Technical Guidelines for Disposal to Land

Waste Management Institute New Zealand (WasteMINZ)

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Waste Management Institute New Zealand Incorporated (WasteMINZ)
Unit 2, 5 Orbit Drive, Rosedale, Auckland 0632
PO Box 305426, Triton Plaza, Auckland 0757
Phone (09) 476 7162

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Technical Guidelines for Disposal to Land Project Team

- Brent Aitken, Taupō District Council
- Mike Baker, New Plymouth District Council
- Dave Beresford, Hastings District Council
- John Cocks, MWH New Zealand Ltd
- Laurence Dolan (Project Manager)
- Simonne Eldridge, Tonkin + Taylor Ltd
- Adrian Heays, Bay of Plenty Regional Council
- Ian Jenkins, AECOM Ltd
- Ian Kennedy, Waste Management NZ Ltd
- Michael LeRoy-Dyson, Fulton Hogan Ltd
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About WasteMINZ

WasteMINZ is the largest representative body of the waste and resource recovery sector in New Zealand.

As the authoritative voice on waste and resource recovery in New Zealand, WasteMINZ seeks to achieve ongoing and positive development of the industry through strengthening relationships, facilitating collaboration, knowledge sharing and championing the implementation of best practice standards.

Disclaimer

Every effort has been made to ensure that these guidelines are as comprehensive and accurate as practicable; however, WasteMINZ will not be held responsible for any action arising out of their use.

If the reader is uncertain about issues raised in these guidelines, they should refer to the Health Act 1956, Resource Management Act 1991, Health and Safety at Work Act 2015, Hazardous Substances and New Organisms Act 1996, Local Government Act 2002, Climate Change Response Act 2002, Waste Minimisation Act 2008 and other applicable legislation, and seek further expert advice as necessary.

Table of Contents

List of Tables

List of Figures

Appendices

1. Glossary and Definitions

Aquifer A geologic formation or layer of rock or soil that is able to hold or transmit water.

Background Level Ambient level (or concentration) of a contaminant in the local area of the site under consideration.

Bio-accumulation Accumulation within the tissues of living organisms.

Biosolids The semi liquid residue from sewage treatment plants, septic tanks and the processing of organic materials.

Clean Fill A Class 4 landfill. Accepts only clean fill material, including clean excavated natural materials.

Clean Fill Material Virgin excavated natural materials (VENM) such as clay, soil and rock that are free of:

- combustible, putrescible, degradable or leachable components;
- hazardous substances or materials (such as municipal solid waste) likely to create leachate by means of biological breakdown;
- 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;
- contaminated soil and other contaminated materials; and
- liquid waste.

When discharged to the environment, clean fill material will not have a detectable effect relative to the background.

Closed Landfill Any landfill that no longer accepts waste for disposal.

Commercial Waste General or non-hazardous waste from premises used wholly or mainly for the purposes of a trade or business or for the purpose of sport, recreation, education, healthcare or entertainment but not including household, agricultural or industrial waste.

Construction and Demolition (C&D) Waste

Non-household, non-putrescible construction and demolition wastes. This includes waste generated from the construction, renovation, repair, and demolition of structures such as residential and commercial buildings, roads, and bridges. The composition of C&D waste varies for these different activities and structures. Overall, C&D waste is composed mainly of wood products, asphalt, plasterboard, and masonry.

Other components often present in significant quantities include metals, plastics, earth, shingles, insulation, and paper and cardboard.

Contaminant Any substance (including gases, odorous compounds, 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.

Contaminated Soil Soil from contaminated land as defined in the Resource Management Act 1991 (RMA).

Corrosivity The ability of a substance to corrode metals or to cause severe damage by chemical action when in contact with living tissue.

Designation A provision in a district plan that provides for a particular public work or project of a requiring authority.

Discharge Includes emit, deposit and allow to escape.

Discharge Permit A consent to do something that otherwise would contravene section 15 of the RMA (other than in the coastal marine area).

Ecosystem A dynamic complex of plant, animal and micro-organism communities and their non-living environment, interacting as a functional unit.

Ecotoxic Capable of causing ill health, injury, or death to any living organism.

Environment Includes:

a) ecosystems, including people and communities: and
b) all natural and physical resources; and
c) amenity values; and
d) the cultural, economic, aesthetic, and social conditions that affect, or which are affected by, the above.

Field Capacity The maximum amount of moisture that can be retained by waste subject to drainage by gravity.

Flammability The ability of a substance to be ignited and to support combustion.

Flexible Membrane Liner (FML)
A manufactured hydraulic barrier consisting of a functionally continuous layer of synthetic or partially synthetic, flexible material, usually high density polyethylene (HDPE), polypropylene (PP) or poly vinyl chloride (PVC).

Geomembrane A polymeric sheet material that is impervious to liquid.

Geosynthetic Clay Liner (GCL)
A manufactured liner product comprising a layer of very low permeability bentonite clay sandwiched between carrier geotextiles, and used as a hydraulic barrier in liner systems.

Geotextile A woven or non-woven sheet material less impervious to liquid than a geomembrane, but more resistant to penetration damage.

Hazardous Waste Any waste that:

- contains hazardous substances at sufficient concentrations to exceed the minimum degrees of hazard specified by Hazardous Substances (Minimum Degrees of Hazard) Regulations 2000 under the Hazardous Substances and New Organism Act 1996; or

- meets the definition for infectious substances included in the Land Transport Rule: Dangerous Goods 1999 and NZ Standard 5433: 1999 - Transport of Dangerous Goods on Land; or
- meets the definition for radioactive material included in the Radiation Protection Act 1965 and Regulations 1982.

Hazardous waste contains contaminants such as heavy metals and human-made chemicals, at levels high enough to require treatment to render them acceptable for landfill disposal.

Hazardous Waste Landfill

Any landfill that accepts waste formally defined as “hazardous waste” in statutory instruments or specifically determined through any special requirements that may be set by the Environmental Risk Management Authority (ERMA).

Household Waste Waste generated from a household that is not entirely from construction, renovation, or demolition of the house. Household waste is composed of wastes from normal household activities, including bottles, cans, food packaging, food scraps, disposable items, clothing, paper and cardboard, and garden waste that originates from private homes or apartments. It may also contain household hazardous waste.

Incidental Items or materials present in small quantities that cannot practically be separated from the materials intended for disposal.

Industrial or Trade Premises

a) Any premises used for industrial or trade purposes; or
b) Any premises used for the storage, transfer, treatment, or disposal of waste materials or for other waste management purposes, or used for composting organic materials; or
c) Any other premises from which a contaminant is discharged in connection with any industrial or trade process; but does not include production land.

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

Land Use Consent A consent to do something that otherwise would contravene section 9 or 13 of the RMA.

Landfill A waste disposal site used for the controlled deposit of solid wastes onto or into land.

Landfill Gas Gas generated as a result of the 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 Liquid that, in passing through waste, extracts solutes, suspended solids or any other component of the waste material through which it has passed. This includes liquid included in the waste as received and that drains as a result of waste compression, or the ongoing breakdown of organic matter.

Managed Fill A Class 3 landfill. Accepts only clean fill material and managed fill material.

Managed Fill Material Predominantly clean fill material that may also contain inert construction and demolition materials and soils from sites that may have contaminant concentrations in excess of local background concentrations, but with specified maximum total concentrations.

Monofill A landfill, which is designated for one specific type of waste.

Municipal Solid Waste (MSW)

Any non-hazardous, solid waste from household, commercial and/or industrial sources. It includes putrescible waste, garden waste, biosolids, and clinical and related waste sterilised to a standard acceptable to the Department of Health. All municipal solid waste should have an angle of repose of greater than five degrees (5°) and have no free liquid component.

It is recognised that municipal solid waste is likely to contain a small proportion of hazardous waste from households and small commercial premises that standard waste screening procedures will not detect. However, this quantity should not generally exceed 200 ml/tonne or 200 g/tonne.

Municipal Solid Waste Landfill
Any landfill that accepts municipal solid waste.

Oxidise In relation to a capacity to oxidise, the ability of a substance to cause or contribute to the combustion of other material by yielding oxygen.

Piezometric Surface The piezometric (or potentiometric) surface is the level to which water rises in a well. In a confined aquifer this surface is above the top of the aquifer unit; whereas, in an unconfined aquifer, it is the same as the water table.

Resource Consent A discharge permit, land use consent, water permit or subdivision consent including all conditions.

Reverse Sensitivity The effects of the existence of sensitive activities on other activities in their vicinity, particularly by leading to restraints in the carrying on of those other activities. The "sensitivity" is this: if the new use is permitted, the established use may be required to restrict its operations or mitigate its effects so as to not adversely affect the new activity.

Solute The minor component in a solution, dissolved in the solvent.

TCLP Test US EPA Test Method 1311. The TCLP (toxicity characteristic leaching procedure) test is designed to determine the mobility of both organic and inorganic contaminants present in wastes. A weak acid, which mimics landfill leachate, is used to leach the contaminants from a sample of waste.

Toxicity 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 which occur a short time following exposure to the toxin, and chronic toxicity means the effects which occur either after prolonged exposure or an extended period after initial exposure.

Treatment In relation to wastes, any physical, chemical, or biological change applied to a waste material prior to ultimate disposal, in order to reduce potential harmful impact on the environment.

Virgin Excavated Natural Material (VENM)

Natural material, such as clay, gravel, sand, soil or rock fines; that:

a) has been excavated or quarried from areas that are not contaminated with manufactured chemicals or process residues, as a result of industrial, commercial, mining or agricultural activities; and
b) does not contain any sulfidic ores or soils or any other waste

Waste

a) any thing disposed of or discarded; and
b) includes a type of waste that is defined by its composition or source (for example, organic waste, electronic waste, or construction and demolition waste); and
c) to avoid doubt, includes any component or element of diverted material, if the component or element is disposed of or discarded.

Water Permit A consent to do something that otherwise would contravene section 14 of the RMA, other than in the coastal marine area.

2. Introduction

2.1 Purpose of the Guidelines

These Technical Guidelines for Disposal to Land (the Guidelines) replace the following publications relating to landfills in New Zealand:

- CAE Landfill Guidelines (2000); and
- A Guide to the Management of Cleanfills (2002).

The purpose of this document is to provide technical guidance relating to the siting, design, operation and monitoring of landfills in New Zealand, based on local and international experience.

The final decision on site-specific requirements for a landfill is made by the appropriate regulatory authority, or Environment Court, under the provisions of the Resource Management Act (1991), following a comprehensive site-specific assessment of effects on the environment. These Guidelines do not reduce the necessity for the development of site-specific requirements for investigations, design, operations and monitoring.

2.2 Scope of the Guidelines

Disposal to Land

Disposal to land means the final (or more than short-term) deposit of clean and managed fill materials and/or waste materials into or onto land set apart for that purpose (landfill).

For the purpose of these Guidelines, disposal to land does not include:

- earthworks operations involving the movement of soil or clean fill material within a site;
- farm dumps used for the disposal of wastes generated on the same farm site;
- offal holes used for the disposal of offal generated on the same farm site; or
- bioremediation of hydrocarbon contained in solid waste (known as land farming).

Activities Covered by the Guidelines

In respect of siting and design, these Guidelines are intended for planned disposal at new landfill facilities, or extensions of existing landfills, including new landfill cells.

These Guidelines do not cover:

- waste minimisation activities prior to the disposal of residual materials;
- materials handling, sorting, separation or transfer activities; and
- initial emergency response to natural disasters (such as landslides, earthquakes, floods or volcanic eruptions) or any other significant event.

However, following the environmental protection measures set out in these Guidelines will be helpful when pre-planning for, or undertaking, waste disposal as part of emergency response.

The Guidelines are forward looking. That is, they are not intended to remedy issues at existing operating or closed landfill sites.

2.3 Objectives

The objectives of the Guidelines are to:

- define clean fill material, managed fill material and waste types intended for disposal to land;
- define classes of landfills based on the types of material to be accepted for disposal, and associated waste acceptance criteria;
- provide a consistent approach to siting, design, operations and monitoring to reduce the actual and potential effects of landfills on the environment and communities; and
- make current best practice recommendations on key technical requirements for siting, design, operations and monitoring of landfills.

