide assurance of the quality of construction of the sub-base, construction of the sub-base must be included in the Construction Quality Assurance (CQA) plan (see section 5.4), verifying that it is fit for its intended purpose.

5.3.2 Clay layer

The ability of clay to retard water movement and absorb exchangeable cations makes it a suitable natural material for a low-permeability liner. To meet the performance standards of the whole liner, the clay component needs to be at least one metre thick, with a hydraulic conductivity of less than 1×10^{-9} m/s using both fresh water and 50,000 ppm NaCl solution. Australian Standard AS 1289.6.7.1 – 1999 gives details on how hydraulic conductivity testing should be performed.

Some of the properties of the soil measured to determine its suitability as a low-permeability liner are particle size distribution, plasticity (described by the soil plasticity index) and cation exchange capacity (CEC). Properties for clays suitable for a low-permeability liner are discussed in Appendix 2 – 'Clay properties'.

A further factor to be considered is the potential for desiccation and subsequent cracking. Montmorillonite clays are high-plasticity clays and can form good liners; however, they are susceptible to desiccation and subsequent cracking during the liner construction and until waste is placed over them.

Clay liners are constructed in series of lifts compacted to the specifications detailed in a CQA plan prepared by the landfill designer (see section 5.4). To achieve bonding between each lift, the thickness of each lift must permit the compaction equipment, typically a sheep'sfoot roller, to penetrate the top lift and knead the previous lift. To improve bonding, scarification of the previous lift may also be required. Bonding is required to overcome the effects of the imperfections within individual lifts.

A further factor is the thickness of the liner and the number of lifts used, with a greater number of lifts and greater total thickness minimising the probability that preferential flowpaths will align. Best practice for minimising the probability that preferential flowpaths align and thus minimise the hydraulic conductivity of the liner, is to bond each successive lift with the preceding lift, construct the liner at least one metre thick, and use a minimum of four to six lifts.

During the installation of the clay liner, continual testing needs to be conducted to ensure that the hydraulic conductivity of the liner is less than 1×10^{-9} m/s. The landfill designer must provide details of how performance requirements of the liner, including the hydraulic conductivity, are to be met in a CQA plan. Section 5.4 gives more detail on the development of CQA plans.

The final surface of a compacted clay liner should be finished to a smooth surface. This promotes the rapid drainage of leachate on top of the liner, minimises the surface area of the liner thereby reducing the loss of moisture from the liner and allows the installation of a geomembrane liner.

5.3.3 Geomembrane

A composite liner is generally a combination of a natural clay low hydraulic conductivity liner with a polymeric geomembrane.

Due to the very low hydraulic conductivity of a geomembrane, the seepage rate through it is usually determined by the number of defects in the liner material, tears or imperfections where it is joined, or holes resulting from folds in the geomembrane or sharp objects penetrating the geomembrane. By placing the geomembrane immediately on top of a clay liner, the seepage rate at a defect through the geomembrane is governed by the performance of the underlying liner and the quality of the interface between the geomembrane and the underlying material. Therefore, porous materials should not be placed between a geomembrane and a clay liner, and the clay liner should be shaped to a smooth surface before installing a geomembrane.

If a geomembrane is used, it must be compatible with the proposed waste type and resistant to chemical attack. It must also have sufficient strength to resist puncture by the drainage layer medium or any sharp objects in the underlying liners. Table 5 (from Frobel & Sadler, 1997) summarises the properties of different types of geomembranes.

Physical and mechanical requirements of geomembranes are summarised in Appendix 2. These are adopted from the German Federal Institute for Materials Research and Testing's publication, Guidelines for the Certification of Geomembranes as a Component of Composite Liners for Municipal and Hazardous Waste Landfills and for Lining Contaminated Land (February 1994).

The landfill designer needs to ensure that the geomembrane to be used is the most appropriate under the circumstances (see Table 5), and that it meets the physical and mechanical requirements summarised in Appendix 2.

Table 5 : Properties of different geomembrane types (from Frobler & Sadler, 1997)

Attribute	HDPE	LLDPE	PVC	EPDM	EIA-R	CSPE-R	FPP
General chemical exposure	Excellent	Good	Fair	Good	Excellent	Excellent (when cured)	Excellent
Hydrocarbon exposure	Good	Good	Fair	Good	Excellent	Good (when cured)	Good
Weathering (UV exposure)	Excellent	Fair	Poor	Excellent	Excellent	Excellent (when cured)	Excellent
Thermal stability	Poor	Poor	Good	Excellent	Good	Excellent	Good-excellent when reinforced
Tensile performance	Good	Good	Good	Good	Excellent	Excellent	Good-excellent when reinforced
Uni-axial elongation performance	Excellent	Excellent	Good	Good	Fair	Good	Excellent
Multi-axial elongation performance	Poor	Excellent	Excellent	Good	Fair	Good	Excellent
Puncture performance	Fair	Excellent	Excellent	Good	Excellent	Good	Good
Installation damage resistance	Fair	Fair	Excellent	Excellent	Good	Good	Excellent

Attribute	HDPE	LLDPE	PVC	EPDM	EIA-R	CSPE-R	FPP
Seaming methods	Thermal-excellent	Thermal-excellent	Thermal or solvent bonding-Good	Tape seams-Good	Thermal-excellent	Thermal or solvent bonding-Good	Thermal-excellent
Repair in service	Good	Good	Good	Good	Good	Poor-requires adhesives	Excellent
Stress cracking	Fair	Good	Does not occur	Does not occur	Does not occur	Does not occur	Does not occur
Flexibility in detailing	Fair	Excellent	Good	Good	Good	Good	Excellent

HDPE	High density polyethylene
LLDPE	Linear low density polyethylene
PVC	Polyvinyl chloride
EPDM	Ethylene propylene diene monomer
EIA-R	Ethylene Interpolymer Alloy – Reinforced
CSPE-R	Chlorosulphonated polyethylene – Reinforced
FPP	Flexible polypropylene

When incorporating a geomembrane into a lining system, in addition to considering geotechnical stability issues as a whole, the landfill designer needs to ensure that the geomembrane is not placed under any long-term tensile forces.

Geomembranes are supplied in rolls and must be fitted and joined at the site. To avoid stress on seams, the rolls are joined with the seams parallel to the slope. As some geomembranes may be affected by long exposure to UV light or by premature wetting, the manufacturer's recommendations for the storage of the geomembrane should be followed.

Care must be taken in the installation of the geomembrane to avoid deformation due to heat stress or the desiccation of the underlying clay liner. The installation must be performed under a CQA plan (see section 5.4), incorporating testing of not only the geomembrane but also of the quality of the joins between the geomembrane sheets.

5.3.4 Leachate collection system

The leachate collection system is an integral component of the overall landfill liner system. The design objectives of the leachate collection system are to ensure that it is:

- able to drain leachate such that the leachate head above the liner is minimised;
- appropriately sized to collect the estimated volume of leachate (predicted by water balance models);
- resistant to chemical attack, and physical, chemical and biological clogging;
- able to withstand the weight of waste and the compaction equipment without crushing; and
- able to be inspected and cleaned by readily available video inspection and pipe-cleaning equipment.

The maximum leachate head on the liner (as measured at the lowest point of the liner) for a landfill situated above the watertable is 0.3 metres. The leachate head in the sump may exceed 0.3 metres as the sump is generally recessed below the level of the liner; some liquid is usually necessary to protect the pump in the sump.

Where a landfill is located below the watertable, the leachate within the landfill must be maintained at least five metres below the surrounding watertable. This ensures that all potential heterogeneities in leachate and groundwater levels are accounted for and that no outflow from the landfill can occur while pumping is maintained.

A leachate collection system typically comprises of a high permeability drainage layer, perforated collection pipes, a sump where collected leachate is extracted from the landfill and geotextiles to protect any geomembrane and prevent clogging of the drainage layer. The liner is sloped into the leachate collection pipes which in turn are sloped to the leachate collection sump. These slopes should be three per cent to the pipes and one per cent to the sump.

The drainage layer is a high-porosity medium providing a preferential flow-path to the leachate collection pipes and/or sump. To avoid clogging and capillary action holding water in the drainage layer, coarse material is used so that there is space within the drainage layer for leachate to drain freely. Using coarse material also ensures leachate flow in the event the event of some clogging within the leachate collection pipes. The hydraulic conductivity of the drainage layer must be greater than 1×10^{-3} m/s.

The drainage layer must be across the entire landfill and comprise at least 0.3 metres of coarse aggregate or the equivalent performance with a geosynthetic drainage material. This ensures that leachate is contained within the drainage layer, thus minimising the potential for clogging of the drainage layer. Properties of aggregate used in the drainage layer can be found in Appendix 2 – ‘Drainage aggregate properties’.

A geotextile filter should be placed over the drainage layer to protect it from clogging as a result of solids transport. Leachate collection pipes must not be wrapped in a filter geotextile, as this has been demonstrated to rapidly clog, rendering the collection pipes ineffective.

In designing the leachate collection system pipes, the key factors are the spacing between the pipes and the sizing of the pipes. Placing collection pipes close together minimises the head on the liner. A recommended maximum pipe spacing is 25 metres. Giroud’s equation can be used to design the liner slope and pipe spacing to ensure the maximum design leachate head is not exceeded (see Appendix 2 – ‘Giroud’s Equation’ for more detail on the equation and its use).

The sizing of leachate pipes is based on leachate flowrates within the pipe and the diameter required for the passage of remote inspection and cleaning equipment. This equipment typically requires pipe diameters greater than 15 to 20 centimetres.

Manning’s equation is used to derive the required pipe size based on leachate flowrate and pipe slope. For landfills located above the watertable, the leachate flowrate is derived from a water balance estimation using a model such as the HELP model. For landfills located below the watertable, inflows of groundwater into the landfill must also be incorporated into the calculations. For landfills below the watertable, groundwater inflows will typically dominate calculations of the volume of leachate generated. For landfills above the watertable, the volume of leachate generated should be based on a 1-in-20 year storm event after only one lift of waste has been placed in the landfill. In designing the slope of the leachate collection pipes, a minimum pipe slope of one per cent should be used, though greater slopes will minimise the sedimentation in the pipe. To prevent clogging of the pipes, they should be designed to remain drowned in the leachate sump.

Leachate collection systems can fail in less than a decade, failing in several known ways:

- they clog with silt or mud;
- micro-organisms clog the pipes;
- precipitation from chemical reactions block the pipes;
- the pipes are damaged in installation or early in the filling of the landfill; or

- the pipes become weakened by chemical attack (acids, solvents, oxidising agents, or corrosion) and are crushed.

To reduce the risk of mechanical failure of the leachate collection pipes, they should be:

- flexible rather than rigid;
- placed in trenches;
- placed on evenly prepared bedding material; and
- protected by a traffic-control program minimising the movement of heavy vehicles across them until sufficient waste has been placed over the drainage layer to avoid puncturing.

The installation of the leachate collection system must be included in the CQA Plan (see section 5.4).

Liner and leachate collection system
Objectives
To maintain groundwater quality as close as practicable to background levels.
Required outcomes:
<ul style="list-style-type: none"> • Design and construction of the best liner and leachate collection system practicable to prevent contamination of groundwater. • Implementation of the best practicable measures to meet all DoE/EPA groundwater quality objectives. • Where an attenuation zone has been designated, assurance that all groundwater quality objectives are met at the boundaries of the premises. • Geotechnically stable sub-base and liner. • Design and construction of the most robust liner and leachate collection system to ensure that the system will continue to achieve the Guideline objectives in the event of several components of the system failing.
Suggested measures:
<ul style="list-style-type: none"> • Design and construct the landfill liner such that the maximum seepage rates shown in Table 4 are not exceeded. • Avoid using slimes as a sub-base. • Clay liner to be greater than one metre thick and compacted to a hydraulic conductivity less than 1×10^{-9} m/s. • Utilise clay with the following properties:- <ul style="list-style-type: none"> – No rock or soil clumps greater than 50 mm in any dimension; – >70 per cent passing through a 19 mm sieve; – >30 per cent passing through a 75 μm sieve; – >15 per cent passing through a 2 μm sieve – soil plasticity index > 10; – CEC > 10 mEq/100 g; and – Minimal long term degradation with exposure to leachate. • Ensure clay liner is placed in at least four to six lifts, and each lift is bonded. • Using Table 5, ensure the geomembrane used is the most appropriate under the circumstances. • Installation procedures to minimise tensile stress on geomembranes due to thermal expansion or contraction of installed components. • Assurance that the geomembrane meets the physical and mechanical requirements summarised in Appendix 2. • Maximum head leachate on the liner not to exceed 0.3 metres.

Liner and leachate collection system

- Drainage layer to be at least 0.3 metres thick with an hydraulic conductivity of not less than 1×10^{-3} m/s.
- Drainage layer extending over the entire base of the landfill.
- Drainage layer aggregate having:
 - $D_{85} \geq 40$ mm;
 - $D_{10} \geq 20$ mm;
 - uniformity coefficient < 2 ;
 - fines content < 1 per cent; and
 - containing no limestone or other calcareous material that would be subject to chemical attack.
- Geotextile filter layer between drainage layer and waste.
- Low permeability liner sloped at not less than three per cent into the collection pipes.
- Leachate collection pipes sloped at not less than one per cent, towards the leachate sump.
- Collection pipes with high resistance to chemical attack, able to withstand anticipated vertical loading stresses and able to be inspected and cleaned.

5.4 Construction Quality Assurance

The development and implementation of a Construction Quality Assurance (CQA) plan provides a means of demonstrating to the public and regulating authorities that the landfill being constructed meets its design requirements.

The CQA plan must be able to verify:

- materials used comply with specifications; and
- method of construction/installation is appropriate and, as a result, design requirements have been met.

The CQA plan must contain the material/construction specifications, testing methods, testing frequency, corrective action and provide for appropriate documentation procedures.

5.4.1 Sub-grade and clay liners

Because of the importance of the sub-grade and clay liner in the overall liner performance, construction of these components must be accompanied by Level 1 geotechnical testing as set out in Appendix B of AS 3798-1996 Guidelines on earthworks for commercial and residential developments. This entails, among other requirements, full-time testing and inspection of all earthworks by the geotechnical testing authority, a geotechnical engineer independent of the liner constructor. The geotechnical testing authority must provide a report of all testing and, prior to the liner being accepted as appropriately constructed, must express the opinion that the works comply with the requirements of the specification and drawings.

For any landfill it must be demonstrated that the natural sub-grade and/or a constructed sub-base is able to support the landfill without affecting the integrity of the liner system as a result of differential settlement.

In the case of a clay liner, the key parameter that must be met is the hydraulic conductivity. It is dependent upon many factors, including clay composition, moisture content, compaction, field placement techniques and liner thickness.

The CQA plan must specify how the materials used to construct the liner will be tested to ensure that the hydraulic conductivity of the liner meets the specification. One means of doing this is to regularly sample the clay liner and test the samples for dry density and moisture content. The results of this testing are then compared with the required zone for dry density and moisture content necessary to ensure that the clay meets the specified hydraulic conductivity. This is discussed in more detail in Appendix 2 – ‘Installation of clay liners’.

