Guidelines for the Siting, Design and Management of Solid Waste Disposal Sites in the Northern Territory

ntepa Northern Territory Environment Protection Authority

Document title	Guidelines for the Siting, Design and Management of Solid Waste Disposal Sites in the Northern Territory
Contact details	NT EPA
Approved by	NT EPA
Date approved	January 2013
Document review	Biennially
TRM number	33-D25-12152

Version	Date	Author	Changes made
1.0	January 2013	Environment Division	First version
1.1	July 2025	Environmental Regulation Division	Introduced numbered sections and revised formatting per 2025 style guide

Acronyms	Full form
BOD	Biological Oxygen Demand
C & D waste	Construction and Demolition waste
C & I waste	Commercial and Industrial waste
CAMBA	China-Australia Migratory Bird Agreement
CQA	Construction Quality Assurance
EMP	Environmental Management Plan
FML	Flexible Membrane Liners
HDPE	High-Density Polyethylene
HWCF	Hazardous Waste Containment Facility
JAMBA	Japan-Australia Migratory Bird Agreement
MSW	Municipal Solid Waste
NT EPA	Northern Territory Environment Protection Authority
TCLP	Toxicity Characteristic Leaching Procedure
VENM	Virgin Excavated Natural Materials
WMPC Act	*Waste Management and Pollution Control Act 1998.*

Contents

1. Introduction

1.1 Purpose

Effective waste management is a high priority in the Northern Territory and the siting, design and management of landfills play an integral role in effective waste management. The primary aim is to conserve resources through effective avoidance and resource recovery. Landfill has an important role to play as part of the transition required to achieve sustainable resource recovery and waste management—the zero waste concept. The role for landfill primarily involves accepting those residual materials that are unable to be 'avoided, reduced, reused, recycled or recovered'.

These guidelines have been written to provide guidance to landfill operators, developers, planning authorities and regulatory bodies on the site selection, development, design, construction, operation, closure and post-closure management of municipal solid waste, and commercial and industrial (C&I) general waste landfill facilities so that they can comply with the *Waste Management and Pollution Control Act 1998*.

The purpose of these Guidelines is to provide a consistent and environmentally responsible approach to managing landfills in the Northern Territory. This guide should be used for the planning of environmental approvals and licensing for new landfill sites and expansion of existing landfill sites. It also applies, where appropriate, to existing landfill sites.

These Guidelines were first published in 2013. The 2025 update is a formatting update only and may not reflect contemporary best practice. Readers are to also refer to guidance material in other jurisdictions for contemporary best practice.

1.2 Scope

Solid waste landfills across the Territory are at various stages of development. Some have been operating for many years whilst others are in the process of closing or have already been closed.

These guidelines have been developed to reflect the various stages in the life cycle of solid waste landfills. The guideline has been arranged into the following major sections:

- Introduction
- Regulation
- Site Selection
- Landfill Design
- Landfill Operation and Management
- Landfill Monitoring.

1.3 Waste Classification and Types of Landfill

In this document waste classification and landfill types are defined as follows.

1.3.1 Waste classification

Waste is classified into four general categories:

- Inert waste (clean fill)
- Municipal solid waste (MSW)
- Listed waste

- Industrial waste.

Inert Waste

Inert wastes are wastes that are non-biodegradable, non-flammable, non-chemically reactive and have no potentially hazardous content once landfilled. Inert waste must not be contaminated or mixed with any other material.

The Northern Territory Environment Protection Authority (NT EPA) considers 'inert waste' to be natural materials such as clay, soil and rock, concrete, brick or demolition product that are free of:

- combustible, putrescibles, degradable or leachable components
- hazardous substances or materials (such as municipal solid waste) likely to generate leachate via biological breakdown
- any products or materials derived from hazardous waste treatment, stabilisation or disposal practices
- materials such as clinical and listed waste that present a risk to human health if excavated
- contaminated soil and other contaminated materials.

Reuse and recycling options should be closely considered for most inert wastes.

Municipal Solid Waste

Municipal solid waste (MSW) is any non-hazardous, solid waste from a combination of domestic, commercial and industrial sources. It includes putrescible waste, garden waste and uncontaminated biosolids. All municipal solid waste should have an angle of repose of greater than five degrees (5°) and have no free liquids.

Listed Waste

Listed waste are a category of hazardous wastes and pose a threat or risk to public health, safety or the environment and include substances which are toxic, infectious, mutagenic, carcinogenic, teratogenic, explosive, flammable, corrosive, oxidising and radioactive. Listed wastes in the Northern Territory are prescribed in Schedule 2 of the *Waste Management and Pollution Control (Administration) Regulations 1998* and are ONLY to be disposed of at facilities that are licensed to receive them. See Appendix D.

Industrial Waste

Industrial waste is that waste specific to a particular industry or industrial process. It may contain somewhat higher levels of contaminants, such as heavy metals and human-made chemicals, than municipal solid waste and needs to be managed with environmental controls appropriate to the specific waste(s) being landfilled.

1.3.2 Types of Landfill

Inert Landfill

An inert waste landfill is any landfill that accepts only clean fill material and inert wastes, including virgin excavated natural materials (VENM).

Municipal Solid Waste Landfill (MSW)

A municipal solid waste landfill (MSW) is any landfill that accepts municipal solid waste. A municipal solid waste landfill may also receive inert waste.

Industrial Waste Landfill

An industrial waste landfill is a landfill that is designed to accept predominantly industrial waste. In many cases industrial waste landfills are monofills, associated with a specific industry or industrial location, such as mining, and are designed and operated in accordance with the specific wastes accepted. Design, operation and monitoring requirements may be more, or less, stringent than for municipal solid waste landfills dependent on the types of waste accepted. An industrial waste landfill may also receive municipal solid waste and inert waste, depending on design.

Hazardous Waste Landfill

A hazardous waste landfill, or hazardous waste containment facility (HWCF) is any landfill that accepts waste formally defined as "hazardous waste" or "listed waste" in statutory instruments. Siting, design, operation and monitoring requirements for landfills accepting hazardous waste will be considerably more stringent than for landfills accepting only municipal solid wastes.

1.4 Guideline Layout

This guideline has been developed following the landfill life cycle concept from siting through to closure. A brief outline of the contents of each section is provided below:

Regulation

This section details the applicable Territory regulatory requirements associated with the siting, design, operation and management of solid waste landfills.

Site Selection

This section addresses strategic planning, the site selection process and landfill siting criteria.

Design

This section addresses design considerations, groundwater management, surface and storm water management, leachate management, leachate containment and liner systems, landfill gas management, landfill cover systems and construction quality assurance and construction quality control.

Operation and Management

This section addresses landfill management plans, waste acceptance and monitoring, waste compaction, cover, vector control, water control, landfill gas management, closure and post closure management.

Environmental Monitoring

Environmental monitoring is required at solid waste landfills to continuously evaluate the effectiveness of the environmental protection systems regarding water resources and gas management. This section addresses:

- monitoring objectives
- leachate monitoring
- groundwater monitoring
- surface water monitoring
- analysis and review of monitoring data
- landfill gas monitoring.

1.5 Acknowledgement

The NT EPA wishes to acknowledge that the content of this guideline has largely been developed on research and publications developed by the following government agencies and educational institutions:

- New South Wales Department of Environment and Climate Change
- Victorian Environment Protection Authority
- South Australian Environment Protection Authority
- New Zealand Centre for Advanced Engineering
- Queensland Department of Environment and Resource Management.

1.6 Disclaimer

The NT EPA has prepared this document in good faith, exercising all due care and attention, but no representation or warranty, express or implied, is made as to the relevance, completeness or fitness for purpose of this document in respect of any user's circumstances. Users of this document should satisfy themselves concerning its application to their situation and, where necessary, seek expert advice.

2 Regulation

Landfills are subject to environment protection legislation in two stages – planning and operation. Regulation at the planning stage involves gaining an Approval to construct a new landfill or for a significant extension or change in operational scope to an existing landfill. Regulation at the operational stage involves gaining an Environmental Protection Licence for waste disposal.

2.1. Approvals

Prior to the construction, installation or carrying out of works in relation to a premises for the disposal of waste by burial (landfills), an Environmental Protection Approval must be obtained from the NT EPA pursuant to Section 30, Part 1 of Schedule 2 of the *Waste Management and Pollution Control Act*.

An Approval is also required if planned modifications or alterations to a landfill are likely to result in an increase in the amounts or type of waste accepted, stored, treated or disposed of at the landfill, or if the modifications pose an increased risk of pollution or harm to the environment.

Applications for an Environment Protection Approval must be accompanied by an application detailing the items described in each of the following sections of these guidelines, along with any other supporting documentation required by NT EPA. Please refer to the NT EPA website for further information regarding the approval process.

A formal assessment under the NT *Environment Protection Act 2019* may also be required in cases where the proposed work may have a significant impact on the environment.

2.2. Licences

Pursuant to Section 30, Part 2 of Schedule 2 of the *Waste Management and Pollution Control Act* a landfill servicing the waste disposal requirements of more than 1000 persons[1] cannot be operated without a Licence.

Applications for an Environmental Protection Licence to *operate* a landfill must be accompanied by an application detailing the items described in each of the following sections of these guidelines, along with any other supporting documentation required by the NT EPA. Please refer to the NT EPA website for further information regarding the licencing process.

A licence is not required to operate a landfill that services a permanent population of less than 1000 persons that only accepts municipal solid waste (MSW). However, facilities that service less than 1000 persons can still use this guide as a tool for effective waste management. Any landfills that receive listed wastes may require a licence for their collection and storage.

[1] equivalent fulltime residents, not peak population loads or baseline permanent resident numbers

3 Site Selection

The selection of a landfill site is critical to minimising the impact of a facility on the environment. Careful site selection will assist in reducing the impact of the landfill on the community and surrounding environment, and can also lead to reduced operational and rehabilitation costs.

It is important that during the site selection process the information presented in this section is taken into consideration. Where appropriate the provisions in this section must be applied to new landfills and to significant expansions or modifications to existing landfills.

3.1 Strategic Waste Management

It is essential that any strategic planning for waste minimisation and management be considered when selecting a particular site. Local government and other landfill operators may develop strategic waste management plans which provide an integrated approach to the management of waste in their jurisdiction or across regions. These plans may identify waste management needs, minimisation strategies, the types and capacity of waste facilities as well as providing information pertaining to potential locations of such facilities for efficient use.

Issues to consider during the strategic planning stage are:

- size and site required to meet current and future disposal requirements
- utilisation of other waste management options such as:
    - Reduction
    - Reuse
    - Recycling
    - Composting, and
    - Incineration
- waste management plan of the region in which the landfill is to be located
- waste management plans of the regions to which the landfill is designed to service
- regional waste management policies
- proximity to communities in which the landfill will service
- seasonal access for vehicles, machinery and equipment
- site environmental parameters and suitability (including but not limited to ground and surface waters, soil types, vegetation, etc.).

3.2 Site Selection Process

The site selection of solid waste landfills requires a careful examination and evaluation of all the components of landfill construction and operation that could potentially result in adverse effects on the environment.

The primary consideration in the landfill site selection process should be the selection of a location, which reduces the potential for adverse effects on the environment, based on sound scientific and engineering principals.

Landfill site selection should also consider design and operational aspects of the landfill. Many site parameters can be improved by engineering design and/or potential adverse effects mitigated through appropriate operational methods.

Decision surrounding the site selection should also be made regarding local community issues, including needs, expectations and resources. While site selection should be based primarily on technical factors, community perception and values may also be critical to the acceptability of a landfill site. Therefore, it is essential to involve the local community early in the site selection process.

The site selection process should normally include the following processes:

- initial desk top study
- site investigations
- Environmental Risk Assessment and Conceptual Model of Site Contamination and migration
- economic assessment (to be repeated at different stages of the process)
- community consultation (to be conducted at different stages of the process)
- suitability for site remediation and rehabilitation.

3.2.1 Initial Desktop Study

Using the following general criteria several possible locations should be identified and considered:

- geology (including soil profiles)
- hydrogeology
- surface hydrology
- environmentally sensitive areas
- vegetation types
- stability
- topography
- appropriate land use
- compatibility with surrounding land use.

This information can be gathered from several sources, including:

- geological maps
- topographical maps
- meteorological rainfall maps
- relevant NT Government departments
- regional plans
- local knowledge.

3.2.2 Site Investigations

Site investigations should follow a staged approach consisting of preliminary investigations, initial technical investigations, non-technical investigations and detailed technical investigations.

Preliminary Investigations

A physical survey should be undertaken at sites identified by the desk-top study. Each site should be assessed with respect to the criteria listed above. Any obvious fatal flaws with respect to geology, surface hydrology and stability should also be identified. Following the survey, sites should be ranked to determine a shortlist of sites for further investigation. Care should be exercised when ranking sites as design and operational techniques may elevate, or reduce, the initial status and community issues may also affect the status of a site.

Initial Technical Investigations

The purpose of initial technical investigations on short listed sites is to identify potential fatal flaws and reduce the shortlist of identified sites to few sites for more detailed technical investigations.

Initial investigations should include:

- detailed mapping of site geology
- geotechnical investigation, by way of pit investigations to assess site soils with respect to containment, stability, seismic risk and suitability for lining and cover material
- identification of nearby groundwater wells and users
- review of historical information on groundwater level and quality, if available
- shallow groundwater bores to assess hydrogeology, ideally these bores should be located where they can be used for monitoring during landfill operation and following closure, if the site proceeds
- sampling of surface water quality and groundwater quality
- assessment of sensitivity of flora and fauna at the site and downstream.

Non-technical Investigations

Non-technical issues such as local social, cultural and amenity values can be the issues of greatest concern to the local community and can be the determining factor on site acceptability. The following factors should be assessed before detailed technical investigations are undertaken at a site:

- location of site neighbours
- location of any sites of cultural significance, including rivers, streams, middens, burial sites (it should be noted that some of these sites are not always identifiable)
- potential for nuisances associated with odour, vermin, birds and flies, noise, litter, dust and visual amenity
- access to the site and potential traffic effects
- location of sites of historical significance.

Detailed Technical Investigations

Initial technical and non-technical investigations in conjunction with preliminary economic assessments, should result in a shortlist of priority sites worthy of more detailed technical investigations.

An investigation program should be developed on a site-specific basis. It should address the site selection criteria detailed in Section 3.3, and potential design, operational and monitoring requirements.

Following detailed investigations, economic assessment and community consultation, it should be possible to determine the most appropriate location with which to proceed with the development application and approval process.

3.2.3 Economic Assessment

A preliminary economic assessment should be undertaken for short listed sites so that the costs of developing and operating landfills at the different sites can be compared.

This assessment should be undertaken using a full costing process, in which all real, definable and measurable costs from all sources, which are paid for by the landfill operator, are identified.

The types of costs that need to be identified and detailed include:

- management, administration and organisational overhead costs
- planning and resource costs
- land cost
- development costs, including investigations, design and construction
- operational costs
- monitoring costs
- closure, rehabilitation and aftercare costs
- potential mitigation costs.

The costs of transporting refuse to different landfill sites should also be considered when comparing sites. Economic assessments should be repeated as the short-listed number of sites is reduced and more information on site conditions and engineering requirements becomes available.

3.2.4 Community Consultation

Any potential new landfill site or any expansion to existing landfill facility will need to consider the concerns of the host community. The establishment of a new landfill or an expansion to an existing landfill can cause smoke, noise, odour and dust emissions which can impact the surrounding community and the local environment. For these reasons, it is important to liaise and engage the community regarding site selection prior to establishing or expanding landfill facilities. This will allow information sharing and early identification of issues that are important to the community and the local environment.

The community should be provided with adequate information and opportunity to comment. The level of detail to be provided will vary depending on the nature and scale of the landfill proposed but should include as a minimum, an assessment of the impact of the proposal on the surrounding community (e.g. employment opportunities, altered traffic volumes, noise, dust and odour, access and distance to travel). Additionally, consultation with the surrounding community may provide useful information on the community waste management needs and requirements of the facility.

All consultation undertaken with persons interested in or affected by a proposal should be formally recorded.

3.3 Site Selection Criteria

Identification of the suitability of potential landfill sites, and modifications to existing facilities, requires a comprehensive assessment of site conditions and potential impacts on the environment. This includes consideration of topography, surface water, drainage, hydrogeology (groundwater), geology, climate (including air quality and odour modelling) and flora and fauna, access and distance from the community the landfill will service.

The following landfill site selection criteria detail the key issues that need to be considered when identifying potential landfill sites and planning site investigations and assessing the suitability of a site for landfilling.

It is unlikely that most sites will meet all necessary criteria, in which case the assessment of the suitability of a site for a landfill needs to consider and appropriately manage and justify the selection of a site that doesn’t meet all the necessary criteria. Consideration needs to be given to the:

- comparison of site characteristics with alternative locations
- potential for engineered systems to overcome site deficiencies
- methods of operation proposed for the site
- social and cultural issues associated with the site.

To minimise future risk to the environment from landfill activities, primary consideration should be given to key issues and potential fatal flaws with respect to geology, hydrogeology, surface hydrology and site stability.

3.3.1. Geology

Suitable geology is important to ensure containment of leachate in the long term, or in the event of engineered containment systems failing. Geology should be assessed with regards to the movement of leachate and landfill gas.

Areas of low permeability ($1x10^{-9}$ m/s) in-situ material are preferred and should be sought. Engineered liner systems have a finite lifetime, the ability of the underlying strata to minimise the potential for liquids to migrate out of the landfill into the environment should the liner either degrade, tear, or crack needs careful consideration. Due to risk of off-site movement of leachate and landfill gas, landfills should not be sited in areas with the following characteristics:

- high permeability soils, sands, gravels, or substrata
- high permeability seams or faults; and/or
- karst geology — regions with highly soluble rocks, sinks and caverns.

An assessment of geology and site soils should consider:

- the availability of on-site materials for lining, cover and capping. Soils with a high percentage of clay particles are generally the preferred soil type
- the suitability of on-site materials for the construction of dams and drainage systems
- potential sediment management problems, with highly erodible soils

- existing site contamination and discharges, if present
- suitability for on-site disposal of leachate by surface or subsurface irrigation
- the potential effects of failure of leachate containment and collection systems.

Geological factors also influence stormwater, erosion controls, the containment and control of leachate and gas, as well as the availability of final cover materials.

3.3.2. Site Stability

Site stability should be considered from both short and long-term perspectives, including the effects of settlement. Landfills should not be sited in the following areas:

- areas subject to instability, except where the instability is of a shallow or surface nature that can be overcome, in perpetuity, by engineering works
- areas susceptible to ground movements that may adversely impact on the integrity of the landfill and engineered systems such as liners, leachate collection and final cover
- within 1km of a major tertiary (first order) fault line that presents risk of seismic activity (e.g. fault lines displaced in the Holocene period)
- areas of geothermal activity; and/or
- karst terrain — regions with highly soluble rocks, sinks and caverns.

In assessing the suitability of a site for a landfill the local soils need to be considered with respect to the following:

- localised subsidence areas. Differential movement could render a landfill unusable due to rupture of liners, leachate drains or other structures
- landslide prone areas. The future weight could, through a wide variety of mass movement, destabilise the landfill. Instability may also be triggered by earthquakes, rain and seepage
- local/onsite soil conditions that may result in significant differential settlement, for example compressible (peat) or expansive soil, or sensitive clays or silts.

3.3.3. Hydrogeology

A suitable hydrogeological location is important to protect groundwater resources and understand the likely fate and rate of discharge of contaminants which may enter groundwater. Landfills must not be in the following areas:

- areas overlying drinking water aquifers; and/or
- areas where, after taking into account specific design proposals, there could be a risk of causing unacceptable deterioration of the groundwater quality in the locality.

All new landfills require a hydrogeological assessment. Existing landfills will require a hydrogeological assessment if the facility has no current monitoring program or the current monitoring program is not adequate to determine whether the landfill is having an impact on the environment. The purpose of a hydrogeological assessment is to determine the relationship between the landfill and surrounding hydrogeology to ascertain the potential risk the landfill facility will have on the environment. In assessing the suitability of a site for a landfill with respect to hydrogeology, the following need to be considered:

- depth to water table and seasonal water table fluctuations

- location of aquifer recharge areas, seeps or springs
- distance to water users
- sensitivity of water users
- dispersion characteristics of aquifers
- variations in groundwater levels
- rate and direction of groundwater flow
- existence of groundwater divides
- baseline water quality
- the potential effects of failure of leachate containment and collection systems.

A hydrogeological assessment report should be prepared by a suitably qualified and experienced person. This report should contain plans, specifications, and descriptions of the hydro-geologic conditions of the site, adjacent and nearby properties, and the regional area in which the site is located, including at a minimum, the following:

- a general description of the regional geologic and hydro-geologic conditions occurring within 5 km of the site. This description should identify any unstable soils or bedrock, indicate the location and nature of any boundaries to groundwater movement, and characterize the significance of groundwater resources and the use made of these resources
- a description of local hydro-geologic conditions occurring at the site, adjacent to the site and other properties within 500 m of the site. The description shall indicate how local conditions relate to regional conditions
- a detailed hydro-geologic investigation of the site which establishes soil, rock, and groundwater conditions
- an interpretation of the results of the detailed hydro-geologic investigation of the site, including plans, specifications, and descriptions
- an assessment of the suitability of the site for waste disposal purposes considering the regional, local, and site-specific hydro-geologic conditions, the design of the site, and the contingency plans for the control of leachate and landfill gas
- a conceptual model of the hydrogeological setting of the landfill and its surrounds. The model will indicate the risk that the landfill and its associated operations may pose to the groundwater.

The conceptual model should include at a minimum, but is not limited to the following:

- representation of how surface water bodies interact with the groundwater and the landfill
- the relationship between the base of the landfill and the groundwater
- the effect the landfill will have on local groundwater flow direction, rate, level and quantity; this will include maps, plans and cross section, any existing groundwater results and schematic diagrams of the environmental setting
- the relationship between different aquifers at the site and the potential for groundwater contamination form them
- describe the geology, hydrogeology and hydrology in the vicinity of the landfill. The design, construction and operation of the landfill and how it could interact with the ground and surface water should be indicated. Possible sources of pollution (i.e. leachate) and the pathways and

receptors should be identified, and the processes that are likely to occur along each of the source-pathway-receptor linkages described.

A regular groundwater monitoring program for the site should be developed in line with the conceptual model. Refer to Section 6 for further information pertaining to monitoring requirements.

The recommended minimum separation distances from the base of the landfill to the groundwater level is two meters for a lined facility. This separation distance is to be measured from the underside of the landfill liner to the highest seasonal groundwater level. Separation distances to the water table for unlined sites will be assessed on a case-by-case basis and will generally be greater than two meters.

3.3.4. Hydrology

The pollution of surface water by leachate is one of the principal concerns in relation to landfill location. If landfills are near waterways there is an increased risk of water pollution. The potential impact of water pollution is greater in waterways that are used for drinking water or aquaculture.

It is generally undesirable to site a landfill in the following areas:

- flood plains – these are generally areas which could be affected by a major (1 in 100 year) flood event
- land that is designated as a water supply catchment or reserves for public water supply
- gullies with significant water ingress, except where this can be controlled by engineering works without risk to the integrity of the landfill
- water courses and locations requiring culverts through the site and beneath the landfill
- estuaries, marshes and wetlands.

When assessing the suitability of a site for a landfill, the local surface hydrology needs to be considered in regard to the sensitivity of the receiving environment, including the following:

- the proximity of water bodies or wetlands
- the risks of pollution of water bodies used for drinking water or aquaculture
- sensitive aquatic ecosystems
- potential for impact from cyclones and tsunamis.

An assessment of the stormwater catchment above the site should be made to identify the extent of any drainage diversion requirements that may need to be addressed.