The Guidelines are not intended to be a detailed technical manual, but rather a source of information from which facility operators and regulatory authorities can seek comprehensive technical, planning and legal advice from appropriately qualified experts.

2.4 Related Landfill Guidelines

The Guidelines should be read in conjunction with the following national guideline documents:

- A Guide to Landfill Consent Conditions (2001);
- A Guide to the Management of Closing and Closed Landfills in New Zealand (2001); and
- Landfill Full Cost Accounting Guide for New Zealand (2004).

2.5 Waste Types

The following waste and fill types are addressed in these Guidelines:

- clean fill material;
- managed fill material;
- construction and demolition (C&D) waste;
- household waste;
- commercial waste;
- municipal solid waste (MSW);
- industrial waste; and
- hazardous waste.

The definition of each waste type is given in the Glossary.

2.6 Types of Facility for Disposal of Waste to Land

These Technical Guidelines for Disposal to Land classify landfills into four types:

- Class 1 – Landfill: Municipal Solid Waste Landfill.
- Class 2 – Landfill: C&D Landfill.
- Class 3 – Landfill: Managed Fill.
- Class 4 – Landfill: Clean Fill.

Class 1 - Landfill

A Class 1 landfill is a site that accepts municipal solid waste as defined in this Guideline. A Class 1 landfill generally also accepts C&D waste, some industrial wastes and contaminated soils. Class 1 landfills often use managed fill and clean fill materials they accept, as daily cover.

Class 1 landfills require:

- a rigorous assessment of siting constraints, considering all factors, but with achieving a high level of containment as a key aim;
- engineered environmental protection by way of a liner and leachate collection system, and an appropriate cap, all with appropriate redundancy; and
- landfill gas management.

A rigorous monitoring and reporting regime is required, along with stringent operational controls. Monitoring of accepted waste materials is required, as is monitoring of sediment runoff, surface water and groundwater quality, leachate quality and quantity, and landfill gas.

Class 2 – Landfill

A Class 2 landfill is a site that accepts non-putrescible wastes including C&D wastes, inert industrial wastes, managed fill material and clean fill material as defined in these Guidelines. C&D waste can contain biodegradable and leachable components which can result in the production of leachate – thereby necessitating an increased level of environmental protection. Although not as strong as Class 1 landfill leachate, Class 2 landfill leachate is typically characterised by mildly acidic pH, and the presence of ammoniacal nitrogen and soluble metals, including heavy metals. Similarly, industrial wastes from some activities may generate leachates with chemical characteristics that are not necessarily organic.

Class 2 landfills should be sited in areas of appropriate geology, hydrogeology and surface hydrology. A site environmental assessment is required, as are an engineered liner, a leachate collection system, and groundwater and surface water monitoring. Additional engineered features such as leachate treatment may also be required.

Depending on the types and proportions of C&D wastes accepted, Class 2 landfills may generate minor to significant volumes of landfill gas and/or hydrogen sulphide. The necessity for a landfill gas collection system should be assessed.

Operational controls are required, as are monitoring of accepted waste materials, monitoring of sediment runoff, surface water and groundwater quality, and monitoring of leachate quality and quantity.

Class 3 – Landfill

A Class 3 landfill accepts managed fill materials as defined in these Guidelines. These comprise predominantly clean fill materials, but may also include other inert materials and soils with chemical contaminants at concentrations greater than local natural background concentrations, but with specified maximum total concentrations.

Site ownership, location and transport distance are likely to be the predominant siting criteria. However, as contaminated materials (in accordance with specified limits) may be accepted, an environmental site assessment is required in respect of geology, stability, surface hydrology and topography.

Monitoring of accepted material is required, as are operational controls, and monitoring of sediment runoff and groundwater.

Class 4 – Landfill

A Class 4 landfill accepts only clean fill material as defined in these Guidelines. The principal control on contaminant discharges to the environment from Class 4 landfills is the waste acceptance criteria.

Stringent siting requirements to protect groundwater and surface water receptors are not required. Practical and commercial considerations such as site ownership, location and transport distance are likely to be the predominant siting criteria, rather than technical criteria.

Clean filling can generally take place on the existing natural or altered land without engineered environmental protection or the development of significant site infrastructure. However, surface water controls may be required to manage sediment runoff.

Extensive characterisation of local geology and hydrogeology is not usually required.

Monitoring of both accepted material and sediment runoff is required, along with operational controls.

Summary of Landfill Classes

Landfill classes are summarised in **Error! Reference source not found.**, with the risk rationale outlined in **Error! Reference source not found.**.

Waste acceptance criteria for each class of landfill are detailed in Section 5.

Table 2-1 Summary of Landfill Classes

Class	1	2	3	4
Waste Types	Clean Fill Material Managed Fill Material C&D Waste Municipal Solid Waste Household Waste Commercial Waste Industrial Waste	Clean Fill Material Managed Fill Material C&D Waste Non-putrescible Industrial Waste	Clean Fill Material Managed Fill Material	Clean Fill Material
Control of Effects	Siting Waste acceptance criteria Engineered redundancy in liner design Leachate management Landfill gas management Operations Capping Monitoring	Siting Waste acceptance criteria Engineered redundancy in liner design Leachate management Operations Capping Monitoring	Siting Waste acceptance criteria Operations Monitoring	Siting Waste acceptance criteria Operations Monitoring

Table 2-2 Landfill Class Rationale

Class	Common Name	Waste Material	Material Source	Contaminant Risk
1	Municipal Solid Waste Landfill	Non-hazardous waste. Typically mixed waste from multiple sources and containing a high content of organic material; may include waste cited for classes 2, 3 and 4. May be developed for specific industrial wastes (for example, monofills or residual waste sites).	Households, industry, institutions, construction sites, contaminated sites.	Leachate, contaminated stormwater and landfill gas (LFG). Odour Dust
2	C&D Landfill	Unsorted/uncontrolled construction and demolition material. May be developed for specific industrial wastes (for example, monofills or residual waste sites).	Construction sites, demolition material, soil from areas with significantly different chemical properties.	Leachate and contaminated stormwater; low risk of LFG, but may get odour due to hydrogen sulphide. Dust
3	Managed Fill	Inert material (e.g. selected inert construction or demolition material) or soils with trace element concentrations greater than applicable regional background concentrations.	Selected materials from construction sites, demolition sites.	Some risk of leachate (e.g. as a result of some extraneous wood products, organics or mineral oils amongst inert material). Sediment contamination of stormwater. Dust
4	Clean Fill	Virgin excavated natural material (VENM).	Slips/road clearance, construction site clearance, earthworks surplus.	Little or no risk of leachate and gas. Sediment contamination of stormwater. Dust

3. Legislation

3.1 Introduction

This section provides a summary of the legislation that relates directly to the development and operation of landfills.

Requirements in respect of the Waste Minimisation Act (2008), Hazardous Substances and New Organisms Act (1996) and the Climate Change Response Act (2002) are addressed in other publications.

Overview of Relevant Legislation

The following legislation also contains provisions that can affect the siting, design, operation and monitoring of landfills:

- Health Act 1956;
- Resource Management Act 1991;
- Health and Safety at Work Act 2015;
- Hazardous Substances and New Organisms Act 1996;
- Local Government Act 2002;
- Climate Change Response Act 2002; and
- Waste Minimisation Act 2008.

The key aspects of each Act are outlined in **Table 3-1** Legislation Relating to Landfills

Table 3-1 Legislation Relating to Landfills

Health Act 1956	Resource Management Act 1991	Health and Safety at Work Act 2015	Hazardous Substances and New Organisms Act 1996	Local Government Act 2002	Climate Change Response Act 2002	Waste Minimisation Act 2008
Provision for waste collection and disposal	District and Regional Plans Resource Consents National Environmental Standards	Requirement to provide a safe working environment and control hazards Health and Safety at Work Act (Asbestos) Regulations 2016	Regulations and group standards relating to waste	Bylaws Long-term plans Undertake an assessment of water and other sanitary services	Disposal facility regulation Emissions Trading Scheme	Waste management and minimisation plans Waste disposal levy Waste minimisation fund Product stewardship

3.2 Health Act 1956

The Health Act 1956 requires local authorities to provide, if required by the Minister of Health:

> *works for the collection and disposal of refuse, nightsoil, and other offensive matter.*

The Health Act enables territorial authorities to raise loans for certain sanitary works.

3.3 Resource Management Act 1991

The Resource Management Act 1991 (RMA) is the key piece of legislation controlling landfills and other waste management facilities in New Zealand.

Detail of the processes related to obtaining consents under the RMA are beyond the scope of these guidelines. The following is a summary of the purpose and principles of the RMA and the related consent framework.

The purpose of the RMA is:

> *To promote the sustainable management of natural and physical resources.*

The RMA addresses waste management through controls on the environmental effects of waste management facilities (transfer stations; waste processing or treatment facilities, and landfills) through local policies, plans and resource consent procedures.

The RMA also provides for the development of national environmental standards.

Under the Act, local government functions are divided between regional councils and territorial authorities (district and city councils).

The functions of regional councils include:

- the preparation and implementation and review of objectives, policies and methods to achieve integrated management of natural and physical resources of the region;
- the preparation and implementation of policies in relation to the actual or potential effects of the use, development or protection of land which are of regional significance;
- the control of the use of water, and land for soil conservation;

- the control of the discharge of contaminants;
- avoidance of natural hazards;
- maintenance of water quality;
- the prevention of adverse effects of hazardous substances; and
- activities in, or affecting, the coastal marine area.

A regional council is responsible for assessing resource consent applications for activities where its policy statement or a regional plan requires this. These applications include:

- a discharge permit;
- a water permit;
- a land use consent; and
- a coastal permit.

The functions of territorial authorities include:

- preparation of district plans, which state the resource management issues, objectives, policies and methods to be used and environmental results envisaged for the district;
- control of the actual or potential effects of activities on land and on the surface of water in lakes and rivers;
- the prevention or mitigation of the actual or potential effects of natural hazards and the storage, use, disposal, or transportation of hazardous substances;
- the control of the subdivision of land; and
- control of noise.

Resource Consents

There are five different types of resource consent:

- discharge permit (for land, air or water);
- water permit;
- land use consent;
- coastal permit; and
- subdivision consent.

A description of those consents relevant to landfills is set out below. The actual consent requirements will be dependent on class of landfill, site location and local district and regional plan provisions.

Discharge Permit - Land

Landfills require a discharge permit for any discharge of water or contaminants directly onto land unless expressly provided for in a regional plan, proposed regional plan, resource consent or regulation.[1]

A single generic discharge permit is usually used to cover all discharges of solid waste to land at the landfill.

Discharge permits for discharge of solid waste to land generally contain conditions relating to:

- location of solid waste discharges;
- extent of the landfill footprint;
- quantity of solid waste to be discharged;
- waste acceptance criteria;
- design and performance of liner and leachate collection systems;
- cover systems;
- acceptance of designs;
- peer review (in some circumstances); and
- a bond or financial assurance (in some circumstances).

Discharge Permit - Water

Landfills require a discharge permit for any discharge of water and/or contaminants directly into water (section 15(1)(a)), or onto land in circumstances where it may result in a contaminant entering water (section 15(1)(b)), unless provided for in a plan, proposed plan, resource consent or regulation.

Activities that require a discharge permit under section 15(1)(a) include discharges of clean and/or contaminated surface stormwater, and groundwater from a groundwater control system.

Discharge permits for discharges of contaminants, or water, to water at landfills generally contain conditions relating to:

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[1] Landfills also meet the definition of "industrial or trade premises" under section 2 of the RMA. Some Councils may require a discharge permit under section 15(1)(d).

- location of discharges;
- design and integrity of structures;
- quantity of contaminants or water to be discharged;
- quality of discharges;
- timing of discharges (in some circumstances);
- monitoring of discharges (groundwater and surface water monitoring);
- sediment control measures; and
- scour protection.

Activities that require a discharge permit under section 15(1)(b) include discharges of leachate from closed landfills to groundwater; discharge of leachate from operating landfills to groundwater; and irrigation of leachate onto land.