Where this method is to be adopted, dry density and moisture content tests need to be quick procedures with a one to two hour turnaround time for results. Timely feedback and instructions can then be given to rework any areas that do not meet compaction standards.

The minimum test frequencies are:

- properties of the clay (grain size distribution, plasticity index and moisture content) tested once every 5,000 m³; and
- field testing for liner density and moisture content at a frequency the greater of:
 - 1 test per 500 m³ of soil;
 - 1 test per 2,500 m² area per clay lift; or
 - 3 tests per site visit.

Following field compaction work, direct permeability testing in the laboratory and/or in the field should be undertaken on undisturbed clay liner samples.

Suitable laboratory permeability testing procedures are described in AS 1289.6.7.1–1999, Soil strength and consolidation tests – Determination of permeability of a soil– Constant head method for a remoulded specimen.

Laboratory permeability testing has some advantages over direct field measurement methods because factors such as evaporation and soil saturation can be controlled in the laboratory to minimise discrepancies.

However, only small samples can be tested in the laboratory, which can affect the accuracy and applicability of the permeability results.

Field permeability measurements can represent larger volumes/areas of soil. using a device such as a Sealed Double Ring Infiltrometer (SDRI). As an SDRI should run for at least four months to ensure that the flow through the material being tested is a long-term steady state flow rather than a transient flow (Parker et al, 1997), this test should be conducted on a test pad that is not part of the liner but is subject to the same construction activities.

In addition to this physical testing, visual inspections should check for the presence of oversized clods of clay, poorly compacted or dry areas and the homogeneity of the clay.

The CQA plan may also need to specify the measures to be taken to protect the clay liner from desiccation and erosion.

Further to the testing of the quality of the installed clay, the CQA must also address the quality assurance with respect to the thickness of the constructed liner. In particular, the liner should be surveyed at the completion of construction to confirm that the correct grades have been attained.

5.4.2 Geomembranes

The CQA plan for a geomembrane must specify procedures for:

- recording condition of materials when unloaded at the site, ie. whether rolls are wrapped;
- documenting how rolls are stored, that is, undercover and when used;
- inspection of the sub-base upon which geomembrane will be placed to remove any objects that may damage the geomembrane;

- inspection of the geomembrane for defects;
- minimising tensile stresses on geomembranes that result from thermal expansion or contraction of installed components;
- testing of the seams; and
- inspection/testing of anchoring points of the geomembrane provided on surfaces with a gradient exceeding 10 per cent.

The geomembrane should generally be installed and tested under the recommended quality assurance guidelines provided by the geomembrane manufacturer.

5.4.3 Leachate collection system

The CQA plan must be able to demonstrate that the drainage layer materials have been placed in a manner that avoids damage to the low permeability liner and have the following properties:

- Washed to remove fines prior to placement;
- Appropriate particle size to provide design hydraulic conductivity;
- Placed so that no damage occurs to the landfill liner;
- Correct grades on all surfaces achieved;
- Correct thickness of material;
- Pipes placed on even bed;
- Proper joining of pipes.

Construction Quality Assurance
Objectives
To ensure that materials, construction methods and installation procedures provide a landfill meeting design criteria.
Required outcomes:
<ul style="list-style-type: none"> • Development and implementation of CQA plan to ensure that the liner and leachate collection system meets the requirements of the specification and drawings. • A statement from an accredited testing authority be obtained stating that the installed liner and leachate collection system meet the requirements of the specification and drawings. • Development and implementation of a CQA plan to ensure that the stability of sub-base and liner are achieved.
Suggested measures:
<ul style="list-style-type: none"> • Level 1 geotechnical testing as set out in AS 3798-1996 for landfill sub-base and liner. • Visually inspect each compacted lift of clay for impurities, poor compaction, cracking and dry areas. • Survey liner to confirm correct grades. • Inspect base of the geomembrane for sharp objects that may puncture the geomembrane or areas of roughness that may prevent the direct contact of the geomembrane on the low permeability base.

5.5 Water Management

Water management relies upon the management of three water streams with the intention of minimising the volumes to be managed and avoiding mixing the streams. The three components to be kept separate are:

1. stormwater;
2. leachate;
3. groundwater.

When considering means of managing water on the site, reusing water onsite is always preferred to discharging the water to the environment.

5.5.1 Stormwater management

Good stormwater management design incorporates interception drains that direct stormwater away from the areas where waste is to be landfilled. Storage ponds and other drainage measures should be designed to contain and control rainfall runoff for a 1-in-20 year storm event for a putrescible landfill or a 1-in-10 year storm event for a solid inert landfill. Storm events up to 1-in-100 year recurrence intervals should also be considered to ensure that they do not result in any catastrophic failures such as flooding of the landfill or failure of dams or leachate storage ponds.

Stormwater can also contribute sediment to the environment if the catchment area is erodible due to a lack of vegetative cover. By retaining and re-establishing as much vegetative cover in the catchment area as possible, this potential for erosion is minimised.

Other means for minimising the potential for erosion are to have stormwater flow over lower gradient or flatter slopes, or to spread the water across the slope. By minimising erosion the need for a settlement pond is reduced.

Sediment control features may be required where there are large stockpiles of earth or expanses of cleared land in the catchment area. Sediment control features should be designed to enable both silty sediments (able to settle out under gravity) and clayey sediments (will not settle out without flocculating agents) to be removed from the water. Typical features that may remove silty and clayey sediments include shallow, heavily vegetated stormwater control ponds and swales. The need for sediment control features will depend on:

- the topography and how this will influence water velocity;
- the nature of the water environment into which the eventual discharge from the site would occur;
- the typical intensity of storm events; and
- the extent of vegetative cover on the catchment area.

Further guidance on sediment control may be found in EPA Victoria Publication 275 Construction techniques for sediment pollution control and EPA Victoria Publication 480 Environmental guidelines for major construction sites.

Where a water supply dam is constructed to provide water for fire fighting, dust suppression or irrigation purposes, water from sediment control features should be channelled into the water supply dam. This places an additional control on the discharge of potentially turbid water, thus ensuring that the environment is better protected; it also maximises the use of this water. All dams should have spillways with erosion-control measures such as rocks and erosion-resistant vegetation.

The discharge of stormwater from the site should only occur from dams, and only after confirmation that the water is not contaminated. This confirmation should at least be visual where the only possible contaminant source is sediment, but where other contaminants are possible, the water should be tested prior to discharging. The degree of testing will be determined by the risk of contamination and the sensitivity of the receiving environment. Water is not to be discharged if it is suspected or found to be contaminated. The maximum permissible turbidity for stormwater is contained in Table 6. Where water does not meet these standards or shows other signs of contamination, the source should be found and actions taken to prevent a recurrence.

Table 6: Stormwater turbidity limits

	Maximum NTU	Median NTU
Dry weather	50	25
Stormwater flows	100	50

5.5.2 Leachate management

As leachate contains high levels of nutrients and salt, it requires treatment before it can be reused onsite or discharged to the environment. Prior to and during treatment, leachate must be stored and managed in a manner such that it will not escape into surface water or groundwater, will not cause offensive odours and will minimise human contact with the leachate. Water used in vehicle and wheel washing should also be managed as leachate.

Management options for leachate are:

- evaporation;
- discharge to sewer, with or without pre-treatment;
- treatment;
- surface irrigation of treated leachate outside the waste disposal area and subject to salinity management;
- dust suppression in the landfill; or
- providing moisture for an enhanced biodegradation landfill (see section 5.8).

In deciding upon any of the above management options, a water balance should be modelled over at least two consecutive wet years to ensure that the proposed system has sufficient capacity to deal with all leachate generated over the operational life of the landfill.

Any ponds containing leachate should have a freeboard of at least one metre to guard against wave action causing leachate to overtop the banks, as well as to provide capacity for any unforeseen events. To prevent seepage from the treatment system into groundwater, ponds should be lined to the equivalent performance standard as the landfill (see section 5.3 for performance standards).

If leachate ponds become anaerobic or where odour is a particularly critical issue due to surrounding sensitive land uses, leachate odours can become an issue. Where odour is an actual or potential issue, then the leachate pond may need to be covered or mechanically aerated.

Where leachate is to be evaporated, it should be within a closed system where no leachate is able to escape to the environment. Ponds are typically used to evaporate leachate (the formula for calculating the pond surface area required to evaporate the required volume of leachate is in Appendix 2).

Evaporation is enhanced by increasing the evaporative surface area using measures such as microsprays in the evaporation pond or devices such as the leachate evaporation pyramid in Figure 1. At the end of the useful life of the evaporation pond, salt that has accumulated in the pond will need to be disposed of.



Figure 1: Leachate evaporation pyramid at Hogbytorp landfill, Sweden

The disposal of leachate to sewer requires the approval of the local sewerage authority, which may impose restrictions on the quality of leachate permitted to be discharged. Restrictions are typically placed on the salinity and ammonia content of leachate disposed of to sewer and, as a result, some pre-treatment of leachate may be required prior to disposal to sewer.

The principal method of treating leachate is degradation by aerobic bacteria. The efficiency of this treatment method depends upon keeping the bacterial floc in suspension and being able to inject sufficient oxygen for the needs of the bacteria.

A further element of effective leachate treatment in aerobic ponds is the avoidance of large fluctuations in leachate quality and volume. The design and management of an aerobic leachate treatment system is discussed in Appendix 2 – ‘Aerobic leachate treatment systems’.

A wide range of alternative leachate treatment methods have been developed, ranging from full physico-chemical treatment where the treated leachate is of an extremely high quality, to thermal treatment where leachate is evaporated by the combustion of landfill gas. Where these alternatives are not feasible or sufficiently protective of the environment, other alternatives need to be investigated on a case-by-case basis.

Where treated leachate is to be irrigated over land that has not received waste, it must be of a standard suitable for land irrigation. In particular, saline water (TDS > 3000 mg/L) should not be irrigated to land as, in general, it is unsustainable and is likely to result in long-term salinisation of the land. Specific requirements for leachate irrigation will be outlined in the licence conditions for individual landfills.

Spraying or otherwise disposing of leachate over any part of the site that has received waste is only to be considered if it forms part of the essential operation of an enhanced biodegradation landfill or dust-suppression operations. Further details on enhanced biodegradation landfill are provided in section 5.8.

5.5.3 Groundwater management

Sites that extract groundwater (such as sites below the watertable) must manage that water so that it does not cause soil or surface water pollution. Many areas of Western Australia contain groundwater that is more saline than the local surface water system; the artificial or accelerated natural discharge of such saline groundwater into a fresh surface water system is likely to adversely affect that ecosystem. Landfills below the watertable should also ensure that groundwater is segregated from leachate and stormwater. This can be achieved by groundwater interception drains surrounding the landfill where groundwater is shallow, or deep

bores or sumps for deeper groundwater. Groundwater will need to be pumped from the vicinity of the landfill until the waste has stabilised – this can be assumed to be 30 years from the cessation of waste disposal.

A further impact that may need to be considered is that of rising watertables. This may manifest itself through groundwater rising to flood a landfill, or landfill operations, causing a localised increase in groundwater recharge, which in turn results in the rise of a saline watertable and thus impacts on surrounding land uses.

5.5.4 Water discharge

Wastewater discharge (excluding uncontaminated stormwater) from landfill sites into receiving waterways requires DoE approval.

Waste management options, such as reducing the volume of water requiring disposal and examining alternatives for reuse onsite or offsite, should all be evaluated prior to seeking approval for an offsite discharge to the environment.

If a discharge of groundwater or treated leachate is necessary, the wastewater should be treated to the advanced level expected of treated effluent. In considering a discharge to the environment, the existing environment of the receiving waters, such as flow rates, water chemistry, turbidity and biology, should be determined, with this information being used to design the location, volume and quality of any discharge in order to minimise impacts on water quality and ecology in the receiving environment. It is not best practice to discharge leachate to surface waters; the need to discharge groundwater to surface waters should be avoided.

Water management
Objectives
To protect beneficial uses of receiving waters and to avoid any adverse environmental impact on surface and ground waters.
<p>Required outcomes:</p> <ul style="list-style-type: none"> • Segregation of stormwater, leachate and groundwater. • Wherever practical, reuse of water onsite. • Management and treatment of leachate to: <ul style="list-style-type: none"> – Prevent it from escaping into surface waters or groundwater; – Prevent offensive odours offsite and; – Minimise human contact with the leachate. • Assurance that waste discharges to surface waterways are minimised and do not cause water quality objectives to be breached. <p>Suggested measures:</p> <ul style="list-style-type: none"> • Use drains or bund walls to direct clean stormwater away from the landfill activities. • Design drainage measures to contain and control rainfall runoff for a 1-in-20 year storm event for a putrescible landfill or 1-in-10 for a solid inert landfill. • Control erosion by minimising disturbed land, treating disturbed land as soon as practical, establishing flatter slopes or spreading the flow of water. • Where sediment cannot be controlled at the source, install sediment control features. • Manage water from vehicle-washing areas (manual or automatic) as leachate. • Model leachate treatment facilities to ensure that they have sufficient capacity to store and treat all leachate generated over two consecutive wet years.

Water management

- Use interception drains to intercept surface water or shallow groundwater.
- Use deep bores or sumps for deeper groundwater.
- Assess potential impacts of rising watertables.
- Prevent the discharge of turbid stormwater to the environment by maintaining turbidity levels within those outlined in Table.
- Prevent any detrimental impacts of saline groundwater on fresh water ecosystems.

5.6 Groundwater

Since a landfill must not impact on beneficial uses of groundwater, the design of the landfill must consider

the local hydrogeological environment. Issues to be considered include:

- liner uplift;
- groundwater monitoring bores; and
- groundwater recovery bores.

5.6.1 Liner uplift

The upward or outward force of groundwater through the base or sides of a landfill can cause a structural failure of the liner. Until the loading on the landfill liner due to waste placement exceeds any inward or upward force exerted by groundwater, this risk of liner uplift needs to be managed.

The key to managing this risk is to reduce the level of groundwater beneath the landfill by extracting groundwater. Two of the strategies that will enable this reduction are groundwater underdrains beneath the liner and groundwater extraction bores surrounding the landfill. If groundwater extraction ceases, the rebounding watertable will exert a force on the landfill that will need to be balanced by the force exerted by the waste for the liner to remain intact.

5.6.2 Groundwater monitoring

Monitoring bores may be installed to:

- establish the groundwater background quality and levels (in mAHD);
- establish the local groundwater flow direction and rate;
- act as an early indicator of leachate contamination in groundwater prior to offsite migration;
- measure compliance with the site licence or notice; and
- provide an indication of the downstream groundwater quality that a permitted groundwater user may find.

The bore(s) to establish the background groundwater quality should be placed up-gradient of the landfill, where they will not be influenced by seepage out or into the landfill or affected by surface water features, such as dams. The location of these bores should also take into account potential impacts from surrounding landfills, such as localised changes in groundwater quality or flow direction.

Monitoring should occur in all aquifers that may be affected by the landfill. The number of monitoring bores should be commensurate with the size of the facility, the risk of contamination and the nature of the groundwater environment; however, at least four groundwater bores are required to understand the direction of groundwater flow. Further guidance on groundwater monitoring programs is contained in EPA Victoria Publication 668 Environmental Guidelines for Hydrogeological Assessments (Groundwater Quality).