As part of the Approval process outlined in Section 2.1, an assessment of the local hydrology needs to be undertaken prior to the establishment or expansion of a landfill site. An assessment report is to be prepared by a suitably qualified and experienced person. The report should contain plans, specifications, and descriptions of the surface water conditions of the site, adjacent and nearby properties, and the regional area in which the site is located, including, at a minimum:

- a general description of the surface water features occurring within 5 km of the site that is based on the contributing/receiving drainage area, catchment, sub-watershed or watershed that is sufficiently large to assess the range and extent of potential effects. This description will include, but not be limited to, flood plains, natural watercourses, drainage paths and boundaries, stream flows, surface water quality, and sources of water supply

- a description of the local surface water features occurring at the site, and adjacent and other properties within 500 m of the site, and the description should include how local features relate to regional features
- a detailed surface water investigation of the site to assess water quality, quantity, and habitat conditions of the surface water features identified on site
- an interpretation of the results of the detailed surface water investigation of the site, including plans, specifications, and descriptions
- an assessment of the suitability of the site for waste disposal purposes considering the regional, local, and site-specific surface water conditions, the design of the site, and the contingency plan for the control of leachate.

Landfills should be sited and designed to prevent surface water from contacting waste. This should be achieved by siting landfills so they will not be inundated by either natural or artificial water courses or water bodies.

3.3.5. Topography

Careful consideration needs to be given to the landforms in the vicinity of the disposal site as they may influence:

- The type of disposal method that can be utilised
- The suitability of the site for construction of service facilities
- Surface water drainage management
- Groundwater conditions
- Soil erosion risk
- Access to the site
- Ability to screen the site from view
- The impact of winds on the site.

Ideally the slope of the site should not be greater than 5% (1 vertical unit to 20 horizontal units), particularly where the trench method of disposal is used. Modest slopes enable easier stormwater control, leachate control and site stability measures, as well as facilitating the operation of the site. When considering potential landfill sites an assessment of the potential for existing topographical features to assist in minimising impacts should be made.

3.3.6. Flora and Fauna

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
- contamination of sensitive ecosystems, such as wetlands, by leachate

- creation of new habitats for scavenger and predatory species
- erosion
- alteration of water courses.

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, considering 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. Sites that contain protected or endangered fauna and/or flora, or sensitive ecosystems are unsuitable for landfill facilities.

As part of the Approval process outlined in Section 2.1 an assessment of the local flora and fauna needs to be undertaken prior to the establishment or expansion of a site. An assessment report is to be prepared by a suitably qualified and experienced person. This report should contain maps, specifications, and descriptions of the flora and fauna of the site, adjacent and nearby properties, and the regional area in which the site is located, including, at a minimum, the following:

- Map of the proposed site location clearly showing existing vegetation, extent of development on the site and all sensitive environments on and adjacent to the site that are likely to be directly, indirectly or cumulatively impacted by the landfill
- A list of all species of flora and fauna (including pest species) identified in the proposed site location or identified as likely to occur (native and introduced species). The species list must cover the proposed site location, and all species on and adjacent to the site that are likely to be directly, indirectly and cumulatively impacted by the landfill development
- Vegetation community description and map indicating structure, spatial distribution, condition, integrity, nature of any disturbance and consideration of the likely original vegetation community
- Fauna habitat description on the site and consideration of corridors, migratory routes and drought refuges
- Assessment of whether the proposal will have or is likely to have a significant impact on rare or threatened species, populations, their habitats and endangered ecological communities.

3.3.7. Climate

Consideration should be given to the local climatic conditions when siting a waste disposal facility. The heavy rainfall situations which can occur in the Northern Territory can cause severe erosion and stormwater drainage issues if landfills are not sited and designed in an appropriate manner. Hot, dry windy conditions can cause dust and windblown waste issues. Landfills should be in an area which facilitates the management of landfill issues.

3.3.8. Environmentally Sensitive Areas

Landfills are not to be in areas of high environmental value, or in areas subject to considerable environmental constraints and high environmental risks (Table 3.1). Such areas should be excluded from further consideration. Table 3.1 is not exhaustive and there may be other areas of high environmental or other significance protected under legislation. Land use separation distances from landfills are also detailed in the 2017 Guideline: Recommended Land Use Separation Distances on the NT EPA website.

Table 3.1: Environmentally Sensitive Areas

A site within 250 metres of an area of significant environmental or conservation value identified under relevant legislation including: • national parks, marine national parks • historic and heritage areas, buildings or sites protected under the Heritage Conservation Act • sites of conservation significance • world heritage areas • wetlands protected under Ramsar, JAMBA and CAMBA treaties.
Sites within an identified sensitive location within a drinking water catchment, including: • potable groundwater or groundwater recharge areas • in Proclaimed Sub-Artesian Districts under the *Water Act* (consult the Water Resources Division of the Department of Lands, Planning and the Environment).
Sites within 250 m of a: • Residential zone • Dwelling, school or hospital not associated with the facility.
Sites located: • In or within 500 m of a permanent or intermittent water body (including rivers, lakes, bays or wetlands) and the 100 year flood plain • Below the regional water table • Within 3 m of the highest seasonal groundwater.
Sites located: • Within a karst region; • Within 1 km of a holocene fault; • With substrata which are prone to land slip or subsidence.
Sites within a floodway which may be subject to washout during a major flood event. A major flood event is considered to be a 1 in 100 year event.

3.3.9. 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 highway 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.

3.3.10. Access

A landfill facility must have all weather access. Access roads should be located to minimise erosion and the alteration of drainage systems.

Landfill development and operations can generate significant flows of heavy vehicle traffic. The following need to be considered when locating and determining access to landfills:

- type and number of vehicles accessing the site
- types of traffic using roads adjoining landfill access road
- the standard and capacity of the road network, with respect to accommodation of traffic generated by the landfill
- whether the traffic can avoid residential areas
- road safety considerations regarding the landfill entrance (vehicles using the landfill should not be required to queue on a main road).

Advice on the design and construction of access roads can be sought from the relevant NT Government department.

3.3.11. Appropriate Land Use

It is important that during the initial stages of site selection that consultation is held between traditional owners, Land Trusts and Land Councils and the NT EPA to ensure that the proposed site is a suitable location for landfill under the relevant planning and cultural controls. A clearance certificate may also be required, which can be obtained from the Aboriginal Area Protection Authority.

3.3.12. Adjacent Land Use

Adjacent existing and future land uses should be investigated to identify sensitive areas and other protected areas that are likely to be adversely impacted by landfill operations. Long term planning projections need to be considered when assessing the suitability of a site.

To protect sensitive areas from impacts associated with landfill operations, such as odours, noise, litter and dust, an adequate separation (buffer zone) distance needs to be maintained between the landfill and adjacent land uses. The requirement for and the extent of buffer areas should be determined on a site-specific basis. Where possible, the buffer area should be controlled by the landfill operator with reference to the NT EPA Guideline: Recommended Land Use Separation Distances (2017).

An assessment of the suitability of a site for a landfill, and/or appropriate buffer zone, regarding reducing the potential for adverse effects on surrounding land use should consider:

- existing property boundaries and ownership
- statutory planning constraints including

- zoning (the protection of amenity associated with residential, commercial or rural zones from nuisances associated with odour, vermin, birds and flies, noise, litter, dust and visual effects, or failure of containment, leachate collection or landfill gas systems)
- land designated for a special purpose (e.g. hospitals and schools)
- airport safety
- proximity to sites with cultural or historical significance.

A buffer zone is not an alternative to adopting the management practices detailed in this guideline, but an adjunct to support these management practices.

3.3.13. Leachate Management

Landfill site selection should consider the potential methods of leachate treatment and disposal and its effect on site neighbours. Methods of leachate treatment and/or disposal could include the following:

- discharge to land by spray or subsurface irrigation, with or without treatment – the effects of runoff, odour from leachate storage ponds, odour and spray drift from irrigation systems and effects on soil structure need to be assessed
- discharge to natural water after treatment and consideration of any cultural constraints
- treatment by recirculation within the landfill – the effects of increased landfill gas production, odour and potential for differential settlement, leachate build-up on the base of the landfill, decreased stability of the refuse mass and leachate breakout on surface slopes needs to be considered
- evaporation using heat generated from the combustion of landfill gas.

3.3.14. Landfill Gas Management

Inappropriate landfill gas management can result in adverse environmental and safety impacts such as:

- odour nuisance
- degradation of the ozone layer
- migration of landfill gas in the surrounding sub-strata
- vegetation die-off within or on the completed landfill surface and adjacent areas
- explosions or fires due to gas release through cracks and fissures at the surface, or in confined spaces such as manholes, chambers and poorly ventilated areas of buildings on or adjacent to the site
- asphyxiation of personnel entering trenches, manholes or buildings on or near the landfill site.

The potential for landfill gas migration in surrounding sub-strata needs to be considered with respect to containment proposals.

Landfill site selection should consider the various potential methods of landfill gas treatment and disposal and its effect on site neighbours. Methods of landfill gas treatment and/or disposal could include:

- venting of landfill gas - effects of odour and non-methane organic compounds on site neighbours need to be assessed along with greenhouse gas emissions
- flaring of landfill gas – the visual and noise effects of landfill gas flares need to be considered
- on-site power generation - the effects of generator noise and backup flares need to be considered

- on-site treatment or gas stripping prior to off-site use - the potential effects of odour and backup flares needs to be considered.

3.3.15.Site Capacity

The life of the landfill and the demand for future landfill space should be considered during the site selection process. Proponents should consider the type and quantities of waste generated within the area being serviced by the landfill, the current disposal pathways for these wastes, projected quantities and types of waste requiring disposal and the remaining landfill capacity at existing landfills sites which service the area. Landfills should be designed to ensure that sufficient capacity exists for the current and future waste management needs of the community into the foreseeable future.

3.3.16.Land Ownership

Land ownership will influence the siting of landfills. Where it is proposed that a site be on Crown 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.

3.4 Checklist

Table 3.2 provides a checklist to assist proponents in confirming that key issues have been considered for the development of a landfill facility. The checklist has been provided for guidance purposes only.

Table 3.2: Site Selection Checklist

Key Requirement	Considered
Is there an opportunity to involve the community in the site selection process?	☐
Have siting criteria been established that address environmental, technical, planning, community and social requirements?	☐
Has future growth and expansion of the community that will utilise the facility been considered?	☐
At a minimum have the following criteria been considered in the site selection process:	
Environmental	☐
Geology	☐
Ground Water	☐
Surface Water	☐
Ecology	☐
Visibility	☐
Traffic	☐
Topography	☐
Noise	☐
Odour	☐
Dust	☐
Technical	☐
Integration with existing/future waste network	☐
Centrality	☐
Accessibility	☐
Existing services and utilities	☐
Area required	☐
Planning	☐
Appropriate zoning	☐
Land ownership	☐
Available buffers	☐
Avoidance of environmental sensitive or inappropriate areas	☐

4 Landfill Design

Once a landfill has been sited, it must be designed to ensure that it is able to protect the environment. The design of the landfill 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.

In determining the appropriate landfill design, consideration must be given to:

- meteorological data including rainfall, evaporation, wind strength and direction
- hydrogeology including:
  - Local and regional geology
  - Depth to groundwater
  - Groundwater gradient and flow direction
  - Groundwater and surface water interactions
  - Groundwater quality and beneficial uses
- containment and collection of leachate
- surface water management
- rehabilitation and final land use.

All landfills should be designed to incorporate the following components:

- landfill liner system
- landfill final cover system
- leachate management system
- landfill gas management system
- surface water management system
- groundwater management system
- disposal material monitoring
- quality control/assurance.

4.1. Design Considerations

4.1.1. Type of Landfill Facility

Two methods of landfilling solid wastes are used in the Northern Territory, the ‘area’ and ‘trench’ methods. Consideration should be given to the factors affecting the siting and design of landfill facilities before the method of waste disposal is finalised.

Area Method

The area method (Figure 4.1), and its variations, involve above ground waste disposal. The area method is suitable for use in a range of terrains and situations but is generally best suited for flat to gently sloping areas where design and operation will be simplified. The area method is also well suited to situations where high rainfall or high groundwater conditions present problems for use of trenches.

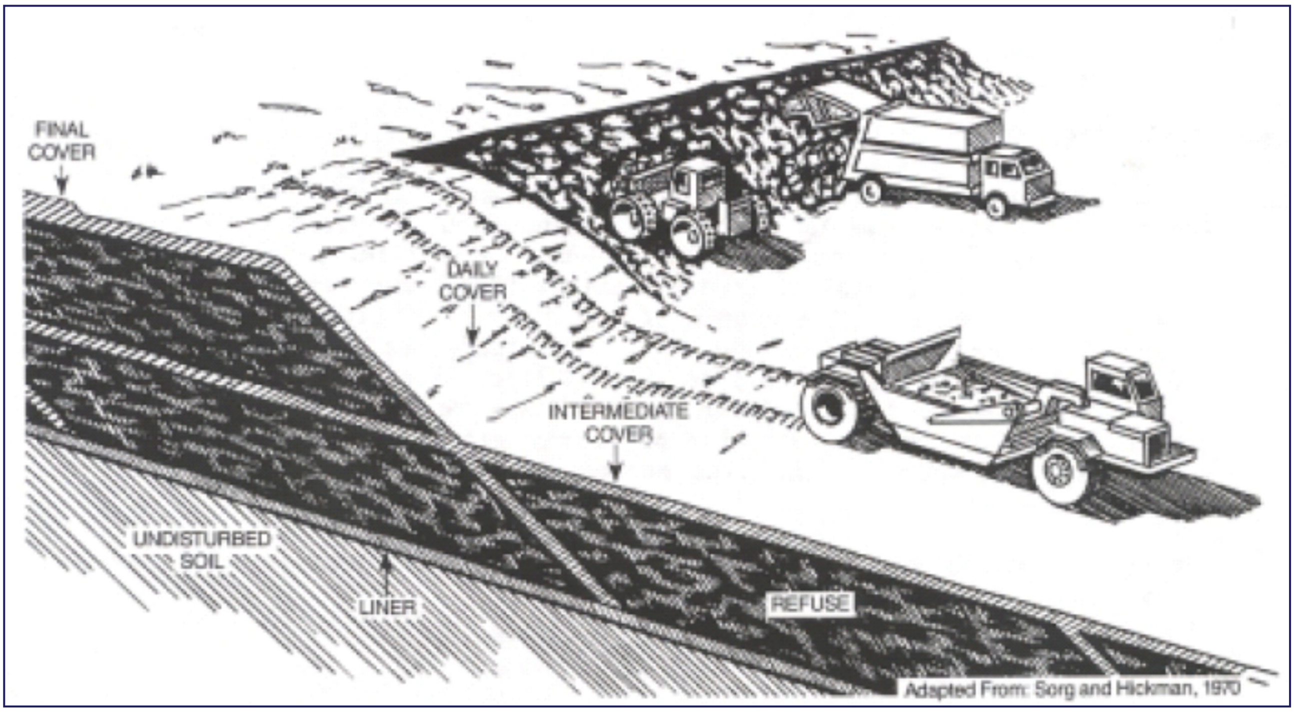

Figure 4.1: Area Method of Landfilling adopted from Sorg and Hickman (1970).

Trench Method

The trench method involves burying waste below ground in excavated trenches (Figure 4.2). Trenches have the advantage that the soil excavated in forming the trench can be used for covering the waste disposed of in the trench. However, in wet areas high groundwater conditions may make the use of trenches impractical. Trenches must be oriented perpendicular to the prevailing wind to help minimise blowing litter.

The depth of the trench is restricted by geology and groundwater levels in the area. If landfilling is occurring within a hard rock area, the depth of the trench is restricted by previous excavations or blasting depths. Trenches should not be in areas of perched groundwater unless careful engineering and design is undertaken. The base of all trenches should be 2 m above the highest seasonal groundwater level to prevent waste contacting groundwater. Trenches should be at least twice as wide as the equipment that will be used for compacting the waste.

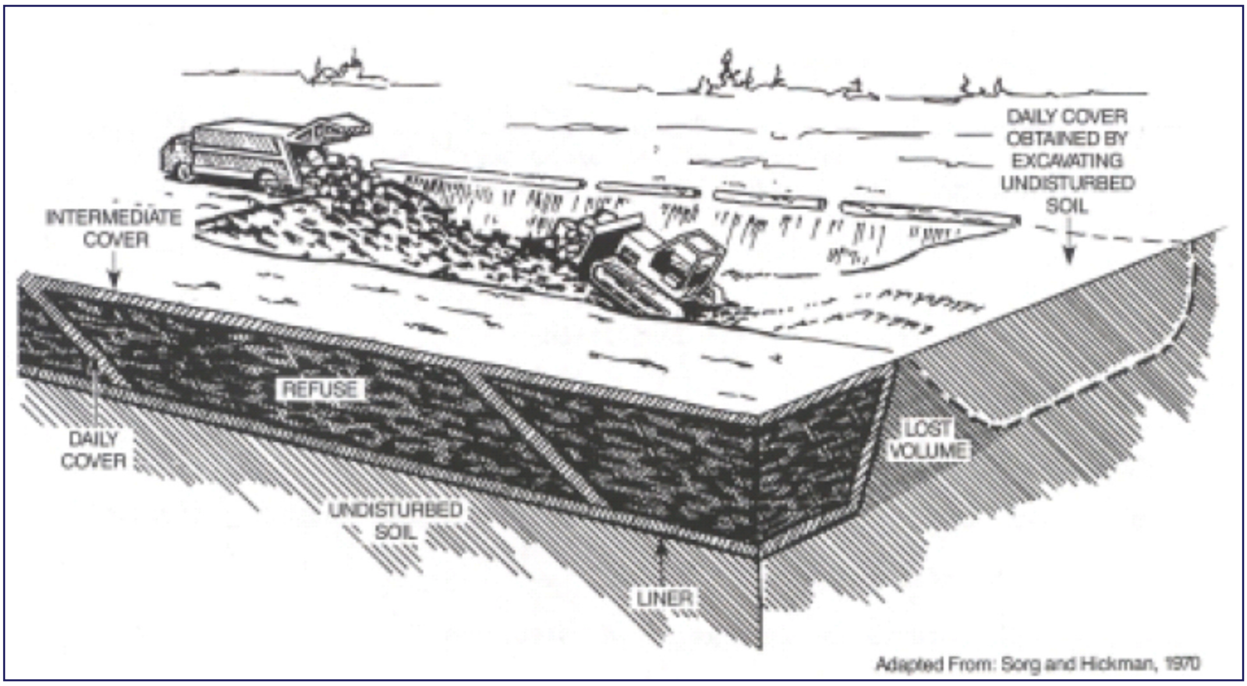

Figure 4.2: Trench Method of Landfilling adopted from Sorg and Hickman (1970).

4.1.2. Landfill Cells

The building block common to both the area and trench type landfills is the cell (Figure 4.3).

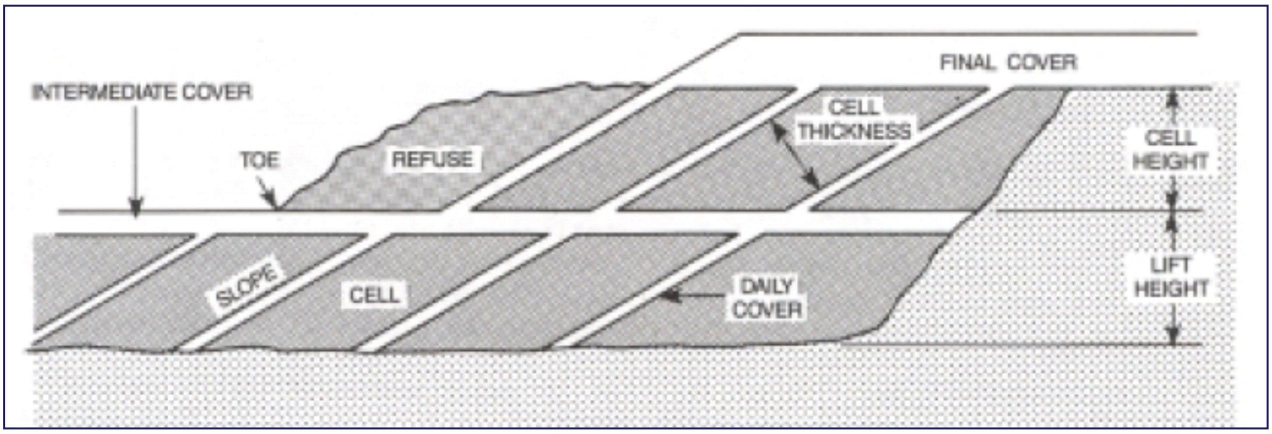

Figure 4.3: Typical Landfill Cell Construction adopted from Parametrix, Inc. (1987).

Cells can vary in size depending on:

- rainfall
- absorptive capacity of waste
- filling rate
- number of vehicle movements.

Cells should be designed to minimise cover material requirements, exposure of landfilled waste and the length of time the landfill cell is kept open, while maximising the volume of waste disposed. Cells should be kept reasonably narrow to minimise the area over which wastes will have to be compacted and to help prevent blowing litter.

Cells should be open for a maximum period of two years, then closed, covered and rehabilitated. In the case of a large area landfill, this will require the establishment of independent landfill cells. In the case of trench landfills, each trench should be sized so that it is able to be filled within 2 years. Larger excavations for trench landfills should be demarcated into cells and each cell filled within 2 years. An example of how landfill cells should be progressively filled, covered and rehabilitated is given in Figure 4.3.

Cells constructed within the landfill should be built from a suitably inert and free-draining material to avoid stratified layers within the landfill. Cell walls should exceed refuse height during filling, and hydraulic lift must be considered in sites prone to varying groundwater tables. It is important that cell wall construction is carried out with suitable structural stability to ensure the continued retention of waste and in such a way that the wall may, if required, be removed when the adjoining cell is constructed. Care should be taken to ensure that leachate does not percolate through the wall.

4.1.3. Site Capacity

Once the final shape of the completed landfill relative to the initial contours has been determined, the total volume of waste to be contained on the site can be calculated. An estimate of the compacted density of the refuse that will be achieved on the site, and of the compacted volume of daily, intermediate and final cover required over the life of the site, must be made to estimate the total refuse tonnage that can be accommodated.

A target minimum in-situ density, excluding cover, of 0.8 tonnes per cubic metre is readily achievable and should be used in design for larger sites (>50,000 tonnes per year) which have specialised compaction equipment. For smaller sites and sites without specialised compaction equipment between 0.6 and 0.8 tonnes per cubic metre is more likely.

When estimating the capacity of the landfill, a waste to daily cover volume of between 4:1 and 5:1 can be expected. Intermediate and final cover volumes can be estimated based on their thickness.

The source of material for linings, daily refuse cover, intermediate cover and final capping materials must be determined. In most instances some of this material may be able to be excavated progressively from within the refuse fill area. This will increase the refuse volume able to be disposed of in the site. The balance of the material not available on-site will have to be imported and an allowance for its volume must be made.

Assuming waste streams to the site can be quantified, taking into consideration predicted changes over the life of the facility, the anticipated lifespan of the landfill can then be predicted. The appropriate range of design densities for compacted refuse will depend on the compaction equipment available and operational methods adopted.

4.1.4. Staging of Site Development

The Northern Territory has a mix of climatic conditions which can generally be divided into two zones, the Northern monsoonal and the Southern arid region. The Northern region is subject to two distinct seasons the wet, with frequent typically high intensity monsoonal rainfall events and the dry, typically infrequent low intensity rainfall events of short duration. The Southern region experiences the typical seasons of summer, autumn, winter and spring. Given the diversity of climatic conditions, it is important that measures are taken to reduce rainfall infiltration into the landfilled refuse, and to control leachate production.

It is essential to develop and operate the site in distinct stages, undertaking landfilling operations on as small a part of the total site as possible at any one time. Areas earmarked for subsequent stages of filling should be prepared just prior to being used, and areas no longer being filled or used for some time, should be capped and remediated, and surface water drainage and erosion control measures installed.