Discharge permits for discharges of contaminants onto or into land at landfills, in circumstances which may result in contaminants entering water, generally contain conditions relating to:

- location of discharges;
- design and performance of liner and leachate collection systems;
- landfill cover system;
- quantity of leachate discharge;
- leachate monitoring;
- groundwater monitoring;
- surface water monitoring;
- contingency measures for unacceptable levels of groundwater or surface water contamination;
- reporting requirements;
- peer review (in some circumstances); and
- a bond or financial assurance (in some circumstances).

Discharge Permit - Air

Landfills require a discharge permit for any discharge of water or contaminants into air unless expressly provided for by a regional plan, proposed regional plan, resource consent or a regulation.

Two types of discharges to air may occur:

- the emission of decomposition gases such as methane, or other greenhouse gases, and odorous compounds; and

- dust.

It is important to note that open burning in a landfill is illegal.

Discharge permits for discharges of contaminants into the air from landfills generally contain conditions relating to:

- odour limits;
- dust limits;
- compliance points for effects of odour and dust discharges;
- monitoring for landfill gas discharges and migration;
- collection and flaring or utilisation of landfill gas;
- operation, performance and monitoring of landfill gas flares;
- odour monitoring provisions (in some circumstances);
- complaint response and recording; and
- reporting requirements.

Water Permits

Landfills require a water permit from a regional council for the collection and control of stormwater unless this is expressly allowed by a rule in a regional plan or proposed regional plan, or a resource consent.

Water permits may be required for diversion or damming of natural streams on or around the landfill site and the taking of groundwater by a groundwater control system. A water permit may also be required for the diversion of stormwater around a landfill site.

In some cases a single consent may be issued to enable all diversions and another for all takes within a single defined catchment. In others, a separate permit may be required for each separate diversion or take.

Water permits for the taking, use, damming, or diversion of water at landfills generally contain conditions relating to:

- location of takes, dams or diversions;
- design and integrity of structures;
- peer review (in some circumstances); and
- scour protection.

Land Use Consents

"Use of land" includes "any deposit of any substance in, on, or under the land" (section 9(4)(d) RMA). Under section 9, no person may use land in a manner that contravenes a rule in a district plan or proposed district plan, or a regional plan or proposed regional plan, unless allowed by a resource consent or existing use rights.

Since it would be unusual for a regional or territorial authority to make any general provision for a landfill within a plan or proposed plan, usually a landfill will require a land use consent from either a territorial authority, regional council or both.

Land use consents issued by territorial authorities for landfills generally contain conditions relating to:

- development plans;
- hours of operation;
- access restrictions;
- noise;
- roading and traffic;
- litter;
- nuisance from birds, flies and vermin;
- fencing;
- separation distances;
- site rehabilitation;
- landscaping and visual effects;
- accidental discovery of archaeological or cultural sites or koiwi; and
- a bond or financial assurance (in some circumstances).

A land use consent may also be necessary from the regional council if a landfill proposal involves excavation or filling, installation of bores, or is otherwise contrary to the provisions of a regional plan.

Land use consents for excavation or filling generally contain conditions relating to:

- erosion;
- silt control; and
- dust control.

Coastal Permits

In the coastal marine area (that is, below mean high water springs) the regional council is responsible for assessing coastal permit applications. A coastal permit would be required before a landfill could be developed in the coastal marine area (for example, in the intertidal area).

Subdivision Consents

Subdivision is the responsibility of territorial authorities. Subdivision may be a necessary part of a landfill project if there are roads to vest in the council or reserves to be set aside as a consequence of the landfill development.

Existing Use Rights

In some circumstances landfills that have been established for some time may be able to claim existing use rights if they contravene a rule in a district plan or a proposed district plan, provided:

- the land use was lawfully established before the rule became operative. This can include a land use established by a designation which has subsequently been removed;
- the effects of the use are the same or similar in character, intensity, and scale to those which existed before the rule became operative or the proposed plan was notified or the designation was removed; and
- the use has not been discontinued for a continuous period of more than 12 months.

Consents previously granted under the Town and Country Planning Act are now land use consents and water rights under the Water and Soil Conservation Act 1967, are deemed to be ‘existing rights and authorities’ and are now either water permits or discharge permits, expiring on 1 October 2026.

The Suite of Typically Necessary Consents

The establishment of a landfill under the Resource Management Act 1991 may require a number of consents from a regional council and/or territorial authority. The number and type of consents required will vary depending on the provisions of the relevant district and regional plans affecting the proposed site. The level of information needed to support the application will vary depending on the type and scale of the landfill, its siting and effects on the surrounding environment.

The types of consent that may be necessary for a landfill, and the authorities from which these can be sought, are set out in **Table 3-2** Regulatory Authority Resource Consent Responsibilities**.**

Table 3-2 Regulatory Authority Resource Consent Responsibilities

Authority	Consent Type	Purpose
Regional Council	Discharge Permit	Discharge of contaminants to: • land • water • air
	Water Permit	The taking, use, damming or diverting of water
	Land Use Consent	Excavation or filling of the land, installation of bores and culverts
Territorial Authority	Land Use Consent	Use of land for purposes of a landfill
	Subdivision Consent	This may be necessary if the project involves any creation of new allotments, amalgamation of titles, vesting of roads or reserves, or partition of the land into different ownerships

Designations

A designation is a provision in a district plan, which provides for a particular public work or project of a requiring authority. Designations for landfills can only be required by a Minister of the Crown, or a regional council or territorial authority. In the case of landfills, the designation procedure is not available to private organisations.

A designation for a landfill provides for the use of the land as a landfill. Resource consents from the regional council are still necessary for excavation/filling, discharges of contaminants, stormwater control and use of water.

District Plans

Territorial authorities may make provision for landfills in their district.

Any person can request a change to an operative district plan that would make provision for a landfill. This request could be for either:

- a site-specific provision; or
- a general provision within the district plan that would permit landfills to be established, subject to certain criteria.

National Environmental Standards

The RMA provides for the setting of national environmental standards (NESs).

NES for Air Quality

The NES for Air Quality is the only NES to contain specific requirements in respect of landfills (class 1 and class 2).

It requires landfills with more than 200,000 tonnes of waste in place and a design capacity of greater than one million tonnes to collect landfill gas and either flare it (to minimum standards) or use it as a fuel to produce energy.

The NES applies to landfills where the waste in or to be included in the landfill is likely to consist of 5% or more (by weight) of matter that is putrescible or biodegradable.

The NES also prohibits the lighting of fires or burning of waste at landfills and the burning of tyres.

NES for Assessing and Managing Contaminants in Soil to Protect Human Health (NES Soil)

The NES Soil provides a set of soil guideline values (SGVs), which are maximum limits for selected contaminants in soil for the protection of human health in respect of the following land uses:

- rural residential / lifestyle block 10% produce;
- residential 10% produce;
- high-density residential;
- recreation; and
- commercial / industrial outdoor worker.

These guideline values and their associated land use categories are discussed further in relation to landfill waste acceptance criteria in Section 5 of this Guideline.

The NES specifies permitted land disturbance activities and activities that require resource consent. The activities triggering the NES are:

- removal or replacement of an underground fuel storage system and associated soil;
- soil sampling;
- soil disturbance; and
- subdivision of land.

3.4 Health and Safety at Work Act 2015

The Health and Safety at Work (HSW) Act 2015's purpose is to provide a balanced framework to secure the health and safety of workers and workplaces.

The Act places duties on *a person conducting a business or undertaking (PCBU) or any individual who carries out work in any capacity for a PCBU to ensure that the work carried out as part of the conduct of the business or undertaking does not put the health and safety of themselves or other persons at risk* (HSW Act 2015).

Under the Act, *PCBUs must ensure so far as is reasonably practicable:*

- *(a) the provision and maintenance of a work environment that is without risks to health and safety; and*
- *(b) the provision and maintenance of safe plant and structures; and*
- *(c) the provision and maintenance of safe systems of work; and*
- *(d) the safe use, handling, and storage of plant, substances, and structures; and*
- *(e) the provision of adequate facilities for the welfare at work of workers in carrying out work for the business or undertaking, including ensuring access to those facilities; and*
- *(f) the provision of any information, training, instruction, or supervision and safety arising from work carried out as part of the conduct of the business or undertaking; and*
- (g) *that the health of workers and the conditions at the workplace are monitored for the purpose of preventing injury or illness of workers arising from the conduct of the undertaking* (HSW Act 2015).

Under the Act, options for managing risks are as follows:

- *eliminate risks to health and safety, so far as is reasonably practicable; and*
- *if it is not reasonably practicable to eliminate risks to health and safety, to minimise those risks so far as is reasonably practicable* (HSW Act 2015).

Examples of minimising risks are following safe work practices, providing suitable protective clothing and equipment, maintaining equipment properly, training employees in safe work methods and supervising untrained or inexperienced employees.

The Act introduces the term 'reasonably practicable' in relation to the duty of a PCBU. *Reasonably practicable means that which is, or was, at a particular time, reasonably able to be done in relation to ensuring health and safety, taking into account and weighing up all relevant matters, including-*

- *(a) the likelihood of the hazard or the risk concerned occurring; and*

(b) the degree of harm that might result from the hazard or risk; and
(c) what the person concerned knows, or ought reasonably to know, about-
  (i) the hazard or risk; and
  (ii) ways of eliminating or minimising the risk; and
(d) the availability and suitability of ways to eliminate or minimise the risk; and
(e) after assessing the extent of the risk and the available ways of eliminating or minimising the risk, the cost associated with available ways of eliminating the risk, including whether the cost is grossly disproportionate to the risk (HSW Act 2015).

The associated Health and Safety at Work Act (Asbestos) Regulations 2016 impose additional duties on PCBUs in relation to work involving asbestos. This includes managing asbestos risks, removal of asbestos and licensing of asbestos removalists.

A PCBU for which asbestos-related work is carried out must ensure that asbestos waste—

(a) is placed in a sealed container that is marked clearly (and in a way that complies with the requirements of any applicable safe work instrument) to indicate the possible presence of asbestos before the waste is removed from an asbestos-related work area; and

(b) is disposed of safely and regularly by depositing it in a place approved for the purpose by a territorial authority under section 73 of the Resource Management Act 1991.

(2) The PCBU must ensure that equipment (including personal protective equipment) used in asbestos-related work and contaminated with asbestos—

(a) is placed in a sealed container that is marked clearly (and in a way that complies with the requirements of any applicable safe work instrument) to indicate the possible presence of asbestos before the waste is removed from an asbestos-related work area; and

(b) so far as is reasonably practicable, is disposed of on the completion of the asbestos-related work in a place approved for the purpose by a territorial authority under section 73 of the Resource Management Act 1991.

(3) If it is not reasonably practicable to dispose of equipment that is clothing, the PCBU must ensure that the clothing—

(a) is laundered at a laundry equipped to launder asbestos-contaminated clothing; or

(b) if it is not practicable to launder the clothing, is kept in the sealed container until it is reused for the purposes of asbestos-related work.

(4) If it is not reasonably practicable to dispose of equipment that is not clothing, the PCBU must ensure that the equipment—

(a) is decontaminated before it is removed from the asbestos-related work area; or

(b) *if it is not practicable to decontaminate the equipment in the asbestos-related work area, is kept in the sealed container until it is reused for the purposes of asbestos-related work.*

(5) *A PCBU must ensure that a sealed container referred to in subclause (2) is decontaminated before the container is removed from the asbestos-related work area.*

Additional details of the Health and Safety at Work Act 2015 are given in **Appendix A**.

3.5 Other Relevant Legislation

Summaries of the provisions of the following Acts are provided in **Appendix A**:

- Hazardous Substances and New Organisms Act 1996.
- Local Government Act 2002.
- Climate Change Response Act 2002.
- Waste Minimisation Act 2008.
- Heritage New Zealand Pouhere Taonga Act 2014.

4. Siting

4.1 Introduction

Location is the key determinant of the extent to which a landfill poses an environmental risk. Careful siting of a landfill is fundamental to protect the environment from potential adverse effects associated with the disposal of fill material or waste materials to land. The aim is to minimise the need for both mitigation of impacts and ongoing management by selecting a site where, to the extent possible, natural conditions protect environmental quality such that the landfill can be sited so there will not be significant adverse impacts on existing and future development, or the environment.

Where an engineered liner system is used it should be recognised that this system will have a finite lifetime, so consideration needs to be made of the ability of the underlying materials to keep discharges from the site to a level which will not cause significant adverse effects on the surrounding environment in the long term. Similarly, engineered management of surface water discharges will degrade over time.