The bores established in close proximity to the landfill are screened so as to intercept any leachate-contaminated groundwater. For a landfill located above the watertable, the top three to five metres of the watertable aquifer would normally be sampled. 'Nested' or multiple bores screened at various depths in the aquifer may be used to establish the water quality profile.

The monitoring of groundwater downgradient of the site provides an indicator of the groundwater quality that a downgradient-permitted groundwater user may extract; it also provides additional assurance that the landfill has not polluted the groundwater.

Permission must be obtained from the DoE to install a groundwater bore, and all groundwater monitoring results should be forwarded to the State Groundwater Database.

5.6.3 Groundwater recovery bores

As an added level of protection for landfills in an area of potable groundwater, a groundwater recovery system provides a means of preventing detrimental impacts to beneficial uses of groundwater. The recovery system works by reversing or otherwise changing the direction of flow so that the polluted water can be extracted.

The installation of recovery bores follows from a risk assessment focused on the sensitivity of the aquifer to seepage from the landfill and the groundwater velocity. The spacing and size of the recovery bores are determined by their proximity to the landfill and hydrogeological conditions such as the transmissivity of the subsurface strata.

While not all sites will physically need to install the recovery bores, all landfills should determine the most appropriate location of the bores and their effectiveness. In operating groundwater recovery bores, the landfill operator needs to be aware that the resulting change in groundwater flow direction will affect conclusions drawn from groundwater monitoring results.

Groundwater Management
Objectives
To protect the beneficial uses of groundwater and to minimise the risk posed by the landfill to those beneficial uses.
Required outcomes:
<ul style="list-style-type: none"> • Development of a groundwater monitoring program to demonstrate compliance with the objective. • Design of bores to sample the potentially contaminated and/or representative groundwater quality found offsite.
Suggested measures:
<ul style="list-style-type: none"> • Assurance that the landfill liner cannot be damaged through groundwater pressure. • Where groundwater pressure poses a risk to the liner integrity, extract groundwater to minimise this risk. • Install at least four bores at suitable locations to understand the direction of groundwater flow. • Install groundwater recovery bores to extract polluted groundwater in the event of detrimental impacts on beneficial uses of groundwater.

5.7 Air quality

Landfills pose a risk to air quality through landfill gas (comprising of methane and odorous compounds) and dust. The objectives for air quality management at a landfill are:

- no safety or environmental impact due to subsurface migration of landfill gas;
- the minimisation of greenhouse gas emissions;

- the prevention of offsite nuisance odours; and
- no reduction in amenity or health impacts due to dust.

5.7.1 Landfill gas

The degradation of putrescible waste is caused by microbes that produce landfill gas as a by-product of this decomposition. The composition of landfill gas varies according to the dominant phase of microbiological breakdown occurring within the site at the time (see Appendix 2, Figure 6). The onset and duration of each phase of landfill gas production vary both within and between sites.

The key phase with respect to potential impacts from landfills on air quality is the anaerobic phase, which is where decomposition occurs in the absence of oxygen. During this phase, methane and carbon dioxide, both greenhouse gases, are the major constituents of the gas produced. With daily covering of wastes and compaction of waste, the available oxygen is quickly depleted; however, the evolution of significant quantities of methane may take from three months to more than a year to start and continue for well in excess of 15 years.

The rate of emissions from a landfill is governed by gas production and transport mechanisms. An estimate of the methane generation rate from a typical landfill can be made using the USEPA Landfill Air Emissions Estimation Model from the USEPA's Control Technology Centre bulletin board (see Appendix 2). Enhanced biodegradation landfills will typically generate methane at a greater rate, so this estimation method is not applicable.

The migration of landfill gas may constitute an environmental and safety risk. Methane is explosive when present in the range of five per cent (Lower Explosive limit) to 15 per cent (Upper Explosive limit) by volume in air. Gravel or sand layers, or even man-made drains, provide ideal migration routes for landfill gas, particularly after the site is capped. A risk assessment will identify those landfills that present a risk that must be managed due to their location, waste type, size and soil strata.

Because anaerobic decomposition is the main process for the degradation of waste within landfills, and because the process generates significant quantities of greenhouse gases, landfills are contributors to climate change as a result of the greenhouse effect. Oxidation of the methane in landfill gas to water and carbon dioxide results in a net reduction of greenhouse impacts as methane has a greater greenhouse effect than carbon dioxide.

Methane-oxidising bacteria in the soil of the landfill cap can oxidise methane in landfill gas migrating through the cap. The degree of methane oxidation is a function of the time it takes the gas to migrate through the cap; the longer it takes to pass through the cap, the greater the degree of oxidation. The oxidation process is enhanced by the addition of mulched material above the low permeability liner, and degraded by cracks in the cap which provide preferential flow paths with minimal oxidation. All landfill caps should include mulched material in their caps to enhance the oxidation of any fugitive emissions of landfill gas.

A further means of oxidising landfill gas is to collect it for subsequent incineration in a power generation facility or a flare. This is discussed in section 5.7.2.

As part of the landfill gas-management strategy, gas monitoring may need to be undertaken. During gas monitoring, atmospheric conditions should be reported as atmospheric pressure influences gas migration. The number and location of gas-monitoring locations will be site specific; however, where the landfill has been capped, the resulting increased lateral movement of landfill gas should lead to more intensive gas monitoring. If landfill gas is found or suspected to be migrating offsite at unacceptable levels, then a landfill gas-extraction system will be required.

For large landfills, there are clear economic and environmental benefits in collecting landfill gas and finding either a direct user of the gas or the energy it could produce. The benefits for

smaller landfills are not so clear, and the landfill gas-management options depend on the size of the landfill. The EPA Victoria Publication 722, Environmental Guidelines for Reducing Greenhouse Gas Emissions from Landfills and Wastewater Treatment Facilities provides more detail on the considerations that need to be taken into account. Table 7 is extracted from these guidelines and sets out the minimum requirements of best practice landfills.

Table 7 : Landfill gas control

Site receiving (tonnes waste per year)	<5,000	5,000 – 40,000	40,000 – 100,000	>100,000
Or containing (tonnes)	<50,000	>50,000 – 400,000	400,000 – 1 million	>1 million
Preliminary greenhouse gas estimation	✓	✓	✓	✓
Preliminary landfill gas monitoring	N/A	✓	N/A	N/A
Detailed landfill gas assessment	N/A	?	✓	✓
Landfill gas control system	N/A	?	✓	✓
Landfill gas flaring	N/A	?	✓	✓
Energy recovery	N/A	?	?	✓
Capping and cover to reduce emissions	✓	✓	✓	✓
System monitoring and maintenance	✓	✓	✓	✓
Periodic site inspections	✓	✓	✓	✓
Greenhouse budgeting and off-setting	✓	✓	✓	✓

✓ = suggested measures – best practice operators should assess need for the measure by landfill gas estimation and testing

? = measures that may be required, subject to the outcomes of landfill gas testing

N/A = measure not applicable

5.7.2 Landfill gas collection

Landfill gas may be collected for reasons such as greenhouse gas control, alternative fuel supply, risk reduction or odour control.

The landfill gas-collection system should be designed prior to establishing the landfill as this enables the operator to best capitalise on the landfill gas resource as well as protect high-risk receptors from any impacts of landfill gas. New landfill proposals are expected to incorporate a landfill gas collection system in the design of the landfill, as well as incorporate operational modifications required to optimise the quality and volume of landfill gas collected.

Existing and closed landfills are expected to assess the alternatives for landfill gas collection. This may be to abate odour or other environmental risks from the site, or it may be to take advantage of the energy resource. Where ambient methane concentrations of 500 ppm or more are found, or when methane concentrations in bores or confined spaces exceed one per cent by volume, landfill gas control measures must be implemented.

Where landfill gas is to be collected, gas wells may be vertical or horizontal. The collection system may be passive (relies upon the pressure difference between atmospheric pressure and the pressure of the landfill gas) or active (gas is drawn off under a vacuum). For a passive gas system, wells need to be spaced not more than 20 to 30 metres apart, whereas for an active system wells may be up to 50 metres apart. In both cases, the cessation of extraction of landfill gas while the gas is being generated may cause offensive odours beyond the site boundary, so auxiliary systems need to be installed to maintain continuous extraction in the event that the main extraction system fails.

Vertical gas wells are installed after the filling of a landfill. They are, typically, 300 millimetres in diameter and are drilled into the waste. A pipe, perforated for all but the top three to five metres, collects the gas. Leaving the top section of the pipe unperforated minimises air being drawn into the pipe, as does maintaining a good quality cap and installing a barrier about the well (such as a geomembrane extending radially from the gas well). After inserting the collection pipe, the space between the pipe and the outer wall of the hole is back-filled with coarse crushed rock, with clay or bentonite sealing the top few metres. Wells extend down to near the base of the landfill or to above the watertable, whichever is closer to the surface.

Horizontal wells are installed as the landfill is filled; provided sufficient waste has been placed over the top of the pipe, gas can be extracted without too much air being drawn into the system. A typical depth of waste required for effective gas collection is five metres. A sample design of such a system is indicated in Figure 2; this design is taken from the system installed at a landfill in Germany (Göttingen). The system works by using horizontal wells to draw gas from horizontal collection pipes into a larger vertical pipe. Since gas is drawn down this vertical pipe, the infrastructure required can be installed with the landfill liner, minimising the risk of equipment being broken during landfill operations and enabling landfill gas to be collected and used very early in the life of the landfill.

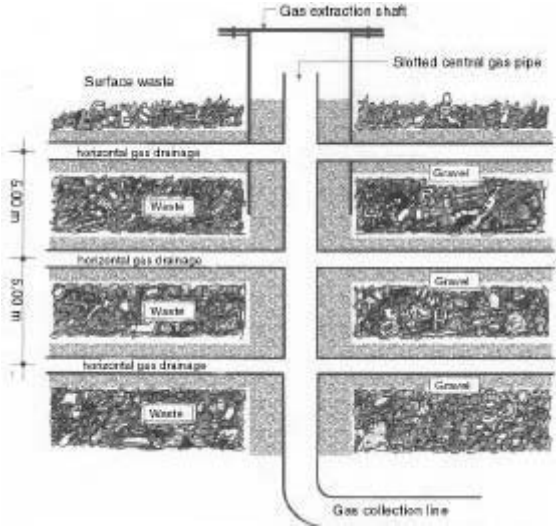


Figure 2 : Landfill gas-collection system installed during filling of landfill

The method of landfill gas disposal will be influenced by energy recovery or greenhouse gas considerations as much as for local environmental or safety reasons. Figure 3 indicates the hierarchy that should be considered in the management of landfill gas, with the minimisation of greenhouse gases being the primary driver.

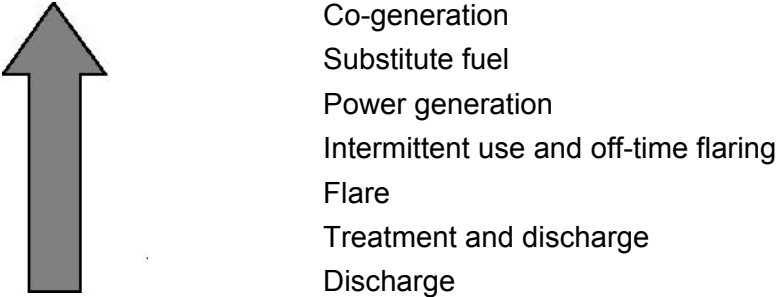


Figure 3: Landfill gas management hierarchy

Depending on the specific circumstances, using landfill gas as a substitute fuel for direct heating may be more appropriate in the management hierarchy than co-generation. This is because,

while cogeneration is far more attractive in terms of greenhouse gas reductions as it generally replaces brown-coal generated electricity, it is a less efficient energy conversion than the use of the gas as a substitute fuel for direct heating. As a result, where landfill gas replaces electricity as a means of heating, it is preferred to use the gas as a substitute fuel rather than generate electricity from it for use in heating. For the purpose of heating calculations, the calorific value of landfill gas can be assumed to be about 15 to 21 MJ/m³ (about half that of natural gas).

Where landfill gas is to be flared, the landfill gas flares should be designed to reduce emissions of volatile organic compounds (excluding methane) by 98 per cent. In addition, the flare should be fitted with auto ignition to ensure that it ignites upon the buildup of gas, and a flame arrestor beneath the combustion zone to prevent the combustion of the landfill itself.

Where several different landfills are clustered together in relatively close proximity, the options for landfill gas utilisation of the combined landfill gas produced from the sites should be investigated.

5.7.3 Odour assessment

Landfill odour is a key consideration in deciding whether a landfill will adversely affect the amenity enjoyed or expected by surrounding neighbours; it also affects the design and operation of the site. At all times, a landfill must be managed to prevent offensive odours beyond the boundary of the premises. In particular, where surrounding land uses include residential, educational and health care uses, the highest degree of care must be taken to protect these areas from landfill odours. The provision of buffers in accordance with requirements outlined in section 4.1.3 will minimise impacts of residual odour on surrounding areas.

While the major constituents of landfill gas, methane and carbon dioxide, are odourless, the residual gases can be very odorous. The key means of managing landfill odour is to manage the landfill gas in general by oxidising it through some of the measures discussed in sections 5.7.1 and 5.7.2.

5.7.4 Dust emissions

Any large area where the land has been disturbed and is subject to vehicular traffic has the capacity to generate dust. Other potential dust sources are stockpiles of earth and the delivery of dusty loads of waste.

The magnitude of the impact will depend on the:

- type and size of the operation;
- prevailing wind speed and direction;
- adjacent land use;
- occurrence of natural and/or constructed wind breaks; and
- wind-abatement measures or buffers.

The PM₁₀ dust concentration set in the NEPM of 50 ug/m³ must be achieved beyond the premises boundary. Measures to achieve this dust level include:

- Vegetation of exposed areas and formation of internal roads, including sealing roads that are used regularly; and
- Use of water or other dust suppressants on roads or stockpiles that are not sealed or vegetated.

While direct measurement of PM₁₀ or dust may only occur at those sites that have been identified as a dust hazard, periodic monitoring should still occur at all sites, even if by visual means only.

Air Quality
Objectives
To ensure that air quality objectives are met, greenhouse gases minimised, and that there is no loss of amenity from landfill gas, odour or dust.
Required outcomes:
<ul style="list-style-type: none"> • Assurance that no safety or environmental impacts are caused by landfill gas. • Prevention of any offensive odours beyond the boundary of the premises. • Decisions made on a gas management strategy using the hierarchy in Figure 3. • Prevention of nuisance dust emissions beyond the boundary of the premises.
Suggested measures:
<ul style="list-style-type: none"> • Design the landfill gas management system prior to establishing the landfill. • Manage landfill gas in accordance with the standards show in Table 7. • Provide a cap containing mulch material in the final soil layer to act as a methane oxidation layer. • Monitor landfill gas, particularly in areas where there are relatively permeable strata. • Where there are multiple landfill sites in relatively close proximity, examine the options for landfill gas utilisation of the combined landfill gas produced from the sites. • Ensure landfill gas flares are designed to reduce volatile organic compound emissions by 98 per cent and that the flare is fitted with: <ul style="list-style-type: none"> – Auto ignition; and – Flame arrestor beneath combustion zone. • Maintain all PM₁₀ dust emissions below 50 ug/m³ beyond the premises boundary. • Vegetate exposed areas and form internal roads. • Use water or other dust suppressants on unsealed roads or un-vegetated stockpiles.