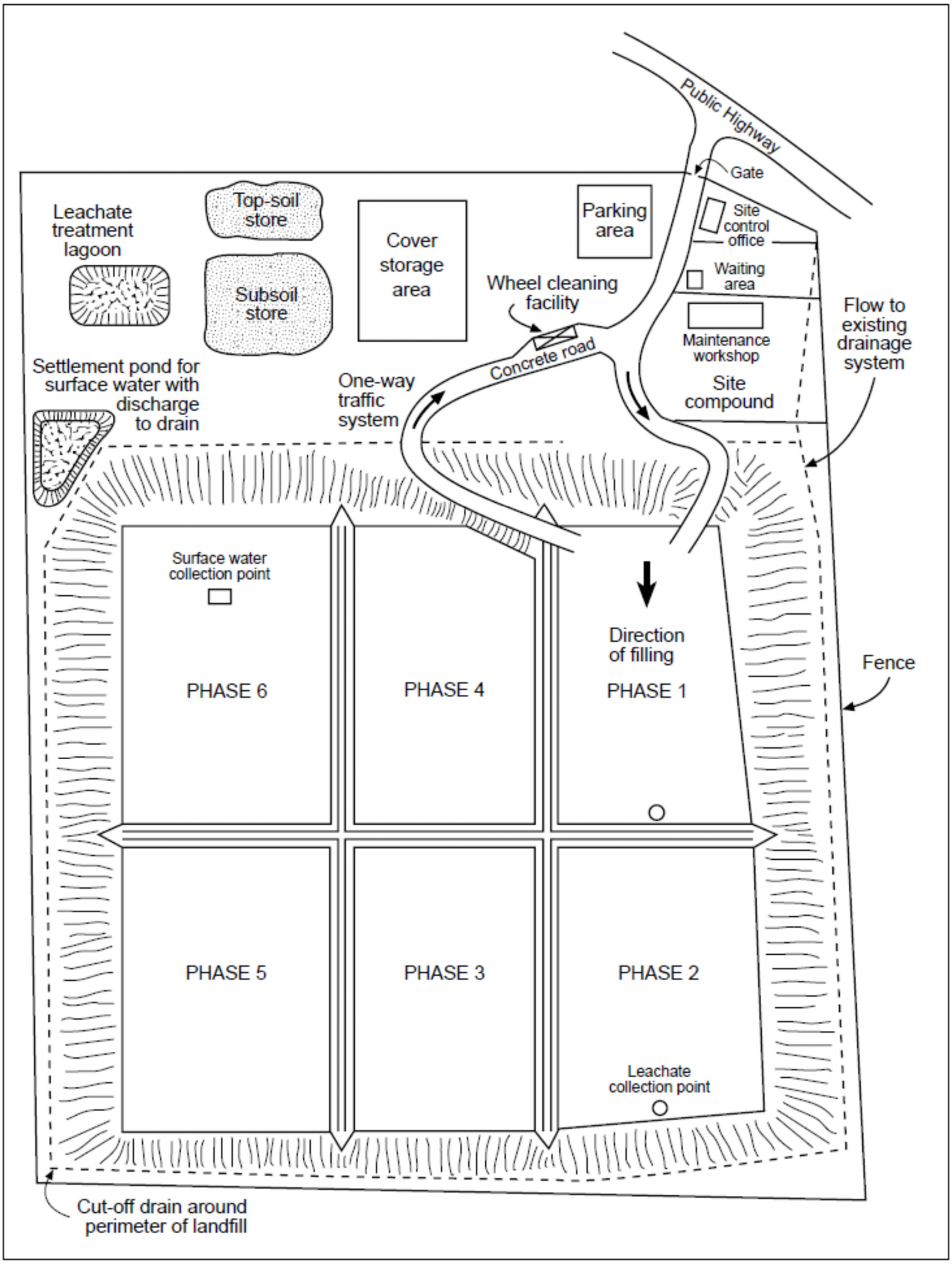

Figure 4.4: Typical Operational Plan for a Landfill Site adopted from DoE (1986).

A program for the development of the proposed landfill should be prepared, using a series of plans that show the areas and sequencing of the landfill operation. These should outline the measures required at each stage for leachate collection, treatment and disposal, landfill gas management, stormwater drainage and sediment control, source of cover material, road access, and how these will be provided throughout the life of the site. Figure 4.4 shows a typical operational plan for a landfill site.

4.1.5. Access

An all-weather access road should be provided from the public road to the site. This road should be designed to safely accommodate the anticipated volume of vehicular traffic and consist of two lanes of sufficient width and strength to carry the delivery vehicles. The access roads intersection with the existing public road should be carefully designed to reflect traffic volumes and safety requirements. Plans should include provisions to keep the access road and adjacent public roads free of mud and litter.

Landfilling operations should, ideally, exclude public access to the working face as allowing public access to the tipping face can have detrimental effects on both public health and the environment. A transfer station should be established, either at the landfill (remote from the tipping face) or at some other location closer to the centre of refuse generation for the public to deposit their waste.

4.1.6. Site Facilities

Site Entrance Notification

The appearance of the entrance to the landfill is important as this will influence the users' perception and, hence, behaviour in the landfill area. Clear and attractive signage which clearly demarcates traffic direction and where different types of waste are to be deposited is imperative at all landfill sites. Signs should ensure that all users are made aware of the following:

- access restrictions
- days and hours of opening
- acceptable (or prohibited) wastes
- materials accepted for recycling
- disposal charges
- documentation that must accompany any waste load
- level of control and inspection of wastes to be undertaken
- Approval/Licence number issued under the *Waste Management and Pollution Control Act 1998*
- name and emergency contact number of the facility operator
- name of the facility owner.

Directional signage should be provided to assist smooth traffic flow to the reception facilities, weighbridge, payment booth, recycling compound and unloading areas, as appropriate. All signs should give information in a concise, easy to read and attractive manner.

Weighbridge

Recording the weights of solid waste delivered to a site not only regulates and controls the landfill operation, as well as the solid waste collection system that serves it, but can also provide an equitable basis for assessment. The scale type and size will depend on the size of the landfill operation and the vehicles using the facility. The scale should be capable of weighing the largest (weight and wheelbase) delivery vehicle that will use the landfill on a routine basis. The platform should be long enough to simultaneously weigh all axles.

Pay Station

A secure pay station booth should be provided for the collection of fees and the recording of user data to enable invoicing of frequent, large-volume users. The position of the pay station should be meet the following criteria:

- cannot be avoided or bypassed
- flat area to enable vehicles to stop
- space for vehicle queue within the site
- minimum disruption to traffic flow.

It is important that there is a secure area for the cash and cashier and the accounting procedures are documented and implemented by staff. Good accounting is essential to achieving efficient and cost-effective management of the landfill. Clear concise accounting records will help when applying for grants for upgrades to landfill facilities, and for applications for funding the operation of the landfill facility.

Operational Facilities

The nature and extent of facilities related to the operational needs of the landfill will, to some extent, depend on the size of the operation. Facilities that would normally be required include:

- staff washroom (toilets and possibly showers)
- staff lunchroom
- first-aid and emergency equipment
- fire-fighting equipment.

Other facilities, such as plant storage sheds and maintenance facilities, may be required for large operations.

Services

Services including telephone, power, water supply and sewage disposal should normally be provided on the site. Often, due to the remoteness of the landfill from serviced urban development, water supply and sewage disposal on the site will need to be self-contained. There should be sufficient water supply for use in firefighting.

Listed (Hazardous) Waste Reception and Storage Compound

Consideration may need to be given to the reception and storage of small quantities of hazardous materials (e.g. used oil, car batteries), particularly if there is no other facility for hazardous waste treatment or disposal within a reasonable distance. Hazardous waste (including listed waste), such as tyres, used oil and car batteries are often stored at landfill facilities. If inappropriately managed they can impact adversely on the environment and thus must be stored at dedicated locations.

The storage and handling of flammable and combustible liquids must be in accordance with the Australian Standard AS1940 *The Storage and Handling of Flammable and Combustible Liquids* as amended from time to time. During storage there must be no visible leakage of the contents from any storage vessel and suitable spill kits must be available.

Waste tyres are not to be stored in the open for more than five days unless:

- The waste tyres are covered by an impervious membrane which excludes water in totality, or
- Waste tyres are made incapable of retaining water, e.g. shredded, or
- Waste tyres are individually treated with larvicide. The concentration of the larvicide is to be of a strength to stop the breeding cycle of the mosquito.

The dimensions of each tyre stockpile must not exceed:

- 5 metres as the maximum base width
- 45 metres as the maximum base length
- 3 metres as the maximum stockpile height.

The minimum distance between the tyre stockpile and any other flammable or combustible material including grass or weeds shall not be less than 10 m in any direction.

Temporary storage could also be provided for possibly hazardous waste awaiting analysis and classification before appropriate decisions can be made regarding disposal.

All landfills, regardless of serviceable population size, require a licence to collect, store, treat, recycle and/or dispose of listed (hazardous) waste. NT EPA has specific handling/disposal requirements for certain types of listed waste (e.g. asbestos, clinical waste, sewage sludge) and further information regarding these requirements can be found in this guide and obtained from the NT EPA website or by contacting the NT EPA directly.

Recycling Facilities

Containers should be provided for recycled materials and a designated area should be included in the site development plan. Access to the recycling area should be controlled by fencing to prevent unauthorized removal of salvaged materials.

Transfer Station

Public access to the working area of the landfill can create conflicts with landfill equipment and large hauling vehicles which could create unsafe conditions. Where these conditions could exist, consideration should be given to providing a drop-box container or transfer station near the entrance of the landfill. This will allow for wastes delivered by individual persons to be deposited properly, while keeping traffic away from the working area.

Wheel Wash Facilities

Vehicles hauling solid waste to the landfill working area often drive over dusty or muddy roads and previously spread solid waste. To prevent mud and debris from dropping from the vehicles when they return to the public roads, consideration should be given to truck wash facilities at the landfill site to routinely clean the trucks. These facilities can also be used to clean the landfill equipment. The need for wash facilities should be considered on a case-by-case basis, but generally the more vehicles entering and leaving the site, the greater the need for wash facilities.

Wash down facilities should be constructed so that they have:

- an impervious hardstand
- a suitable water supply
- an appropriate wastewater collection and disposal system.

Wash water should be tested for contamination and drained to sedimentation ponds prior to discharge. If contaminated, wash water will need to be treated prior to discharge or be disposed of to the leachate disposal system. All discharges of wastewater to surface or groundwater requires a licence under the *Water Act*. Further information regarding licensing of discharges can be obtained from the *Guidelines on waste discharge licencing under the Northern Territory Water Act 1992* available on the NT Government website.

Fencing and Gate

Landfills should be fully fenced along all site boundaries to ensure the safety of the general public and prevent unauthorised entry and disposal. Controlling access to the site minimises the possibility of illegal dumping of hazardous waste and reduces the risk of fires. An 1800 mm high wire mesh security perimeter fence is to be installed at all landfill sites. A gate is required at the site entrance and should be locked when the site is unattended or otherwise closed to users. Additional fencing should be installed to:

- control access to, and movement within, the site
- reduce the dumping area to a minimal, practical size
- provide litter control
- protect areas which are undergoing decommissioning and rehabilitation.

Consideration should be given to the security of the site outside the hours of operation to prevent damage to buildings and equipment and/or danger to unauthorised personnel.

Landscaping

It is desirable that the landfill should present an attractive appearance to the passing public. Areas of the site, which are not screened by natural topography or existing vegetation, should be surrounded by a tastefully designed fence or planted shelterbelt to screen operations from the view of the passing public and any nearby residences. The establishment of a planted shelterbelt requires early planning to allow for adequate growth before commencement of landfill operations.

4.1.7. Final Use and Final Landform

Key aspects of landfill design are the determination of the final landform, the method of final reinstatement and final uses for the site. The most common final uses for completed landfills are:

- passive recreation (gardens, parks, golf courses), or
- controlled farming (agriculture or horticulture).

Integrating the issues of final use and final landform will be significant in the determination of critical parameters such as fill volume and potential lifespan. Factors to consider include:

- points of access
- drainage patterns
- landfill cap requirements.

The end use options and final landform should be canvassed during the initial site selection, public consultation and resource consent processes. The plan of the final landform contours should be prepared as part of the design process prior to development consent and approval applications. The final filling levels should be carefully controlled in accordance with this plan.

4.2. Groundwater Management and Control

Groundwater management is an important consideration in the design and operation of a landfill. The groundwater needs to be managed so that:

- the groundwater does not adversely affect the landfill, in particular the liner system
- the normal flow of groundwater is not adversely affected by the landfill
- the quality of the groundwater is not adversely affected by the landfill.

Site investigations should clearly determine groundwater flows around the site and the maximum range of groundwater levels. The base of the landfill and liner system should be located above the groundwater table with an unsaturated zone immediately below the liner of at least 2 m. Methods for the protection of groundwater from the impacts of landfill leachate are discussed in Section 4.5.

4.3. Surface Water and Storm Water Management

Surface water and stormwater management are two of the most important aspects of successful landfill operation. Stormwater control is a critical aspect of landfill design and generally cannot be successfully retrofitted. Surface water management is required to ensure that:

- contaminated surface run-off from the active fill area does not enter water courses
- rainfall run-off from surrounding areas does not drain into the landfill
- surface water and stormwater does not generate excessive quantities of leachate
- ponding and erosion on filled and capped landfill surfaces are minimised.

4.3.1. Surface Water and Stormwater Control

Consideration should be given to the local climatic conditions when designing the stormwater drainage system. The heavy rainfall situations which can occur in the Northern Territory can lead to overflow of landfill stormwater drains and cause severe erosion and landfill stability problems. Diversion structures should be placed in drains to divert stormwater away from disposal areas, where possible, site contours should be utilised during the planning stage to facilitate this. Such planning may reduce the need for costly drainage works in the future.

The following control measures are mechanisms for achieving surface water management objectives:

- interception drains surrounding the active fill area to prevent overland flow from entering the active fill area should be provided
- rainfall falling on the active fill area should be collected and managed as leachate via the leachate collection, treatment and disposal system
- rainfall run-off from slopes outside and above the landfill should be intercepted and diverted to watercourses.

Diversion drains and channels must be designed to prevent scouring and leakage into the landfill:

- drainage channels or drains constructed on the completed landfill surface should be designed and constructed to accommodate settlement, minimise or eliminate erosion, and cope with localised storms
- completed fill areas and areas of intermediate cover should be contoured to direct stormwater into drains leading away from the active filling area and working face
- permanent or temporary access roads should be designed to prevent them acting as stormwater channels that may direct water into the landfill.

4.3.2. Discharge to Water

Water discharged from any of the above sources to surface or ground water courses must be disposed of in accordance with license conditions, which may stipulate both quality and quantity limits.

Any stormwater that has been diverted from the filling site is likely to carry a high silt load and should be held in sedimentation ponds prior to discharge. Sedimentation ponds should be developed prior to discharge of surface waters to natural stream or river flows. The ponds and traps should be designed to ensure easy maintenance and cleaning.

4.4. Leachate Generation and Characteristics

4.4.1. Leachate Characteristics

Numerous physiochemical and biological processes control the production and composition of leachate in landfills. In general, the composition of leachate will be a function of the types and age of waste deposited, the prevailing physiochemical conditions, and the microbiology and water balance of the landfill.

Microbial action commences the decomposition of the putrescible waste, and it occurs in three stages. In the first stage, degradable waste is attacked by aerobic organisms, resulting in production of organic compounds, carbon dioxide, water and heat.

The second stage commences when all the oxygen is consumed or displaced by carbon dioxide. Aerobic organisms, which thrived when oxygen was available, die off and the degradation process is then taken over by facultative organisms that can thrive in either the presence or absence of oxygen. These organisms can break down the large organic molecules present in food, paper and similar waste into more simple compounds such as hydrogen, ammonia, water, carbon dioxide and organic acids.

In the third and final stage (the anaerobic, or methanogenic phase) methane-forming organisms multiply and break down organic acids to form methane gas and other products. The water-soluble degradation products from these biological processes, together with other soluble components in the waste, are present in leachate. In addition, pH changes and acid formation may mobilise metals and increase their content in the leachate. Table 4.1 shows the changes in leachate composition that occur as a landfill proceeds through the various phases of decomposition.

Table 4.1: Difference between Leachate Composition in Different Stages in a Landfill[2]

	Acetic Phase		Methanogenic Phase	
	Average	Range	Average	Range
pH	6.1	4.5 - 7.5	8	7.5 – 9
BOD (mg/L)	13,000	4,000 – 40,000	180	20 – 550
COD (mg/L)	22,000	6,000 – 60,000	3,000	500 – 4,500
BOD/COD	0.58	-	0.06	-
SO_4 (mg/L)	500	70 – 1,750	80	10 – 420
Ca (mg/L)	1,200	10 – 2,500	60	20 – 600
Mg (mg/L)	470	50 – 1,150	180	40 – 350
Fe (mg/L)	780	20 – 2,100	15	3 – 280
Mn (mg/L)	25	0.3 – 65	0.7	0.03 – 45
Zn (mg/L)	5	0.1 – 120	0.6	0.03 – 4

The main components in the leachate from landfill sites can be grouped into four classes as follows:

- major elements such as calcium, magnesium, iron, sodium, ammonia, carbonate, sulphate and chloride
- trace metals such as manganese, chromium, nickel, lead and cadmium
- a wide variety of organic compounds, which are usually measured as total organic carbon (TOC) or chemical oxygen demand (COD). Individual organic species such as phenol can also be of concern
- microbiological components.

Household waste is reasonably consistent in composition over all landfill sites, as is the resulting leachate. However commercial and industrial waste can significantly alter the composition of leachate at a landfill facility and thus the leachate composition of facilities that are licensed to accept commercial and industrial waste may vary considerably.

To determine leachate composition, leachate analysis needs to be undertaken at regular intervals. It is important to note that leachate monitored at a collection point receiving leachate from different areas of a landfill can be a mixture of old and new, weak and strong leachate. In addition, leachate concentrations can be lower than those presented in Table 4.1 for the methanogenic phase for very stable landfills or those with a high degree of water infiltration.

Sound landfill design requires calculation of expected leachate production in addition to composition as the amount of leachate generated will affect operating costs. The amount of leachate generated can also affect the potential for liner leakage and hence the potential for groundwater contamination. The amount of leachate generated will also affect the cost of post-closure care. Predicting leachate generation

[2] Adopted from Table 4.1 in CAE (2000).

quantities requires water balance calculations that consider precipitation, surface runoff, evapotranspiration, leachate production and storage.

There are several factors that can influence the production of leachate at landfills, which need to be considered as part of the design process, these include:

- Climate – Landfills located in regions of high precipitation can generally be expected to generate more leachate
- Topography - Topography affects the site's run off pattern and the amount of water entering and leaving the site. Landfills should be designed to limit leachate generation from areas peripheral to the site by constructing perimeter stormwater drainage systems to divert surface water "run-on" away from the site and by constructing the landfill cover to promote runoff and reduce infiltration. All areas of a landfill should maintain at least two percent grade over the waste at all times to prevent ponding of surface water
- Landfill Cover - Landfill cover at the site affects the amount of water percolating into the landfill to generate leachate. In general, the greater the permeability of the soil used for final cover the greater the amount of leachate produced
- Vegetation - Vegetation limits water infiltration by intercepting precipitation directly (thereby improving evaporation from the surface) and by taking up soil moisture and transpiring it back to the atmosphere. A landfill with poor vegetative cover may experience erosion that cuts gullies through the cover soil and allows precipitation to flow directly into the landfilled waste
- Type of waste - The type of waste, the water content of the waste and the form that it is in (bulk, shredded, etc.) affect both the composition and quantity of leachate.

4.5. Leachate Retention and Liner Systems

Both new landfills and lateral extensions of existing landfills need to provide an appropriate level of retention to protect the environment from the adverse effects of leachate entering the groundwater and surface waters. This would generally comprise:

- a leachate retention or liner system, and
- a leachate collection system.

At some sites, significant retention and attenuation can potentially be provided by the underlying geology of the site, which may be able to act as a component of the liner system. At others, it will be necessary to rely on a well-engineered liner system over the entire base area of the landfill for both retention and reduction.

4.5.1. Landfill Liner Systems

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 contacts 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 landfill liner system should be designed to contain leachate over the period of time that the waste poses a potential environmental risk. The liner system should be designed and installed in accordance with the quality requirements specified in an approved Construction Quality Assurance plan. The benchmark technique for a liner system for new landfills and lateral expansions of operating landfills is a system that forms a barrier between groundwater, soil and substrata, and the waste.

The following three liner designs are recommended, as they have been shown to provide suitable level of protection to the receiving environment, for a landfill sited in accordance with these guidelines.

- single liner systems
- composite liner systems
- double liner systems.

All medium and large landfills should have a composite liner system consisting of the following components as a minimum:

- subbase
- clay liner
- geomembrane
- a drainage layer/leachate collection system.

For small landfills, a single liner system consisting of a prepared sub-base, compacted clay liner and leachate drainage layer may be sufficient. For putrescibles landfills in sensitive locations a thicker clay liner or a double liner system should be considered. A double lined landfill will also allow for the acceptance of wastes with high levels of contaminants or more types of Listed Wastes.

Single Liner System

Single liner systems consist of a clay liner, a geosynthetic clay liner, or a geomembrane. Single liner systems are often used in landfills designed to hold construction and demolition (C&D) waste. C&D waste includes concrete, asphalt, shingles, untreated wood, bricks and glass. These landfills are not designed to contain putrescibles, listed waste or special listed wastes, as such single liner systems are usually adequate to protect the environment. Figure 4.5 is a cross section of a typical single liner system.

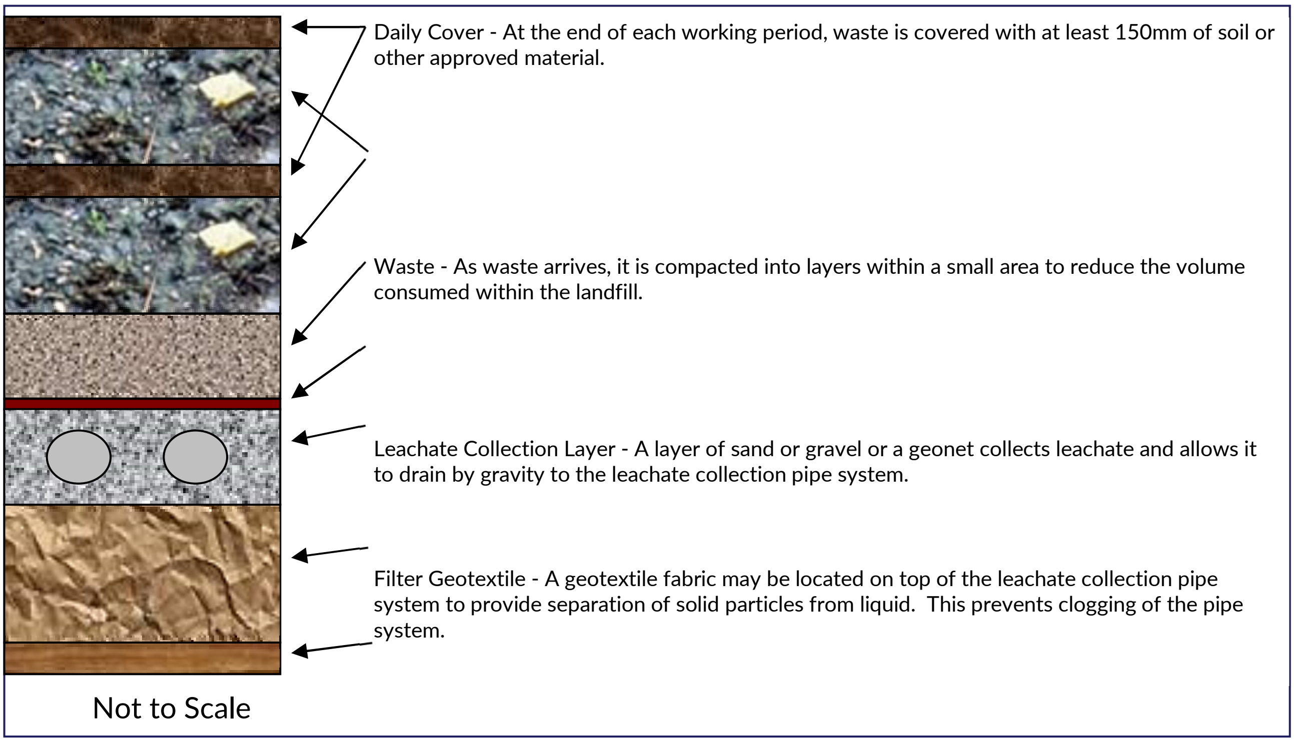

Figure 4.5: Single Liner System

A single liner system should generally comprise 900 mm of clay or other low permeability soil compacted in layers a maximum of 150 mm thick, to achieve a coefficient of permeability not exceeding 1×10^{-9} m/sec.