The site selection and assessment process needs to consider not only direct environmental impacts, but also broader issues such as community impacts and operational considerations. Examples include traffic hazards, noise, unpleasant odours, contamination of water, windblown litter and dust, an increase in the populations of vermin; and threats to household water supplies.

A successful landfill project relies on a combination of careful siting, robust engineering and effective operations and monitoring. Careful siting has the potential to:

- reduce consenting risks (e.g. avoiding sensitive land use, utilising natural containment to support engineering solutions, and considering impacts on local communities);
- reduce design costs and/or risk (by selecting sites where conventional engineering solutions are supported by in situ conditions); and
- reduce operational costs and risks (by selecting sites to minimise impact on local communities, e.g. appropriate buffer distances and prevailing wind direction).

New Zealand has seen a shift from having landfills which accept a wide variety of waste materials being sited in every community, to fewer, larger specialised sites which either accept a tightly defined subset of fill material or waste, or are highly engineered and accept municipal solid waste and/or industrial waste.

The general approach to siting a landfill is the same, regardless of the materials to be accepted. The following issues need to be considered:

- landfill siting approach;
- site selection or assessment process;
- site investigations;
- consultation; and
- landfill siting criteria.

The key siting constraints for each class of landfill are summarised in **Table 4-1** below. For each type of constraint and landfill, the circumstances in which development is inappropriate are specified. Section 3.4 provides further information, focussing on considerations for a class 1 site. **Table 4-1** also provides guidance on where the differences lie for class 2, 3 and 4 sites.

Table 4-1 Siting Criteria – Technical Constraints

Class	**1**	**2**	**3**	**4**
Type of facility	MSW Landfill	C&D Landfill	Managed Fill	Clean Fill
Site stability constraints	Geothermal areas Karst areas Active faults	Geothermal areas Karst areas Active faults	Geothermal areas Karst areas	Geothermal areas
Hydrogeology constraints	Drinking water aquifers	Drinking water aquifers	Drinking water aquifers	NA
Surface hydrology constraints	Flood plains Water supply catchments Estuaries, marshes and wetlands	Flood plains Water supply catchments Estuaries, marshes and wetlands	Water courses Water supply catchments Estuaries, marshes and wetlands	Water courses Estuaries, marshes and wetlands
Environmentally sensitive areas - constraints	Significant wetlands Inter-tidal areas Significant areas of native bush and areas able to comply with the requirements for Q.E.II Trust status Recognised wildlife habitats Any areas with sensitive fish/wildlife/aquatic resources			

4.2 Siting Approach

General

The governing approach adopted for the siting guidelines is to assist the selection of landfill sites which, to the extent practicable, provide an appropriate level of natural containment, through their inherent geological, hydrogeological and topographical characteristics. However, other features of a site are also important. These include its ability to be accessed in a way that causes minimum disruption to the community and the ability to provide buffer to neighbours surrounding the site. These key physical features need to be considered together with the engineered containment options available (Class 1 and 2 landfills) and operational controls in order to minimise the overall adverse impacts of a landfill.

The criteria set out in this section are broadly applicable to all landfills. Siting criteria relevant to different classes of landfill are set out in **Table 4-1**.

Class 1 and Class 2 Landfills

A balanced approach to site selection is required. Locating a site with good natural containment is clearly a major technical advantage, but in some instances such a site benefit may be outweighed by constraints related to access or other community considerations, in particular the availability of buffer. In some instances, developing robust engineered solutions to containment may be required to offset less-than-ideal natural containment.

The use of a robust selection process and siting criteria to select the most appropriate landfill sites will help avoid or reduce potential environmental problems by reducing the potential impact on people and the environment. The adoption of appropriate siting criteria is important in relation to gaining resource consents for any new site.

Class 3 and Class 4 Landfills

Rather than being a planned process, siting criteria are likely to be based predominantly on financial considerations in respect of:

- proximity to fill material sources;
- opportunity for site development post filling;
- existing land ownership; and
- site development cost.

4.3 Site Selection Process

While siting should be based primarily on technical factors, community perception and values may also be critical to the acceptability of a landfill site.

Site selection should normally include the following processes:

- initial desk top study;
- site investigations;
- economic assessment (repeated at different stages of the process); and
- consultation (early and then ongoing throughout the process);

Class 1 landfills (municipal solid waste (MSW)) require a comprehensive siting process and/or assessment.

Class 2 landfills (construction and demolition (C&D) waste) should be sited in areas of appropriate geology, hydrogeology and surface hydrology. A site environmental assessment is required, as are an engineered liner, leachate collection system, groundwater and surface water monitoring.

For **Class 3** landfills site ownership, location and transport distance are also the predominant siting criteria. However, as materials with contaminants at concentrations greater than local background may be accepted, an environmental site assessment should be completed. This assessment should consider geology, hydrogeology, stability, surface hydrology and topography.

For **Class 4** landfills site selection is generally focussed on issues of practicality and commercial viability (site ownership, location and transport distance). Issues such as stability, surface hydrology and topography will be relevant in relation to sediment control and likely end use of the site.

Initial Desk-top Study

A number of possible localities or sites should be identified, considering the following factors:

- geology;
- hydrogeology;
- surface hydrology;
- stability;
- topography;
- meteorology;

- location (logistics of waste transport);
- potential pathways for the release of contaminants e.g. migration in groundwater to production wells; and
- compatibility with surrounding land uses.

A range of constraint mapping approaches can be used to inform this process. GIS systems can assist in the analysis, and a wide variety of information is available in the public domain in New Zealand. The setting of criteria (the constraints 'coded' into the spatial analysis) needs to be informed by sound judgement alongside the raw data. Information from a number of sources can be used in a constraint mapping process, including:

- geological maps;
- topographical maps;
- meteorological data (rainfall, wind speed/direction, sunshine hours);
- Department of Conservation/conservation management strategies;
- Heritage New Zealand Register;
- district plans;
- regional plans;
- local knowledge, including knowledge of culturally significant sites; and
- surrounding land use.

Site Investigations

Site investigations should be appropriate to the nature of the disposal site being considered, ensuring that a robust assessment of risk can be undertaken. Site investigations should build on the desktop assessment and generally follow a staged approach using:

- preliminary investigations;
- initial technical investigations;
- review of non-technical matters; and
- detailed technical investigations.

Preliminary Investigations

An initial walkover 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 initial assessment, sites are typically ranked to determine a shortlist for further, more detailed investigation. Care should be exercised when ranking sites as:

- design and operational considerations may elevate, or reduce, the initial assessed ranking;
- access needs to be carefully considered; and
- community issues may affect the assessed ranking of a site.

Initial Technical Investigations

The purpose of initial technical investigations on shortlisted sites is to identify potential fatal flaws and reduce the shortlist of identified sites to one or more sites for more detailed technical investigations.

Initial investigations should include:

- mapping of site geology;
- geotechnical assessment of overall site stability, seismic risk and suitability;
- geotechnical investigations using drill holes and pits to assess site soils with respect to their suitability for natural containment and as engineered liner and cover materials;
- 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 possibly groundwater quality;
- assessment of sensitivity of biota and fauna at the site and downstream;
- availability of cover;
- suitability of existing vegetation for screening;
- wind data/wind rose for each site; and
- rainfall data/hydrology.

Review of Non-technical Matters

Non-technical matters 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;
- access to the site and potential traffic effects, including the relevance of main haul routes (this can prove to be a key siting consideration in many instances);

- location of any sites of cultural significance including, rivers, streams, marae, ancestral land, waahi tapu and other taonga (some of these sites may not be readily identifiable);
- potential for nuisances associated with odour, vermin, birds and flies, noise, litter, dust and visual effects; and
- location of sites of historical significance.

Detailed Technical Investigations

The results of initial technical and non-technical investigations, coupled with preliminary economic assessments, should result in a shortlist of priority sites worthy of more detailed technical investigation.

A detailed investigation programme should be developed on a site-specific basis. It should address the site selection criteria detailed in Section 3.4, and potential design, operational and monitoring requirements.

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

Economic Assessment

A preliminary economic assessment should be undertaken for shortlisted sites so that the costs of developing and operating a disposal facility at the different sites can be compared.

Additional information on full costing of landfill options is provided in the Landfill Full Cost Accounting Guide for New Zealand (MfE, 2004).

Consultation

Consultation with the community, including tangata whenua, is a critical component of any landfill site selection process.

The Fourth Schedule of the Resource Management Act requires consultation to be undertaken with all persons interested or affected by a proposal, and the consultation recorded. See 'An Everyday Guide to the Resource Management Act Series 2.2: Consultation for Resource Consent Applicants' (MfE, 2009) for more information.

4.4 Landfill Siting Criteria

The following landfill siting criteria detail the key issues which need to be considered when:

(i) identifying potential landfill sites (Class 1, 2 3 and 4); and
(ii) planning site investigations and assessing the suitability of a site for landfilling.

It is unlikely that any site will meet all criteria. Therefore, the assessment of the suitability of a site for a landfill becomes a balance of trade-offs with respect to:

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

In order to minimise future risk to the environment from landfilling activities, primary technical consideration should be given to key issues and potential fatal flaws with respect to geology, hydrogeology, surface hydrology and site stability. Each of these issues is discussed in more detail below.

The wide range of other issues to consider while selecting a landfill site are also discussed in the remainder of this section.

Geology

For sites accepting anything other than clean fill material, suitable site geology is an important consideration to ensure containment of leachate in the long term through the natural containment provided, should an engineered containment system ever fail. Geology should be assessed with respect to the movement of leachate and also landfill gas. In instances where a site is preferred for other reasons but natural containment is limited, then the robustness of engineered containment systems needs to be considered in the context of the natural geology to ensure that a balanced approach is taken and that site risks can be adequately managed.

In general, and particularly for Class 1 and 2 landfills, areas of low permeability in-situ material are preferable. Because engineered liner systems have a finite lifetime, the ability of the underlying materials to limit the potential for liquids and gases to migrate into the wider environment (should the liner ever degrade) is a key benefit. However, this aspect of site selection needs careful consideration alongside other key features such as access and the ability to provide buffer.

Due to risk of off-site movement of leachate and landfill gas, it is generally undesirable to site a Class 1 or 2 landfill in areas with the following characteristics:

- high permeability soils (such as sands or gravels), or fractured rock, where there is no ability to provide additional mitigation;
- close to active faults that have the potential to impact on containment systems (natural or engineered);
- karst geology - limestone regions with sinkholes and caverns; and
- active coastal erosion.

Where a landfill is developed in these geological environments, the design should incorporate a higher level of engineered containment and appropriate contingency measures.

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 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; and
- the potential effects of failure of leachate containment and collection systems.

Geological factors also influence stormwater, silt and groundwater controls, the containment and control of leachate and landfill gas, and the availability of final cover materials.

Key technical constraints in respect of site geology for different classes of landfills are summarised in **Table 4-2** Geology - Technical Constraints

Table 4-2 Geology - Technical Constraints

Class	1	2	3	4
Geology constraints (without site-specific additional mitigation)	High permeability soils, sand and gravels High permeability or active faults Karst geology	High permeability soils, sand and gravels High permeability faults Karst geology	High permeability faults Karst geology	NA

Hydrogeology

A suitable hydrogeological location is important to protect groundwater resources and to understand the likely fate and rate of discharge of contaminants which may enter groundwater.

It is generally undesirable to site a landfill in areas overlying significant aquifers used for drinking water.

In assessing the suitability of a landfill site with respect to hydrogeology, the following factors need to be considered:

- depth to water table and seasonal water table fluctuations;
- potential to create an inward gradient or control groundwater level;
- location of aquifer recharge areas, seeps or springs;
- distance to water users;
- sensitivity of water users (i.e. type of water use);
- dispersion characteristics of aquifers;
- variations in groundwater levels;
- rate and direction of groundwater flow;
- existence of groundwater divides;
- baseline water quality; and
- the potential effects of failure of leachate containment and collection systems.