5.8 Enhanced biodegradation landfills

Enhanced biodegradation landfills involve managing the landfill to promote rapid decomposition of the putrescible waste within the landfill. Since enhanced biodegradation landfills are currently the subject of considerable research within the geoenvironmental community they are not considered to be an established technology. As such, while the DoE is supportive of the principle of ensuring that any waste that has been landfilled is as stable as possible as quickly as possible, it cannot endorse the implementation of the enhanced biodegradation landfill concept at this stage. The key reasons for this are as follows:

- Since research on critical aspects of the concept is still being conducted, it would be premature to encourage these landfills throughout Western Australia.
- The management requirements are significantly greater than those for typical landfills; landfill operators need to demonstrate that they are able to manage a significantly more complex system than a typical landfill.
- The stabilisation of waste in the ground potentially undermines preferred trends in resource recovery where waste is sorted and stabilised outside the landfill, with methane captured for subsequent use and the remaining solid material used as compost. This technology is also in the development stage; however, it promises far greater resource recovery potential than enhanced biodegradation landfilling.

The key parameter for biodegradation is usually moisture content, and while the optimum moisture content for biodegradation is still being agreed upon, it is generally considered to be around 60 to 80 per cent of saturation.

Enhanced biodegradation is argued to have many benefits, including reducing the long-term risk posed by the landfill and increasing landfill gas production to make collection and utilisation of the gas more viable.

An enhanced biodegradation landfill should not require any lining and leachate-collection controls in addition to those required of a best practice landfill. However, the enhanced landfill gas production imposes additional demands on landfill gas collection very early in the life of the landfill and these demands need to be addressed. Further design elements imposed by enhanced biodegradation landfills include mechanisms for adding moisture to the landfill, means of monitoring and controlling moisture content and methods for minimising channelling and dead zones within the landfill.

Where a landfill is to be managed as an enhanced biodegradation landfill, various parameters can be monitored to determine the stability of the waste. These include landfill gas yield and quality, and the BOD:COD ratio in leachate.

5.9 Noise

Landfill operations generally involve the use of noisy plant equipment and can impact detrimentally on the amenity of surrounding areas. Sources of noise at a landfill include truck noise (body, engine and exhaust), reversing sirens, external telephone bells, mobile machinery and equipment used for resource recovery operations such as concrete-crushing equipment.

Site operations should be set out to minimise noise impacts by using natural and/or constructed features such as earthen bunds and depressions as well as minimising steep-haul roads. Another means of minimising noise is by planning to schedule potentially noisy activities to minimise impacts on the community.

Where noise is considered an actual or potential concern (due to changing land use), then the predicted noise levels at the nearest current or future sensitive receptor should be derived. Where operations are likely to occur outside normal business hours, noise-control measures need to be investigated and adopted where appropriate.

Irrespective of location, the requirements of the *Environmental Protection (Noise) Regulations 1997* must be met at all times.

Noise
Objectives
To ensure that the noise objectives are achieved and to minimise noise annoyance.
Required outcomes:
<ul style="list-style-type: none"> • Compliance with the <i>Environmental Protection (Noise) Regulations 1997</i>.
Suggested measures:
<ul style="list-style-type: none"> • Set the site out to minimise noise impacts. • Plan operating hours for various elements of the site to minimise impact on the community. • Where noise is an actual or potential concern, predicted noise levels at the nearest current or future sensitive receptor should be derived.

5.10 Traffic considerations

Due to safety concerns, noise, road grime and the increased cost of road maintenance, movement of trucks on local roads may be a concern to local residents and councils.

Limiting access routes and speeds of vehicles, as well as limiting the hours of operation, can minimise noise disturbance to the local community. Another consideration is the design of the site layout to ensure that trafficked areas, such as the location of parking, the entrance gate and the weighbridge, are away from sensitive land uses.

Provision of traffic control devices, such as traffic islands and merging lanes at the entrance to the landfill, may need to be considered to minimise the impact of traffic. Recessing the entrance into the landfill helps to minimise vehicles queuing along public roads, as well as assisting in the control of dirt from the site.

The accumulation of dirt on sealed external access roads can be avoided by vehicles exiting via a wheel wash or some other equivalent wheel and underbody cleaning mechanism. The road layout within the landfill should encourage the use of wheel-cleaning devices by truck drivers, and be placed so that the gatehouse attendant can visually check that the vehicle has been cleaned. Where external access roads are sealed, the road from the wheel wash should also be sealed and regularly cleaned to reduce the dirt re-entrained by the vehicle. Internal roads should also be sealed as far as possible into the site to reduce the amount of dirt accumulating on the vehicle and allow more time for dirt already accumulated on the vehicle to fall off before it leaves the site.

Traffic Considerations
Objectives
To minimise nuisance from traffic movement.
Required outcomes:
Minimisation of safety concerns, noise and road grime on external roads.
Suggested measures:
<ul style="list-style-type: none">• Encourage trucks, where possible, to use access roads that will have the least impact on the surrounding community.• Locate trafficked areas away from sensitive land users.• Provide traffic-control devices and signage near the landfill entry.• Assurance that all vehicles leaving the landfill have all soil removed from the wheels and underbody before entering public roads.• Seal the road from the wheel wash to the public road where the public road is sealed.

5.11 Site security and fencing

Active landfill sites can present a safety risk to the public and livestock. The site should be securely fenced to prevent the unauthorised entry of people or livestock. When unattended, the gates should be securely locked. Fencing should be regularly inspected and any damage to the fence that would allow unauthorised access be repaired as quickly as possible. When designing a fence, consider the probability that unauthorised people will want to gain entry to the site.

Any particularly dangerous areas, such as disposal areas for slimes or leachate ponds, should have signs to indicate the danger posed.

The minimum fencing requirements are summarised in Table 8.

Table 8: Minimum fencing requirements

	Population Served			
	Class I	Class II	Class III	Class IV
Extractive industry sites	A	A	A	A
Trench-and-fill	A	B	A or C	A
Topography change	A	B	A or C	A

- A A wire mesh fence at least two metres high constructed around the landfill site perimeter.*
- B A stock proof fence constructed around the perimeter of the landfill site, and relocatable litter screens erected near the tipping area.*
- C A wire mesh fence at least two metres high constructed around the tipping area only, and a stock proof fence around the perimeter of the site.*

In areas where there may be a higher risk of unauthorised people entering the site, such as where the landfill is next to a recreational area, these minimum fencing requirements may need to be upgraded.

Site Security and Fencing
Objectives
To prevent the unauthorised entry of people or livestock.
Required outcomes:
<ul style="list-style-type: none"> Assurance that the site fencing meets the minimum requirements summarised in Table 8.
Suggested measures:
<ul style="list-style-type: none"> Design fencing to minimise unauthorised access to the site. Signal any particularly dangerous areas with signs.

6. BEST PRACTICE OPERATION

Protection of the environment from landfilling activities goes beyond the design of the landfill to include operational practices which further enhance the protection of the environment. In particular, the elements of a landfill's operations that need to be considered are:

- environment improvement plan;
- financial assurance;
- waste minimisation;
- waste acceptance;
- waste pre-treatment;
- waste placement
- waste cover;
- litter control;
- fires;
- contingency planning;
- management of chemicals and fuel;
- disease vector control;
- noxious weed control; and
- performance monitoring and reporting.

The DoE will require this section of the guideline to be implemented for all new Class III landfills, and new cells for existing Class III landfills from the date of publication of this document.

6.1 Environment Improvement Plan

Landfill operators are expected to develop and implement an environment improvement plan (EIP) tailored to meet their specific needs. The complexity of the EIP depends on the potential and actual environmental risks inherent in operating the landfill.

The key framework for any EIP contains the following elements:

- commitment from senior management to an environmental policy which is clearly communicated to all staff;
- articulation of statutory requirements;
- a thorough review of the actual or potential environmental impacts and preparation of plans to reduce them, which include specific objectives and targets;
- mechanisms to implement improvements including the designation of responsibilities, communication processes, document control and operation procedures;
- training of all relevant staff in the implementation of improvements;
- mechanisms to check and review environmental performance;
- management reviews of the system's performance; and
- commitment to continuous improvement.

International Standards ISO 14001 and ISO 9001 provide guidance on environmental management systems and quality management systems respectively, while Appendix 1 of this document, 'Summary of Key Elements of an Environment Improvement Plan,' provides more detail on the key elements of an EIP.

Environment Improvement Plan
Objectives
To develop and implement a site-specific environment improvement plan.
Required outcomes:
<ul style="list-style-type: none"> • Development and implementation of an EIP for the landfill. • Training of all relevant staff in the implementation of the EIP.
Suggested measures:
<ul style="list-style-type: none"> • Use ISO 140001 and Appendix 1 for guidance on the development of an EIP.

6.2 Financial assurance

Alongside an EIP, landfill operators may be required to provide a financial assurance to guarantee that any costs incurred in the operation, closure and aftercare of a landfill are not borne by the community in the event that the landfill operators abandon the site, become insolvent or incur clean-up costs beyond their financial capacity. Financial assurances are usually only required in exceptional circumstances.

A financial assurance has three components:

- remedial action;
- site rehabilitation; and
- site aftercare.

The financial assurance should be held for the period that the landfill continues to pose a risk to the environment.

Financial assurance
Objectives
To provide a financial assurance for environmental management costs incurred during the operation, closure and aftercare of a landfill.
Required outcomes:
<ul style="list-style-type: none"> • Provision of a financial assurance by all licensed landfills. • Consideration of the provision of a financial assurance by all unlicensed landfills to cover potential future liabilities.
Suggested measures:
<ul style="list-style-type: none"> • The EPA Victoria Publication 777 Determination of financial assurance for landfills provides guidance on the development of an appropriate level of financial assurance.

6.3 Waste minimisation

Landfilling is the last resort for the management of unwanted material. Municipal landfills are part of a waste management system where every opportunity should have already been taken to avoid waste production and remove recyclable material from the waste stream before it arrives at the landfill. This is particularly pertinent for wastes generated in significant volumes at a single site, such as construction and demolition waste from large projects.

Material presented at a landfill should be sorted either by the waste generator or at some intermediate facility such as a transfer station to remove and recover recyclable material prior to deposition in the landfill. Where the landfill takes unsorted waste, infrastructure such as a transfer station or drop-off bins should be provided at the landfill to facilitate the recovery of recyclable material. The site recording system should record the waste diverted from landfill separately from waste landfilled.

In some exceptional cases it may be more efficient to sort the waste on the tipping face rather than at a transfer station. This will typically be the case at sites that only receive waste from commercial operators. Where a transfer station is installed, it should be designed in accordance with the documents such as the Guide to Best Practice at Transfer Stations (EcoRecycle Victoria, September 1998).

Many materials may be salvaged from the waste stream. These materials include:

- paper and cardboard;
- plastic and glass bottles;
- concrete;
- steel and other metals;
- timber;
- green waste;
- organic waste such as food scraps;
- bricks;
- roof tiles;
- white goods; and
- oil.

These materials should be removed from the waste stream being landfilled and either stockpiled for recycling onsite or for offsite removal. Where recycling is proposed to occur onsite, adequate space needs to be set aside for the raw material stockpile, the recycling operation (such as a concrete crusher) and for the material awaiting sale or reuse on-site.

Where soil is to be excavated for cover or for a trench-and-fill operation, topsoil should be stockpiled for use during site rehabilitation works.

Green waste should be mulched, after which it may be sold or used on the rehabilitated landfill surface to improve the quality of the topsoil and to help prevent erosion. Green waste used for this purpose should be free of noxious weed seeds.

Waste minimisation
Objectives
To divert suitable wastes from landfill.
Required outcomes:
<ul style="list-style-type: none"> Establishment of an operation to salvage and recycle suitable wastes delivered to the landfill.
Suggested measures:
<ul style="list-style-type: none"> Carry out a waste minimisation assessment that examines opportunities for waste avoidance, reduction, reuse and recycling. Where possible, ensure that waste received is sorted prior to deposition. Work with the waste generator to ensure that the waste to be landfilled is minimised. Preserve topsoil for use during site rehabilitation works and use mulched green waste to improve this topsoil and help control erosion.

6.4 Waste acceptance

Signs advising which wastes may be deposited at the landfill should be provided. Signs should be provided to show where recyclable materials from waste that has not been through a transfer station or municipal recycling facility may be placed.

The recyclable materials depot should be staffed at all times it is open for the receipt of waste by staff who know what types of wastes the landfill may accept and who are trained in recognising non-conforming wastes. Landfill staff should be vigilant to ensure that only appropriate wastes are deposited at the premises.

Loads containing non-conforming wastes can sometimes be identified by visual inspection, such as observing drums on a truck or other unusual characteristics.

Facilities such as elevated mirrors, viewing platforms or video cameras may be used to screen incoming waste loads. Random inspections of incoming loads should, however, be conducted. Records of these inspections should be kept. In particular, a random inspection program should be developed for all waste loads not from secure sources such as transfer stations. The frequency of inspection will depend on the type and quantity of waste received and whether problems have previously been identified. A typical inspection frequency is, on average, one in 10 vehicles being physically inspected.

There should be a communication system linking staff at the landfill tipping area to the gatehouse. Procedures should be developed to deal with the dumping of non-conforming wastes at the landfill, and should contain procedures for the identification of the waste dumper, isolation of the waste and notification of authorities. These procedures should be contained in the site EMS and implemented where such wastes are dumped.

Where contaminated soils and industry wastes are received at the landfill, a sampling and analysis program is needed to assure landfill operators that the waste has been correctly classified and accords with their acceptance criteria.

Sampling and analysis should be conducted in accordance with the *Waste Classification and Waste Definitions 1996 (as amended)*.

Waste acceptance
Objectives
To ensure that only appropriate wastes are deposited at the landfill.
Required outcomes:
<ul style="list-style-type: none"> • An assurance by the landfill that the waste received at the site is able to be accepted.
Suggested measures:
<ul style="list-style-type: none"> • Ensure that the landfill is staffed at all times it is open for the receipt of waste. • Provide signs advising customers of acceptable and unacceptable wastes. • Conduct random inspections and sampling of waste loads. • Train landfill staff to recognise non-conforming wastes. • Develop and implement procedures for how to deal with the dumping of non-conforming wastes.

6.5 Waste pre-treatment

The pre-treatment of waste prior to landfilling is intended to reduce the long-term risk posed by the waste and to improve general landfill performance. Approaches to pre-treatment include:

- recovering fractions that have high calorific value, are recyclable or are compostable; and
- modifying the physical form or mix of wastes going to landfill through shredding, baling or compacting.

By removing the waste that has a high calorific value or is compostable, landfills containing the residual waste stream require a shorter aftercare period and have fewer landfill gas emissions to the environment (see section 5.7.1 for more information on landfill gas generation). Best practice is to continually improve efforts to remove putrescible fractions from the waste stream.