Composite Liner System

Composite liner systems consist of a geomembrane in conjunction with a clay liner. Composite liner systems are more effective at limiting leachate migration than either a clay liner or a single geomembrane layer. Composite liners are required in all medium and large Municipal Solid Waste (MSW) landfills. MSW landfills can contain waste collected from residential, commercial and industrial (C&I) and C&D sources. Landfills designed with a composite liner system can accept wastes up to a certain leachability concentration. Figure 4.6 is a cross section of a typical composite liner system.

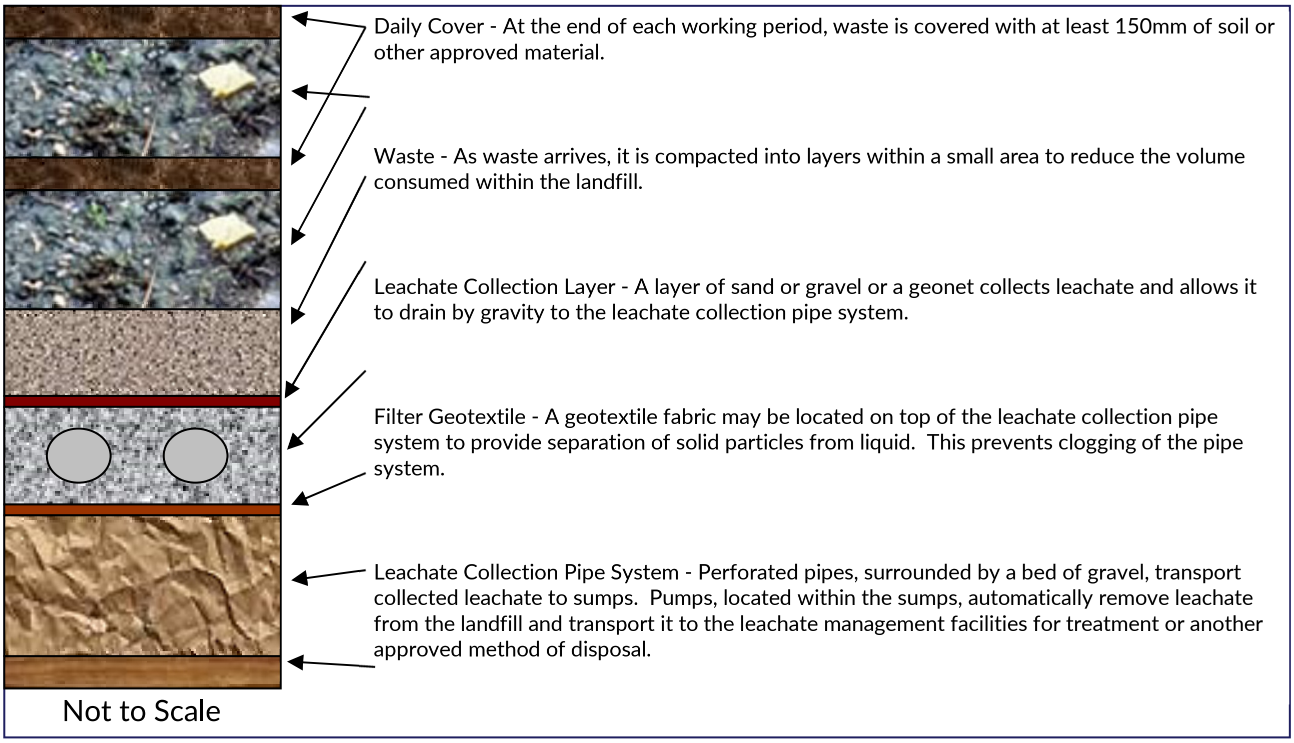

Figure 4.6: Composite Liner System

A composite liner system should generally comprise a synthetic flexible membrane, 1.5 mm thick, overlying 600 mm of clay with a coefficient of permeability not exceeding 1 x 10^{-9} m/sec.

Double Liner System

Double liner systems consist of either two single liners, two composite liners, or a single and a composite liner. The upper (primary) liner collects the leachate, whilst the lower (secondary) liner acts as a leak detection system and a backup for the primary liner. Landfills designed with a double liner system can accept wastes of a higher leachability concentration than composite liner systems, see Appendix C for further details.

4.5.2. Landfill Liner System Components

Sub-base

The sub-base of the landfill liner system is the lowest point of the excavated area upon which the liner system is to be placed. The sub-base will be an in-situ material of sufficient bearing capacity to support the material to be placed above it during the lifespan of the facility. Material encountered in the sub-base which does not meet the required bearing capacity shall be excavated and replaced with appropriate structural fill material.

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. All plans for the construction of a sub-base must be verified and approved by a geotechnical engineer.

Clay Liner

The ability of clay to retard water movement and absorb exchangeable cations makes it a suitable natural construction material for a low-permeability liner. When assessing the suitability of soil as a low-permeability liner, soil properties such as particle size distribution and plasticity (described by the soil plasticity index) and cation exchange capacity (CEC) should be determined. The potential for desiccation and subsequent cracking must also be considered.

Clay used for the liner construction should have the following properties:

- no rock or soil clumps greater than 50 mm in any dimension
  - 70 per cent passing through a 75 mm sieve
  - 30 per cent passing through a 19 mm sieve
  - 15 per cent passing through a 2 mm sieve
- soil plasticity index > 10
- CEC > 10 meq/100 g
- minimal long-term degradation with exposure to leachate.

The clay liner must comprise a thickness of 900 mm and a hydraulic conductivity of less than $1x10^{-9}$ m/s using both fresh water and 50,000 ppm NaCl solution according to Australian Standard AS 1289.6.7.1 – 1999: *Soil strength and consolidation tests – Determination of permeability of a soil – Constant head method for a remoulded specimen*.

The liner must undergo construction by uniform moisture conditioning and compaction using a sheepsfoot roller (refer to AS3798:2007) in layers with a maximum compacted thickness of 200 mm. There must be effective bonding between successive layers that include kneading between layers, scarification and moisture conditioning. Successive layers must have a minimum horizontal overlap of 1m to ensure that a preferential pathway for leachate flow is not created. Clay liners must have a smooth final surface that is graded at a minimum of 2% towards drainage lines and 1% along drainage lines.

A Construction Quality Assurance (CQA) plan must be developed and implemented as a means of managing quality during construction and reporting, so that the materials used, construction methods and complete works comply with the landfill design.

Geosynthetic Clay Liner (GCL)

The geosynthetic liner system for the base and side liner must be designed by a person with demonstrated understanding of and experience in the design and installation of the proposed geosynthetics, and in the geotechnical considerations related to lining the base of landfills. The installation of the geosynthetic liner must be carried out in accordance with an effective construction quality assurance (CQA) system, as developed in consultation with the NT EPA before commencement of construction.

Geomembrane

Geomembranes are also called flexible membrane liners (FML). These liners are constructed from various plastic materials, including polyvinyl chloride (PVC) and high-density polyethylene (HDPE). The preferred material for use in MSW landfills is HDPE. This material is strong, resistant to most chemicals, and is considered impermeable to water. Therefore, HDPE minimises the transfer of leachate from the landfill to the environment.

The following minimum requirements for geomembranes must be satisfied:

- joins must be permanently bonded, taking into consideration the geomembrane type, e.g. heat bonding for HDPE geomembranes
- the geomembrane must be installed in intimate contact with the underlying layer
- the geomembrane must be at least 1.5 mm thick
- have a minimum tensile strength at rupture of greater than 10 kN/m.

4.5.3. Liner Construction Issues

Low permeability soils are often used for the construction of landfill liners and, where they are available in-situ, they provide a cost-effective solution. They are often used in conjunction with synthetic flexible membranes. The design and construction of an engineered liner must be undertaken with an extensive quality assurance and quality control (QA/QC) program, complemented by a well-defined materials testing program. Section 4.10 addresses QA/QC tests and testing frequencies for liner construction.

It should be noted that certain organic solvents in leachate can shrink the thickness of compacted clays. Consequently, the permeability of compacted clay may increase for certain leachates.

4.6. Leachate Collection and Removal Systems

The leachate collection and removal system is placed at the base of the landfill above the retention system. The functions of the leachate collection and removal system are:

- to remove leachate for treatment, disposal, and/or recirculation into the landfill
- to control the head of leachate on the liner system to minimise the quantity of leachate leakage.

A leachate collection system is to be integrated into all liner systems. The design objectives of the leachate collection system must ensure that it is:

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

A typical leachate collection system consists of the following components:

- a drainage layer consisting of highly permeable aggregate material, either sand or gravel
- a network of perforated pipes laid within the aggregate layer
- filter layers of aggregate or geotextile fabric where needed to prevent clogging
- sump(s) at low points within the system from where leachate can be collected.

In double liner systems, the upper drainage layer is the leachate collection system, whilst the lower drainage layer is the leak detection system. The leak detection layer contains a second set of drainage pipes. The presence of leachate in the secondary pipes will alert landfill management that there is a leak in the primary liner.

Leachate collected in the collection system is drained away from the landfill by a series of non-perforated pipes. Pumps are usually required to transfer the leachate to an on or off-site treatment or disposal facility.

New or expanding landfills require a leachate collection system designed to ensure that leachate accumulation at the topographical low point does not exceed a depth of 300 mm. The design variables that affect the depth of leachate in the collection system are:

- The porosity of the aggregate in the drainage layer
- The rate of leachate percolation into the drainage layer
- The hydraulic conductivity of the drainage layer
- The flow distance to a perforated pipe
- The hydraulic conductivity of the bottom liner
- The thickness of the bottom liner
- The hydraulic conductivity of the drainage layer must be greater than 1×10^{-3} m/s.

4.7. Leachate Recirculation

Leachate recirculation can offer significant benefits in reducing the strength of leachate regarding Biological Oxygen Demand (BOD) and some metal ion concentrations. Other benefits of leachate recirculation include:

- increased rate of waste stabilisation and settlement
- increased quantity and quality of methane gas production
- provision of a viable on-site leachate management method.

Leachate should only be recirculated in landfills that are designed and equipped with a liner and leachate collection system capable of containing a 300 mm depth of leachate over the liner. Leachate recirculation systems require careful design to address potential problems associated with:

- leachate seepages and breakout on side slopes
- increase in leachate head on the base of the landfill
- initial increase in leachate strength
- increase in landfill gas production and odour nuisance
- differential settlement
- stability of the waste mass.

Recirculated leachate is generally discharged via a subsoil perforated pipe extending the length of the trench just below the surface of the fill and remote from the leachate collection system, to maximise the percolation distance. Recirculation rates need to be carefully monitored and controlled to ensure that areas of refuse do not become saturated, as this could result in surface outbreaks, and could potentially jeopardise the slope stability of the landfill. Rates and areas of recirculation should be carefully chosen and will invariably require seasonal adjustment to maintain optimum landfill performance.

4.8. Leachate Treatment and Disposal

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.

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 (refer to section 4).

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.

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

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.

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 other alternatives are not feasible or sufficiently protective of the environment, these 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.

4.9. Landfill Gas Management

Landfill gas will generally be produced in almost all landfills. The degradation of putrescible waste is caused by microbes that produce landfill gas as a by-product of decomposition. The composition of landfill gas varies according to the dominant phase of microbiological breakdown occurring within the site at the time. Although mainly methane and carbon dioxide, it may also contain other gases, including volatile organic compounds. In the early aerobic decomposition phase, the gas is predominantly carbon dioxide. In the later anaerobic decomposition phase, the gas has a relatively high methane content. The onset and duration of each phase of landfill gas production varies both within and between sites.

The anaerobic phase has the greatest potential to impact on air quality as the major constituents of the gas are methane and carbon dioxide, both of which are greenhouse gases. With daily compaction and covering 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 more than 15 years.

The migration of landfill gas can present an environmental and safety risk. Potential problems of landfill gas include:

- detrimental effects on soils and vegetation within the completed landfill and adjacent sites
- risks to human health (on-site and off-site)
- risks of explosions or fires due to gas migrating and collecting in confined spaces such as manholes and chambers and poorly ventilated areas of buildings on or adjacent to the site
- odour nuisance
- ignition of landfill gas upon release through cracks and fissures at the surface (methane fires are generally not visible in daylight)
- asphyxiation of personnel entering trenches, manholes or buildings on or near the landfill site.

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 to purchase it. The benefits for smaller landfills are not so clear, and the landfill gas management options depend on the size of the landfill.

4.9.1. Landfill Gas Production

The rate of gas production can be controlled largely by the adoption of appropriate landfill management techniques. Site design may require that gas production be either encouraged or minimised, depending on whether the gas is to be utilised.

The rate of gas generation can be influenced by controlling conditions within the fill, particularly moisture, through such measures as controlling the integrity of surface capping, recirculating leachate through the landfill, or irrigation.

Ensuring that the waste is well-chopped and compacted as it is placed will hasten the onset of the anaerobic phase of degradation for the more readily degradable materials. Rapid filling of small areas of the site will shorten the aerobic degradation phase and tend to keep waste temperatures down.

Where large volumes of high BOD leachate are produced and removed from the site without recirculation, the resultant loss of nutrients, on which gas production relies, will reduce the overall quantities of gas produced.

Daily or intermediate cover and the use of low permeability materials in cell construction may result in the development of perched water tables and have effects on moisture movement, transmission of gases and buffering of leachates. Such effects will be important in terms of gas production, migration pathways and proposed methods of gas control. Even active gas extraction systems can further contribute to the gas production process by drawing moist saturated gases through the body of the fill.

4.9.2. Landfill Gas Control

The requirement for a landfill gas control system will depend on:

- the quantity and rate of landfill gas production
- the potential for odour nuisance to site neighbours
- potential risks associated with landfill gas migration.

A landfill gas control system, if required, would generally incorporate:

- a system to retain gas within the landfill site and prevent offsite migration
- a landfill gas collection and utilisation or flaring system
- a separate system for controlling gas migration at the perimeter of the site that is capable of independent operation from the collection system for gas within the waste body
- gas monitoring boreholes/wells outside the waste boundary.

To effectively design and operate a landfill gas control system it is necessary to understand that two largely independent mechanisms for gas migration are:

- gaseous diffusion (concentration gradient)
- advection (pressure gradient).

To make the gas control system robust, it is usually necessary to have more than one level of control at any site. The levels of control must be site specific.

4.9.3. Migration Control and Monitoring

It is important to detect possible gas migration from the site towards sensitive areas. Purpose-designed gas monitoring boreholes should be installed between the site and sensitive property boundaries and regular monitoring should be undertaken. Landfill gas monitoring is discussed in more detail in Section 6.4.

Appropriate measures should be taken to adequately control the accumulation and migration of landfill gas. Migration control systems should primarily be established and concentrated around the perimeter of the landfill if there is a risk of lateral migration towards adjacent developed property. Control systems should be progressively installed as filling is completed adjacent to susceptible areas.

No single form of gas migration control may be adequate to protect sensitive adjacent property. Thus, in addition to an on-site gas collection system, other measures, such as the use of low-permeability barriers between the site and the adjacent strata, may be necessary.

Because of differences in the viscosity of liquids and gas, clay and bentonite clay barriers are orders of magnitude less effective at restricting the flow of gas than that of leachate. Hence the designer may need to consider whether the proposed leachate retention liner/ barrier is adequate for gas control or whether a higher specification liner using a synthetic flexible membrane is required for gas control purposes.

Currently three types of systems are used, either individually or in combination, to control lateral migration of landfill gas. These are:

- passive venting
- physical barriers
- suction-driven landfill gas extraction.

Passive venting systems should only be used in landfills where the rate of gas generation is low (e.g. small or biologically old sites).

Physical barriers range from stone-filled trenches to low permeability constructions including combinations of flexible geomembranes, bentonite slurry walls and piles and cut-off walls. To be fully effective against gas migration, clay barriers should incorporate a geomembrane. The performance of all physical barriers is improved when combined with a means of gas removal (i.e. extraction using suction or passive venting).

Design of passive venting systems needs to take account of hazardous area classifications (AS 2430 Classification of Hazardous Areas) potential as odour sources and potential flammability at the discharge point.

Landfill gas extraction systems comprise up to five main components and rely on suction to extract landfill gas from the landfill. The five main components of the system are:

- gas wells or drains constructed in the landfill
- associated pipe network and pumping mains
- condensate traps for the removal of condensed liquid from the system
- landfill gas extraction pumps (blowers)
- landfill gas diffusers, flares or a utilisation plant.

Individual gas wells should be located to achieve an appropriate radius of influence for gas extraction, with due regard to any possible end use restriction. Gas wells should be sited to avoid penetrating the liner and avoid coincidence with listed waste burial locations as identified by the listed waste disposal location records.

4.9.4. Landfill Gas Disposal

Disposal of gas from a collection system is a continuous process. Landfill gas should either be flared or otherwise used to provide an economic return in such processes as electricity generation or leachate evaporation.

Regardless of the end use of the gas, some provision for flaring should be made, particularly if migration is a concern. Flaring might be necessary to deal with excess gas flow and instances when the utilisation process is not operational.

Flare systems should be designed to ensure that the gas is completely burnt at the highest possible temperature. Enclosed flares will provide the best combustion, however open, or candle, flares may be appropriate, depending on landfill size and location.

Energy recovery should always be considered in preference to flaring as landfill gas utilisation, as besides being environmentally beneficial, it helps offset the costs of landfill gas control. Where there are local users, direct use of the gas is more efficient than electricity generation.

4.10. 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.

4.10.1. Sub-Base and Clay Liners

Because of the importance of the sub-base 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-base and/or a constructed sub-base is able to support the landfill without affecting the integrity of the liner system 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.

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 m^3, and
- field testing for liner density and moisture content at a frequency the greater of:
    - 1 test per 500 m^3 of soil
    - 1 test per 2,500 m^2 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.

4.10.2.Geomembranes

The CQA plan for a geomembrane must specify procedures for:

- recording condition of materials when unloaded at the site, i.e. 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 geomembrane for defects
- minimising tensile stresses on geomembranes that result from thermal expansion or contraction of installed components
- testing of the seams
- 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.

4.10.3.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.

4.11. Closure and Post Closure Plans

4.11.1. Closure Plan

A closure plan ensures that the landfill is closed in accordance with applicable local, state and federal regulations. It ensures that all appropriate controls are in place for the management of leachate, landfill gas and surface drainage, as well as ensuring that the approved final land use is achieved.

Elements of a closure plan are to include:

- hydrogeological report
- final site topographic plan
- final cover design
- source of cover material
- final landscaping plan or site plan
- specification of construction details for on-site structures
- operating plan for phased closure of the landfill
- surface water management plan
- ground water management plan
- leachate management plan
- landfill gas management plan
- environmental monitoring plan
- cost estimate to implement the closure plan
- implementation schedule and notification procedures

Not all sites will require every element if it can be demonstrated through appropriate data analysis. New landfills that have been designed and developed in accordance with this guideline will already have completed most of the design aspects of the closure plan. However existing landfills will require hydrogeologic and site engineering investigations to develop a suitable closure plan.

A closure plan is to be submitted to NT EPA for assessment at least twelve months prior to the final load of waste being landfilled.

4.11.2. Post Closure Plan

A post closure plan is essential to ensure the long-term integrity of the closed landfill. The elements of a post closure plan are to include:

- maintenance of surface drainage systems

- maintenance of leachate management systems
- maintenance of gas control/recovery systems
- maintenance of final cover including revegetation, restoration or eroded areas and grading of areas experiencing compaction
- surface water monitoring program
- ground water monitoring program
- landfill gas monitoring program
- cost estimates for plan implementation.

It is common for the closure and post closure elements to be combined into a single plan. Most elements required in the closure and post closure plans have been discussed throughout this guideline.

5 Operation and Management

Even a correctly sited and designed landfill can cause significant environmental and health impacts if not operated correctly. The following sections outline the recommended management practices for both remote and metropolitan landfills. In particular, the elements of a landfill's operations that need to be considered are:

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

5.1. Environmental Management Plan

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

The key framework for any EMP 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
- commitment to continuous improvement.

International Standards ISO 14001 and ISO 9001 provide guidance on environmental management systems and quality management systems respectively, while Appendix B of this document provides more detail on the key elements of an EMP. The NT EPA website also has a Guideline for the preparation of an Environmental Management Plan (2015).

5.2. Financial Assurance

Alongside an EMP, landfill operators should develop and 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 if the landfill operators abandon the site, become insolvent or incur clean-up costs beyond their financial capacity. A financial assurance is required by licence of all licensed landfills.

Financial assurance has three components:

- remedial action
- site rehabilitation
- site aftercare.

The financial assurance should be held for the period that the landfill continues to pose a risk to the environment and may be discharged by NT EPA when monitoring and regular inspection demonstrate that the landfill no longer poses a risk to the environment.

5.3. 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 be taken to avoid waste production and to 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.

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

- paper and cardboard
- plastic and glass bottles
- concrete
- steel
- timber
- green waste
- organic waste such as food scraps
- bricks

- roof tiles
- white goods
- 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 onsite.

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.

5.4. Waste Acceptance

Signs advising which wastes are received at the landfill should be provided and 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 to ensure the receipt of wastes the landfill accept are followed and to detect any prohibited wastes. Landfill staff should be vigilant to ensure that only appropriate wastes are deposited at the premises. Loads containing prohibited 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 CCTV 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. 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 ten 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 Environmental Management Plan (EMP) and implemented where such wastes are dumped.

5.4.1. Waste Acceptance Criteria

The purpose of establishing waste acceptance criteria is to ensure that all wastes being disposed in the landfill are compatible with the operation of the landfill, do not lead to immediate or long term adverse environmental effects, and meet licensing conditions. The types of waste that a facility is capable of receiving are dependent on the site location, leachate collection and treatment/disposal systems installed and licensing conditions.

The disposal of untreated hazardous/listed waste with municipal solid waste is no longer considered an appropriate management practice. Only a few hazardous/listed wastes can be licensed for disposal in municipal solid waste landfills. Waste acceptance criteria should comprise prescribed lists that set out those wastes that are not acceptable and leachability criteria for wastes, which may include treated hazardous/listed waste that may be accepted, subject to specific licensing conditions.

5.4.2. Listed Wastes

Listed waste pose a threat or risk to public health, safety or the environment and include substances which are toxic, infectious, mutagenic, carcinogenic, teratogenic, explosive, flammable, corrosive, oxidising and radioactive. Listed wastes may be stored and/or disposed of at landfills and licences are required for either activity. Schedule 2 of the *Waste Management and Pollution Control (Administration) Regulations* detail Listed Wastes, and a copy of the Schedule is provided in Appendix D.

Subject to licensing conditions, some listed wastes may be disposed in landfills that have engineered retention and high standard leachate collection and treatment systems, following treatment to remove their hazardous characteristic(s). Waste acceptance criteria for these wastes should ensure that:

- landfill leachate does not differ from that which would be expected from non-hazardous municipal solid waste
- there is no threat to groundwater and/or surface water receptors from wastes deposited in the landfill.

In the absence of any national requirements for landfill waste acceptance criteria, the following approach is recommended for well-sited landfills, which provide an equivalent level of environmental protection as those using designs recommended in Section 4.5.

Use of the US EPA Toxicity Characteristic Leaching Procedure (TCLP) and maximum leachability limits, using the leachability criteria detailed in Appendix C, are recommended in setting waste acceptance criteria. The use of the leachability criteria for acceptance of listed waste provides a reasonable assurance that wastes accepted at an appropriately sited and designed landfill will not result in adverse effects on the surrounding environment.

Landfills that do not have demonstrated retention and leachate collection systems, or where groundwater or surface water is already contaminated, should not accept listed waste.

5.4.3. Notifying the NT EPA

The landfill owner/operator should notify the regulatory body if listed/hazardous waste is presented at the landfill for disposal without prior approval and appropriate documentation. If the landfill owner/operator identifies the listed/hazardous waste while it is in the possession of the transporter, the load should be rejected and will remain the responsibility of the transporter. If the listed/hazardous waste is identified after deposition at the tipping face, then immediate steps must be taken to secure the waste. Contingency plans for identification of the waste must be urgently implemented. If the waste is identified as unacceptable, then a plan for removal or neutralisation of the waste must be actioned as quickly as practicable. Landfill users and staff must be protected from any health and safety hazards that might be caused by the listed/hazardous waste.