Key technical constraints in respect of site hydrogeology for different classes of landfill are summarised in **Table 4-3** Hydrogeology - Technical Constraints**.**

Table 4-3 Hydrogeology - Technical Constraints

Class	1	2	3	4
Hydrogeology constraint	Drinking water aquifers	Drinking water aquifers	Drinking water aquifers	NA

Surface Hydrology

There are risks of surface water pollution if landfills are sited in close proximity to waterways. The potential impact of water pollution is greater in those waterways used for drinking water or aquaculture.

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

- flood plains (generally areas which could be affected by a major flood event, taking into account the latest projections for climate change);
- land that is designated as a water supply catchment or reserved 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 (if waterways are unable to be diverted);
- estuaries, marshes and wetlands; and
- areas that may be subject to coastal erosion or the impact of climate change.

In assessing the suitability of a site for a landfill, the local surface hydrology needs to be considered with respect 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; and
- the latest climate change projections in respect of surface water levels.

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

Key technical constraints in respect of site surface hydrology for different classes of landfill are summarised in **Table 4-4** Surface Hydrology - Technical Constraints**.**

Table 4-4 Surface Hydrology - Technical Constraints

Class	1	2	3	4
Surface hydrology constraints	Water courses Flood plains Water supply catchments Estuaries, marshes and wetlands	Water courses Flood plains Water supply catchments Estuaries, marshes and wetlands	Water courses Flood plains Water supply catchments Estuaries, marshes and wetlands	Water courses Flood plains

Site Stability

Site stability should be considered from both the short and long term perspectives, including the effects of landfill settlement.

It is generally undesirable to site a landfill 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;
- close to active geological faults;
- areas of geothermal activity; and
- karst terrain: regions with highly soluble rocks, sinks and caverns (for example, limestone areas).

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, freezing and thawing, seepage and excavations.
- Local/onsite soil conditions that may result in significant differential settlement, for example, compressible (peat) or expansive soil, or sensitive clays or silts.

Where there is potential seismic risk, the ability to design containment structures, including liner, leachate collections systems and surface water control systems, to resist the maximum acceleration in lithified earth material for the site must be assessed.

Key technical constraints in respect of site stability for different classes of landfill are summarised in **Table 4-5** Site Stability - Technical Constraints**.**

Table 4-5 Site Stability - Technical Constraints

Class	1	2	3	4
Site stability constraints	Active faults Geothermal areas Karst areas	Active faults Geothermal areas Karst areas	Geothermal areas Karst areas	Geothermal areas

Environmentally Sensitive Areas

Landfills should generally be located to avoid areas where sensitive natural ecosystems would be adversely affected, such as those in **Table 4-6** Environmentally Sensitive Areas - Technical Constraints**.**

Table 4-6 Environmentally Sensitive Areas - Technical Constraints

Class	4	3	2	1
Environmentally sensitive areas (technical constraints)	Significant wetlands Inter-tidal areas Significant areas of native bush including Forest Parks and areas able to comply with the requirements for Q.E.II Trust status Recognised wildlife habitat including areas with regionally or nationally significant flora or fauna National/regional and local parks and reserve lands (for example, cemeteries) Any areas where release of contaminants from the site could adversely affect fish/wildlife/aquatic resources.			

Other areas that should be avoided include:

- sites of cultural or historical significance;
- historic and scenic reserves; and
- significant natural landscapes.

Compatibility with Surrounding Land Uses

The proximity of a potential landfill site to other existing or proposed land uses needs to be considered.

Ensuring adequate separation distances and/or buffer areas can help to preserve the amenity of surrounding areas, or avoid unwanted impacts from landfill operations. The requirement for, and extent of, buffer areas should be determined on a site-specific basis. Where possible, the buffer area should be controlled by the landfill operator.

An assessment of the suitability of a site for a landfill, and the extent of available buffer (with respect to 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), and
  - land designated for a special purpose (for example hospitals or schools);
- airport safety[2];
- the impact of site features such as topography;
- the impact of prevailing weather conditions; and
- proximity to sites of cultural or historical significance.

Topography

Site topography can reduce or increase the potential for nuisance effects (odour, noise, litter and dust) and visual effects on neighbouring properties.

Site assessment should include an assessment of the potential for existing topographical features to assist in minimising impacts.

[2] The CAA 'Guidance Material for land use at or near airports' (2008) notes that the International Civil Aviation Organisation (ICAO) Bird Control and Reduction Manual recommends that [municipal solid waste landfill] sites be located no closer than 13 kilometres from the airport property.

Moderate slopes enable easier stormwater control, leachate control and site stability measures, as well as facilitating the operation of the site. Engineering techniques can also improve site stability.

Climatic Conditions

Climatic conditions will have an influence on the choice of site. The following should be considered during site selection:

Rainfall

Landfills in high rainfall areas are generally undesirable and require greater attention to drainage than those in drier areas.

Sunshine

Higher sunshine areas and north facing slopes have increased evaporation, reducing infiltration.

Wind

Natural shelter from winds will reduce windblown waste and dust. Escarpments or valleys facing the prevailing wind should normally be avoided. Calm conditions are when odour may become an issue as can katabatic drainage[3] or unusual local weather patterns.

Climate Change

The potential effects of climate change should be considered, taking into account long term projections for the local area, e.g. droughts, increased rainfall, sea level rise, stronger winds etc.

Access and Traffic

Landfill development and operations can generate significant flows of heavy vehicle traffic. Site access should therefore be as close as possible to main feeder routes. When locating and determining access to landfills, consider:

- the type and number of vehicles accessing the site;
- other types of traffic using feeder roads;
- the standard and capacity of the road network, and its ability to accommodate traffic generated by the landfill;
- whether the traffic can avoid residential areas;

[3] Flow of high density cold air from a higher elevation down a slope, which occurs in calm conditions

- road safety considerations with respect to the landfill entrance. Vehicles using the landfill should not be required to queue on the highway;
- other transport options, for example rail.

Leachate Management

Landfill siting should take into account the potential methods of leachate treatment and disposal and its effect on site neighbours. See Section 4.8, Leachate Management.

Landfill Gas Management

Landfill gas can give rise to the following adverse effects:

- 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; and
- asphyxiation of personnel entering trenches, manholes or buildings on or near the landfill site.
- odour nuisance;
- greenhouse effects of methane;
- migration in surrounding sub-strata;
- vegetation die off on the completed landfill surface and on adjacent areas;

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

Landfill siting should take account of the requirements of the National Environmental Standard for Air Quality, the potential methods of landfill gas treatment and disposal, and potential effects on site neighbours. See also Section 4.9, Landfill Gas Management.

Cultural Issues

Areas of cultural significance should be avoided. While local authorities may have records of identified areas, engagement with local iwi is the best way to ensure that all known sites of cultural significance are identified early and negative cultural impacts avoided or resolved. However, sites or artefacts of cultural significance are sometimes exposed during excavation or construction. Protocols should be in place to enable an appropriate response and actions if this occurs.

Community Issues

Many of the matters which can be of greatest concern to the local community may not be those identified through technical studies or investigations.

Community issues typically include, but are not limited to:

- design life of the landfill;
- nuisances associated with odour, vermin, birds and flies, noise, litter, dust and visual effects;
- the potential effects of failure of containment, leachate collection or landfill gas systems;
- protection of local amenity values;
- traffic effects;
- health risks;
- cultural issues;
- heritage issues;
- loss of property values;
- long term compliance with consent requirements; and
- end use of the site.

Consultation with the community is an important step and may be required to identify issues of importance, related to actual (or perceived) risks and appropriate measures to avoid, remedy or mitigate adverse effects on the environment.

End Use of Land

The planned or likely end use of the proposed site is also an important consideration in site selection. Class 3 and Class 4 landfills sites often return to previous or similar land use, while other sites often end up being covered, vegetated and set aside as landscaped areas, or used for passive recreation or similar low impact uses compatible with the final landfill form.

5. Design

5.1 Introduction

The degree of environmental protection provided at a specific facility is strongly influenced by the quality of the engineering design. The level of environmental protection required is determined by:

- the class of landfill;
- the type of waste to be deposited in the landfill;
- the size and scale of the proposed filling operation;
- the surrounding environment; and
- the site location and physical characteristics.

Facility design should be site specific, based on an assessment of actual and potential effects on the environment. This assessment requires appropriately detailed technical evaluation and justification.

This section provides guidance on the following design aspects:

- design approach;
- design considerations, including:
  - groundwater management and control;
  - leachate containment and liner systems;
- surface water and stormwater management;
- leachate management and control;
- landfill gas management;
- landfill cover systems; and
- construction quality assurance and construction quality control.

5.2 Design Approach

General

Protecting groundwater and surface water from leachate contamination and protecting people from the adverse effects of landfill gas are the principal environmental performance objectives for landfill design. While many of the potential risks associated with landfills can be mitigated by judicious siting, additional engineered protection is critical for Class 1 and 2 landfills to avoid adverse effects on the environment from leachate and landfill gas discharges.

For Class 3 and 4 landfills, the primary environmental controls are appropriate site selection and the waste acceptance criteria. Therefore the design of a Class 3 and 4 landfill does not tend to focus on containment. Hence landfill features such as leachate collection, removal and treatment, low-permeability liners, gas management, cover and capping are also not as relevant because of the nature of the materials being disposed. However, erosion and sediment control are both very important considerations at such sites. Class 3 and 4 landfill design should be based on sound engineering principles and should be specific to the particular site.

New Zealand Landfill Design Trends

In New Zealand a number of trends (paralleling overseas practice) have emerged in relation to landfill design for Class 1 and Class 2 landfills. These include:

- a tendency towards centralisation of landfill facilities and an increase in waste transfer to fewer, larger (sometimes regional) facilities;
- greater recognition of the siting sensitivity attached to landfills and the need for both good design, stringent operating practices and comprehensive monitoring requirements;
- acceptance that an engineered liner and leachate collection system is necessary for sites where leachable material may enter the groundwater and affect human health or the natural environment; and
- development of landfills for differing levels of engineered redundancy and environmental controls, based on the types of waste(s) proposed to be accepted.

Furthermore, the introduction of the Waste Minimisation Act 2008 and the Climate Change Response Act 2002, and associated Regulations, have led to changes in waste disposal practices. There is now more waste disposal segregation and a further trend towards more specialised facilities, designed specifically for the types of fill material/waste being disposed.

Design Objectives

The level of environmental protection required, and consequently the level of design, is dependent on the types of fill material/waste to be accepted at a specific facility. Section 1.6 of these Guidelines sets out four classes of facility, according to the nature of the material received at the site, as follows:

- **Class 1**: for municipal solid waste (MSW), household waste, commercial and industrial waste, as well as waste suitable for Class 2 to 4 landfills. Class 1 landfills may also be for industrial wastes.

- **Class 2**: for construction and demolition waste, inert industrial wastes, as well as waste suitable for Class 3 and 4 landfills;
- **Class 3**: for managed fill and clean fill material.
- **Class 4**: for clean fill material.

5.3 Design Considerations

The designer should consider the potential environmental impact of the landfill throughout its life and post closure, and incorporate mitigation measures into the design appropriate to the class of landfill or fill material/wastes to be accepted. The effectiveness of the design will have a significant influence on the environmental performance, operation, restoration and aftercare of the facility. The following aspects need to be considered in the design:

- Waste type, acceptance rate and total quantity;
- water control;
- protection of soil and water;
- leachate management;
- landfill gas management;
- environmental nuisances;
- stability;
- visual appearance and landscape;
- operational and restoration requirements;
- monitoring requirements;
- whole of life costs;
- post closure use of the site;
- construction; and
- risk assessment and mitigation.

Landfill design and operations practice are not static and over time should respond to changes in knowledge, technology and legislation. Consequently, design requires periodic review to reflect the changes in knowledge and the findings of performance monitoring over time. It is not uncommon for environmental protection requirements to change significantly over the life of a particular landfill.

5.4 Siting

Appropriate site selection is an important step in mitigating the potential impacts of a facility. For example, the potential for effects on human health and the environment by leachate is more critical if the landfill is located where there is significant downstream use of surface or groundwater resources, or where conditions result in significant physical or local amenity risk. Landfills can cause a localised loss of amenity due to litter, dust, odour, noise, and vermin problems where inadequate buffer or separation is able to be provided. Hence proximity to existing and proposed developments, the adequacy of proposed site management procedures and local climatic conditions are key issues in this regard, with reverse sensitivity also being an issue to consider, as well as the fundamental issue of containment system design.