A waste pre-treatment approach that reduces the risk of landfilling waste is mechanical-biological pre-treatment. This involves the mechanical separation of waste into different fractions and the biological treatment of the putrescible fraction to a relatively stable material. The gas generation potential is significantly reduced and leachate volume and strength reduced in pre-treated wastes compared with untreated wastes. This means that the aftercare period may be considerably reduced.

Besides the reduced gas and leachate generation potential, pre-treated wastes can be placed at a greater density and are subject to less settlement. Dependent upon the degree of biological treatment, the residual wastes landfilled could be considered as inert wastes.

Shredding or baling wastes may reduce some environmental effects of landfilling but do not in themselves reduce the putrescible fraction within the waste stream.

Shredding involves the ripping of waste into strips and also may entail the removal of recyclable and reusable materials still contained in the waste stream. The shredded waste is generally more homogeneous than the non-treated waste and therefore not subject to the same amount of differential settlement. After compaction, the density of shredded waste is usually greater than that of the non-shredded waste; however, shredding may result in significant litter problems. Baling involves compacting and binding waste into solid bales. Baled wastes can be neatly stacked and may reduce the amount of litter and demand for cover material. High-density balers can also increase the quantity of waste that may be deposited in a landfill.

Waste pre-treatment
Objectives
To reduce the long-term risk posed by the waste and to improve general landfill performance.
Required outcome:
<ul style="list-style-type: none"> • Maximisation of the stability of waste going to landfill through pre-treatment.
Suggested measures:
<ul style="list-style-type: none"> • Separate putrescible fractions from waste streams where possible, and continually improve in the separation of putrescible wastes. • Shred and/or bale wastes to improve landfill management and performance.

6.6 Waste placement

By maintaining tight controls on waste placement, litter and birds can be controlled and the degree of waste compaction maximised.

To contain litter and to reduce the attraction to birds and other pests at Class III landfills, the size of the active tipping area should be kept as small as possible. The width of the active tipping area can be estimated by allowing about 4–5 metres per truck, though trucks with trailers may require more space. During peak times, the width of the tipping face needs to be balanced against waiting times for trucks; however, the tipping area should be no greater than 30 metres x 30 metres.

Waste should generally be placed at the base of the face, with a compactor pushing waste up the face and compacting it in thin layers. The thickness of the waste layer should not exceed two metres, and the compactor should make three to five passes over the waste to maximise compaction and thus minimise settlement. Cover should be applied at the same time to maintain the length of the tipping area at less than 30 metres.

Operating a landfill on a cellular basis, particularly in a former extractive industry site, will often mean that at least one face or side of the cell will not be confined. In these circumstances, waste must be placed so that it is stable and can be covered by earth or other approved cover materials.

The limiting factor for the gradient of an unconfined volume of waste within a landfill will usually be governed by the stability of the cover soil placed over that exposed area. Gradients steeper than two horizontal to one vertical units should be avoided, unless it can be demonstrated that both the waste and the cover material are mechanically stable. An initially safe, dry cover may subsequently slide down a slope due to water saturation which increases the weight of the cover and decreases the friction resistance along the waste.

The stability of waste and cover material may be further enhanced by terracing the unconfined face.

Whenever special wastes such as quarantine wastes are deposited, they should be immediately buried and covered. If trenches need to be excavated in the landfill to allow immediate burial of the waste, excavations should be made just before the arrival of the load.

Waste placement
Objectives
To place waste in a manner that is mechanically stable and that controls litter and birds and maximises the degree of compaction.

Waste placement
Required outcomes:
<ul style="list-style-type: none"> • Maintenance of as small as possible the active tipping area. • Compaction of all waste deposited in the landfill. • Assurance that waste is placed so that all unconfined faces are mechanically stable and capable of retaining cover material.
Suggested measures:
<ul style="list-style-type: none"> • Keep covering waste to maintain the active tipping area at less than 30metres x 30metres. • Place wastes at the base of each lift and compact wastes in layers of less than two metres. • Immediately bury special wastes. • Avoid unconfined waste slopes with gradients steeper than two horizontal to one vertical units.

6.7 Waste cover

An essential part of landfilling operations is the placement of cover over wastes. The purpose of cover is to:

- minimise landfill odours;
- control litter;
- prevent the spread of fire;
- control disease vectors such as birds, flies, mosquitoes and rodents; and
- ensure that the landfill is trafficable.

To achieve these outcomes, waste should be covered at the end of every day, though landfills that receive significant volumes of waste in a day might need to cover waste during the day to maintain the length of the active tipping area at less than 30 metres.

Where soil is used as cover, the soil should contain some organic matter as this helps to attenuate landfill odours; the thickness of soil applied should be sufficient to achieve the above points. A typical cover thickness is 0.3 metres.

Materials other than soil, such as foams, mulch, paper-mâché, gravel or cover mats, may also achieve these purposes and may meet other operational needs such as landfill gas collection and enhanced biodegradation.

Materials other than soil must not be used without approval from DoE via the landfill licence.

Cover material with a high moisture content, such as slimes from sand mining operations, should be avoided as such material may release water into the waste. Wet waste will decompose faster than a dry waste, so significant quantities of gas may escape from an open cell before a gas-extraction system can be installed. If wet material is used to cover waste, then a gas-collection system, such as the horizontal well system described in section 5.7.2, needs to be installed during filling of the landfill.

Acid sulfate soils are not appropriate for use as cover material as they oxidise and produce acid run-off when exposed to the atmosphere. Once started, this reaction continues in the absence of oxygen, that is, after the cover material has been filled over. As cover material may be open to the atmosphere for extended periods, acid sulfate soil in cover material would be expected to generate acid. A landfill must not accept acid sulfate soil unless it has approval via its licence.

With the lateral movement of the active tipping area across a landfill cell, it may be some time before the next lift of waste is placed over an older area. Cover material rich in clay may dry and crack during dry weather, thus releasing landfill gas and odours. It is good practice to consolidate the cover on older areas of the landfill cell by running a roller over the cover. It may also be necessary to moisten the cover to close any cracks that have formed.

Where soil is used for cover, a stockpile of soil to be used as cover material needs to be provided. Regardless of the material used as cover, sufficient material should be available at the tipping face for at least two weeks of operations.

Waste cover
Objectives
To ensure that wastes are covered by appropriate material to mitigate against any environmental or health impacts.
Required outcomes:
<ul style="list-style-type: none"> • Covering of the landfill, at least daily, with soil or another approved cover material. • Assurance that there is sufficient cover material available at the tipping face for at least two weeks of operation.
Suggested measures:
<ul style="list-style-type: none"> • Where soil is used as cover, cover with 0.3meters of soil. • Avoid covering with wet material and acid sulfate soil. • Close cracks in old, exposed cover layers to contain landfill gas and odour.

6.8 Litter control

Municipal waste, especially plastic bags, can be spread over wide areas by the wind. This litter not only looks unsightly but might also foul drains and waterways as well as interfere with neighbouring activities such as quarrying or farming.

Litter control at landfills will vary throughout the year and with the elevation of the tipping area. No single control option will be entirely successful for the entire life of the landfill. A litter control strategy must, therefore, be flexible and include both engineering solutions and management options.

As a minimum, a best practice landfill will use litter screens and train staff in the appropriate placement of the screens to trap as much litter as possible. These litter screens should be portable to be able to follow the tipping area, and should be capable of withstanding wind loads when loaded with litter. Litter screens should be at least four metres high and wide enough to collect most litter blowing from the tipping face.

A best practice landfill will also minimise the size of tipping areas and have at least a daily litter program in which fences and surrounding areas are cleaned of any litter. It will also have contingency plans for which resources are engaged to deal with extreme events that cause gross litter problems.

In areas where litter is especially problematic, this may involve a dedicated litter crew, more frequent covering and enhanced litter screens. Such landfills may also have dedicated areas for waste deposition that are more sheltered from winds from particular directions, and therefore minimise litter from the landfill.

Litter control
Objectives
To keep the landfill and surrounding environment in a litter-free condition.
Required outcomes:
<ul style="list-style-type: none"> • That no litter from the landfill operation reaches beyond the boundary of the premises.
Suggested measures:
<ul style="list-style-type: none"> • Minimise the size of the tipping area. • Use litter screens at least four metres high to control litter at the active tipping area. • Establish a program of at least daily cleaning litter from fences and the surrounding area. • Deposit waste in areas of the landfill that are sheltered from the wind. • Establish contingency plans to deal with extreme events that cause gross litter problems.

6.9 Fires

Landfill fires can cause significant impacts on local air quality through odour and smoke. They can also spread outside the landfill, triggering a grass or bushfire. Subterranean landfill fires may burn for many years before they are detected. The smell of smoke may be the first sign that a landfill is burning and, in some cases, the surface of the landfill may collapse as a result of the fire burning out a subsurface cavity. If this collapse is triggered by the passage of a vehicle over the cavity, it could be fatal for the vehicle's occupants.

Once started, landfill fires are difficult to extinguish, so the primary objective should be to prevent a fire from starting. This is done, as far as is practical, by removing potential ignition sources, such as hot coals and lead-acid batteries, from the tipping area. Other measures include not burning waste and not lighting fires on or near areas where wastes have or are being deposited.

Finally, wastes should be covered with noncombustible material.

If a fire should start, every effort must be made to extinguish it before it gets established. Equipment to extinguish a fire must be readily available at any time to enable a prompt response to any part of the premises. A water supply, either reticulated water or from dams or tanks, combined with a means of delivery (pump and hoses or a tanker truck) allows the prompt extinguishment of a fire on the site. Groundwater and stormwater stored in dams might be suitable for combating a fire. Leachate should not be used unless all parties are aware of the possible risks and adequate measures are taken to reduce human exposure. Where reticulated water is not provided, at least 50,000 litres should be stored onsite for the purpose of combating small fires. In the event of a significant fire, this volume will need to be supplemented by another source of water.

It is not usually possible to extinguish deep-seated fires using water except where the operator has sufficient plant and water to excavate and extinguish all burning waste. Where extinguishment is not possible, adding water to the landfill exacerbates the fire because the water adds oxygen to the fire. To combat deep-seated fires, key elements are to minimise oxygen ingress to the fire by capping off the area, and displacing oxygen from the fire by injecting an inert gas, such as nitrogen, into the fire.

In some areas, the local fire authority might require a firebreak to prevent the spread of fire into or out of the site. This, in conjunction with developing a fire management plan with the local fire authority, is best practice in areas where grass or bushfires might be a concern.

Fires
Objectives
To prevent landfill fires and efficiently extinguishing any that should occur.
Required outcomes:
<ul style="list-style-type: none"> • Maintenance of a water supply capable of being delivered to any point on the landfill. • That all practical steps have been taken to prevent landfill fires.
Suggested measures:
<ul style="list-style-type: none"> • Develop a fire-management plan in conjunction with the relevant fire authority. • Do not burn waste at the landfill or light fires on or near areas where wastes have been or are being deposited. • Where the reticulated water supply is not adequate for fire fighting purposes or not available, maintain at least 50,000 litres of water onsite. • Remove ignition sources such as hot coals, and car and marine batteries from the waste at the tipping area. • Cover combustible waste with inert material. • Construct a firebreak around the perimeter of the landfill to the satisfaction of the relevant fire authority.

6.10 Contingency planning

To ensure that appropriate measures are taken in the event of an incident or anomaly, contingency plans should be developed to deal with such incident or anomaly. All staff at the landfill should be trained in the implementation of the contingency plan.

The contingency plan should consider all impacts discussed in this guideline, and in particular:

- the detection of contamination of surface or groundwaters;
- blockage of leachate collection pipes;
- a landfill fire;
- deposit of unauthorised waste;
- offensive odours or dust beyond the boundary of the premises; and
- litter beyond the boundary of the premises.

The contingency plan should be reviewed after the occurrence of any incident covered by the plan to ascertain the effectiveness of the contingency plan and where, if necessary, it could be further improved.

Contingency planning
Objectives
To ensure that all potential incidents are considered and that appropriate measures are planned to deal with them.
Required outcomes:
<ul style="list-style-type: none"> • All likely impacts are covered in preparation of the contingency plan. • All staff are trained in the implementation of the contingency plan.
Suggested measures:

Contingency planning

- Review the document after any incidents covered by the plan.

6.11 Management of chemicals and fuels

Landfill operations may use a variety of chemicals and fuels. If these are inappropriately managed they can impact adversely upon the environment.

The storage and handling of flammable and combustible liquids should be in accordance with the provisions of the AS 1940:1993, The Storage and Handling of Flammable and Combustible Liquids, and/or the requirements of the Department of Industry and Resources.

Particular measures include keeping inventories to a minimum, bunding liquid storage areas and locating them away from waterways or areas prone to flooding, and having a contingency plan for the management of any spills as part of the site EMS.

Management of chemicals and fuels

Objectives

To manage the storage and handling of chemicals and fuels so as to minimise the risk of impact on the environment.

Required outcomes:

- Storage and handling flammable and combustible liquids in accordance with the provisions of the AS 1940:1993, The Storage and Handling of Flammable and Combustible Liquids and DoIR requirements.

Suggested measures:

- Keep onsite chemical and fuel inventories to a minimum.
- Construct bunds for liquid storage areas in accordance with the appropriate regulatory guidelines and/or standards.
- Locate storage areas away from waterways or areas prone to flooding.
- Implement a contingency plan to handle spills to avoid environmental damage.

6.12 Disease vector control

Flies, mosquitoes, rats, cats and birds (typical disease vectors) are attracted by food wastes and still waters at landfills. If uncontrolled, these pests can affect public health and surrounding ecosystems. The main mechanisms for the control of disease vectors are the use of cover material to cover waste daily (see section 6.7) and eliminating any waterbodies that are not required for fire, sediment and leachate control; however, other measures, such as scare devices and traps, may be used to reduce or control infestations.

Professional pest exterminators should be employed to reduce problem infestations of vermin.

Landfills located near airports, close to a surface water supply, or industrial or residential areas that may be affected by bird droppings, need a high level of bird control.

The most successful bird deterrent strategies rely upon a variety of techniques. While the immediate spreading of cover material over the wastes may not entirely deter birds, it can be supplemented with other options such as nets or monofilament wires over glide-paths or water dams, anti-perch strips on buildings, and active measures such as acoustic bird scaring devices (gas guns or mimicking distress calls), predator decoys or even using dogs. Since birds become accustomed to one particular measure, some variation in the active measures used is necessary.

Disease vectors
Objectives
To minimise disease vectors emanating from the landfill by denying pests food and shelter.
Required outcomes:
<ul style="list-style-type: none"> • Elimination of any waterbodies at the landfill that are not required for fire, sediment or leachate control.
Suggested measures:
<ul style="list-style-type: none"> • Cover waste daily. • Use professional pest exterminators to reduce problem infestations of vermin. • Vary bird scare methods to avoid any patterns in methods.