5.4.4. Record Keeping

Landfill owners/operators should maintain an operating record that includes information on waste acceptance, on-site recycling, load inspections, and operational activities. Information on waste acceptance and on-site recycling should include the quantity and, classification of wastes.

The measurement of waste quantities must be conducted using the most appropriate of the following four methods.

1. Landfills with weighbridges

   If the landfill has a weighbridge installed, waste quantities in tonne must be derived from the computer system or weighbridge docket.

2. Landfills with staffed gate (vehicle count method)

   If the landfill does not have a weighbridge but is staffed at the gate, record the number of vehicles entering and transporting wastes from the premises daily. Record the vehicles according to their vehicle type, waste stream and material composition code. At the end of the day multiply the number of vehicles by the appropriate weight factor to determine the tonnage of waste received and transported that day. Successively add each day's waste to obtain the annual tonnage of waste received and transported.

3. Landfills with no staff at the gate (vehicle survey method)

   If the landfill is not staffed at the gate, conduct a survey of vehicles entering and transporting waste from the landfill site. The survey is to be conducted for a week (7 days) every quarter. To conduct each survey, count the number of vehicles entering and transporting waste from the premises every day for a week. Record the vehicles according to their vehicle type waste stream and material composition code. At the end of each week multiply the number of vehicles by the appropriate weight factor to determine the tonnage of waste received and transported that week. Add all four weeks data together for each waste stream and multiply by 13 to estimate the annual amount of waste received and transported.

4. Landfills with a total capacity of <1000 tonnes and no staff at the gate (waste survey method)

   The waste survey method requires measuring the void space consumed during the reporting year and then converting the volume to tonne.

   Steps to be taken:

   - The void space consumed during the reporting year must be determined by volumetric survey undertaken by a registered surveyor or a qualified local government employee. The void space is determined by subtracting the void space remaining at the end of the reporting year from the void space remaining at the beginning of the reporting year. The void space remaining at the beginning of the year can be determined by volumetric survey or by keeping a running total of void space consumed, and subtracting this each year from an earlier volumetric survey or the initial capacity of the landfill.
   - Estimate the proportion of waste from each waste stream (that is, municipal, commercial and industrial or construction and demolition) by visually inspecting waste received at the landfill during the reporting year.
   - Using the following conversion factors (derived from Perry and Green 1984), convert the void space used during the reporting year to tonnes:

Table 5.1: Density Conversion Factor

Waste Stream	Density (tonnes/m^3)
Municipal Waste	0.13
Commercial and Industrial	0.2
Construction and Demolition	0.7

If void space information is not available, method 3 must be used.

An annual waste data report template can also be downloaded from the NT EPA website to facilitate annual waste reporting requirements.

5.4.5. Recording of Disposal Location

A landfill owner/operator at a site receiving wastes that require special handling procedures (e.g. asbestos), must record the location of those wastes when placed into the landfill, including:

- type of waste;
- quantity of waste; and
- GPS coordinates of location of waste.

The landfill owner/operator must ensure that they are licensed to receive the type of waste for which they are disposing.

5.5. 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
- 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 5.17 for more information on landfill gas management). 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 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.

5.6. 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 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 m 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 m x 30 m.

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 m.

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.

5.7. Waste Compaction

5.7.1. Equipment Selection

A landfill should utilise appropriate equipment for environmentally responsible and safe operation of the site. Several factors should be taken into account when selecting equipment to be used on-site, including:

- site characteristics
- site preparation requirements
- daily waste input quantity
- type of waste
- density of waste
- cover requirements including the type of cover
- operator comfort and safety.

Backup equipment should be available for use in the event of mechanical breakdown and to cover for routine maintenance.

5.7.2. Waste Compaction

The amount of landfill space and land used to dispose of waste can be minimised by proper compaction. Compaction also improves the stability of landfills, and minimises the voids that would encourage vermin, fires or excess generation of leachate. Refuse should be placed against a clay starter embankment or the previous day's refuse. As soon as it is unloaded, the refuse should be spread out in thin layers to form individual lifts. Pushing waste over a vertical face is not considered to be acceptable. The layers should be sloped away from the sides and final surfaces of the landfill, to minimise the chance of leachate tracking to the edge of the fill and breaking out on the surface.

Each progressive layer should be 300 mm to 600 mm thick. The number of passes by a machine over the waste to achieve optimum compaction will depend on several factors, including the type of machine, its ground pressure, the type of waste and the slope. Obviously, the more passes made over the waste, the better its compaction, but operational considerations generally limit the number to between three and five passes.

Landfill operators are expected to ensure that maximum compaction is achieved for the capacity of the machines used. For landfills receiving over 50,000 tonnes of waste per annum, the waste compaction goal should be at least 800 kg/m3, excluding cover material, as measured by a compaction test. For landfills receiving less than 50,000 tonnes of waste per annum, the waste compaction goal should be at least 600 kg/m3, excluding cover material.

Bulky refuse items require special measures in their placement. Such items should be crushed by some mechanical means to reduce void space prior to placement at the base of the working face. These items should not be placed in the first lift of refuse, due to the risk of liner damage. Similarly, bulky items should not be placed in the final lift since settlement of the refuse may result in such items piercing the cap.

5.8. Cover

Use of soil cover material limits run-on and infiltration of water, controls and minimises the risk of fire, minimises emissions of landfill gas, suppresses site odour, reduces fly propagation and rodent attraction, and decreases litter generation.

Cover material is usually classified as daily, intermediate and final.

5.8.1. Daily Cover

Cells should be covered periodically to stop odours, wind-blown waste, fly breeding, vermin and spread of fires. At least 150 mm of soil should be spread over the waste deposited at the landfill tipping face so that no waste is left exposed. The frequency of covering wastes is dependent on the volume of waste being accepted at the landfill and should be specified in the Operations Plan in accordance with the Department of Health requirements.

The frequency and depth of the soil cover on the waste are important factors in achieving the following objectives:

- reducing fire risk
- minimising water infiltration into the waste
- reducing access by pests to the waste
- minimising odours and wind-blown litter
- controlling fly breeding.

Where municipal waste is delivered to the site, cover should be applied on the day of delivery or within 24 hours of the delivery. Landfill operators should endeavour to coordinate tipping times and the availability of plant to achieve this result.

It is important that cover material is always readily available on site. This applies particularly to above ground sites where no excavation has taken place. All landfills should maintain a minimum of two week's cover reserve on-site. As a guide, this is estimated to be one cubic metre of soil for every six tonnes of waste received.

Soil used as landfill cover should preferably have the following qualities:

- good compaction characteristics
- good trafficability under all weather conditions
- resistance to swelling and cracking when wet and dry
- resistance to wind erosion
- good resistance to slumping under all conditions
- ability to support plant growth.

Loam, clay loam and some clay soils have these preferred characteristics, however where these are not available the best of the soils which are readily available should be used.

To maximise the available landfill capacity and avoid excessive stratification of the refuse, consideration should be given to the use of alternative daily cover materials. Alternative daily cover is typically placed on the active face in lieu of soil. Types of alternative daily cover include:

- geosynthetic blankets
- shredded green waste
- sawdust
- spray on foam
- stabilised sludge
- paper pulp
- composted material
- small weave netting
- heavy-duty reusable plastic sheets or tarpaulins.

The selection and use of appropriate alternative cover materials requires consideration of several factors, including:

- availability of material
- ease of material handling
- climatic conditions
- additional nuisance potential
- potential contaminants within the material
- potential effect on site stability.

Landfill operators can specify alternative cover materials provided they can demonstrate compliance with performance requirements.

5.8.2. Intermediate Cover

Intermediate cover is used to close off a cell which will not receive additional lifts of waste or final cover for some time. At least 300 mm of soil should be spread over the waste so that no waste is left exposed. The cover should always be sloped and graded to prevent ponding of water.

When refuse is placed over an area where intermediate cover has been applied, it is imperative that the cover is adequately penetrated or removed to render the surface permeable to gas and leachate. If this is not done, the landfill may become stratified with impermeable layers, and perched leachate lenses could develop, with can potentially break through the surface.

5.8.3. Final Cover

In addition to the daily and intermediate cover, the final layer of cells must be covered with additional soil during decommissioning to further isolate the wastes and help ensure long-term stability for the site.

The design of the final cover system is discussed in Section 7 and should meet the requirements specified in that section. However, where the specifications detailed in Section 7 are unable to be addressed the final cover should be a minimum of 600 mm of low permeable soil and be compacted and graded to shed water and prevent ponding.

Site capping and revegetation should ensure that the final surface provides an appropriate barrier to water infiltration, controls emissions to water and the air, promotes sound land management and conservation, prevents hazards and protects amenity. A final cover system generally includes (from bottom to top):

- intermediate soil cover
- low permeability layer
- topsoil layer.

Final cover material should be placed as soon as practicable over finished areas of the landfill above the previously placed intermediate cover, when weather conditions are suitable. Details of final cover design are discussed in Section 7.

Vegetation on the final cover should be established immediately following completion of the cover. Ongoing monitoring and maintenance of final cover following placement is also necessary to mitigate the effects of settlement, cracking or vegetation die-off.

5.9. Staff and Training

The level of staffing should be adequate for environmentally responsible and safe management of the landfill. Staff requirements are dependent on the size, types of waste, and diversity and complexity of site operations. Landfill operators should provide sufficient staff to ensure that during operating hours all tasks are completed in accordance with the landfill management plan. All operational staff should complete training courses relevant to their duties. As a minimum, staff training should ensure that:

- staff who inspect or direct the placement of incoming wastes are capable of accurate data recording, and proficient at identifying wastes that are unacceptable
- operators of compaction or earthworks equipment have received the necessary training and deemed competent to operate equipment and undertake all tasks required of them

- staff who undertake sampling or testing are familiar with required testing and sampling protocols
- all staff have received environmental awareness training
- all staff are familiar with site safety practices and procedures
- all staff are familiar with site emergency procedures.

All new employees should receive basic training as part of their orientation and refresher training should be performed on an annual basis. A record of training undertaken by each member of staff is to be kept and updated as required.

5.10. Health and Safety

Landfill operations must be performed in accordance with the requirements of the *Workplace Health and Safety Act*, and the Workplace Health and Safety Regulations. An Occupational Health and Safety Management System (OHSMS) should be prepared for each site detailing the plans, actions and procedures to facilitate legal obligations under the Act and associated Regulations. Components of and OHSMS should include, at a minimum, the following:

- identification of hazards present on the site, e.g. traffic, landfill gas, sharp refuse, steep and uneven terrain, hazardous/listed waste.
- hazard control should be in accordance with the safety hierarchy of control as illustrated in Figure 5.1.
- the provision of information concerning identified hazards, management procedures, and possible emergency occurrences to employees engaged on the site.
- appropriate training and supervision of employees at the site, including provision and use of safety equipment.
- development of emergency procedures.
- recording, reporting and investigation of accidents and near misses.

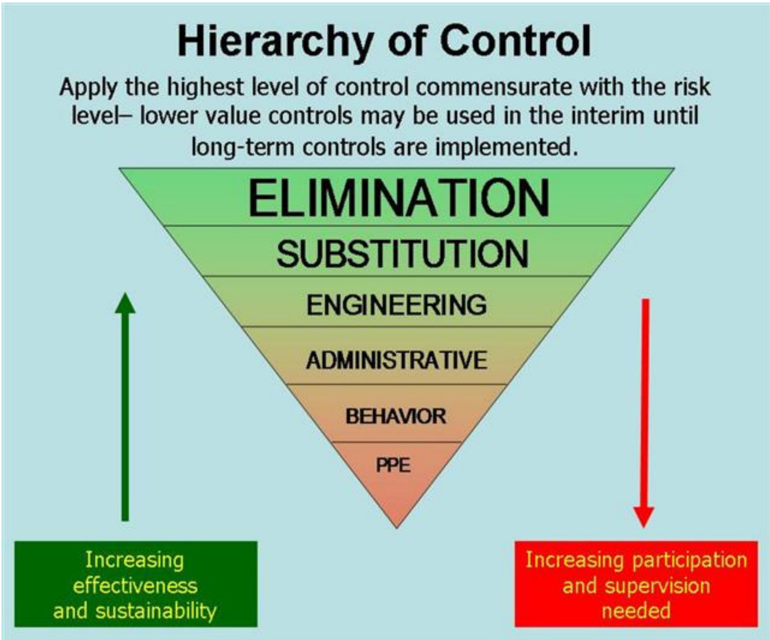

Figure 5.1: Hierarchy of Control

The OHSMS will apply to all employees, subcontractors and visitors at the site. It is important to ensure that any capital works contractors engaged on the site are fully conversant with the OHSMS. These contractors should be made fully aware of potential hazards associated with the landfill operations activities.

The OHSMS should be reviewed annually to ensure that all hazards are identified and controlled, training and supervision are provided in a satisfactory and timely manner, and accident and near miss reporting systems are operational and functional.

Further information regarding Health and Safety obligations can be sought from NT WorkSafe at www.worksafe.nt.gov.au.

5.11. Site Access

Unauthorised entry to landfills can lead to illegal waste dumping, exposures to landfill hazards, fires, and vandalism of pollution control devices, as well as loss of amenity. To control site access, the perimeter of the landfill site should be securely fenced and the gates locked outside normal operating hours. All landfill site entrances should be sign-posted with the following information:

- landfill name
- owner and operator
- contact details for the owner and operator
- emergency telephone contacts
- hours of operation
- a general description of the types of wastes accepted at the site
- a list of prohibited wastes
- Environmental Protection Licence number (where applicable).

Roads within the landfill facility should be regularly maintained to always ensure access to the disposal and recycling areas. Adequate traffic barriers and signs should be installed along the roads to help direct patrons to disposal and recycling areas and prevent access to areas undergoing rehabilitation.

5.12. Roads

Roads at landfill sites provide access to the working face, leachate control systems, stormwater control systems, and landfill gas control equipment, and for construction traffic. Permanent access roads between the site boundary and entrance facilities, including reception areas, weighbridge and wash-down facility, should, ideally, be sealed.

5.13. Visual Amenity

Visual impacts associated with the operation of landfills can be minimised by following the recommended operating practices and conducting waste disposal activities behind purpose-built earth screening bunds. Landfills can also be screened by means of vegetation and/or placing shade-cloth screening at specific locations around the property. The benefit of these measures is to reduce visual impacts associated with landfill operations. Perimeter planting of the site should be commenced at the earliest opportunity, utilising vegetation that rapidly establishes itself to establish both a visual barrier and some degree of wind protection to site operations.

5.14. Nuisance Control

5.14.1. Litter

Uncontrolled litter can contribute significantly to the loss of amenity experienced at a landfill site. The primary management strategy for litter control is regular cover of the waste material, however, this cannot always be achieved and other options available to the landfill operator for effective litter control are:

- where the prevailing wind direction is consistent, the use of windbreaks such as earth bunds or portable wind breaks is effective
- where the prevailing wind direction is inconsistent, mobile litter screens may be more practical.

Litter control nets and fences should be erected around the perimeter of the area being filled. Transportable barrier fences can be placed immediately adjacent to the active working face as required to facilitate the control of windblown litter. Nets and fences should be inspected and cleared daily, or more often if needed.

Litter fences should be maintained in good repair and the moveable fences should be checked periodically to ascertain whether they are working effectively, since changes in the orientation of the disposal area or in the direction of prevailing winds may significantly alter the situation.

5.14.2. Dust

The main activities responsible for dust generation on site are:

- disturbance of dried soils on access roads because of wind or traffic movements
- earthworks, such as the placing of cover material during dry periods
- filling and compaction of dust generating refuse.

To minimise dust emissions, permanent access roads between the site boundary and entrance facilities, including reception areas, weighbridge and washdown facility, should be graded or sealed to a good standard. Unsealed roads should be sprayed by water cart and sealed roads cleaned by mechanical road sweepers as required, especially during dry periods. Care needs to be taken when using water as a dust control measure to ensure that it does not contribute to the formation of leachate.

5.14.3. Odour

The main sources of odour on a landfill site are:

- inadequately covered waste at the working face
- highly putrescible loads of refuse
- excavations into old refuse
- leachate
- landfill gas.

The landfill operator needs to ensure good housekeeping measures are implemented to prevent the production of odours. To facilitate the prevention of off-site migration of odours the working face should be kept to a minimum and cover applied daily. Odours originating from the generation of landfill gas can be controlled by the implementation of landfill gas control systems. Odours derived from leachate can be controlled by the implementation of a leachate management system to limit the escape of volatile organic compounds.

A landfill that is identified as having a potential odour impact should install and operate an on-site meteorological station which monitors wind speed, wind direction, fluctuations in wind direction, and temperature. The landfill operator should maintain a record of complaints regarding odours which should be correlated with weather conditions and deliveries of waste types.

5.14.4. Birds

Birds can be attracted to landfill sites in large numbers for water, food, nesting or roosting. The birds may transfer pathogens to drinking water collection or storage areas, as well as depositing excreta and food scraps. Birds can also present a hazard if the landfill is located near an airfield.

Measures can be implemented to minimise the attraction of birds to the landfill which include:

- good litter control
- minimising the uncovered working face
- prompt and thorough compaction of refuse
- covering refuse at the end of each day
- special handling of highly organic waste
- minimising exposed earthworks and shallow pools and puddles of water.

If birds start to develop a pattern of attraction to the site there are additional control measures that can be implemented, including:

- increasing cover thickness
- changing cover type, density or frequency of application
- composting or processing of organic wastes before disposal
- shredding, milling or baling of waste containing food sources.

Varying bird control techniques may prevent birds from adjusting to a single method.

5.14.5. Flies

Flies may become a problem at landfills particularly when there are delays between collection and deposition of waste. Flies are capable of transmitting salmonella and other food-borne diseases through mechanical transmission. Prompt, thorough compaction and application of cover are essential to control flies. In circumstances where fly infestation is significant the application of insecticides may be necessary.

5.14.6. Vermin

Landfills can harbour vermin and other animal pests, such as rats, feral cats and dogs. These pests can seriously threaten local native animal populations and transfer disease causing organisms to humans, either directly, or through contamination of food or other animals.

Measures that can be adopted to minimise the attraction of vermin to a landfill include:

- increasing cover thickness

- changing cover type, density or frequency of application
- composting or processing of organic wastes before disposal
- shredding, milling or baling of waste containing food sources.

If alternative cover materials or systems are used, the landfill operator should identify the method by which it can quantitatively monitor changes in vermin population with the new cover.

To protect public health and minimise harm to native animals an operational plan for vermin control should be developed and implemented. Elements of the plan should include:

- installation of appropriate fencing to prevent animals from gaining access to the wastes disposed of at the site
- implementation of other controls (listed above) to eradicate pests and to prevent animals from gaining access to and residing in the landfill.

5.14.7. Biting Insects

Poorly operated and managed landfill sites can facilitate rapid breeding of insects. The following measures should be taken to reduce the nuisance and risk to health associated with mosquitoes and other biting insects:

- all items likely to collect water should either be removed from the site, buried or punctured to prevent water from accumulating in them
- the surface of the landfill should be shaped and drained to prevent water from ponding
- during the wet season, there should be weekly inspections for mosquito breeding in any areas that are ponding water. Any mosquito breeding should be treated with the biological larvicide *Bacillus thuringiensis* subsp. *Israelensis*
- wash down areas and other areas that receive water runoff from irrigation should also be periodically checked for mosquito breeding during the dry season.

Further advice on eradicating biting insects and their breeding habitats can be sought from the Department of Health.

5.14.8. Weed Management

Declared weeds disposed of at a landfill facility (e.g. mission grass) can readily spread from the site and cause problems with native plant populations and/or be poisonous to animals. Declared weeds should not be disposed of at a landfill unless the facility has been declared a designated weed disposal area under the *Weeds Management Act*. In general, landfills that have less than fulltime supervision are inappropriate areas for disposal of declared weeds.

Signage at the entrance to the landfill facility should indicate whether declared weeds are accepted at the site, and:

- if not, should direct the persons wanting to dispose of the weeds to the NT Government Weeds Branch for advice on proper treatment and destruction of the weeds, or
- if so, should list any measures or restrictions the disposer should be observing within the landfill.

Note that the *Weeds Management Act* prohibits transportation of declared weeds over public roads, or from one property to another, without a permit. Permits must be obtained through the Weeds Branch.

Where declared weeds are illegally disposed of at the landfill or are found growing at the landfill they should be treated and destroyed in accordance with the requirements of the Weeds Branch. Personnel maintaining the landfill should be able to identify the various types of declared weeds which may exist in the region so that they can monitor for their presence at the facility and undertake appropriate treatment and destructive action.

5.14.9. Noise

Excessive noise can also contribute significantly to the loss of amenity experienced at a landfill site. The noise generated during the operation of a landfill should be managed so that the following objectives can be met:

- noise from any single source does not intrude generally above the prevailing background noise level
- the background noise level does not exceed the level appropriate for the locality and land use.

The determination of an appropriate noise limit for a site will therefore depend on the adjacent land use, the existing background noise and the nature of the noise source.

Acceptable noise reduction measures could include buffer zones (refer Section 3.3), acoustical barriers, and acoustical treatment of equipment. All on-site mechanical plant and equipment should be maintained in a good state of repair and be fitted with appropriate silencers or mufflers to reduce noise. Effective noise control can also be accomplished by restricting hours of operation to coincide with adjacent land uses.

5.15. Fire Prevention and Management

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 non-combustible 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.

5.16. 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:

- stormwater
- leachate
- groundwater.

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

5.16.1. Stormwater

Stormwater should be controlled to prevent water ingress into the landfill and consequent formation of leachate. In addition, stormwater should be controlled to prevent erosion and excessive sediment discharge to waterways.

Surface water from outside the area of exposed earthworks should be diverted around the perimeter of the works. Surface water from within the area of exposed landfill earthworks should be treated in silt retention systems prior to discharge in accordance with licence requirements. The access road to the working face should be aligned to prevent it from channelling surface water to the face. Side channels on access roads should be intercepted short of the face and diverted away from the filling area. Surface water that mixes with waste is contaminated and should be treated as leachate.

A regular program of preventative maintenance for stormwater control systems should be undertaken. Typical items that should be addressed include:

- regular inspection of stormwater drainage and treatment systems
- cleaning sumps
- dredging silt ponds
- clearing culverts
- servicing pumps
- reinstatement of eroded areas.

The extent of exposed or cleared areas of the landfill should be minimised, and topsoil set aside for revegetation purposes. All completed areas of the landfill should be progressively revegetated, and any areas exposed for greater that a month should be stabilised to minimise soil erosion.

Landfill washouts can occur during periods of high intensity rainfall. Remedial work must be undertaken as soon as practicable to minimise any adverse environmental effect. If not repaired, relatively minor washouts can result in a release of refuse, leachate and gas, and promote landfill instability.

Stormwater Monitoring

Because of potential environmental effects, monitoring is essential to confirm that the stormwater control system is behaving in the ways predicted when the site was designed and permitted, and to provide management information. Environmental monitoring will also be necessary to confirm that water quality is of a sufficient standard to be discharged. The monitoring program will be site-specific, but ambient measurements should be obtained prior to commencement of operations to determine the environmental effect that can be directly attributed to landfilling operations.

5.16.2. Leachate

The control of leachate is fundamental to the protection of water quality. Surface water should be controlled to prevent water ingress into the landfill and consequent formation of leachate. Groundwater entry is another potential contributory source to the formation of leachate. Control of groundwater entry is primarily dependent on the design and construction of the landfill liner system.

Prohibition of the disposal of bulk liquid wastes should also be implemented to control waste that may also become a source of leachate. Liquid waste refers to any waste material that is determined to contain free liquids. One common waste stream that may contain a significant quantity of liquid is sludge.

Leachate Control

Leachate collection, removal and disposal systems should be fully operable prior to the disposal of refuse in a particular area. A regular program of preventative maintenance for leachate control systems should be required. Typical items that should be addressed include:

- regular inspection of leachate drainage and treatment systems
- flushing of leachate systems
- servicing of pumps.