Investigations and Site Characterisation

Investigation requirements for a landfill will vary from site to site. For a particular site the extent of investigations will depend on:

- geological/geotechnical complexity;
- hydrogeological complexity;
- size of site and landfill; and
- class of landfill.

Sufficient investigations, testing and preparatory work need to be undertaken to provide:

- appropriate characterisation of the geological, hydrogeological and geotechnical conditions at the site;
- a conceptual model of site hydrogeology, including the piezometric surface;
- specific data on site soil properties for materials to be used in construction and operation of the facility such as for a soil liner or capping material and for assessing site stability;
- background analysis of surface and groundwater quality, together with background analysis of site soil contaminant concentrations for future reference in relation to potential effects of the landfill;
- definition and characterisation of surface waters, including receiving waters;
- identification of any areas to be protected (e.g. watercourses, wetlands, areas important to local Iwi, archaeological sites, vegetation, steep slopes, etc.);
- location of any services on the site (such as buried or overhead power or telephone cables, water, sewer or gas pipes);
- base contour information for design purposes (colour aerial photographs are also very useful for design development and presentation of concepts); and
- photomontages for assessment of visual and landscape effects.

Materials Requirement and Balance

Soil materials are required for all stages of a landfill development (construction, operation and restoration). Therefore, in the early stages of a project, it is important to establish what materials are required, where and when these materials will be sourced and what surplus, unsuitable, materials will be generated. Consideration of material sources may have a significant impact on how the site is developed.

Site Access

Access to a landfill needs to be controlled to restrict the mixing of private, commercial and landfill operations vehicles. In particular, access to the tipping face should be limited to authorised vehicles.

Appropriate provision should be made for diversion of recycled materials. This could be extended to providing for separation of recycled materials from mixed loads delivered to site, depending on the scale and circumstances.

External Access

A landfill will generate heavy vehicle movements. The standard of all roads and bridges forming part of the principal access route to the landfill and their construction should be reviewed. Upgrading of roads and bridges may be required.

Access to a landfill should be planned so that it creates minimal hindrance to existing road users. Access should, where possible, be along primary regional roads where heavy traffic movement is usual (such as state highways) and on sealed roads to reduce dust and mud nuisance, reduce maintenance and facilitate road cleaning.

Careful consideration should be given to the requirements of national and local road control authorities.

Internal Access

The layout of the site entrance should facilitate smooth traffic flow. Access from a public road should be by a sealed road to the reception control area, laid out such that queuing vehicles do not back up onto public roads. This may require the inclusion in the design of slip lanes, passing bays, turning areas etc.

The appearance of the access-way is important as this will influence both the public and the user perception of a site and hence behaviour in the landfill area.

Traffic control by clear, attractive signage and an appropriate road layout is required to direct vehicles to the weighbridge, payment booth and unloading area(s).

At larger landfills, internal roads that are permanent, or that will have a substantial service period should be sealed, particularly if on steep gradients. Temporary access roads should be all-weather standard.

It is recommended that public access to tip faces be eliminated completely. If public drop off areas are required they should be in a separate area of the site where the safety of users can be effectively managed.

Consideration should also be given to access to the tipping area. In particular, it is important that the access does not put the base liner at risk. Typical access ramps will be up to 10m wide, depending on the need for two-way traffic, and should have slopes no steeper than 10% for full road truck access down-hill, and 8% for full road truck access up-hill. The maximum haul road gradient for off-road trucks (e.g., trucks hauling cover material) is typically in the order of 12.5% maximum gradient.

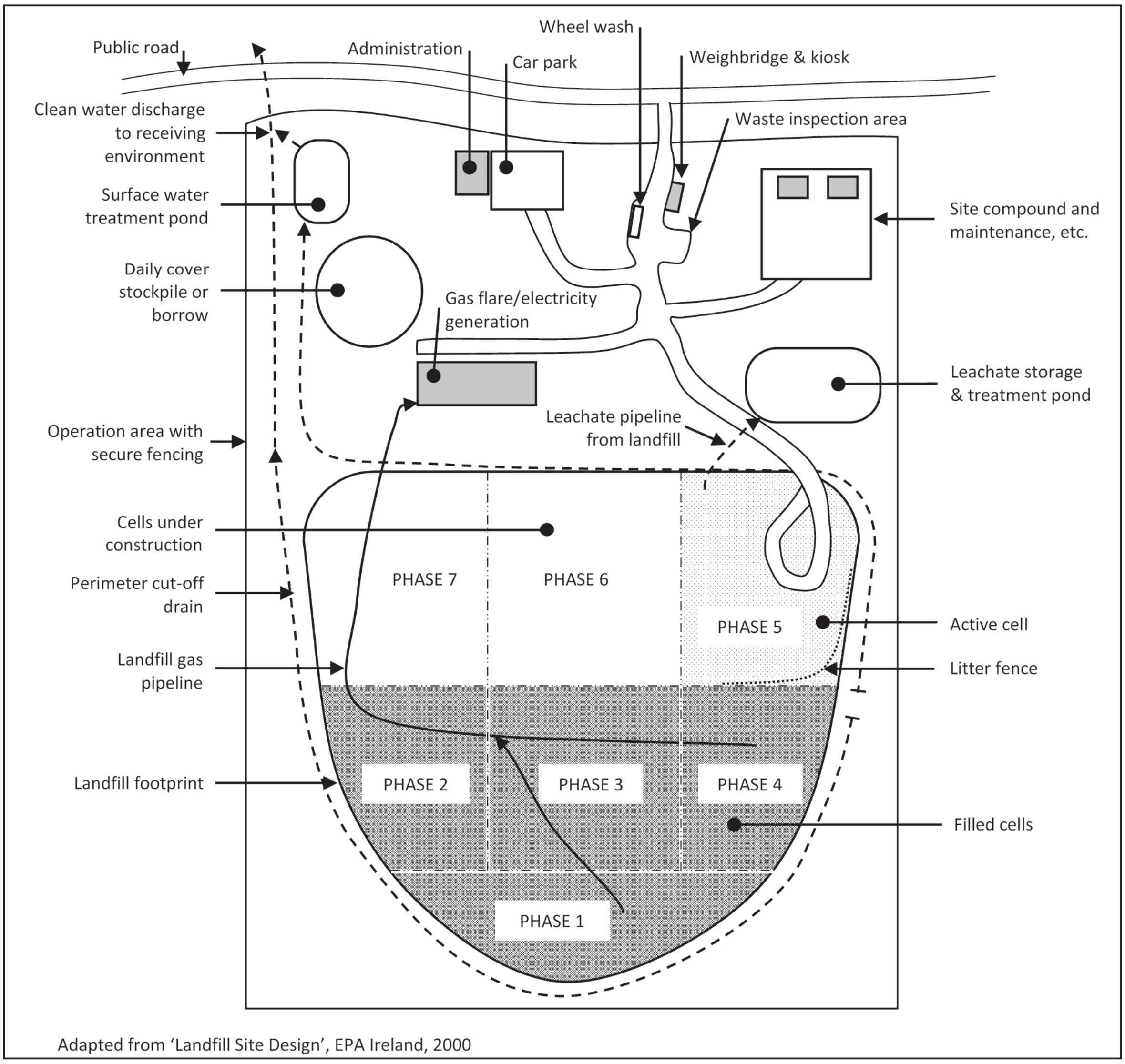
Site Facilities

The extent of the site facilities required will depend on site-specific conditions such as the size of the landfill, the waste accepted and the agreed charging and waste control measures. Facilities generally include:

- a barrier arm;
- a weighbridge for charging and waste control;
- a booth for collecting dockets, housing weighbridge control and record equipment and controlling entrance to the site (waste acceptance control);
- staff facilities, including office, lunchroom and toilets;
- site services, including power, telephone, water supply and sewage disposal;
- emergency shower;
- wheel wash facilities to prevent soil and debris being deposited on local roads;
- appropriate fencing and a lockable gate to control access to the site, including by animals;
- visitor parking; and
- landscaping to help reduce visual effects and control dust.

A typical operational plan for a landfill site is shown in **Figure 5-1** Typical Operational Plan for a Landfill Site**.**

Figure 5-1 Typical Operational Plan for a Landfill Site.



Phasing

The filling period at a site is typically the time during which the risk of environmental harm is at its highest. Therefore, the landfill should be constructed as a series of phases to limit the extent of the active footprint at any time. Phasing also allows for the progressive development of construction, operation and restoration and the spreading of capital expenditure. Given the weather-dependent nature of construction, phases are typically developed with sufficient void space for a minimum of two to five years filling. Actual phasing will depend on the size and waste acceptance rate of the facility, with a site with low waste acceptance rates tending to be at the longer end of that range.

The appropriate phasing for a specific site will depend on the extent to which:

- progressive construction, filling and operation can be undertaken without interface complications;
- progressive development can be undertaken in a timely manner to align with construction season;
- on-site material use can be maximised and double handling minimised;
- leachate and landfill gas management infrastructure can be constructed in a timely manner; and
- stormwater can be managed to minimise the potential for contamination.

5.5 Groundwater Control

Objectives: Maintain separation of leachate from groundwater
Prevent distortion or uplift of liner due to excessive groundwater pressures

A hydrogeological assessment is required to establish the groundwater control required for site development as a landfill. The level of detail required for the hydrogeological assessment will depend on the type of facility, the sensitivity of the surrounding groundwater environment, and current or potential groundwater uses. The information obtained will assist in the development of a conceptual site model that should include:

- geological profile;
- hydrogeological properties of all strata, including permeability, transmissivity/groundwater flow rates and velocities, attenuation potential;
- groundwater quality;
- groundwater flow directions;
- groundwater contours beneath and surrounding the site;
- groundwater catchment boundaries;
- groundwater protection and usage zones; and
- relationship with surface waters.

The base of an unlined landfill should preferably be above the groundwater table, with a low permeability unsaturated zone immediately below it, with a thickness of at least 2m. Ideally the base of a lined landfill should also be located several metres above the groundwater table.

Groundwater Drainage

In situations where a Class 1 or 2 landfill needs to be located with the cell base levels at or below the water table, an underdrainage system is usually required. This is needed to intercept groundwater seepage and to control groundwater pressures beneath the landfill cell base to reduce potential hydrostatic uplift pressures on the basegrade and liner.

If there is any significant seepage from side walls and the cell base, this should be intercepted with an appropriate underdrainage system, to avoid the risk of uplift and distortion of the liner until sufficient waste is placed in the landfill to counteract long term hydrostatic pressure.

A gravity drainage system is preferred for long term operation, but in some cases a temporary pumped system may also be appropriate.

Design of an underdrainage system should consider the following:

- pipes should be sized to carry the maximum probable flow and designed for full cell depth overburden loads to eliminate the risk of crushing;
- incorporation of specific drainage requirements to accommodate discrete spring flows;
- careful selection of filter stone or filter fabric size to avoid potential clogging of drainage layers by fine materials; and
- selection and protection of pipes to ensure risk of construction damage is negligible.

In general, the designer will need to demonstrate by way of calculation that the proposed design is robust. Drainage layers and pipes should be over-designed to allow for biological, chemical and physical clogging and a resulting reduction in flow capacity. In addition, it is preferable to design the underdrainage system to enable use of closed circuit television (CCTV) and remote control hydro-jetting equipment for inspection and cleaning of primary underdrain pipework.

Where appropriate, groundwater drainage discharge quality should be accessible for monitoring to detect and assess possible leachate contamination. This is addressed in Section 7, Monitoring.

Table 5-1 Summary of Minimum Groundwater Drainage Requirementssummarises under drainage requirements for the different classes of landfill.

Table 5-1 Summary of Minimum Groundwater Drainage Requirements

Class	1	2	3	4
Underdrains	Yes	Yes	NA	NA

5.6 Surface Water and Stormwater Management

Objectives: Maintain separation of stormwater from waste/leachate
Minimise leachate generation by preventing infiltration into the waste
Prevent surface water contamination by sediment and leachate
Minimise potential for erosion of the liner system during waste placement
Minimise potential for erosion of intermediate or final capping systems
Prevent uncontrolled off-site discharges

Design of surface water management systems should consider the following:

- Interception drains surrounding the active landfill area to prevent overland flow from entering the active landfill area.
- Rainfall falling on the active landfill 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. These diversion drains/channels may require invert protection to prevent scour and/or lining to prevent 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 design storms.
- Completed landfill 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.