6.13 Noxious weed control

Where noxious weeds become established at a landfill, these weeds can spread through surrounding areas and impact on farming activities or natural ecosystems. Noxious weeds can become established through colonisation or through introduction by contaminated seed- or weed-infested mulch used to revegetate exposed areas of earth. To minimise the risk of introducing weeds through planting, only-high quality seed, free from any noxious weeds, should be used. Where an area is to be mulched, ensure that the mulch is free of noxious weeds. Where site mulching is conducted, a degree of diligence is required to prevent noxious weeds from being added to the green waste heap. Such waste should be landfilled.

The site should be managed by regularly inspecting for noxious weeds and eradicating any weeds present through appropriate means.

Noxious weed control
Objectives
To manage the landfill site so that it does not become a source of noxious weeds.
Required outcomes:
<ul style="list-style-type: none"> • Minimise the introduction of noxious weeds to the site. • Eradicate any noxious weeds that have established themselves on site.
Suggested measures:
<ul style="list-style-type: none"> • Ensure that all plantings from seed are from only high quality seed. Mulch should be completely free of noxious weeds. • Regular inspection of the site for the presence of noxious weeds. Record their presence and, if necessary, implement a control program. • Where pest plants need eradication this is to be done by appropriate means. If the problem is large or current methods are not working, seek the advice of the local council or the DoE. • Become involved in the local landcare group to develop regional strategies to eradicate regional noxious weeds.

6.14 Performance monitoring and reporting

In order to assess the performance of the measures taken to protect the environment from the impacts of landfilling, monitoring, assessment and reporting of the results are required.

A monitoring program should include monitoring of leachate, groundwater, surface waters and landfill gas. Monitoring should be conducted at least twice a year, with quarterly monitoring for

the first few years to establish an accurate baseline. All water sampling should be conducted in accordance with the DoE's monitoring guidelines and or the requirements in the landfill licence.

Environmental conditions such as atmospheric pressure, temperature, precipitation and stream flows should be recorded when samples are taken.

Monitoring results should be interpreted and analysed to identify either long-term trends or significant changes between sampling events. This is facilitated by a plot of analyte levels over time. Where analytes change significantly between sampling events, a further sampling round should be conducted immediately to verify the result. If either a long-term trend is identified or a significant change between sampling events is verified, the DoE should be advised and the reason for the change investigated as a matter of priority.

For any perceived long-term trends to be true trends rather than normal fluctuations in environmental quality, they need to be based on a number of years of data.

The results of the monitoring program should be reported to the DoE in accordance with licence conditions; problems should be reported as soon as possible after being identified. This report should include details of any complaints received and their resolution, the effectiveness of programs to control litter, dust and other nuisance emissions and details of any extraordinary events that occurred at the landfill over the year, such as fires.

Where there is community interest in the landfill operations, the landfill operator should also report to the community. This is particularly important in the event of a highly visible incident – the community should be advised immediately of what happened and what is being done to rectify the situation and prevent a recurrence.

Monitoring reports will include the raw data, plots of the data over time and an analysis and interpretation of what the results mean. This analysis and interpretation should be conducted by an expert in the field. The report will also contain a statement of volumes of waste received, volumes of leachate and groundwater pumped and landfill gas extracted. The report is intended to examine the operations during the preceding year, as well as to identify trends and potential areas of improvement. In particular, the report will identify areas for improvement in environmental management and the outcomes of initiatives to reduce wastes going to landfill.

Performance monitoring and reporting
Objectives
To monitor and report on the performance of measures taken to protect the environment from potential impacts from a landfill.
Required outcomes:
<ul style="list-style-type: none"> • Regular monitoring of leachate, groundwater, surface waters and landfill gas. • Assurance that monitoring results are interpreted by an expert in the field. • A report, submitted at least annually, to DoE with problems reported within seven days of observation.
Suggested measures:
<ul style="list-style-type: none"> • Include the community in any reporting. • Report on complaints, litter and dust control programs and extraordinary events that occurred over the year. • Plot data to identify trends and anomalous results. • In the event of anomalous results, conduct another round of monitoring immediately to verify the results. • Where anomalous results are verified, consult with DoE, identify the source and

Performance monitoring and reporting
implement measures to rectify the problem.

7. BEST PRACTICE REHABILITATION AND AFTERCARE

Many of the chronic impacts of landfilling occur long after the landfill has closed, and while these can be mitigated against by good design and operation of the landfill, best practice rehabilitation and long-term aftercare of the site will further minimise the potential of any detrimental impacts from the landfill. Best practice for rehabilitation and aftercare is considered very early in the design and operation phase of the landfill.

The DoE will require this section of the guideline to be implemented for all existing landfills. The DoE may also require this section to be implemented for landfills that are currently closed where the rehabilitation and/or aftercare is, or is likely to be, inadequate to guard against pollution.

7.1 Rehabilitation

The design of modern landfills operating on a cellular basis allows the landfill to be progressively rehabilitated. While wastes are deposited in the new cell, the old landfill cell is rehabilitated, and, depending on the life span of the new cell, construction of the next cell may commence.

The advantages of progressive rehabilitation include:

- full cost recovery during the economic life of the landfill;
- collection and treatment of landfill gas during its peak generation period;
- a clear demonstration to the community that the site will be rehabilitated; and
- minimising the generation of leachate and offensive odours.

To ensure that the objectives of rehabilitation are achieved, a conceptual rehabilitation plan should be developed as part of the initial landfill design.

The rehabilitation plan should deal with afteruse options for the site and provide a blueprint for the final surface contours and cap design of the landfill. The rehabilitation plan should include:

- the potential afteruses of the site, taking into consideration trends in the surrounding area;
- operational requirements, to ensure that the highest value afteruse can be achieved;
- surface contours before and after settlement;
- specifications and materials to be used in the final cap; and
- preservation/installation of environment performance control or monitoring features.

7.1.1 Site afteruse

In considering options for the use of the site after landfilling, the location of the landfill, the needs of the local community, the surrounding land uses and the nature of the operation should all be considered. The relevant regulatory and planning authorities should be consulted, as they might have a strategic plan for the area that identifies how that land could potentially be used.

Proposals for the use of the filled landfill site should be flexible enough to allow for changes in community attitudes or planning requirements in the long period between commencement of landfilling and final rehabilitation.

Regular reviews of afteruse options are a good way of ensuring that the operation of the landfill does not alienate desired afteruses of the site. In particular, understanding the afteruse during operation ensures that the final surface profile of the landfill is consistent with the desired afteruse.

Common afteruses of landfills include sports grounds, public open space and golf courses. Depending on the age of the landfill and the type of waste deposited, some landfills have been

developed for commercial or industrial building development, though this requires particular consideration of the impacts of settlement on buildings and services such as water mains, gas and roads.

Water features, such as ornamental lakes or ponds, should be avoided on landfills as they may leak due to cracking of their liner from differential settlement of the landfill over time. This leakage will release significant volumes of water to the landfill, thus generating significant volumes of leachate.

7.1.2 Settlement and final surface profile

A landfill is subject to long-term settlement, as waste decomposes and consolidates; this settlement has significant impacts on the final surface profile, the landfill cap and potential afteruses for the site. The rate and degree of settlement are dependent upon:

- proportion of putrescible wastes;
- thickness of the landfill;
- period over which wastes were placed in cell;
- the degree of compaction;
- the moisture content of the wastes, and
- the degree of surcharging or loading placed on the cap.

Long-term settlements for well-compacted landfills vary significantly and can range from 10 to 30 per cent. Most of the settlement occurs within the first few years of the cell closure, the result of waste compressing under its own weight and the weight of the cap. After this initial compression, settlement will continue for many years as a result of consolidation and biodegradation processes within the waste. A landfill receiving largely non-putrescible wastes will have a lower rate of settlement. Where landfill cells are filled rapidly, the settlement of the closed landfill will be higher than for an equivalent thickness of wastes placed over a longer period.

The landfill cap design is governed by limiting water infiltration into the landfill, which is a function of the materials used in the cap and its shape. The gradient for a completed cap should be sufficient to ensure that most water hitting the cap runs off to minimise infiltration through the cap. Gradients of about five per cent will adequately shed water, though steeper gradients will provide a higher runoff potential.

Caps should not be steeper than 20 per cent. Caps steeper than this can cause erosion problems and can be more difficult to maintain than flatter caps. Steep caps will require specific engineering controls to ensure that they are stable; these controls will, typically, relate to relieving any seepage water pressures within the cap. They will also require features such as cut off drains and rock beaching on drainage lines to control water erosion and, therefore, erosion. In addition, the surface layer should be vegetated as quickly as possible to further control erosion. Until the vegetation becomes established, this revegetation program should be augmented with measures such as mulch or erosion mats to control erosion.

Since compaction of wastes along near-vertical side walls is difficult, the wastes along the walls of the landfill may exhibit the highest initial rate of settlement. The landfill cap needs to make allowance for this by providing sufficient thickness of the cap to ensure that runoff from the cap is not collected in depressions along the perimeter of the landfilled area.

The landfill aftercare program must include inspections of the cap, checking for differential settlement and indicators that the integrity of the low permeability cap has been compromised. The frequency of the inspection program will be largely determined from the observed rate of settlement.

When buildings are constructed on a filled landfill, permission must be obtained from the Department of Health and special support and protection from landfill gas may be required. Where structures are to be built on landfills, the landfilling should be planned to provide for

selective disposal of wastes, special compaction and a thicker cap. These will all increase the bearing capacity of the landfill, making the construction of these structures more viable. Where small trees and shrubs are to be planted on the landfill, the cap will need to be thicker to ensure that the roots do not penetrate the cap. The thickness of the cap will also affect the species selected.

7.1.3 Landfill cap

A key element of the rehabilitation is the capping of the landfill. The design objectives for the final landfill surface or capping are:

- minimising infiltration of water into the waste ensuring that the infiltration rate does not exceed the seepage rate through base of the landfill;
- providing a long-term stable barrier between waste and the environment in order to protect human health and the environment;
- preventing the uncontrolled escape of landfill gas; and
- providing land suitable for its intended afteruse.

The long-term protection of the groundwater environment is provided by the landfill cap. The cap must be designed such that the infiltration through the cap does not exceed the calculated seepage rate through the landfill liner. This avoids the so-called 'bathtub' effect, in which leachate levels within the landfill build up and eventually break out through the surface of the landfill.

Table 9 indicates the required performance standards of caps, as well as indicative cap designs, which are based on preventing infiltration by providing a very low permeability layer (clay or composite barrier).

Table 9 : Indicative landfill cap designs

Landfill type	Cap performance	Indicative landfill cap	
Class III	75 per cent of the anticipated seepage rate through the liner	Topsoil / mulch	> 1 m
		Soil sub base	
		Geomembrane Geotextiles	
		Drainage layer	
		Low permeability clay	
		Gas collection layer	
Class II	75 per cent of the anticipated seepage rate through the liner	Earthen cover	0.3 m
		Waste	
		Topsoil / mulch	
		Soil sub base	0.5 m
		Low permeability clay	0.5 m
		Earthen cover	0.3 m
		Waste	

Where the proposed afteruse of a landfill is to require vegetation of the site, the top-most layer must be able to support vegetation and be of sufficient depth to ensure that roots do not penetrate the cap, thus providing a conduit for water into the landfill and water out of the landfill.

The surface layer should reflect the type and depth of top soils normally found in the local area. Where it is not possible to duplicate the local topsoil conditions or the natural soil is too thin to support adequate vegetation for erosion control, then an appropriate mix of soils 200 to 300 millimetres thick should be used provided it is capable of sustaining vegetation. Any mulch used in the cap should be pasteurised to remove weed seeds, plant pathogens and pests.

Introduced plantings on the landfill should not include any noxious weed variety for that area, nor should the landfill provide a haven for weeds migrating from the surrounding area (see section 6.13 for more detail on the management of noxious weeds). Advice should be sought on species selected for planting to prevent them from becoming local pests. In general, it is advised that planting be restricted to species indigenous to the area and of local provenance, so as to:

- avoid inappropriate planting;
- ensure the species are adapted to the local climate; and
- enhance the local habitat.

To limit seepage, a layer of low-permeability clay and/or a flexible membrane liner may be required in the cap. Care needs to be taken in the selection of the particular geomembrane to be used, particularly with respect to the tensile strain that may be expected to be placed on the geomembrane as a result of settlement. To ensure the best results, consult with the manufacturer of the geomembrane. To avoid damage to geomembranes within a cap by vehicle traffic, the geomembrane should be placed at least 0.6 metres beneath the surface.

The construction and maintenance of a low permeability clay layer for a cap is difficult for a number of reasons, including:

- the spongy foundation of waste on which it is built;
- differential settlement of the waste causing cracking of the clay; and
- desiccation of the clay from above due to evapotranspiration and below due to heat released from the landfill.

All of these significantly increase the effective hydraulic conductivity of the clay; the estimate of seepage rates through the cap should make allowance for this.

A drainage layer is sometimes placed between the soil layer and the low permeability capping layer. The purpose of the drainage layer is to remove excessive moisture that has permeated through the soil layer and will not be removed by evapotranspiration. Due to problems with desiccation of the surface or low permeability layer, drainage layers are generally only used in high rainfall areas or where the cap has a very shallow gradient.

If a drainage layer is incorporated into the landfill cap then it must be designed such that it does not dry out the surface layer thereby killing vegetation, and does not prevent the continued hydration of the low-permeability barrier layer, which prevention would cause it to dry and crack. The drainage layer may be a sandy soil or even gravel, which conveys water to a drainage system at the toe of the landfill cap. Care must be taken to ensure that the drainage layer is able to drain water from the landfill as an accumulation of water at the toe of the cap may cause instability in the cap.

An alternative means to achieving the cap performance standards is to construct a cap based on water storage principles. The fundamental objective of such a cap is to store water during periods of elevated precipitation and low evapotranspiration for subsequent release during drier periods. A cap of this type is made up of a thick, vegetated layer of fine-textured soil that has a high water storage capacity, and may be underlaid by a capillary barrier of material, such as gravel. These caps are best suited to areas where precipitation is well distributed throughout the year, and where evaporation exceeds precipitation for much of the year. Modelling of unsaturated water-flow through the cap is required to ensure that it meets the required

performance standards. This modelling should be based on data accurately reflecting local conditions, and should be run for a series of at least three consecutive wet years.

Rehabilitation plan
Objectives
To ensure that landfills are rehabilitated to minimise the seepage of water into the landfill and maximise the collection and oxidation of landfill gas from the landfill.
Required outcomes:
<ul style="list-style-type: none"> • Preparation, early in its design, of a rehabilitation plan for the landfill, including a detailed consideration of afteruse options for the site. • That the seepage through the landfill cap is no more than 75 per cent of the anticipated seepage rate through the landfill liner. • Design and construction of the best cap practicable to prevent pollution of groundwater and degradation of air quality through the escape of landfill gas. • Design and construction of the most robust cap to ensure that the system will continue to achieve the objective in the event of several components of the system failing. • Progressive rehabilitation of the landfill.
Suggested measures:
<ul style="list-style-type: none"> • Strive for the highest value afteruse of the site in operation and rehabilitation considerations. • Design and operate the landfill to accommodate the desired afteruse. • Develop the rehabilitation plan in consultation with the local community and regulatory and planning authorities. • Regularly review the rehabilitation plan to ensure that changed circumstances are reflected in the plan. • Consider impacts of settlement on any potential afteruses of the landfill. • Design the cap gradient to be between five and 20 per cent. • Where a geomembrane is to be used in the cap, consider manufacturers' recommendations during design and installation. • Vegetate cap or take other measure to minimise erosion as soon as possible. • Where trees or shrubs are to be planted on the site, incorporate a greater thickness of soil in the cap to prevent the roots from penetrating the cap.