To improve the flow of leachate and prevent perched leachate lenses, the operator should break up or remove previously applied daily or intermediate cover prior to further filling.

Leachate should generally be disposed of by one of the following methods:

- discharge to community sewerage system, with or without pre-treatment
- discharge to land by spray or subsurface irrigation, with or without pre-treatment
- discharge to natural water after treatment
- injection/recirculation into the landfill
- evaporation using heat generated from the combustion of landfill gas.

Leachate Monitoring

As a result of the complex processes operating within a landfill, and their potential environmental effects, monitoring is required to confirm that the landfill is behaving as predicted and to provide management information. The monitoring program will be site-specific, but ambient measurements should be obtained prior to commencement of operations to determine the environmental effect that can be directly attributed to landfilling operations. For further details pertaining to leachate monitoring requirements refer to Section 6.2.

5.17. Landfill Gas Management

Landfill gas is produced when solid wastes decompose. The quantity and the composition of gas depends on the types of solid waste that are decomposing. Methane (CH_4) and carbon dioxide (CO_2) are the major constituents of landfill gas. Other gases are also present and some may impart odour. Hydrogen sulphide may be generated at a landfill if it contains a large amount of sulphate such as gypsum board. Non methane organic compounds are also present and may impact on air quality when emitted through the cover or vent systems.

5.17.1. Landfill Gas Control

A landfill gas control system can have several objectives, including:

- sub-surface migration control, to reduce or eliminate the risk of explosion on or off the site
- odour control, to eliminate odour nuisance that can affect neighbours and site personnel
- landfill gas to energy by electricity generation or direct gas use
- greenhouse gas emission control, to reduce the methane discharge to the atmosphere.

Landfill operations should encourage gas movements that are consistent with the collection system provided.

The landfill will generally be stratified in a way that results in horizontal gas flow within the layers. These pathways should be intercepted by elements of the gas collection system. These will include horizontal collectors, vertical extraction wells, or cut-off trenches if migration is severe. Care should be taken to ensure that no unintentional gas routes (for example service trenches) result in uncontrolled gas migration.

Gas will build up under the finished landfill final cover system. Gas migration or emission is likely if measures are not taken to prevent pressure build up and maintain the integrity of the cover system. This can be particularly important in times of very dry weather if the final cover system is susceptible to cracking. Other factors to be considered from an operational perspective include the effect of a change in atmospheric pressure on gas migration patterns.

Any landfill gas condensate collected should be handled in the same manner as leachate, with the exception that it should not be spray irrigated because of low pH and potential odour.

A regular program of preventative maintenance for all gas control systems should be undertaken. A large, complex landfill gas control system may require dedicated technical staff to be established on-site. Simple systems may only require routine inspection. Service personnel should normally be available on an on-call basis in the event of a system malfunction.

6 Landfill Monitoring

This section discusses the basic factors to be considered in the design, installation and operation of a successful and cost-effective monitoring program. A complete monitoring program would include routine or periodic sampling of surface water, ground water, leachate and subsurface landfill gases.

The physical, chemical and biological breakdown of refuse within a landfill produces leachate and landfill gas. Leachate discharging through the base of a landfill can contaminate groundwater, leading to contamination of surface water. Leachate can also contaminate surface water via discharges from the landfill surface and stormwater management systems. Landfill gas can give rise to asphyxiation and explosion hazards, and odour nuisance.

The objectives of monitoring at and around landfill sites are to:

- determine baseline environmental conditions at and around the landfill site
- determine processes occurring within landfills through monitoring of leachate production, leachate composition and landfill gas composition
- determine effects on the environment due to the landfill through monitoring of groundwater, surface water and landfill gas
- check compliance with regulatory requirements
- identify the need for, and the extent of, remedial/ mitigation measures to reduce effects on the environment.

Monitoring of groundwater, surface water and landfill gas needs to be continued during the aftercare period of the landfill, until the strength of any discharges has reduced to a level at which they are unlikely to have any adverse effects on the environment. This aftercare period is likely to be at least 30 to 50 years.

Monitoring requirements need to be developed on a site-specific basis, considering:

- landfill size
- geological and hydrogeological characteristics of the site
- proximity to, and sensitivity of, surrounding environments.

This section addresses:

- objectives of monitoring
- leachate monitoring
- groundwater monitoring
- surface water monitoring
- analysis and review of monitoring data
- landfill gas monitoring.

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, NT EPA 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 several years of data.

The results of the monitoring program should be reported to NT EPA annually; problems should be reported within seven days of 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.

An annual monitoring report will give 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.

6.1. Ground Water Monitoring

As prime receptors of wastes located within natural settings, landfills inherently pose issues for retention of contaminants. Groundwater can be at risk from escape of leachates through the base of the fill materials and/or from ancillary activities such as composting. In some situations, groundwater can be directly disturbed by site construction activities.

Groundwater monitoring seeks to identify actual or potential effects on the resource as part of the overall environmental management of the site. Groundwater monitoring seeks to achieve the following purposes:

- provide data for engineering design and obtaining regulatory consent for a landfill
- provide pre and post construction baseline water quality data
- check compliance with landfill operating and regulatory standards
- identify any need for mitigation and/or remediation.

Monitoring objectives usually seek to achieve reliable, long-term information about the behaviour of groundwater at a site and the effects from the landfill. However, obtaining reliable and pertinent information on groundwater behaviour and characteristics requires a sufficient understanding of hydrogeological conditions in the site vicinity. The basic details of a monitoring program cannot be developed without knowledge of fundamental information on groundwater flow directions, aquifer configuration and characteristics.

Due to the high cost of typical groundwater investigation programs, monitoring and investigation objectives are often integrated so that boreholes serve both purposes as much as possible. Specific objectives for investigation/monitoring include:

- characterisation of the groundwater regime including pressures, flows and quality
- identification and tracking of baseline conditions over time

- characterisation and tracking of effects of the landfill on groundwater
- characterisation of the interactions of groundwater with surface waters
- characterisation of the interactions of leachate components with groundwater, migration pathways and attenuating effects likely in the groundwater system.

At sites where a groundwater drainage system is installed beneath the liner, groundwater discharge flow rate and quality need to be regularly monitored to detect any leachate contamination. This should form part of the overall landfill monitoring program. In the first instance, monitoring could be for an indicator prevalent in leachate. If contamination is indicated, then more detailed analysis is required to determine the characteristics of the contaminant. Chemical parameters and characteristics that would generally be measured include but are not limited to:

- pH
- conductivity
- organic carbon
- total dissolved solids
- metals
- chloride
- phosphates and nitrates
- ammoniacal nitrogen.

The results of regular sampling and analysis provide an audit to ensure that the liner retains its integrity.

6.1.1. Ground Water Monitoring Program Design

Monitoring programs for groundwater require the integration of many factors that can influence the value of the results obtained. Consideration needs to be given to:

- purposes of groundwater monitoring
- specific objectives in relation to each purpose
- integration of objectives to achieve efficiency and rationalised outcomes
- selection of monitoring locations and target strata
- monitoring well design
- selection of suitable monitoring parameters
- monitoring frequency
- sampling methods and requirements
- analytical detection limits
- analysis and review of monitoring data
- trigger levels.

Appropriate positioning of monitoring points in a groundwater monitoring network is a key aspect of any monitoring program. Selection of well locations needs to consider the potential pathways for migration of contaminants and travel rates. Degree of certainty in understanding the ground conditions affects the number of wells. Complex hydrogeology normally requires a larger number of wells than simple, uniform conditions. Various analytical or computer analysis methods can be applied to estimate the possible positions of contaminant plumes from landfills to assist in the selection of well locations.

Sensitivity of the surrounding environment is an important factor in monitoring well network selection. In shallow aquifers with a water table where the environmental risk is low, a basic monitoring well system could comprise one well hydraulically upgradient, and three wells hydraulically downgradient of the landfill. For large-scale regional landfill facilities, 20 to 50 monitoring/investigation wells may be required. As a minimum for landfill sites that cover only a small area, it is recommended that at least one upgradient and two downgradient groundwater monitoring wells (possibly screened at different depths) be installed.

Key factors for selecting well sites include:

- potential sources and nature of contaminants within the landfill site, including refuse, transfer stations and composting areas, if appropriate
- sources of contaminants from external unrelated activities such as industry, farming and mining/ quarrying
- design of leachate retention systems
- potential pathways for migration of contaminants during movement below ground
- potential rate of travel along migration pathways
- potential residence time of leachate species in the groundwater system from source location to potential receptor. Priority should focus on pathway sections with residence times of less than 200 years
- changes to pathways and characteristics due to ongoing landfilling or other new developments
- proximity of potential receptors along pathways and associated environmental/health risks.

Pathways for the movement of contaminants can be affected by:

- the nature of the unsaturated zone
- the presence of perched aquifers
- fractured or porous aquifers
- geological formation boundaries
- bedding and tilting of strata
- geological faults
- groundwater divides
- seasonal and short-term climatic influences
- neighbouring pumping wells.

The rate of movement of contaminants along the pathways is controlled by four key hydrogeological parameters that usually require field and laboratory testing to be determined adequately:

- Hydraulic conductivity, K
  - very slow $K < 10^{-8}$m/s
  - slow 10-6 > $K > 10^{-8}$ m/s
  - medium 10-4 > $K > 10^{-6}$ m/s

  - rapid K > 10^{-4} m/s.
- Effective porosity
- Hydraulic gradient
- Soil/rock/leachate species interaction as given by the Distribution Coefficient, Kd
  - very mobile Kd < 1 ml/g
  - mobile 100 ml/g > Kd > 1 ml/g
  - immobile Kd > 100 ml/g.

6.1.2. Monitoring Well Design Requirements

The purpose of monitoring wells is to provide 'representative' samples of the groundwater in terms of its physical and chemical properties. Most wells are also used to monitor groundwater level. The design needs to consider the potential configuration and nature of the contaminants in the groundwater, the potential for chemical alteration of the samples and the sampling techniques to be used.

Wells can use single or multiple monitoring facilities. Multilevel installations, where two or more casing/screen units are placed in the same borehole at different levels can offer cost savings but introduce the risk of cross-leakage. Post construction testing is necessary to confirm the integrity of seals.

Well design should cover:

- *Screen Length and Position*. Screens are normally 1 m to 3 m long. Longer screens lose detection sensitivity to vertically variable water quality and provide only a gross measure of contamination. Screens should be positioned on main flow pathways and intersect the water table, where immiscible floating contaminants such as petrol, and some solvents are likely to be found, if present
- *Casing and Screen Materials*. Common practice is to use PVC materials due to their chemical and corrosion resistance. Stainless steel is also suitable. Joints should use mechanical connections without the use of glues that can affect the sample integrity
- *Casing Diameter*. 50 mm diameter casing meets common sampling and construction objectives. Special sampling tools are available for smaller diameters
- *Drilling and Construction Limitations*. Drilling methods need to be appropriate for the target zone(s) and soil/rock type, along with secure emplacement and sealing of screen sections. Wells should be developed following construction to remove drilling fluid contaminants, clean the well and remove fines from around screens
- *Filter Pack and Annular Seals for Screened Zones*. Filter materials selected for packing screens should be non-reactive to the groundwater environment. Geotextile sheaths can be appropriate for fine grained formation materials but are susceptible to clogging and no data on the adsorption of organics and other compounds is available. Annular seals using cement should not be used in screen zones to avoid leached residues from the cement impacting water quality
- *Surface Completion*. Security of the well head from surface water ingress and external damage are prime design considerations
- *Quality Assurance/Quality Control Procedures*. Specifications for monitoring well construction need to cover quality requirements for materials, methods and testing to ensure satisfactory performance of the completed well.

6.1.3. Monitoring Parameters

Contaminants that enter groundwater systems undergo various degrees of transformation depending on their chemical composition and the nature of the groundwater environment. Factors such as soil/rock geochemistry, redox state, and background groundwater quality, can affect the evolution of groundwater chemistry along flow paths. Parameters selected for groundwater monitoring programs need to:

- characterise the overall background chemistry of the natural groundwater
- characterise the range of contaminant sources likely to be at the landfill
- be measured consistently, quickly and cost-effectively.

Generally, contaminants that move in groundwater systems are in a dissolved form. Unless the strata contain large openings such as sometimes occur in fractured rock or dissolved cavity aquifers (for example, karst limestone aquifers), entrained solids in fluid contaminants are filtered in the first layers of soil.

However, some contaminants may be in pure liquid form (such as petroleum products) beneath or floating on the water table. Others, such as some metals, may move by intermittently changing between solid and dissolved phases. In cavity flow systems, contaminants can move by attachment to colloids or very fine sediment.

The focus is normally on parameters that are soluble in the ambient groundwater at the site. Table 6.1 contains a list of parameters that could be measured for a regional scale municipal solid waste landfill. The list is by way of example and may need to be amended for specific situations according to the characteristics of the wastes in the landfill.

As a minimum, for small landfill sites, it is recommended that groundwater monitoring be undertaken for the following, as leachate indicator parameters:

- water level
- pH
- conductivity
- total dissolved solids
- alkalinity
- chloride
- ammoniacal nitrogen
- nitrate nitrogen, or total nitrogen
- total organic carbon
- metals
- soluble zinc.

If the concentrations of these chemical parameters increase by a significant amount, or show a trend of increasing concentration, then monitoring should be carried out for a more comprehensive suite of parameters.

Table 6.1: Groundwater Monitoring Program

Parameters	Monitoring Frequency by Landfill Type		
	Inert	MSW	Hazardous
Bore Depth	Biannually	Biannually	Biannually
Groundwater Depth	Biannually	Biannually	Biannually
Static Hydraulic Head	Biannually	Biannually	Biannually
pH	Biannually	Quarterly	Quarterly
Conductivity	Biannually	Quarterly	Quarterly
Total Dissolved Solids	Biannually	Quarterly	Quarterly
Redox Potential (Eh)	N/A	Quarterly	Quarterly
Turbidity	Biannually	Quarterly	Quarterly
Total Suspended Solids	Biannually	Quarterly	Quarterly
Alkalinity (as $CaCO_3$)	Biannually	Quarterly	Quarterly
Total Nitrogen	Biannually	Quarterly	Quarterly
Ammonia	Biannually	Quarterly	Quarterly
Nitrate	Biannually	Quarterly	Quarterly
Nitrite	Biannually	Quarterly	Quarterly
Total Phosphorous	N/A	Quarterly	Quarterly
Orthophosphate	Biannually	Quarterly	Quarterly
Dissolved Organic Carbon	N/A	Quarterly	Quarterly
Chemical Oxygen Demand	N/A	Quarterly	Quarterly
Escherichia Coli	N/A	Quarterly	Quarterly
Entero Cocci	N/A	Quarterly	Quarterly
Iron	N/A	Quarterly	Quarterly
Aluminium	N/A	Quarterly	Quarterly
Copper	N/A	Quarterly	Quarterly
Zinc	N/A	Quarterly	Quarterly
Chromium	N/A	Quarterly	Quarterly
Manganese	N/A	Quarterly	Quarterly
Nickel	N/A	Quarterly	Quarterly
Lead	N/A	Quarterly	Quarterly
Cadmium	N/A	Quarterly	Quarterly
Chloride	N/A	Quarterly	Quarterly

Parameters	Monitoring Frequency by Landfill Type		
	Inert	MSW	Hazardous
Calcium	N/A	Quarterly	Quarterly
Sulphate	N/A	Quarterly	Quarterly
Sodium	N/A	Quarterly	Quarterly
Potassium	N/A	Quarterly	Quarterly
Magnesium	N/A	Quarterly	Quarterly
Arsenic	N/A	Annually	Biannually
Mercury	N/A	Annually	Biannually
Selenium	N/A	Annually	Biannually
Total Petroleum Hydrocarbons	N/A	Annually	Biannually
Benzene, Toluene, Ethyl Benzene and Xylene	N/A	Annually	Biannually
Polynuclear Aromatic hydrocarbons	N/A	Annually	Annually
Organophosphate Pesticides	N/A	Annually	Annually
Organochlorine Pesticides	N/A	Annually	Annually
Polychlorinated Biphenyls	N/A	Annually	Annually

6.1.4. Monitoring Frequency

Development of specifications describing when and how often samples should be taken, needs to be set in the context of an overall monitoring strategy. Key factors that influence frequency and timing include those discussed above that determine the positioning of monitoring wells. Other factors are:

- velocity of groundwater movement
- regulatory requirements
- operational factors such as landfill development staging, and leachate, stormwater and gas control
- the cost and value of each data item within the overall program.

Monitoring frequency should be determined based on groundwater velocity and travel time to environmental receptors. This should ensure that contaminants can be detected before reaching receiving environments.

Normally, there is no requirement for continuous monitoring of groundwater, except perhaps if water levels fluctuate daily in an irregular manner or if groundwater is being extracted under a contingency action following a contamination incident.

The timing of quarterly, six monthly and annual monitoring rounds should consider seasonal groundwater behaviour to incorporate extremes in the variability of parameter values. Co-ordination with the surface water monitoring program is desirable where objectives are not compromised. This can achieve efficiency and provide advantages in the assessment of interactions between the two types of water body.

As a minimum for small landfill sites, it is recommended that groundwater monitoring be undertaken at least twice a year, to coincide with high and low groundwater levels.

6.1.5. Sampling and Analytical Requirements

The capture of representative groundwater samples, and the achievement of a subsequent unbiased analysis of results, can present considerable challenges for groundwater monitoring programs. A groundwater sample may be subjected to several different environments and ambient conditions before it is analysed.

Programs need to recognise the physical and chemical changes that can occur through the various stages of sampling and analysis and be tailored according to the objectives for each sample. Often, the most sensitive species to be measured controls the approach and protocols that are used.

A sampling program should consider the following factors in its compilation:

- ambient conditions in the aquifer
- location, condition and access constraints to sampling points
- the range of parameters to be tested
- number and frequency of samples
- appropriate sampling protocols and equipment
- sample field pre-treatment requirements including filtration and preservation
- sample shipment to the analytical laboratory
- sample documentation
- sample chemical analysis protocols
- QA/QC requirements.

Factors that need to be considered in these steps include:

- *Sampling Methods and Equipment*. Methods for sampling groundwater range widely and are continually being improved. In general, the less disturbance that a sample receives before capture in a sample bottle, the more likely it is to retain its integrity. Some types of pumps, for example, may release volatile components such as benzene from the sample, while others may draw in sediment by pumping too hard
- *Sample Collection Protocols*. The well should be purged of stagnant water before taking a sample. Normal practice is to purge three to five well volumes. Samples for trace metals analysis should normally be field filtered prior to placement in the sample bottle. In some cases, laboratory pre-filtering may be more practical if samples are highly turbid and transit time to the laboratory is short. Micro-purging (Stone, 1997) is an alternative method, usually undertaken at pumping rates of less than 1 L/min, that can avoid highly turbid samples (and the need for pre-filtering) and large purge volumes
- *Sample Storage and Transport*. The use of laboratory supplied bottles and transport containers is usually the most secure and quality-assured sample holding method
- *Sample Analysis Protocols*. Selection of analysis methods needs to consider factors including likely parameter concentrations, detection limits, regulatory requirements, and cost

- *QA/QC Requirements*. QA/QC requirements vary depending on elements of the monitoring program. Some standardisation is possible but specific plans are required for each site. Approximately 10% to 15% of the sampling effort should be devoted to QA/QC. Plans should cover:
  - cleaning and decontamination of sampling equipment
  - maintenance and calibration of instrumentation
  - requirements for field blanks, bottle blanks, and replicate samples
  - laboratory safeguards including reagent blanks, duplicates and reference materials
  - requirements for independent certification of the laboratory test method
  - checks by independent third parties
  - checking of analysis results by comparison with previous measurements.

6.2. Leachate Monitoring

The quantity, composition and strength of leachate produced from a landfill depends on the composition of the landfilled waste and the rate of infiltration of rainwater and, possibly, groundwater.

Leachate monitoring should be undertaken at any landfill where it is collected to:

- monitor the degradation processes taking place within the landfill
- manage and protect leachate treatment and disposal systems
- monitor compliance with trade waste discharge limits (where applicable)
- refine groundwater and surface water monitoring programs.

Monitoring should include:

- regular measurement of the quantity of leachate produced
- determination of leachate strength and composition
- monitoring changes in leachate strength and composition over time.

To monitor landfill processes in different parts of the site and over time, it is preferable to monitor leachate quantity and composition from each discrete cell, or each leachate abstraction location.

6.2.1. Monitoring Parameters and Frequency

In general, leachate should be monitored regularly for a full range of parameters appropriate to the types of refuse accepted at the site. Analysis of the leachate chemistry can be used to modify the parameters to be monitored in groundwater and surface water, in cases where monitoring uses a small number of leachate indicator parameters.

If the concentration of a parameter increases by a significant amount in leachate it should be added to groundwater and surface water monitoring programs, particularly if leachate contamination is already evident.

Leachate monitoring should, ideally, be undertaken on at least an annual basis, and more frequently depending on:

- requirements for the management of leachate treatment/ disposal systems

- groundwater level fluctuations
- rate of leachate migration or groundwater flow.

Table 6.2 gives is a list of chemical parameters that would typically be included in a leachate monitoring program for a regional landfill.

Table 6.2: Leachate Monitoring Program

Parameters	Monitoring Frequency by Landfill Type		
	Solid Inert	Putrescible	Hazardous
Flow	Biannually	Quarterly	Quarterly
pH	Biannually	Quarterly	Quarterly
Conductivity	Biannually	Quarterly	Quarterly
Total Dissolved Solids	Biannually	Quarterly	Quarterly
Redox Potential (Eh)	N/A	Quarterly	Quarterly
Turbidity	Biannually	Quarterly	Quarterly
Total Suspended Solids	Biannually	Quarterly	Quarterly
Alkalinity (as $CaCO_3$)	Biannually	Quarterly	Quarterly
Total Nitrogen	Biannually	Quarterly	Quarterly
Ammonia	Biannually	Quarterly	Quarterly
Nitrate	Biannually	Quarterly	Quarterly
Nitrite	N/A	Quarterly	Quarterly
Total Phosphorous	Biannually	Quarterly	Quarterly
Orthophosphate	N/A	Quarterly	Quarterly
Dissolved Organic Carbon	N/A	Quarterly	Quarterly
Chemical Oxygen Demand	N/A	Quarterly	Quarterly
Escherichia Coli	N/A	Quarterly	Quarterly
Enterococci	N/A	Quarterly	Quarterly
Iron	N/A	Quarterly	Quarterly
Aluminium	N/A	Quarterly	Quarterly
Copper	N/A	Quarterly	Quarterly
Zinc	N/A	Quarterly	Quarterly
Chromium	N/A	Quarterly	Quarterly
Manganese	N/A	Quarterly	Quarterly
Nickel	N/A	Quarterly	Quarterly
Lead	N/A	Quarterly	Quarterly
Cadmium	N/A	Quarterly	Quarterly

Parameters	Monitoring Frequency by Landfill Type		
	Solid Inert	Putrescible	Hazardous
Chloride	N/A	Quarterly	Quarterly
Calcium	N/A	Quarterly	Quarterly
Sulphate	N/A	Quarterly	Quarterly
Sodium	N/A	Quarterly	Quarterly
Potassium	N/A	Quarterly	Quarterly
Magnesium	N/A	Quarterly	Quarterly
Arsenic	N/A	Annually	Biannually
Mercury	N/A	Annually	Biannually
Selenium	N/A	Annually	Biannually
Total Petroleum Hydrocarbons	N/A	Annually	Biannually
Benzene, Toluene, Ethyl Benzene and Xylene	N/A	Annually	Biannually
Polynuclear Aromatic hydrocarbons	N/A	Annually	Annually
Organophosphate Pesticides	N/A	Annually	Annually
Organochlorine Pesticides	N/A	Annually	Annually
Polychlorinated Biphenyls	N/A	Annually	Annually

6.3. Surface Water Monitoring

Landfill operations may present a range of adverse environmental effects and risks to surface waters, including water quality and aquatic biota. Surface water monitoring is a key tool to:

- warn of potential significant adverse environmental effects on surface water resources
- identify the need for mitigation and remediation
- check compliance with landfill operations and regulatory requirements.