Depending on the circumstances, temporary surface management systems typically should be designed for at least a 1-in-10 year storm (10% AEP) and permanent systems for a 1-in-100 year storm (1% AEP).

Any stormwater that has been diverted from the filling site is likely to carry a high silt load and should be treated in sedimentation ponds prior to discharge. This is usually a consent requirement.

Sedimentation ponds should be developed prior to discharge of surface waters to natural streams or rivers and hence are required early in the construction process. Ponds and traps should be designed to ensure easy maintenance and cleaning.

In summary, drainage systems for landfills should contain provision for diversion, retention and testing of surface water and stormwater. Retention and testing requirements for Class 4 landfills should be assessed on a site-specific basis. See **Table 5-2** Summary of Minimum Surface Water and Stormwater Drainage requirements.

Table 5-2 Summary of Minimum Surface Water and Stormwater Drainage requirements

Class	1	2	3	4
Diversion	Yes	Yes	Yes	Yes
Retention e.g. sedimentation ponds	Yes	Yes	Yes	Site Specific
Testing	Yes	Yes	Yes	Site Specific

5.7 Liner Systems

Objectives: Contain leachate for collection and treatment/disposal

Minimise leachate leakage to groundwater

Liner Design

The liner system protects the surrounding environment from contamination from leachate and landfill gas, as well as controlling the ingress of groundwater. The selected liner system needs to be physically robust and designed to provide containment until the point the waste material no longer poses a risk to the environment. The type of liner system selected depends on the nature of the site, the waste type(s) and hence the anticipated characteristics of the leachate.

The recommended liner for each class of landfill covered by these Guidelines is:

Class 1 Liner

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

Type 1

A composite liner comprising a synthetic flexible membrane liner (FML) (usually 1.5 mm thick high density polyethylene (HDPE)) but may be an alternative with similar chemical resistance and performance), overlying 600 mm of compacted cohesive soil with a coefficient of permeability not exceeding 1×10^{-9} m/s, compacted in layers a maximum of 150 mm thick.

Type 2

A composite liner comprising a synthetic flexible membrane liner (FML) 1.5 mm thick, overlying a geosynthetic clay liner (GCL) a minimum of 5 mm thick, with a coefficient of permeability not exceeding 1×10^{-11} m/s, overlying a:

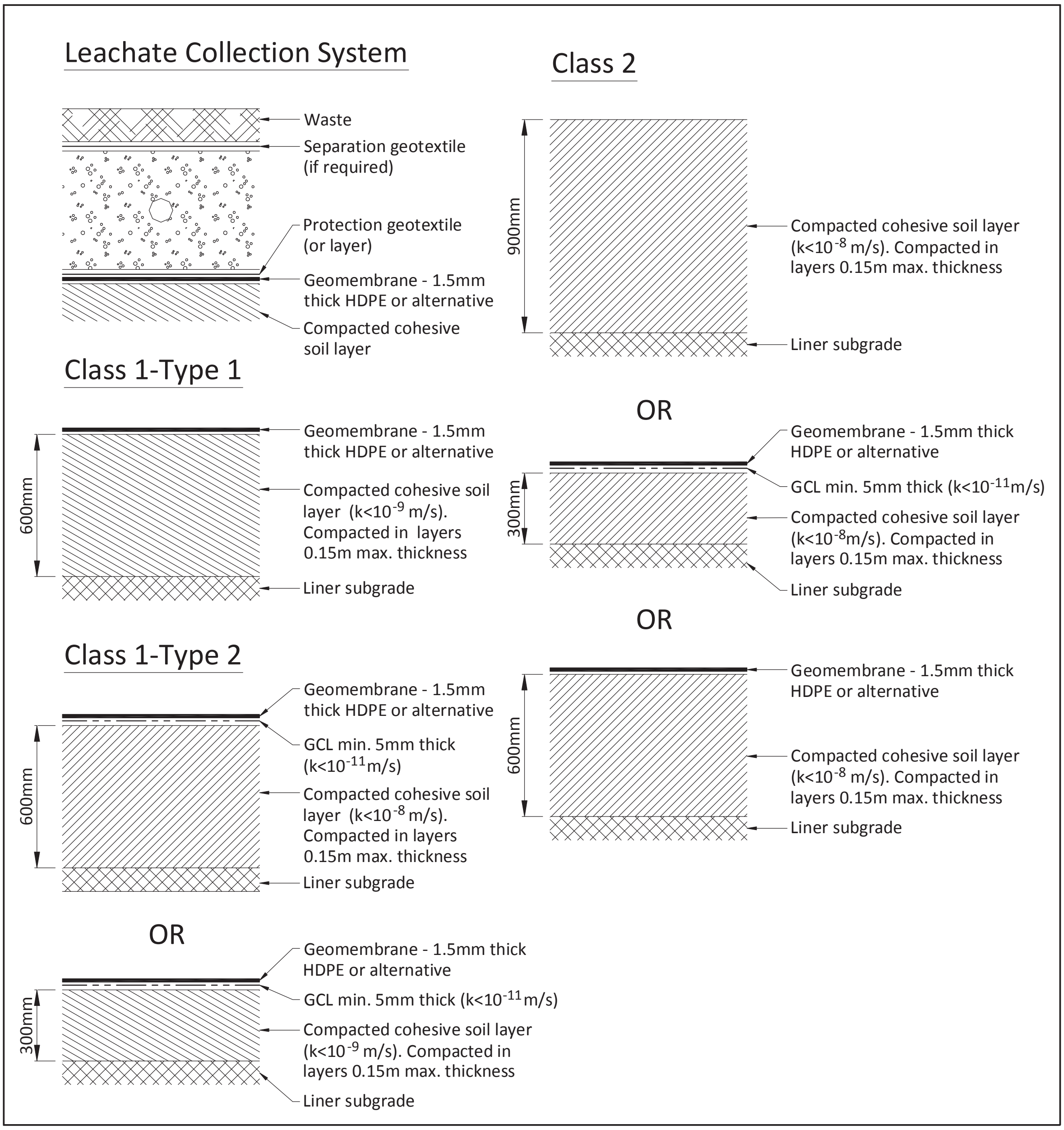
- 600 mm thick layer of compacted cohesive soil with a coefficient of permeability not exceeding 1×10^{-8} m/s, compacted in layers a maximum of 150 mm thick; or
- 300 mm thick layer of compacted cohesive soil with a coefficient of permeability not exceeding 1×10^{-9} m/s, compacted in layers a maximum of 150 mm thick.

Class 2 Liner

The following liner designs are recommended, **(Figure 5-2 Liner Types**), as they have been shown to provide a suitable level of protection to the receiving environment for a Class 2 landfill sited in accordance with these Guidelines:

- a single liner comprising 900 mm of compacted cohesive soil compacted in layers a maximum of 150 mm thick, to achieve a coefficient of permeability not exceeding 1×10^{-8} m/s; or
- a composite liner comprising a synthetic FML 1.5 mm thick, overlying a geosynthetic clay liner (GCL), a minimum of 5 mm thick, with a coefficient of permeability not exceeding 1×10^{-11} m/s, overlying a 300 mm thick layer of compacted cohesive soil compacted in layers a maximum of 150 mm thick, to achieve a coefficient of permeability not exceeding 1×10^{-8} m/s;
- a composite liner comprising a synthetic FML 1.5 mm thick, overlying a 600 mm thick layer of compacted cohesive soil compacted in layers a maximum of 150 mm thick, to achieve a coefficient of permeability not exceeding 1×10^{-8} m/s.

Figure 5-2 Liner Types



Class 3 Liner

No engineered liner or leachate collection system is required for a Class 3 landfill as the environmental effects are controlled primarily by waste acceptance criteria.

Class 4 Liner

No engineered liner or leachate collection system is required for a Class 4 landfill as the environmental effects are controlled primarily by waste acceptance criteria.

Soil Liners

Natural low permeability materials, such as clays, silty clays and clayey silts, have the potential to be used as landfill liners, either on their own or in conjunction with geosynthetic materials. The permeability and uniformity in performance of natural in-situ materials are difficult to predict and expensive to prove. It is therefore recommended that if natural materials are used, they are used in engineered liners. The thickness and permeability of an engineered soil liner will depend on the landfill type as outlined above.

Additional details of soil liner design and construction are contained in **Appendix B1**.

Geosynthetic Clay Liners

A Geosynthetic Clay Liner (GCL) typically consists of a thin bentonite layer, approximately 5 to 10 mm thick, sandwiched between two layers of geotextile. The factory manufactured composite material is held together by stitching, needle punching or gluing. The primary function of component GCL in a landfill is to act as a hydraulic and/or gas barrier in liner and capping systems.

Additional details of geosynthetic clay liners are contained in **Appendix B1**.

Geomembranes

Geomembranes are flexible polymeric sheets mainly used as liquid and/or vapour/gas barriers. Their primary function in a landfill is to act as a hydraulic and/or gas barrier in liner and capping systems. There are many types of geomembrane available. Design considerations which may affect the choice of a geomembrane include:

- chemical resistance of the material to the anticipated leachate characteristics;
- tensile strength and elasticity;
- thermal stability;
- puncture, tear and shear resistance;
- interface friction characteristics;
- design life; and
- local conditions such as subsoil stability.

The majority of geomembranes used in landfills are manufactured from thermoplastics (i.e. can be re-melted) as these tend to have the required strength and durability characteristics, and sheets are relatively easy to weld together to form a continuous barrier.

Polyethylene is by far the most common polymer used in landfills, with high density polyethylene (HDPE) typically used in base and side liner systems. Either HDPE or linear low density polyethylene (LLDPE) geomembranes are typically used in capping systems. The favourable strain characteristics of LLDPE means it is able to accommodate settlement better than HDPE.

Additional details of geomembrane liners are contained in **Appendix B1**.

Protection Geotextiles

Geotextiles consist of polymeric filament, fibres or yarns made into woven and nonwoven textile sheets. The sheets are flexible and permeable and generally have the appearance of a fabric. The primary uses of geotextiles in landfills include separation, filtration, drainage, erosion control and protection. However, this section covers only the use of nonwoven geotextiles used to protect geomembranes from mechanical damage during construction and throughout their design life.

Where a geomembrane is present, it usually needs to be protected from mechanical damage from the materials it is directly in contact with. Typically a protection layer is provided in the form of a nonwoven, needle-punched geotextile. The protection layer can be required below the geomembrane, due to the properties of the founding layer, although more typically it is placed above. The type of polymer selected (i.e. polyester or polypropylene) depends on the waste composition and resulting leachate strength, with polypropylene having better performance than polyethylene based geotextiles.

The purpose of a protection layer is to:

- minimise the risk of damage or puncture of the geomembrane during construction and subsequent operation of the landfill; and
- minimise the strains in the geomembrane and hence the risk of rupture.

Additional details of design using protection geotextiles are contained in **Appendix B1**.

Liner and Global Stability

Careful consideration of the global and local stability of a landfill and its liner system is required.

Details of stability, waste settlement and slope considerations are contained in **Appendix B1**.

Contaminant Transport

There are two mechanisms whereby contaminants in leachate may migrate from the landfill, namely:

- **Advection:** the transport mechanism by which contaminants migrate with a fluid by the fluid's bulk motion (seepage).
- **Diffusion:** the chemical process by which contaminants migrate from areas of higher concentration to areas of lower concentration, even when there is no flow of water. It is the mechanism that tends to control contaminant transport through well-constructed barrier systems, where good quality-assurance and quality control is applied during the construction of the liner system, and where there is no significant liner damage.

As part of the design of a liner system, the potential for, and extent of, both mechanisms should be assessed. The rate and extent of diffusion depends on the behaviour of the contaminants and their interaction with the liner system, and should be considered as part of the liner system design and when assessing alternative liner components.

Seepage of leachate through a soil (clay) liner is governed by the thickness of liner, the head of leachate above the liner, the coefficient of permeability of the liner material and the degree of saturation of the clay. Darcy's Law can be used to estimate the seepage rate through a soil liner once the liner has become fully saturated. For a composite liner that includes a geomembrane, the design seepage rate can be estimated based on known field data related to liner defect frequency for geomembranes, and assumed soil permeabilities using the method developed by Giroud et al (1998).