7.2 Aftercare management

Until the waste within the landfill has sufficiently decomposed or stabilised such that it no longer presents a risk to the environment, it must be managed so as to prevent any environmental impact.

The following areas must be considered in preparing the aftercare management plan:

- maintenance of landfill cap, in particular to: prevent/control erosion; restore depressions, and seal and monitor cracks in the cap caused by settlement; and restore/maintain vegetation.
- maintenance and operation of leachate collection and treatment system;
- maintenance and operation of landfill gas-extraction system;
- environmental monitoring of groundwater; surface water; landfill gas; leachate; and settlement.

As these activities will continue beyond the income-producing period for the landfill, funds should be allocated during the operational life of the landfill to provide for aftercare management. The typical period of aftercare is about 30 years.

The aftercare management plan should address the level of monitoring and frequency of inspection of the landfill and infrastructure. These elements are dependent upon the location of the landfill, the types of wastes and the landfill’s environmental performance. Accordingly, putrescible landfills would require a more extensive aftercare management plan than a solid, inert landfill.

During the aftercare period, the frequency of monitoring and inspection may be decreased, frequency being based on the stability of the landfill cap and the consistency of environmental monitoring results. As most settlement occurs within the first two years after closure, the inspection program needs to be more frequent during this period.

The data and observations collected in accordance with the plan should be reviewed by an expert in the field (see section 6.14 for more information on performance monitoring and reporting; the elements discussed in this section apply to monitoring during the operation of the landfill and after its closure). Buildings on the landfill must not prevent the continuation of aftercare programs, such as groundwater monitoring and landfill gas collection.

The leachate collection and treatment system will need to be inspected and maintained for as long as the landfill is actively generating leachate. This will include inspection and cleaning of leachate collection pipes, maintenance of leachate treatment plants and inspection after periods of heavy rain to ensure that the system is not overloaded. This must continue until the DoE has given written confirmation that the landfill is no longer generating leachate able to detrimentally impact on the environment.

The landfill gas-extraction system needs to be maintained for the life of landfill’s gas generation. This includes maintaining the plant, such as cogeneration equipment used to control the gas. This must continue until the DoE has given written confirmation that it is no longer required or that the system may be downgraded to a less intensive form of management.

In determining whether maintenance is still required, the DoE will refer to monitoring results information on groundwater, surface water, landfill gas and leachate. If monitoring is conducted regularly, and the trend clearly demonstrates that leachate is clean and minimal landfill gas is being generated, then the DoE can be assured that the site no longer poses a risk to the environment and may remove maintenance requirements. Where this monitoring is patchy and trends are inconclusive, then the DoE cannot have this degree of assurance and will not remove maintenance requirements.

To ensure in the long-term that prospective owners of the land are aware that it was once a landfill, measures such as a caveat on the land title or a planning overlay can alert people of the prior use of the site. The DoE may also serve an Environmental Protection Notice on the site to ensure ongoing management of the site and place the site on the Contaminated Sites Register to ensure that all potential future stakeholders are aware of the ongoing management requirements of the site.

Aftercare management
Objectives
To manage the site after closure so that environmental protection and monitoring systems are maintained until the landfill has stabilised.
Required outcomes:
<ul style="list-style-type: none"> • Preparation of a Landfill Aftercare Management Plan.
Suggested measures:

Aftercare management

- Regularly inspect site to check the integrity of the cap and monitor the environmental impact of the landfill.
- Inspect and maintain leachate collection and treatment and landfill gas-extraction systems.
- Conduct regular monitoring and analyse data for any trends.
- Ensure that any buildings at the landfill do not interfere with monitoring and maintenance of the landfill.

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APPENDIX 1: SUMMARY OF KEY ELEMENTS OF AN ENVIRONMENT IMPROVEMENT PLAN

Key elements of an environment improvement plan (EIP) are provided below with the development/implementation of an EIP program. Some of these elements are discussed in greater detail in section 5 of the guidelines.

The elements outlined are based on the concept of an EMS elaborated in ISO 14001. While an EIP does not have to meet the requirements of ISO 14001 to be suitable for use at a site, the requirements of ISO 14001 are useful as a model because they are based on the underlying premise that for such a system to work effectively, commitment is required at all levels of the organisation.

1. Environmental policy

A corporation's environmental policy is a concise public statement of the company's intentions with respect to the environment. The policy should be written such that it:

- is relevant to the company's activities, products and services, and their environmental effects;
- is communicated, implemented and maintained at all levels in the organisation;
- is made publicly available;
- includes a commitment to continual improvement of environmental performance;
- provides for the setting and publication of environmental objectives;
- states which of the organisation's activities are covered by the particular environmental management system; and
- indicates how the environmental objectives will be made publicly available.

2. Organisation and personnel

The organisation shall define and document the responsibility, authority and interrelation of key personnel who manage, perform and verify activities having a significant effect, actual or potential, on the environment. This includes those who need the organisational freedom and authority to:

- provide resources and personnel for implementation;
- initiate action to ensure compliance with environmental policy;
- identify and record any environmental problems;
- initiate, recommend or provide solutions to those problems through designated channels;
- verify the implementation of such solutions;
- control further activities until any environmental deficiency or unsatisfactory condition has been corrected; and
- act in emergency situations.

The organisation should also appoint a management representative who, irrespective of other responsibilities, shall have defined authority and responsibility for ensuring that the requirements of the EIP (and/or ISO 14001) are implemented and maintained.

Training procedures should also be implemented so that employees are aware of the company's environmental requirements and objectives, as well as of the requirements of the EIP (and/or ISO 14001).

Employees should also be aware of the significant environmental effects, actual or potential, of their work activities and the environmental benefits of improved performance, and their roles in achieving compliance with company policy and the EIP.

Contractors also need to be made aware of the company's EIP.

3. Environmental effects evaluation and register

An organisation should evaluate the environmental effects of its activities, products and services and compile a register of the identified significant effects.

The identification of these effects must apply not only to normal operations but also to abnormal operating conditions including shut-down and start-up, incidents, accidents, and also past and future activities.

4. Environmental objectives and targets

An organisation should establish and maintain, at all levels relevant within the organisation, procedures to specify its environmental objectives and consequent targets.

5. Environment management manual and documentation

The elements of the EIP should be documented. The documentation may be in electronic form. A manual to cover policies, objectives, targets, key roles and responsibilities is required. It should describe the interactions of system elements and provide direction to related documentation.

The procedures should cover normal operation as well as emergency situations. The documents should be reviewed and revised periodically and approved by authorised personnel prior to issue. They should be legible, dated and be available at defined locations. Obsolete documents should be removed.

The need to generate 'new' manuals should be minimised. The preferred approach is, wherever possible, to augment existing operational manuals.

6. Environment management records

Separate from the environment management manual and documentation control, ISO 14001 makes certain provisions about record keeping. Records are to be established and maintained in order to demonstrate compliance with the requirements of the EIP and to record the extent to which planned environmental objectives and targets have been met. Aspects covered include records indexing, filing, storage, maintenance and disposition. Records of contractors and procurement, results of audits and reviews, and training records are required to be kept.

7. Audits

The organisation should establish and maintain procedures for audits. The audits are required to cover organisational structures, such as administrative and operational procedures, work areas, operations and processes. Frequency of audits depends on the significance of the potential environmental effects and the results of previous audits.

The audit protocols are required to deal with:

- procedures for conducting audits;
- procedures for reporting the findings to those responsible
- documentation, reports and records;
- environmental performance;
- audit personnel; and
- methodologies.

8. Environment management review

This is a different activity to the auditing function. Here, the organisation's management is to itself review the EIP adopted to satisfy the requirements of the policy and to ensure its continuing suitability and effectiveness.

In particular, the review is to address whether there is a need to change policy or objectives.

APPENDIX 2: TECHNICAL GUIDANCE

Example of groundwater impacts from liner designs

Using a number of assumptions to simplify the problem, the likely impact from various liner seepage rates can be modelled. The key assumptions used here are:

- Modelling for conservative species, that is, species that do not degrade as they are transported;
- Leachate mixes completely with groundwater in the top 5 m depth of the aquifer;
- Groundwater hydraulic gradient is 0.06;
- Groundwater hydraulic conductivity is 0.2 m/day; and
- Leachate total dissolved solids (TDS) is 6,000 mg/L.

Table 10 : Modelled groundwater impacts resulting from various liner seepage rates

Seepage rate	10 (L/ha/day)	1,000 (L/ha/day)
Groundwater TDS		
500 (mg/L)	509 (1.8%)	1,286 (157%)
3,000 (mg/L)	3,005 (0.2%)	3,429 (14.3%)

In each of these cases, the seepage rate of 1,000 L/ha/day results in an unacceptable impact on the TDS of groundwater.

It is incorrect to conclude that the contamination of groundwater caused by a seepage rate of 1,000 L/ha/day into groundwater with a TDS of 3,000 mg/L is not pollution simply because it is still within the band of 1,001 to 3,500. An increase in TDS of over 400 mg/L results in significant reductions in beneficial uses that may be made of this groundwater, and is therefore unacceptable.

This example is just one, simple element of what should be a detailed study of potential impacts on groundwater from the landfill operations. This study should include analytes other than TDS, and should consider the beneficial uses lost by incremental increases in contaminants.

Clay properties

Clay to be used in liners should have the following properties:

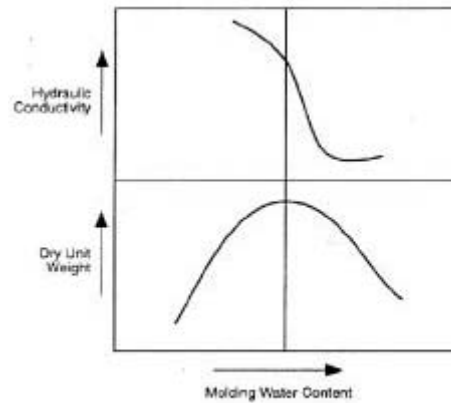
- no rock or soil clumps greater than 50 mm in any direction;
- more than 70 per cent passing through a 19 mm sieve;
- more than 30 per cent passing through a 75 μ m sieve;
- more than 15 per cent passing through a 2 μ m sieve; and
- soil plasticity index exceeding 10.

The ability of clay to absorb exchangeable cations is measured by the cation exchange capacity, a measure of the total amount of exchangeable cations that a soil can adsorb. A cation exchange capacity (CEC) of 10 mEq/100g is a minimum level for clay used in a best practice landfill. Given this elevated CEC, there is the potential for the clay to degrade through clay-pollutant chemical reactions over a long period of time. To guard against this risk, long-term permeation tests should be conducted on the clay to assess any variations in intrinsic permeability over the long term. Kodikara & Rahman (1997) suggest that using a 50,000 ppm NaCl solution over 2-3 months should indicate any such long-term variations.

Installation of clay liners

Before a clay is used to construct a liner, samples of the clay to be used should be submitted to a laboratory for determination of the soil properties for a range of compaction efforts. This will enable the development of laboratory compaction and hydraulic conductivity curves which should be assessed to determine the suitability or otherwise of the material as a low permeability barrier.

The relationship between the water content and the density of the clay is the key relationship determining the suitability of the material as a low permeability liner. Figure 4: shows the effect of moulding water content (moisture content of the clay when compacted) and the dry density of the clay (dry unit weight). Maximum dry density is achieved at the optimum moisture content. The lowest hydraulic conductivity of the compacted clay liner is achieved when the soil is compacted at a moisture content slightly higher than the optimum moisture content.



Source: U.S. EPA, 1969.

Figure 4: Relationship between hydraulic conductivity, density and moisture content of a clay soil

By specifying compaction to be undertaken at a percentage above optimum moisture content to achieve a density defined as a percentage of maximum dry density, an envelope or 'acceptable zone' of performance criteria can be derived for undertaking quality control checks in the field both during and after construction. Best practice is to compact the clay at about two to three per cent wet of optimum moisture content to a maximum dry density of 95 to 98 per cent of Proctor Standard.

Clay liners are constructed in series of 'lifts' compacted to the required maximum dry density at the specified moisture content. To achieve bonding between each lift, the thickness of each lift must permit the compaction equipment, typically a sheep'sfoot roller, to penetrate the top lift and knead the previous lift. Scarification of the previous lift may also be required to improve bonding. This bonding is required to overcome the effects of imperfections within individual lifts.

Within individual lifts of the clay liner, microscopic and/or macroscopic zones may exist of lower and higher hydraulic conductivity. These exist due to small stones or dry clods of clay within the liner material. Zones of lower hydraulic conductivity form preferential flow paths which enable rapid localised leachate flows through the lift. Where successive lifts are not bonded with the preceding lift, leachate may flow along the horizontal seams between the lifts to further preferential flowpaths. As a result, the hydraulic conductivity of the whole liner is compromised. A further factor is the number of lifts used, with a greater number minimising the probability that preferential flowpaths will align. By bonding each successive lift with the preceding lift and using a minimum of 4 to 6 lifts, the hydraulic conductivity of the liner can be optimised.

The final surface of a compacted clay liner should be finished to a smooth surface. This minimises the surface area of the liner thereby reducing the loss of moisture from the liner, promotes the rapid drainage of leachate to the top of the liner and allows the installation of a geomembrane liner.

Drainage aggregate properties

The aggregate to be used in constructing a drainage layer should be selected to maximise drainage of leachate in the long term. Recommended properties are:

- D_{85} not less than 40 mm
- D_{10} not less than 20 mm

- uniformity coefficient less than 2
- fines content less than 1 per cent by weight and
- no limestone or other calcareous material that would be subject to chemical attack.

To achieve these characteristics, the aggregate may need to be pre-washed.

Giroud's equation

Giroud's equation is used to derive the required spacing between sub-surface drainage pipes given the maximum permissible head over the pipes and a number of physical parameters. The equation is:

$$L = T_{\max} (2 \cos 2B) / (\tan 2B + 4q/k - \tan B)^{0.5}$$

- L = spacing between drainage pipes (m)
- T_{\max} = maximum leachate head over liner (m)
- k = permeability of drainage layer (m/sec)
- B = slope of the liner
- q = leachate seepage rate into drainage layer (m/sec).

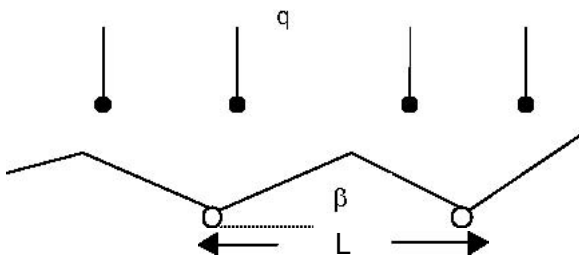


Figure 5: Parameters for Giroud's equation

Since Giroud's equation assumes a constant permeability of the drainage layer, the pipe spacing may need to be less than that calculated using the equation to take into account clogging of the drainage layer. Alternatively, the permeability of the drainage layer used in the calculations could be assumed to be two orders of magnitude worse than its design permeability.