Leachate and sediment runoff pose the primary risks of contamination by landfills to surface waters. Overall, landfill operations with the potential to contaminate surface waters include:

- sub-surface migration of leachate because of normal seepage or an accidental breach/failure of the landfill liner
- discharge of sediments from the landfill because of earthworks or structural failure
- above-surface leachate breakouts or spills
- other surface spills of hazardous substances
- other activities with the potential to contaminate surface waters, for example discharge of vehicle or machinery wash water.

Surface water monitoring programs are usually based on a tiered strategy, according to the following structure:

- Baseline monitoring to establish the general status of surface waters prior to commencement of, or change to, landfill operations
- Comprehensive monitoring to establish any changes to the general status of surface waters once landfill operations have commenced/changed
- Indicator monitoring based on selected key indicator parameters to provide rapid feedback on operational processes and any problems such as a leachate escapes and excessive sediment runoff.

Prior to embarking on a surface water monitoring program, it is important to establish the objectives for surface water monitoring and to develop a monitoring plan. Both the objectives and the monitoring plan are landfill and site-specific. The following sections provide guidance on undertaking this process.

Surface water monitoring programs need to be carefully designed. They must protect the receiving environment while enabling effective management of the landfill. They should also be designed to enable the reliable collection of information, to avoid the accumulation of redundant data, and to be cost-effective.

To be able to operate effectively, any surface monitoring program must have controls in place. These include statistical reliability, temporal and spatial controls, and quality assurance and control (QA/QC) measures, as follows:

- The design of a surface water monitoring program must be based on statistical considerations. These must consider the variability and accuracy of the data collected and their ability to identify change and non-compliances
- Temporal controls are normally in the form of baseline data. These are collected to document the status of surface water quality before landfill operations commence or change. They are used as a benchmark for evaluating changes in surface water quality once the landfill is operating
- Spatial controls are usually based on control sites. These are placed at an upstream location from landfill operations or in nearby, similar surface waters that are unaffected by landfill operations. Again, data collected from such sites serve as benchmarks against which any changes in surface water quality resulting from landfill operations can be evaluated.

QA/QC measures form an important part of any surface monitoring program. They are based on suitable procedures to ensure that monitoring data are accurate and reliable.

Samples should be taken by a suitably qualified person, in accordance with AS 5667.1:1998 *Water Quality – Sampling – Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples* and AS 5667.6:1998 *Water Quality – Sampling – Guidance on sampling of rivers and streams.*

6.3.1. Design of a Surface Water Monitoring Program

The design of a surface monitoring program for landfill operations should consider:

- the objectives of the monitoring program
- nature and location of hazards with the potential to contaminate surface waters
- selection of suitable monitoring points
- selection of suitable monitoring parameters

- monitoring frequency
- sampling requirements
- analytical detection limits
- analysis and review of monitoring data
- trigger levels.

6.3.2. Determining Locations for Stormwater and Surface Water Monitoring

Locations for a surface monitoring program need to cover all surface water resources that could potentially become contaminated by landfill operations. Key criteria that should be considered when selecting monitoring stations include:

- potential sources of contamination associated with the landfill and their above and below ground pathways
- other external sources of contamination that may affect surface water resources
- location of surface water sources, in particular sensitive environments
- requirements for control site(s)
- extent of receiving water dilution and mixing
- site accessibility.

6.3.3. Parameters for Surface Water Quality Monitoring

Surface water monitoring programs require a range of parameters to be monitored. It is important that parameters are carefully selected at the outset. Parameters chosen for surface water monitoring programs should be able to:

- adequately describe the overall status of surface waters, including water/sediment quality and aquatic ecology
- reliably pick up contaminants discharged from the landfill or other relevant sources
- be measured consistently, quickly and cost-effectively.

Samples should be analysed by a NATA accredited laboratory or a laboratory otherwise approved by the Regulatory Authority.

Parameters to be sampled and analysed should be selected from Table 6.3. While the list is representative, it needs to be reviewed for different landfill operations and locations. For smaller landfills, some parameters may be omitted. Conversely, for a regional landfill that receives large quantities of treated hazardous waste, specific parameters may need to be added. Operators may wish to put forward a case justifying a reduced list of monitoring parameters.

Table 6.3: Surface Water Monitoring Program

Parameters	Monitoring Frequency by Landfill Type		
	Solid Inert	Putrescible	Hazardous
Flow	Biannually	Quarterly	Quarterly
pH	Biannually	Quarterly	Quarterly
Conductivity	Biannually	Quarterly	Quarterly
Total Dissolved Solids	Biannually	Quarterly	Quarterly
Redox Potential (Eh)	N/A	Quarterly	Quarterly
Turbidity	Biannually	Quarterly	Quarterly
Total Suspended Solids	Biannually	Quarterly	Quarterly
Alkalinity (as $CaCO_3$)	Biannually	Quarterly	Quarterly
Total Nitrogen	Biannually	Quarterly	Quarterly
Ammonia	Biannually	Quarterly	Quarterly
Nitrate	Biannually	Quarterly	Quarterly
Nitrite	N/A	Quarterly	Quarterly
Total Phosphorous	Biannually	Quarterly	Quarterly
Orthophosphate	N/A	Quarterly	Quarterly
Dissolved Organic Carbon	N/A	Quarterly	Quarterly
Chemical Oxygen Demand	N/A	Quarterly	Quarterly
Escherichia Coli	N/A	Quarterly	Quarterly
Enterococci	N/A	Quarterly	Quarterly
Iron	N/A	Quarterly	Quarterly
Aluminium	N/A	Quarterly	Quarterly
Copper	N/A	Quarterly	Quarterly
Zinc	N/A	Quarterly	Quarterly
Chromium	N/A	Quarterly	Quarterly
Manganese	N/A	Quarterly	Quarterly
Nickel	N/A	Quarterly	Quarterly
Lead	N/A	Quarterly	Quarterly
Cadmium	N/A	Quarterly	Quarterly
Chloride	N/A	Quarterly	Quarterly
Calcium	N/A	Quarterly	Quarterly
Sulphate	N/A	Quarterly	Quarterly

Parameters	Monitoring Frequency by Landfill Type		
	Solid Inert	Putrescible	Hazardous
Sodium	N/A	Quarterly	Quarterly
Potassium	N/A	Quarterly	Quarterly
Magnesium	N/A	Quarterly	Quarterly
Arsenic	N/A	Annually	Biannually
Mercury	N/A	Annually	Biannually
Selenium	N/A	Annually	Biannually
Total Petroleum Hydrocarbons	N/A	Annually	Biannually
Benzene, Toluene, Ethyl Benzene and Xylene	N/A	Annually	Biannually
Polynuclear Aromatic hydrocarbons	N/A	Annually	Annually
Organophosphate Pesticides	N/A	Annually	Annually
Organochlorine Pesticides	N/A	Annually	Annually
Polychlorinated Biphenyls	N/A	Annually	Annually

Monitoring of sediment quality may be necessary for those landfills located in the vicinity of depositing surface water environments such as slow-flowing rivers, lakes or estuaries. In these environments, certain contaminants with an affinity to particulate matter may accumulate in sediments, particularly trace metals and organic constituents.

The monitoring of aquatic biological parameters may become necessary for those landfills located in the vicinity of sensitive and/or valuable surface water environments. Several biological parameters can be monitored, including aquatic plants (emergent and sub-surface, higher and lower plants), fish and benthic invertebrates (bottom-dwelling lower animals).

6.3.4. Monitoring Frequency and Timing

Requirements for the frequency and timing of surface water monitoring varies between landfills, depending on:

- landfill layout and operations
- sensitivity of the receiving environment
- variability of the receiving environment.

Frequency and timing of surface water monitoring vary from landfill to landfill, depending on location, size, operations and environmental risks or events (such as heavy rainfall or flooding). For example, where leachate is treated and irrigated on-site or in the vicinity of sensitive surface water resources, surface water monitoring should be more frequent. Requirements for monitoring frequency may be reduced over time if a high level of landfill performance can be demonstrated.

Monitoring frequency and timing must also consider the variability of the receiving environment through time and space, such as high and low tides in estuarine/marine environments, seasonal low and high flows in rivers, or daily water quality changes in lakes.

Therefore, monitoring needs to reflect the spectrum of environmental change and, as a minimum, worst case conditions. Worst case conditions are represented by extreme conditions where the risk of adverse environmental effects is high, such as during low flow or high temperatures.

6.3.5. Analytical Requirements

As part of implementing a surface water monitoring strategy, a sampling plan is required. This plan needs to specify:

- a schedule for sampling locations, parameters, frequency and timing
- sampling and analytical protocols
- requirements for sample handling, preservation, processing, transport and storage
- QA/QC requirements.

The sampling schedule also needs to specify the number (replicates) of samples to be collected at any time. Ideally, the number of samples is determined by an acceptable level of uncertainty specified at the 95% confidence level. However, due to the high costs incurred by replication, this guideline is seldom achieved. Rather, the approach taken to reduce the uncertainty of monitoring data is to average them over time or space.

Sampling and analytical protocols should specify the methods used for visual observations, field measurements, sample collection and analytical testing. There are several references that may be used for this purpose, the ANZECC Guidelines for Fresh and Marine Water Quality (ANZECC 2020) provides a range of protocols. Sampling protocols also need to address sample handling, preservation, processing, transport and storage.

The sample plan also needs to outline a series of QA/ QC protocols, specifically relating to:

- maintenance and calibration of field instrumentation
- use of field and bottle blanks to verify sampling and bottle cleanliness
- use of reagent blanks, duplicates, known additions and references material by laboratories involved in analytical testing
- use of independently certified contractors
- checks by independent third parties.

Approximately 10% to 15% of the total effort of a surface water monitoring program should be devoted to QA/QC. All QA/QC protocols and results should be documented in a manner that enables them to pass regulatory authority scrutiny.

6.4. Landfill Gas Monitoring

Landfill gas monitoring should be undertaken at all landfill sites, primarily to determine whether gas production is giving rise to a hazard or nuisance. Monitoring should commence approximately six months after establishment of the landfill and continue until landfill gas production has fallen below the level where it constitutes a risk. For most sites this will be more than 30 years after closure.

Control system monitoring should include the quantity, temperature (in the landfill), pressure and primary composition of gas extracted from the landfill. Minor constituents (hydrogen sulphide, non-methane organic compounds) should be monitored depending on the treatment (if any) of the landfill gas.

Migration monitoring should be concentrated at locations considered to be most at risk and should provide a clear indication of the changes in gas quantity, composition and movement with respect to time. Pressure and temperature can also be relevant. Surface emission monitoring should demonstrate that the cover material and extraction system is controlling the emission of landfill gas. The landfill operator should arrange testing of the atmosphere with appropriate equipment a short distance above the ground surface in areas of intermediate or final cover where wastes have been placed.

Monitoring of landfill gas is important to enable effective management of on-site and off-site risks. The safety of personnel involved in monitoring must be carefully considered. Written safe working procedures should be adopted and practised prior to undertaking gas monitoring. On landfills operating active gas extraction systems, the surface and sub-surface monitoring results also provide supplementary information for the effective operation of the extraction system. Monitoring results provide the ability to:

- determine the effectiveness of landfill gas control measures and identify any requirements for modification
- permit a gas field to be “tuned” effectively to provide optimum gas control
- determine the extent of landfill gas migration offsite
- identify migration pathways
- assess risks to neighbouring properties
- assess the fire risk potential of the landfill gas both within and outside the refuse.

The nature and frequency of landfill gas monitoring is governed by several site parameters including:

- landfill size
- refuse type and age
- surrounding land use
- site geology and groundwater conditions
- landfill gas control measures in place
- results from previous monitoring.

6.4.1. Subsurface Gas Monitoring

Where developments are within 250 m of a landfill site, or underlying geology makes migration likely, landfill gas should be monitored using installed probes around the site boundary. As a preliminary assessment, and to assist the siting of monitoring probes, it may be useful to conduct a gas spiking survey around the landfill site boundary. Spiking surveys involve creating holes in the ground and measuring gas concentrations via a tube inserted into the hole (with a seal around the tube at the top of the hole made during sampling).

Spiking surveys are only of limited use if gas migration at depth is occurring. Permanent monitoring probes should consist of a length of pipe made from an inert material such as PVC with a perforated section over the required sampling length. The pipe is usually installed in a gravel pack and appropriately sealed over the upper one metre. A sampling point should be installed in the capped top of the probe to enable measurement of landfill gas without having to open the sampling probe. Probe depths should generally be at least 3 m, although deeper probes may be required in areas of low groundwater tables, where deep unsaturated permeable layers/fissures exist, or refuse depths are high and water levels low.

At some sites it may be necessary to install stacked probes, which incorporate several pipes with screens at discrete depths (corresponding to differing strata/fissures) with seals between each screen.

Monitoring of the probes is preferable during low and falling barometric pressures as these conditions provide closer to "worst case" results in terms of gas migration. A systematic procedure should be used for monitoring the probes to ensure consistency and should include:

- recording barometric pressure and ground pressure
- measurement of concentrations of methane, carbon dioxide and oxygen, purging the probe of at least twice the probe volume using an intrinsically safe vacuum pump to provide a representative gas sample.

The probe should remain sealed between monitoring periods. Opening of the probe cap (to obtain water table levels, etc.) should only be done at the completion of a monitoring procedure. The number and locations of monitoring probes depends on several site parameters as listed earlier. Probe spacing and depths will be site specific and should be determined only after a detailed review of site conditions by specialists in the field of landfill gas monitoring.

6.4.2. Monitoring Frequency

Probe monitoring frequencies will vary depending on site circumstances. Where site conditions change (e.g. extraction rates, surrounding land use, water table), the frequency of monitoring should be increased until gas concentrations are found to stabilise.

As a minimum, monitoring of each probe should be carried out six monthly until probe gas concentrations have stabilised below 1% by volume methane and 1.5% by volume carbon dioxide. In the absence of buildings within 250 m of the landfill boundary, the US EPA guidance value, above which gas control is required, is 5% methane in a boundary probe.

More frequent monitoring will be required where gas is found near properties. In the case of residential properties, permanent gas monitoring equipment may be necessary.

6.4.3. Surface Gas Monitoring

Several techniques exist for monitoring surface emissions from a landfill. It is unlikely that all techniques will be required for any one landfill, however they have been listed below for completeness:

- Visual Inspection – although not adequate as a means of monitoring, visual inspection can provide useful information as to potential areas of elevated landfill gas emissions. Key indicators are areas of distressed vegetation, evidence of cap cracking and discernible landfill gas odours. Findings from a visual inspection should be confirmed using instantaneous surface monitoring
- Instantaneous surface monitoring (ISM) – an ISM is conducted over a prescribed or random walk pattern across a site using a flame ionisation detector (FID). Methane is sampled via a wand with a funnelled inlet held 50 mm to 100 mm above the ground surface. Site conditions should be dry and wind velocities less than 15 km/hr on average. During the monitoring process the technician makes recordings at regular intervals and includes any areas of elevated emission levels
- Integrated surface sampling (ISS) – an ISS is like instantaneous surface monitoring with the exception that gas collected during the walk pattern is pumped to a non-contaminating sample bag. The methane reading in the bag can then be measured, giving an average concentration over the

walk pattern. Trace constituents can also be measured from the gas sample. Extreme care is required using this system to obtain representative results

- Ambient Air Sampling — ambient air up-wind and down-wind of a site is collected via integrated ambient air samplers into non-contaminating bags. This form of sampling is usually focused on measuring total non-methane hydrocarbons and traces of pollutants and is likely to be required only in exceptional and specific circumstances
- Flux Box Testing — flux boxes are containers (typically drums cut lengthways) with the open end embedded approximately 2 cm into the landfill surface. A small hole is formed in the side of the container to allow venting. A flux box testing program requires a specific design to ensure that a dependable outcome is achieved.

Where surface emissions may present a risk to a site, or create an odour nuisance, visual inspections and ISM surveys should be carried out to assess areas requiring remedial work. Other techniques may be utilised in specific situations. For sites with active gas extraction, ISM results can also provide useful information for optimising the effectiveness of the extraction system and capping maintenance.

6.4.4. Monitoring Buildings

Where a building is determined to be at potential risk, based on probe monitoring results or other monitoring information, the building should be regularly monitored to check for the presence of landfill gas. During the monitoring, a portable gas sampler should be used to measure methane and carbon dioxide concentrations in all voids and areas in the basement and/or ground floor and wall cavities of the building. If possible, measurements should be made in each location before allowing ventilation to occur (e.g. measure under a door before opening).

If landfill gas is detected, the cause should be remedied as soon as practically possible. Generally, if methane more than the 10% lower explosive limit is detected, gas control measures will be required. If concentrations are found to exceed 1% by volume methane or 1.5% by volume carbon dioxide, the building should be evacuated, all ignition sources (including electricity) switched off, and remedial work carried out as soon as possible under an approved health and safety plan prior to reoccupation.

Monitoring frequencies will vary depending on the level of risk to the building and/or occupiers. Generally monitoring should be carried out at least every six months and stopped only if risks can be demonstrated to be low. For higher risk situations it is advisable to install a permanent gas monitor, an alarm system, and to establish clear protocols in the event of an alarm activating.

6.4.5. Landfill Gas Control System Monitoring

Where landfill gas is actively collected and flared, and/ or removed from site for utilisation, monitoring of the system is necessary to ensure:

- air is not sucked into the landfill, creating the potential for an underground fire
- gas quality is appropriate for the flaring system or end use
- gas is flared at an adequate destruction efficiency (where a flare is used)
- there is adequate control to permit areas of the site to be isolated or gas extraction rates adjusted
- condensate from the gas extraction system is adequately managed.

Monitoring requirements will be specific to the design of the control system. However, monitoring for the following parameters should generally be undertaken at each well head, or combination of well heads, and at all flare or gas utilisation facilities:

- gas pressure
- gas flow
- methane
- carbon dioxide
- oxygen
- residual nitrogen (by calculation)
- temperature (as an indicator of landfill fire)
- carbon monoxide (as an indicator of landfill fire).

Monitoring frequency should be as frequent as possible and ideally weekly. However, monthly monitoring is commonly adopted once a gas field has been adjusted to a stable condition.

In addition, monitoring of hydrogen sulphide and non-methane organic compounds (NMOCs) may need to be undertaken to check for total NMOCs emissions.

Flares

There are two common types of flare used, candle (open flame) flares and ground flames. Ground flares provide a significantly higher level of gas combustion control capability. Both types of flare station must be fitted with appropriate safeguards to prevent flame flashback or ignition of the incoming gas stream.

Typically, these safeguards will include:

- a flame arrestor
- an automatic slam-shut isolation valve
- an oxygen sensor.

It is usual for the oxygen sensor to alarm at between 4% to 6% oxygen (depending on gas control requirements) and automatically shut down the extraction system. Candle flares are typically monitored for methane flow rate and oxygen on the incoming gas contents. There are usually no specific combustion controls other than flame outage monitoring equipment. Ground flares usually have facilities to measure methane flow rate and oxygen on the incoming gas, combustion temperature monitoring and facilities for high temperature gas sampling.

It is important that all flare stations comply with the appropriate hazardous area classifications in terms of all electrical and control equipment installed.

6.5. Analysis and Review of Monitoring Data

Monitoring data from landfill sites needs to be collated, reviewed and analysed to:

- establish baseline conditions
- track changes to baseline conditions in relation to site activities, climatic and external factors
- provide a basis for interpretation of overall groundwater and surface water behaviour and effects over time
- check compliance against site performance standards and licensing conditions
- provide information for reporting to regulatory authorities

- review QA/QC information
- prepare monitoring reports.

Analytical methods applied to the data should take account of:

- the purpose of the analysis
- the form, precision and spread of the data
- the validity of the method and its professional acceptance
- the form and ease of interpretation of the results.

7 Closure and Post Closure

Many of the chronic impacts of landfilling occur long after the landfill has closed, and while these can be mitigated 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.

NT EPA will require this section of the guideline to be implemented for all existing landfills. NT EPA 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.

7.1.1 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
- 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 future use 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 after uses of the site, taking into consideration trends in the surrounding area
- operational requirements, to ensure that the highest value after use can be achieved
- surface contours before and after settlement
- specifications and materials to be used in the final cap
- preservation/installation of environment performance control or monitoring features.

7.1.2 Future Use

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 future use options are a good way of ensuring that the operation of the landfill does not alienate desired future uses of the site. In particular, understanding the future use during operation ensures that the final surface profile of the landfill is consistent with the desired future use. Common future uses 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 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.

7.1.3 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 future uses 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
- 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 because 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 with 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 (or 5 horizontal units to 1 vertical unit). 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, special support and protection from landfill gas may also need to be provided. 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.

7.1.4 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 to protect human health and the environment
- preventing the uncontrolled escape of landfill gas
- providing land suitable for its intended future use.

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.

Figure 7.1 provides an indicative cap design, which is based on preventing infiltration by providing a very low permeability layer (clay or composite barrier). Where the proposed future use of a landfill is to require vegetation of the site, the topmost 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 and out of the landfill.

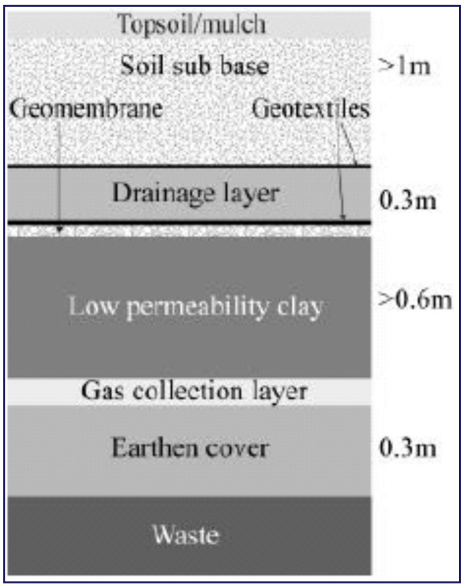

Figure 7.1: Indicative Landfill Cap Design[3]

The surface layer should reflect the type and depth of topsoils 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 mm 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 5 for more detail on the management of 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 to:

- avoid inappropriate planting
- ensure the species are adapted to the local climate
- 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 geomembrane to be used, particularly with respect to the tensile strain that may be expected to be placed on the geomembrane because 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 m beneath the surface.

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

- the spongy foundation of waste on which it is built
- differential settlement of the waste causing cracking of the clay

[3] Adopted from EPA Victoria Siting, Design, Operation and Rehabilitation of Landfills October 2001

- desiccation of the clay from above due to evapotranspiration and below due to heat released from the landfill.

All 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 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 under laid 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.

7.1.5 After-care

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 to prevent any environmental impact.

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

- maintenance of landfill cap to:
    - prevent/control erosion
    - restore depressions, and seal and monitor cracks in the cap caused by settlement
    - 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
    - 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 for more information on 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 NT EPA has given written confirmation that the landfill is no longer generating leachate which can have a detrimental 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 NT EPA 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, NT EPA will refer to monitoring of 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 NT EPA can be assured that the site no longer poses a risk to the environment and may remove maintenance requirements. Where this monitoring is sporadic and trends are inconclusive, then NT EPA 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. NT EPA will also serve a Pollution Abatement Notice on the site to ensure ongoing management of the site and to ensure that all potential future stakeholders are aware of the ongoing management requirements of the site.

Appendix A: Definitions

Aquifer	Means a geologic formation or layer of rock or soil that is able to hold or transmit water.
Asbestos	means the fibrous form of mineral silicates that belong to the serpentine or amphibole groups of rock-forming minerals, including actinolite, amosite (brown asbestos), anthophyllite, chrysotile (white asbestos), crocidolite (blue asbestos) and tremolite.
Asbestos waste	means any waste that contains asbestos.
Background level	Means the ambient level of a contaminant in the local area of the site under consideration.
Bioaccumulation	Means the accumulation within the tissues of living organisms.
Biosolids	Means the semi-liquid residue from sewage treatment plants, septic tanks and the processing of organic materials.
Clean fill	Means material that when discharged into the environment, will not pose a risk to people or the environment, and includes natural materials such as clay, soil, rock and other materials such as concrete, brick or demolition products that are free of: • combustible, putrescible or degradable components; • hazardous substances or materials (such as municipal solid waste) likely to create leachate by means of biological breakdown; • any products or materials derived from hazardous waste treatment, stabilisation or disposal practices; • materials such as medical and veterinary waste, asbestos or radioactive substances that may present a risk to human health if excavated; and • contaminated soil and other contaminated materials.
Clinical and Related Waste	Clinical and related waste includes: • Clinical Waste; • Cytotoxic Waste; • Pharmaceutical, Drug or Medicine Waste; • Sharps Waste.
Clinical waste	means any waste resulting from medical, nursing, dental, pharmaceutical, skin penetration or other related clinical activity, being waste that has the potential to cause injury, infection or offence, and includes waste containing any of the following: • human tissue (excl. hair, nails and teeth) • bulk body fluids or blood; • visibly blood stained body fluids, materials or equipment; • laboratory specimens or cultures; • animal tissue, carcasses or other waste from animals used for medical research but doesn’t include any such waste that has been treated by a method approved in writing by the Chief Executive Officer of the Department of Health.