Calculation of area required for evaporation of leachate

If evaporation is to be used as the primary means of disposing of leachate, then an appropriately sized pond needs to be designed to ensure that the system can handle the volume of leachate expected to be generated over a year. This can be calculated by using the following formula:

$$A = 1,000 V / (0.8E - R)$$

Where:

- A = pond surface area (m²)
- V = annual volume of leachate (kL)
- E = median annual evaporation (mm class A pan)
- R = median annual rainfall (mm).

Aerobic leachate treatment systems

An aerobic leachate treatment system comprises:

- leachate collection pond;
- treatment pond; and
- treated leachate pond.

The leachate collection pond allows a steady flow of leachate into the treatment pond, thereby providing a volumetric buffering role. This avoids large-scale fluctuations of the chemistry of the leachate undergoing treatment and prevents the flushing of bacteria essential for the breakdown of organic material. A typical volume to be released to the treatment pond is 10 per cent of the volume of this pond.

If the treatment pond is aerated, then a period of a few hours should be allowed for the bacteria floc to settle before treated leachate is transferred to the treated leachate pond. Only a small proportion of the leachate contained in the treatment pond should be transferred to the treated leachate pond to retain as many of the bacteria in the treatment pond as possible. All ponds should be designed to enable these controlled releases.

USEPA landfill air emissions estimation model

$$Q_{CH_4} = L_0 R (e^{-kc} - e^{-kt})$$

Where:

Q_{CH_4} = methane generation rate at time t , (m^3/yr);

L_0 = methane generation potential, ($m^3 CH_4/t$) refuse;

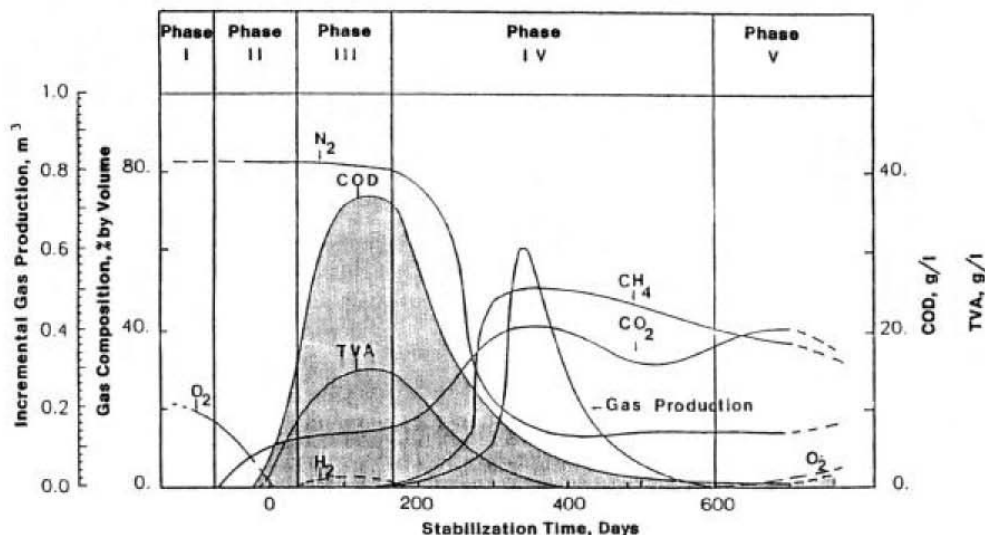
R = average annual refuse acceptance rate during active life, (t/yr);

k = methane generation rate constant, (yr^{-1});

c = time since landfill closure, (yrs) ($c=0$ for active landfills); and

t = time since initial refuse placement, (yrs).

Non decomposable material should be subtracted from the quantity of waste being deposited in the landfill. Default values used for Australian landfills are $k = 0.058/yr$, $L_0 = 79 m^3/tonne$ for calculating non-methane volatile organic compounds (NMVOC) using the spreadsheet 2000 for NMVOC (*National Greenhouse Gas Inventory Committee, 1996*).



Phase 1 aerobic; phase II anaerobic, non methanogenic; phase III anaerobic, development of methane; phase IV anaerobic, steady methane, phase V recovery

Figure 6 : Typical phases of landfill gas production with time
(Reinhart and Townsend, 1998)

Physical and Mechanical Requirements of Geomembranes

Property	Characteristic	Standard values	Test methods
Performance under tensile load	Biaxial tensile test, out-of-plane elongation	Out of plane elongation \geq 15 per cent without yielding of the material	Based on DIN 53861
	Uniaxial tensile test, yield stress, elongation at yield, elongation at break at 23°C	<ul style="list-style-type: none"> Yield strength \geq 15N/mm² Elongation at yield \geq 10 per cent Elongation at break \geq 400 per cent 	DIN 53455
	Uniaxial tensile test, yield stress, elongation at yield, elongation at break at 70°C	<ul style="list-style-type: none"> Yield strength and elongation at yield not yet determined Stress \geq 2 N/mm² at 5 per cent elongation 	DIN 53455
Tear propagation resistance	Tear propagation strength	Tear propagation strength \geq 500N Tear propagation strength \geq 300N	DIN 53356-A DIN 53515
Resistance to punctiform quasi-static single loads	Penetration strength	Penetration strength \geq 6,000N	DIN 54307, punch speed 50 mm/min
Perforation test	Mechanical resistance to perforation	No failure of watertightness at point tested	DIN 16726, drop height 2,000 mm
Relaxation performance	Drop in stress in the time-stress curves	After 1,000 hours the stress must be \leq 50 per cent of the stress after 1 minute	DIN 53441
Seam strength	Short term shear test, failure performance	No shearing off of the seam, significant yielding of base material near to but outside the seam	DIN 53441, tensile test in: DIN 53455 speed 50 mm/min
	Peeling test, failure performance	No peeling off of the seam, significant yielding of the base material near to but outside the seam.	DIN 16726 sec 26.1

APPENDIX 3 : SUMMARY OF OBJECTIVES AND REQUIRED OUTCOMES

Siting	
Screening for potential landfill sites	<p>To identify and rank those sites that require the fewest engineering and management controls to meet the objectives of all State Environmental Protection Policies.</p> <ul style="list-style-type: none"> • Use regional waste management planning to identify the sites within or adjacent to the region which are best suited for future landfilling. • Develop landfill sites in the sequence specified in the relevant regional waste management plan. • Ensure that sufficient buffer is available for the life of the landfill. • Consider the most appropriate landfill type to meet the requirements imposed by local conditions. • Ensure that the landfill is sited to protect surface waters, groundwater and flora & fauna.
Design	
Environmental assessment	<p>To gain a thorough understanding of the environment where the landfill is to be sited in order to design the landfill to minimise impacts on the environment.</p> <ul style="list-style-type: none"> • Conduct a hydrogeological assessment to assess the potential for impacts on local groundwater quality. • Investigate water management requirements. • Investigate landfill gas and odour control options.
Site layout	<p>To ensure that the site layout minimises environmental and health and safety risks, encourages recycling and makes the most efficient use of onsite resources.</p> <ul style="list-style-type: none"> • Site layout and filling sequence planned to ensure that landfill cells are open for the minimum period of time and site operations are optimised. • Minimisation of public access to the tipping face and, where appropriate, assurance that waste received at the landfill can be vetted and recycled.
Liner and leachate collection system	<p>To maintain groundwater quality as close as practicable to background levels.</p> <ul style="list-style-type: none"> • Design and construction of the best liner and leachate collection system practicable to prevent contamination of groundwater. • Implementation of the best practicable measures to meet all groundwater quality objectives. • Where an attenuation zone has been designated, assurance that all groundwater quality objectives are met at the boundaries of the premises. • Geotechnically stable sub-base and liner. • Design and construction of the most robust liner and leachate collection system to ensure that the system will continue to achieve the objective in the event of several components of the system failing.

Construction quality assurance	<p>To ensure that materials, construction methods and installation procedures provide a landfill meeting design criteria.</p> <ul style="list-style-type: none"> • Development and implementation of CQA plan to ensure that the liner and leachate collection system meets the requirements of the specification and drawings. • A statement from an accredited testing authority be obtained stating that the installed liner and leachate collection system meet the requirements of the specification and drawings. • Development and implementation of a CQA plan to ensure that the stability of sub-base and liner are achieved.
Water management	<p>To protect beneficial uses of receiving waters and to avoid any adverse environmental impact on surface and ground waters.</p> <ul style="list-style-type: none"> • Segregation of stormwater, leachate and groundwater. • Wherever practical, reuse of water onsite. • Management and treatment of leachate to: <ul style="list-style-type: none"> – Prevent it from escaping into surface waters or groundwater; – Prevent offensive odours offsite and; – Minimise human contact with the leachate. • Assurance that waste discharges to surface waterways are minimised and do not cause water quality objectives to be breached.
Groundwater management	<p>To protect the beneficial uses of groundwater and to minimise the risk posed by the landfill to those beneficial uses.</p> <ul style="list-style-type: none"> • Development of a groundwater monitoring program to demonstrate compliance with the objective. • Design of bores to sample the potentially contaminated and/or representative groundwater quality found offsite.
Air quality	<p>To ensure that air quality objectives are met, greenhouse gases minimised and that there is no loss of amenity from landfill gas, odour or dust.</p> <ul style="list-style-type: none"> • Assurance that no safety or environmental impacts are caused by landfill gas. • Prevention of any offensive odours beyond the boundary of the premises. • Decisions made on a gas management strategy using the hierarchy in figure 3. • Prevention of nuisance dust emissions beyond the boundary of the premises.
Noise	<p>To ensure that the noise objectives are achieved and to minimise noise annoyance.</p> <ul style="list-style-type: none"> • Compliance with the <i>Environmental protection (Noise) Regulations 1997</i>.
Traffic considerations	<p>To minimise nuisance from traffic movement.</p> <ul style="list-style-type: none"> • Minimisation of safety concerns, noise and road grime on external roads.
Site security and fencing	<p>To prevent the unauthorised entry of people or livestock.</p> <ul style="list-style-type: none"> • Assurance that the site fencing meets the minimum requirements summarised in Table 8.

Operation	
Environment Improvement Plan	<p>To develop and implement a site-specific environment improvement plan.</p> <ul style="list-style-type: none"> • Development and implementation of an EIP for the landfill. • Training of all relevant staff in the implementation of the EIP.
Financial assurance	<p>To provide a financial assurance for environmental management costs incurred during the operation, closure and aftercare of a landfill.</p> <ul style="list-style-type: none"> • Provision of a financial assurance if required by the DoE.
Waste minimisation	<p>To divert wastes from landfill.</p> <ul style="list-style-type: none"> • Establishment of an operation to salvage and recycle suitable wastes delivered to the landfill
Waste acceptance	<p>To ensure that only appropriate wastes are deposited at the landfill.</p> <ul style="list-style-type: none"> • Systems to ensure compliance with the <i>Landfill Classification and Landfill Definitions 1996 (as amended)</i>.
Waste placement	<p>To place waste in a manner that is mechanically stable and that controls litter and birds and that maximises the degree of compaction.</p> <ul style="list-style-type: none"> • Maintenance of as small as possible an active tipping face. • Compaction of all waste deposited in the landfill. • Assurance that waste is placed so that all unconfined faces are mechanically stable and capable of retaining cover material.
Waste cover	<p>To ensure that wastes are covered by appropriate material to mitigate against any environmental or health impacts.</p> <ul style="list-style-type: none"> • Covering of the active tipping area, at least daily, with soil or another approved cover material. • Assurance that there is sufficient cover material available at the tipping face for at least two week's of operations.
Litter control	<p>To keep the landfill and surrounding environment in a litter-free condition.</p> <ul style="list-style-type: none"> • That no litter from the landfill operations reaches beyond the boundary of the premises.
Fires	<p>To prevent landfill fires and efficiently extinguish any that should occur.</p> <ul style="list-style-type: none"> • Maintenance of a water supply capable of being delivered to any point on the landfill. • That all practical steps have been taken to prevent landfill fires.
Contingency planning	<p>To ensure that all potential incidents are considered and that appropriate measures are planned to deal with them.</p> <ul style="list-style-type: none"> • All likely impacts are covered in the preparation of the contingency plan. • All staff are trained in the implementation of the contingency plan.
Management of chemicals and fuels	<p>To manage the storage and handling of chemicals and fuels so as to minimise the risk of impact on the environment.</p> <ul style="list-style-type: none"> • Storage and handling flammable and combustible liquids in accordance with the provisions of AS 1940:1993, The Storage and Handling of flammable and Combustible Liquids.

Disease vectors	<p>To minimise disease vectors emanating from the landfill by denying pests food and shelter.</p> <ul style="list-style-type: none"> • Elimination of any water bodies at the landfill that are not required for fire, sediment or leachate control.
Noxious weed control	<p>To manage the landfill site so that it does not become a source of noxious weeds.</p> <ul style="list-style-type: none"> • Minimise the introduction of noxious weeds to the site. • Eradicate any noxious weeds that have established themselves on-site.
Performance monitoring	<p>To monitor and report on the performance of measures taken to protect the environment from potential impacts from a landfill.</p> <ul style="list-style-type: none"> • Regular monitoring of leachate, groundwater, surface waters and landfill gas. • Assurance that monitoring results are interpreted by an expert in the field. • A report, submitted to the DoE as required by licence, with serious problems reported as soon as possible after discovery.
Rehabilitation and Aftercare	
Rehabilitation	<p>To ensure that landfills are rehabilitated to minimise the seepage of water into the landfill and maximise the collection and oxidation of landfill gas from the landfill.</p> <ul style="list-style-type: none"> • Preparation, early in its design, of a rehabilitation plan for the landfill, including a detailed consideration of afteruse options for the site. • That the seepage through the landfill cap is no more than 75 per cent of the anticipated seepage rate through the landfill liner. • Design and construction of the best cap practicable to prevent pollution of groundwater and degradation of air quality through the escape of landfill gas. • Design and construction of the most robust cap to ensure that the system will continue to achieve the objective in the event of several components of the system failing. • Progressive rehabilitation of the landfill.
Aftercare	<p>To manage the site after closure so that environmental protection and monitoring systems are maintained until the landfill has stabilised.</p> <ul style="list-style-type: none"> • Preparation of a Landfill Aftercare Management Plan.

APPENDIX 4: SUMMARY OF IMPLEMENTATION REQUIREMENTS

Section	Implementation requirements
Siting	<ul style="list-style-type: none"> • To be implemented by Class III landfill proponents. • To be implemented by all planning authorities in their planning around current or future landfills.
Design	<ul style="list-style-type: none"> • All new Class III landfills to implement or for new cells in existing Class III landfills. • Notwithstanding anything to the contrary above, to be implemented for all new landfill cells where groundwater pollution has been demonstrated.
Operation	<ul style="list-style-type: none"> • On publication of this document.
Rehabilitation and Aftercare	<ul style="list-style-type: none"> • All landfills to implement upon closure. • Currently closed landfills to implement on a case-by-case basis where the rehabilitation and/or aftercare is, or is likely to be, inadequate to guard against pollution.