Contaminant	Means any substance (including gases, liquids, solids, and microorganisms) or energy (excluding noise) or heat, that either by itself or in combination with the same, similar, or other substances, energy or heat: a) when discharged into water, changes or is likely to change, the physical, chemical or biological condition of water; or b) when discharged onto or into land or into air, changes or is likely to change, the physical, chemical or biological condition of the land or air onto or into which it is discharged.
Cytotoxic waste	means any substance contaminated with any residues or preparations that contain materials that are toxic to cells principally through their action on cell reproduction.
Ecosystem	Means a dynamic complex of plant, animal and microorganism communities and their non-living environment, interacting as a functional unit.
Ecotoxicity	Means an adverse toxic effect on ecosystems or ecological communities.
Environment	Includes: • ecosystems, including people and communities; and • all natural and physical resources; and • those qualities and characteristics of an area that contribute to the community's reasonable enjoyment; and • the cultural, economic, aesthetic, and social conditions that affect the above.
Flammability	Means the ability of a substance to be ignited and to support combustion.
Geomembrane	Means a polymeric sheet material that is impervious to liquid as long as it maintains its integrity.
Geosynthetic Clay Liner (GCL)	Means a relatively thin layer of processed clay (typically bentonite) either bonded to a geomembrane or fixed between two sheets of geotextile.
Geotextile	Means a woven or non-woven sheet material less impervious to liquid than a geomembrane, but more resistant to penetration damage.
Hazardous Waste	Means waste that poses a present or future threat to people or the environment as a result of one or more of the following characteristics: • explosiveness; • flammability; • capacity to oxidise; • corrosiveness; • toxicity; and • eco-toxicity.
Industrial Waste	Means waste specific to a particular industry or industrial process. It typically contains somewhat higher levels of contaminants (up to four times), such as heavy metals and human-made chemicals, than municipal solid waste and needs to be managed with environmental controls appropriate to the specific waste(s) being landfilled.
Landfill	Means a waste disposal site used for the controlled deposit of solid wastes by burial onto or into land.

Landfill Gas	Means the gas generated from decomposition processes on biodegradable materials deposited in a landfill. It consists principally of methane and carbon dioxide, but includes minor amounts of other components.
Leachate	Means the liquid effluent produced by the action of water percolating through waste, and that contains dissolved and/or suspended liquids and/or solids and/or gases.
Municipal Solid Waste	means any non-hazardous, solid, degradable waste from a combination of domestic, commercial and industrial sources. It includes putrescible waste, garden waste, uncontaminated biosolids and clinical and related waste. All municipal solid waste shall have an angle of repose of greater than five degrees (5) and have no free liquids.
Pharmaceutical, drug or medicine waste	means waste that has been generated by activities carried out for business or other commercial purposes and that consists of pharmaceutical or other chemical substances specified in the NT *Poisons and Dangerous Drugs Act*. It does not include pharmaceutical, drug or medicine waste generated in the home.
Sharps	means things that: • have sharp points or edges capable of cutting, piercing or penetrating the skin (such as needles, syringes with needles or surgical instruments); • are designed for the purpose of cutting, piercing or penetrating the skin; • have the potential to cause injury or infection.
Sharps waste	means any waste collected from designated sharps waste containers used in the course of business, commercial or community service activities, being waste resulting from the use of sharps for any of the following purposes: • human health care by health professionals and other health care providers; • medical research or work on cadavers; • veterinary care or research; • skin penetration or the injection of drugs or other substances for medical or non-medical reasons.
Toxicity	Means the adverse effects caused by a toxin (poison) that, when introduced into or absorbed by a living organism, destroys life or injures health. Acute toxicity means the effects that occur a short time following exposure to the toxin, and chronic toxicity means the effects that occur either after prolonged exposure or an extended period after initial exposure.
Transfer Station	Means a facility where wastes are transferred from smaller vehicles (cars, trailers, trucks) into larger vehicles for transport to a disposal site.
Treatment	In relation to wastes means any physical, chemical or biological change applied to a waste material prior to ultimate disposal, in order to reduce potential harmful impacts on the environment.
Waste	Means any contaminant, whether liquid, solid, gaseous, or radioactive, which is discharged, emitted or deposited in the environment in such volume, constituency or manner as to cause an adverse effect on the environment and which includes all unwanted and economically unusable by-products at any given time, and any other matter which may be discharged, accidentally or otherwise, into the environment.
Waste tyres	means used, rejected or unwanted tyres, including shredded tyres or tyre pieces.

Appendix B: Environmental Management Plan

The NT EPA priority is to ensure that waste management and disposal activities achieve the best environmental outcome. In the Northern Territory waste management, pollution prevention and control are legislated under the *Waste Management and Pollution Control Act 1998* (WMPC Act). Landfills are a scheduled activity under Schedule 2 of WMPC Act and therefore an Approval is required for the construction of a premise associated with the disposal of waste by burial regardless of serviceable population size. A Licence is required for the operation of a landfill that services, or is designed to service, the waste disposal requirements of more than 1000 persons.

A Landfill Environmental Management Plan (LEMP) can be submitted as part of an Approval application (under the WMPC Act) for the construction of new landfill sites or significant expansion of existing landfill sites. A LEMP can also be submitted as part of a Licensing application (under the WMPC Act) for the operation of existing landfill sites.

Introduction

A Landfill Environmental Management Plan (LEMP) provides the framework for the management and mitigation of environmental impacts during construction, operation and closure of the landfill, as well as for the post-closure period.

The LEMP serves as a technical reference document, design record, and general management and monitoring plan for the development and ongoing operation of a landfill site. The LEMP should include all relevant details of other activities such as waste treatment, storage, recycling and composting which are undertaken on site.

Waste management planning from site selection through to final rehabilitation will have long term economic and environmental benefits and will provide a sound basis for the effective ongoing management of waste facilities.

The suggested minimum content requirements for the LEMP are outlined and provide a measure of direction and consistency in the approach that should be taken in preparing the plan. It should be noted that the items included under the separate components of the management plan are not mutually exclusive, and cross-referencing between the components is anticipated.

General Requirements

The general details component of the LEMP should provide a general description of the landfill site and include the following sections as a minimum.

Site Environmental Context

- Ownership and tenure details, council area, zoning and adjacent zoning and buffer distances (including to nearest buildings and residences);
- Development approval – reference and related documents;
- Location and site layout plan;
- Site overview – infrastructure details, hours of operations (public and private), access and security provision;
- Nature of operation and capacity – waste streams, filling rates, lifespan, site capacity, waste management strategies;

- Site conditions - geology and soils, hydrogeology, ground and surface water, topography and climate, flora and fauna, heritage;
- Proposed end use.

Scope and Purpose of LEMP

Environmental Policy

Management should define an environmental policy which:

- Is appropriate to the nature, scale and environmental impacts of activities, products and services;
- Is committed to continual improvement and pollution prevention;
- Is committed to complying with all applicable legislative requirements, standards and codes of practice;
- Provides a framework for setting and reviewing environmental objectives and targets;
- Is communicated to all employees, contractors and sub-contractors.

Environmental Aspects and Impacts

Identify the environmental aspects of the activities, products and services of the landfill taking into consideration planned or new developments or new or modified activities.

Determine those aspects that have or can have a significant impact(s) on the environment (significant environmental aspects). All significant environmental aspects need to have appropriate mitigation/management procedures in place in order to minimise the impact, these need to be documented and include in the LEMP.

Legal and Other Requirements

Identify applicable legal requirement and other requirements, such as standards, codes of practice etc., and determine how these requirements apply to your activities environmental aspects.

Legal and other requirements need to be considered when developing, implementing and maintaining mitigation/management procedures for environmental aspects.

Objectives, Targets and Programs

Establish, implement and maintain environmental objectives and targets pertaining to operations. Objectives and targets need to be measurable and consistent with the environmental policy, applicable legal and other requirements, pollution prevention and continual improvement.

Programs need to be developed and documented for achieving objectives and targets. Programs need to identify the means and time frame for which they are to be achieved.

Resources, Roles and Responsibilities

The management structure - roles, resources and responsibilities are to be defined in order to demonstrate the effective implementation and operation of the LEMP.

Competence, Training and Awareness

Detail training procedures for on-site staff and contractors for environmental training and awareness. For example environmental inductions, tool boxes etc.

Monitoring and Measurement

An environmental monitoring plan outlining impact indicators, analytical methods, location and frequency of sampling and the criteria to be used for evaluation of the effectiveness of the proposed mitigation measures must be included as part of the LEMP. The monitoring programs and reporting component of the LEMP should include sections addressing the following issues as a minimum:

- groundwater;
- surface water;
- leachate;
- landfill gas;
- air quality and noise—dust, mud, litter, noise and odour;
- vermin, birds, weeds etc.

The monitoring programs should provide the following details as a minimum:

- Locations—site plan and details;
- Monitoring interval and duration;
- Performance indicators and target levels for each parameter;
- Sampling protocols including quality control, referring to relevant guidelines and/or standards (as appropriate);
- Reference to development approval, NT EPA licence requirements and relevant NT EPA guidelines;
- Compliance criteria, including framework for the implementation of recommendations resulting from monitoring events;
- Procedures for non-compliance;
- Procedures for reporting on monitoring programs - internally and externally.

Monitoring programs must:

- Ensure safeguards are being effectively applied;
- Be capable of identifying any differences between predicted and actual impacts;
- Identify the party responsible for undertaking corrective actions; and
- Identify the actions that will be taken to address any issues.

Emergency Preparedness and Response

An emergency response and action plan for identified emergency scenarios, based on a risk assessment approach, including fire prevention and control.

Evaluation of Compliance

A procedure for periodically evaluating compliance with applicable legal and other requirements.

Nonconformity, Corrective Action and Preventative Action

A procedure for dealing with actual and potential non-conformities and for taking corrective actions and preventative action. The procedure must define requirements for:

- Identifying and correcting nonconformities and taking actions to mitigate their environmental impacts;
- Investigating nonconformities, determining their cause and taking actions to avoid their recurrence;
- Evaluating the need for actions to prevent nonconformities and implementing appropriate actions designed to avoid their recurrence;
- Recording the results of corrective and preventative actions taken, and
- Reviewing the effectiveness of corrective actions and preventative actions taken.

Actions taken should be appropriate to the magnitude of the problems and the environmental impacts encountered.

Management Review

Define the process for the review of the LEMP by management. Management should review the LEMP at planned intervals to ensure continuing suitability, adequacy and effectiveness. The review should include assessing opportunities for improvement and the need for changes to the LEMP, including the environmental policy and environmental objectives and targets. Reviews should include:

- Results of internal audits and evaluation of compliance with legal and other requirements applicable to the landfill facility;
- Communication form external interested parties, including complaints;
- The environmental performance of the facility;
- The extent to which objectives and targets have been met;
- Status of corrective and preventative action;
- Follow up actions from previous management reviews;
- Changing circumstances, including developments in legal and other requirements pertaining to environmental aspects;
- Recommendations for improvement.

The review period for LEMPs for medium and large landfill sites will be on an annual basis, unless otherwise specified in the licence.

The review period for LEMPs for small landfill sites will be every three years or as otherwise specified in the licence.

Given the ongoing record keeping, monitoring and reporting associated with the landfill site, the review of the LEMP should demonstrate that the sufficiency of the operational, design and monitoring systems for the current development stage of the site has been addressed.

The review process should be established to ensure continual improvement in the management and operation of the landfill site.

Site Management

The site management component of the LEMP should include the following sections as a minimum.

Water and Leachate Management

A procedure for water management on the site and the prevention of off-site pollution by leachates. Information to include:

- a surface water drainage plan giving the layout and design of all drains;
- a leachate management plan including drainage and earthworks for prevention, retention, collection and recycling of leachates;
- leachate monitoring program including the frequency and methodology of water sampling and the location of sampling points.

Soil Erosion Control

A procedure for the prevention of soil erosion on the site and the prevention of any off-site erosion by water and wind of areas disturbed by roads, drainage and other earthworks should be addressed.

Pest and Vector control

A procedure for the control of rodents, insects and other potential disease carriers or vectors.

Litter Control

A procedure for the control of litter on the site and on access roads and land adjacent to the site.

Site Rehabilitation

The rehabilitation plan for the site should describe the methodology and sequence of rehabilitation and should address the following matters:

- final site contour site drainage;
- species of vegetation to be planted;
- site security following closure; and
- proposed future use (if known).

Information

A description of the information plan for the facility including:

- the nature and extent of information to be provided at the site including the location of all signs; and
- any supporting community awareness programs.

Plant and Equipment

Site materials and equipment—procedures for handling and storing materials associated with site operations, including site machinery, equipment and maintenance.

Waste Management

The waste management section of the LEMP should include the following as a minimum.

Description of landfill staging, method of filling and proposed management

This should include a description of the:

- design and dimensions of each landfill cell or trench;
- proposed plan for landfill operations including expected lifespan of each cell or trench and the sequence in which new cells or trenches are to be opened and worked;
- management of cells or trenches including the method to be used for waste burial, compaction, type of cover and frequency of cover;
- source and amount of soil cover to be stored on site;
- final capping and contour of landfill cells or trenches.

Provisions for recycling/ re-use

Procedures for diversion and/or separation of recyclable and reusable materials, including stockpile and associated environmental control measures. This should include:

- type of wastes to be recovered;
- location and description of recovery areas or containers;
- any on-site treatment processes involved including vegetation mulching;
- proposed promotion of recycling and re-use opportunities;
- proposed facilities for resale of goods if a scavenging contract is to be operative.

Description of wastes to be disposed on site

A description of the types of wastes that are to be accepted at the landfill and an estimate of the anticipated quantities of specific wastes to be managed each year.

Listed wastes

A description of the types of listed wastes that you propose to handle at the site and the arrangements for the management of these wastes including:

- the public information to be provided regarding wastes not acceptable for burial at the site;
- location and design of facilities for secure storage of listed wastes which can be left at the site pending appropriate disposal;
- arrangements for the appropriate disposal of listed wastes.

Appendix C: Listed Waste Leachability Concentrations

	Composite Liner		Double Liner	
Category	**Upper Limits**		**Upper Limits**	
Contaminant concentration thresholds (dry weight)	$ASLP_1$	TC_2	$ASLP_2$	TC_2
Units	(mg/L)	(mg/kg)	(mg/L)	(mg/kg)
Inorganic Species				
Antimony[3,8]	2	75	8	300
Arsenic	0.7	500	2.8	2000
Barium[3]	70	6250	280	25000
Beryllium[5]	1	100	4	400
Boron	30	15000	120	60000
Cadmium	0.2	100	0.8	400
Chromium (VI)	5	500	20	2000
Copper	200	5000	800	20000
Lead	1	1500	4	6000
Mercury	0.1	75	0.4	300
Molybdenum[6]	5	1000	20	4000
Nickel	2	3000	8	12000
Selenium[6]	1	50	4	200
Silver[6]	10	180	40	720
Tributyltin oxide[3]	0.1	2.5	0.4	10
Zinc	300	35000	1200	140000
Anions				
Chloride	25000	N/A	N/A	N/A
Cyanide (amenable)[5]	3.5	1250	14	5000
Cyanide (total)	8	2500	32	10000
Fluoride6	150	10000	600	40000
Iodide	10	N/A	40	N/A
Nitrate	5000	N/A	20000	N/A
Nitrite	300	N/A	1200	N/A
Organic Species				
Benzene	0.1	4	0.4	16
Benzo(a)pyrene[7]	0.001	5	0.004	20
C6-C9 petroleum hydrocarbons[6]	N/A	650	N/A	2600
C10-C36 petroleum hydrocarbons[6]	N/A	10000	N/A	40000
Carbon tetrachloride	0.3	12	1.2	48
Chlorobenzene	30	1200	120	4800
Chloroform[5]	6	240	24	960

2 Chlorophenol	30	1200	120	4800
Cresol (total)[5]	200	8000	800	32000
Di (2 ethylhexyl) phthalate	1	40	4	160
1,2-Dichlorobenzene	150	6000	600	24000
1,4-Dichlorobenzene	4	160	16	640
1,2-Dichloroethane	0.3	12	1.2	48
1,1-Dichloroethene	6	240	12	480
1,2-Dichloroethene	6	240	24	960
Dichloromethane (methylene chloride)	0.4	16	1.6	64
2,4-Dichlorophenol	20	800	80	3200
2,4-Dinitrotoluene[5]	0.13	5.2	0.52	21
Ethylbenzene	30	1200	120	4800
Ethylene diamine tetra acetic acid (EDTA)	25	1000	100	4000
Formaldehyde	50	2000	200	8000
Hexachlorobutadiene	0.07	2.8	0.28	11
Methyl ethyl ketone[5]	200	8000	800	32000
Nitrobenzene[5]	2	80	8	320
PAHs (total)[7,10]	N/A	100	N/A	400
Phenols (total, non-halogenated)[5,11]	14	560	56	2200
Polychlorinated biphenyls[4]	See note 4	See note 4	See note 4	See note 4
Styrene	3	120	12	480
1,1,1,2-Tetrachloroethane[5]	10	400	40	1600
1,1,2,2-Tetrachloroethane[5]	1.3	52	5.2	210
Tetrachloroethene	5	200	20	800
Toluene	80	3200	320	12800
Trichlorobenzene (total)	3	120	12	480
1,1,1-Trichloroethane[5]	30	1200	120	4800
1,1,2-Trichloroethane[5]	1.2	48	4.8	190
Trichloroethene[5]	0.5	20	2	80
2,4,5-Trichlorophenol[5]	400	16000	1600	64000
2,4,6-Trichlorophenol	2	80	8	320
Vinyl chloride	0.03	1.2	0.12	4.8
Xylenes (total)	60	2400	240	9600
Pesticides				
Aldrin + dieldrin	0.03	1.2	0.12	4.8
DDT + DDD + DDE[9]	2	50	N/A	50
2,4-D	3	120	12	480
Chlordane	0.1	4	0.4	16
Heptachlor	0.03	1.2	0.12	4.8

Notes:

1. Where not otherwise specified, ASLP criteria are derived from the NHMRC Australian Drinking Water Guidelines (1996) Guideline Health Values, multiplied by 100.
2. Where not otherwise specified, TC criteria for 'inorganic species' and 'anions' has been adopted as the National Environment Protection Measure on the Assessment of Site Contamination 1999, Health Investigation Level for Commercial/Industrial land.
3. TC adopted from the Risk-based Assessment of Soil and Groundwater Quality in the Netherlands, Intervention Values for Soil.
4. Waste containing polychlorinated biphenyls (PCBs) must be managed in accordance with the Commonwealth Department of Environment, Water, Heritage and the Arts Polychlorinated Biphenyls Management Plan.
5. ASLP adopted from TCLP2 value specified in Department of Environment and Climate Change NSW, Waste Classification Guidelines Part1: Classifying Waste, 2008.
6. TC adopted from SCC2 value specified in Department of Environment and Climate Change NSW, Waste Classification Guidelines Part 1: Classifying Waste, 2008.
7. TC value adopted from the National Environment Protection Measure on the Assessment of Site Contamination 199, Health Investigation Level for Commercial/industrial land.
8. ASLP adopted from World Health Organisation (WHO) Antimony in drinking water. Background document for development of WHO guidelines for Drinking-waster quality 2003, multiplied by 100.
9. TC values adopted from the ANZECC Organochlorine Pesticides Waste Management Plan 1999.
10. Total sum of naphthalene, acenapthylene, acenapthne, anthracene, bezo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluorene, fluoranthene, indeno(1,2,3-c,d)pyrene, phenanthrene and pyrene.
11. Total sum of phenol, 2-methylphenol(o-cresol), 3-methylphenol(mcresol), 4-methylphenol(p-cresol), 2,4-dimethylphenol, 2,4-dinitrophenol, 2-methyl-4,6-dinitrophenol, 2-nitrophenol, 4-nitrophenol, 2-cyclohexyl-4,6-dinitrophenol and dinoseb.

Appendix D: Schedule 2 WMPC (Admin) Regulations

Acidic solutions or acids in solid form
Animal effluent and residues (abattoir effluent, poultry and fish processing waste)
Antimony, antimony compounds
Arsenic, arsenic compounds
Asbestos
Barium compounds other than barium sulphate
Basic solutions or bases in solid form
Beryllium, beryllium compounds
Boron compounds
Cadmium, cadmium compounds
Ceramic-based fibres with physico-chemical characteristics similar to those of asbestos
Chlorates
Chromium compounds that are hexavalent or trivalent
Clinical and related wastes
Cobalt compounds
Containers that are contaminated with residues of a listed waste
Copper compounds
Cyanides (inorganic)
Cyanides (organic)
Encapsulated, chemically fixed, solidified or polymerised wastes
Ethers
Filter cake
Fire debris and fire washwaters
Fly ash
Grease trap waste
Halogenated organic solvents
Highly odorous organic chemicals (including mercaptans and acrylates)
Inorganic fluorine compounds excluding calcium fluoride
Inorganic sulfides
Isocyanate compounds
Lead, lead compounds
Mercury, mercury compounds
Metal carbonyls
Nickel compounds
Non-toxic salts
Organic phosphorus compounds
Organic solvents excluding halogenated solvents
Organohalogen compounds that are not otherwise specified in this Schedule

Perchlorates

Phenols, phenol compounds including chlorophenols

Phosphorus compounds other than mineral phosphates

Polychlorinated dibenzo-furan (any congener)

Polychlorinated dibenzo-p-dioxin (any congener)

Residue from industrial waste treatment or disposal operations

Selenium, selenium compounds

Sewage sludge and residues including nightsoil and septic tank sludge

Soils contaminated with a listed waste

Surface active agents (surfactants) that contain principally organic constituents and that may contain metals and inorganic materials

Tannery wastes (including leather dust, ash, sludges and flours)

Tellurium, tellurium compounds

Thallium, thallium compounds

Triethylamine catalysts for setting foundry sands

Tyres

Vanadium compounds

Waste chemical substances arising from research and development or teaching activities, including those substances which are not identified and/or are new and the effects of which on human health and/or the environment are not known

Wastes containing peroxides other than hydrogen peroxide

Waste, containing cyanides, from heat treatment and tempering operations

Waste from the manufacture, formulation and use of wood-preserving chemicals

Waste from the production, formulation and use of biocides and phytopharmaceuticals

Waste from the production, formulation and use of inks, dyes, pigments, paints, lacquers and varnish

Waste from the production, formulation and use of organic solvents

Waste from the production, formulation and use of photographic chemicals and processing materials

Waste from the production, formulation and use of resins, latex, plasticisers, glues and adhesives

Waste from the production and preparation of pharmaceutical products

Waste mineral oils unfit for their original intended use

Waste mixtures, or waste emulsions, of oil and water or hydrocarbon and water

Waste pharmaceuticals, waste drugs and waste medicines

Waste resulting from surface treatment of metals and plastics

Waste tarry residues arising from refining, distillation and any pyrolytic treatment

Waste substances and articles containing or contaminated with polychlorinated biphenyls (PCBs), polychlorinated naphthalenes (PCNs), polychlorinated terphenyls (PCTs) and/or polybrominated biphenyls (PBBs)

Waste of an explosive nature not subject to the *Dangerous Goods Act 1998* or the *Work Health and Safety (National Uniform Legislation) Act 2011*

Wool scouring waste

Zinc compounds

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