Alternative Liner Designs

Liner designs other than those recommended here could be suitable for some sites. In undertaking a site-specific assessment the following should be considered:

- landfill size;
- the influence of actual geological and natural containment characteristics on designs;
- proximity to, and sensitivity of, the surrounding environment; and
- settlement of underlying materials, for example, when a liner and leachate collection system is placed over an existing unlined landfill (piggy-back liner).

In considering design options, a quantitative evaluation of liner leakage and effects on the receiving environment – including attenuation, should be undertaken. This will require:

- an assessment of the composition of leachate likely to be produced;
- an assessment of the quantity of leachate leakage expected through the engineered containment system, by both advection and diffusion;
- if appropriate, leachate attenuation tests on materials underlying the site, using leachate similar to that expected at the site;
- an assessment of likely leachate concentrations in groundwater at the site boundary or compliance point in the receiving environment; and
- an assessment of the effects of leachate contamination on the receptor environment(s).

A summary of liner requirements is provided in **Table 5-3** Summary of Recommended Minimum Liner Requirements**.**

Table 5-3 Summary of Recommended Minimum Liner Requirements

Class	1	2	3	4
Minimum base grade slope	2%	2%	NA	NA
Liner – compacted cohesive soils	NA	900 mm compacted cohesive soil @ < 1 x 10^{-8} m/s	NA	NA
Liner - composite	HDPE 1.5 mm, and 600 mm compacted cohesive soil @ k< 1 x 10^{-9} m/s	HDPE 1.5 mm, GCL, and 300 mm compacted cohesive soil @ k < 1 x 10^{-8} m/s	NA	NA
	HDPE 1.5 mm, GCL, and 600 mm compacted cohesive soil @ k < 1 x 10^{-8} m/s	HDPE 1.5 mm, and 600 mm compacted cohesive soil @ k< 1 x 10^{-8} m/s		
	HDPE 1.5 mm, GCL, and 300 mm compacted cohesive soil @ k < 1 x 10^{-9} m/s			

5.8 Leachate Management

Leachate Generation

Leachate is any liquid that, in passing through waste, extracts solutes, suspended solids or other components of the waste material through which it has passed. This includes liquid included in the waste as received and that drains as a result of waste compression, or the ongoing breakdown of organic matter.

Leachate needs to be controlled to:

- reduce the potential for seepage out of the landfill through the sides or base either through defects in the liner system or by flow through its matrix;
- prevent liquid levels within the landfill reaching a level that may cause an uncontrolled discharge to the surrounding environment, or results in waste mass instability;
- influence the biodegradation of the waste and consequently the generation of landfill gas.

The factors that influence leachate generation at landfills include:

- climate;
- topography;
- on-site stormwater and cell management practices;
- landfill cover material use and timing of its application;
- type of waste;
- final cap composition, maintenance and its vegetation

Leachate Generation Estimates

Developing reliable leachate generation estimates is an important part of the design process for landfills. The amount and bio-chemical strength of leachate generated will affect operating costs, both during filling and following closure. The amount of leachate formed is also a factor in the potential for liner leakage and hence the potential for groundwater contamination.

A water-balance approach is typically used to assess likely leachate generation volumes. This process can be approached in different ways and an appropriate water-balance model may be used to develop estimates. Key input parameters include:

- waste quantities;
- waste input rates and adsorptive capacity;
- operational areas;
- rainfall and evapotranspiration data over an extended period;
- infiltration and other site parameters;
- areas of cover and capping;
- soil properties of the cap; and
- groundwater intrusion (for unlined landfills).

As the landfill operation progresses estimates of leachate generation are usually able to be refined based on field data and experience. Refinement of generation estimates may take into account factors such as moisture losses via landfill gas and waste fermentation (Knox, 1991).

More information on leachate generation is contained in **Appendix B2**.

Leachate Characteristics

In general, the composition of leachate is a function of the types and age of waste deposited, the prevailing physicochemical conditions, and the microbiology and water balance of the landfill.

Decomposition of putrescible waste takes place through the action of microbes. It occurs in three stages.

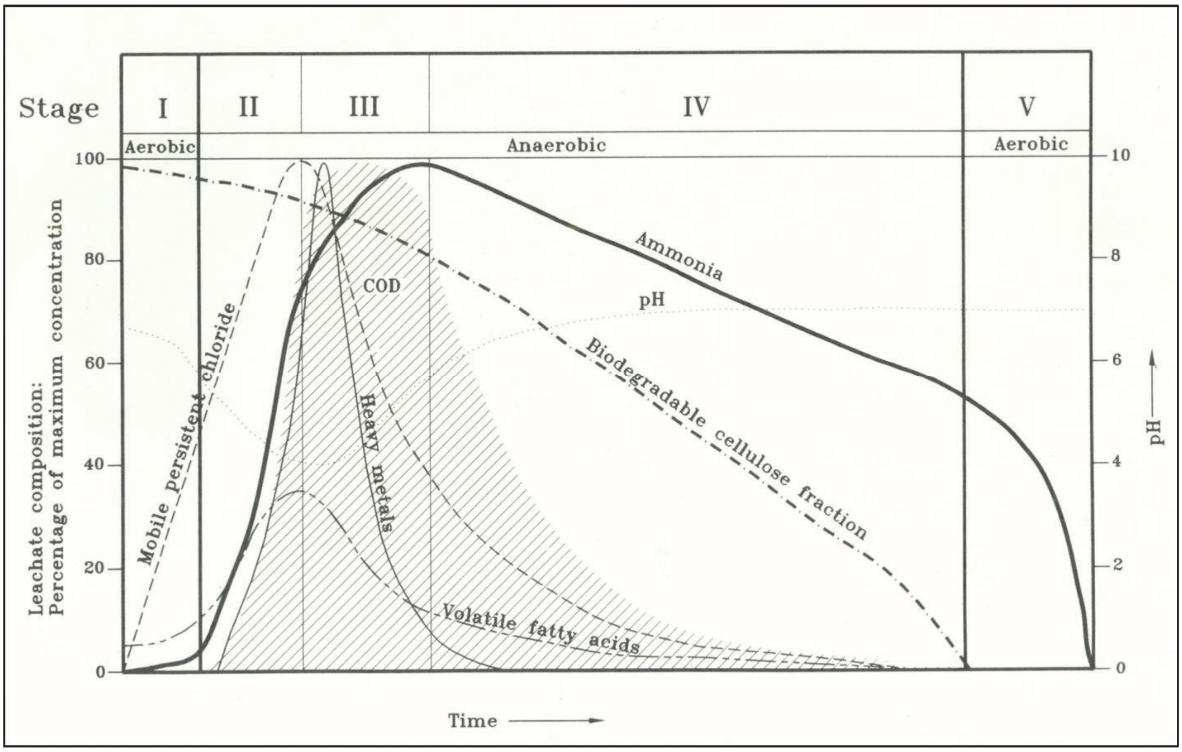
In the first stage, readily degradable organic material is decomposed by aerobic organisms, resulting in the production of simpler organic compounds, carbon dioxide and water. Heat is generated, and the aerobic organisms multiply.

The second stage commences when all the available oxygen is consumed, or is displaced by carbon dioxide. Aerobic organisms, which thrived when oxygen was available, then die off. The degradation process is then taken over by facultative organisms that can thrive in either the presence or absence of oxygen. These organisms continue to break down the organic material present into simpler compounds such as hydrogen, ammonia, water, carbon dioxide and organic acids. During this stage carbon dioxide concentration can reach a maximum of 90 percent, although concentrations of about 50 percent are more usual.

In the third and final stage (the fully 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 the leachate that forms. In addition, pH changes and acid formation may mobilise metals and increase their concentration in the leachate. **Figure 5-3** Changes in Leachate Composition with Time and **Table 5-4** show the changes in Class 1 landfill leachate composition that occur as a landfill proceeds through the various phases of decomposition.

An indication of the range of strengths of leachate from Class 1 and Class 2 landfills is given in **Table 5-5**.

Figure 5-3 Changes in Leachate Composition with Time



Source: UK Department of Environment 1991

Table 5-4 Changes in Leachate Composition in Different Stages of a Landfill

Parameters with differences between acetic and methanogenic phase			Parameters for which no differences between phases could be observed		
Acetic phase	**Average**	**Range**		**Average**	**Range**
pH	6.1	4.5-7.5	Cl (mg/l)	2100	100-5000
BOD_5 (mg/l)	13000	4000-40000	Na (mg/l)	1350	50-4000
COD (mg/l)	22000	6000-60000	K (mg/l)	1100	10-2500
BOD_5 /COD ratio	0.58	--	Alkalinity (mg CaCO3/l)	6700	300-11500
SO_4 (mg/l)	500	70-1750	NH_4 (mg N/l)	750	30-3000
Ca (mg/l)	1200	10-2500	Org N (mg N/l)	600	10-4250
Mg (mg/l)	470	50-1150	Total N (mg N/l)	1250	50-5000
Fe (mg/l)	780	20-2100	NO_3 (mg N/l)	3	0.1-50
Mn (mg/l)	25	0.3-65	NO_2 (mg N/l)	0.5	0-25
Zn (mg/l)	5	0.1-120	Total P (mg P/l)	6	0.1-30
			AOX (ug/Cl/l)*	2000	320-3500
Methanogenic phase			As (ug/l)	160	5-1600
pH	8	7.5-9	Cd (ug/l)	6	0.5-140
BOD_5 (mg/l)	180	20-550	Co (ug/l)	55	4-950
COD (mg/l)	3000	500-4500	Ni (ug/l)	200	20-2050
BOD_5 /COD ratio	0.06	--	Pb (ug/l)	90	8-1020
SO_4 (mg/l)	80	10-420	Cr (ug/l)	300	30-1600
Ca (mg/l)	60	20-600	Cu (ug/l)	80	4-1400
Mg (mg/l)	180	40-350	Hg (ug/l)	10	0.2-50
Fe (mg/l)	15	3-280			
Mn (mg/l)	0.7	0.03-45			
Zn (mg/l)	0.6	0.03-4			

Source: Ehrig, H. J., 1989. Water and Element Balances of Landfills. In *Lecture Notes in Earth Sciences: The Landfill.*
Note:
* adsorbable organic halogen

Table 5-5 Leachate from Class 1 and Class 2 Equivalent Landfills

Parameter	Class 1*	Class 2**	C&D Landfills (USA)
	8 Sites, 1998-1999 (CAE Guidelines, 2000)	2 Sites , 2007-2012 (Waikato Regional Council)	Melendez (1996) *** Figure in parenthesis is the mean.
pH	5.9 - 8.5	5.9 - 8.3	6.45 - 7.60 (6.95)
Conductivity	264 - 27900 mS/m	120 – 554 mS/m	
Alkalinity	264 - 6820 mg/l	70 - 1930 mg/l	38.2 - 6,520 mg/l (970)
Ammoniacal N	3.4 - 1440 mg/l	0.86 - 99 mg/l	0.1 – 170 mg/l (20.42)
TOC	17.2 - 822 mg/l	55 - 191 mg/l	15 – 2100 mg/l (306)
BOD_5	12 - 3867 mg/l	1.4 - 38 mg/l	5.7 – 920 mg/l (87.3)
COD	84 - 5090 mg/l	15 - 610 mg/l	
SO_4B	1 - 780 mg/l	360 - 1900 mg/l	11.7 - 1,700 mg/l (254)
Cl	0.54 - 20 mg/l	0.3 - 28 mg/l	(2.65 mg/l)
As	45 - 2584 mg/l	18 - 200 mg/l	52.7 - 262 mg/l (158)
Cr	0.006 - 0.191 mg/l	0.027 - 0.64 mg/l	0.0014 - 0.046 (0.012)
Cu	0.005 - 50.4 mg/l	0.001 - 0.102 mg/l	
Fe		0.0023 - 0.3 mg/l	
Pb	1.6 - 220 mg/l	0.001 - 103 mg/l	0.050 - 275 mg/l (36)
Zn	0.001 - 0.42 mg/l	0.0025 - 5.5 mg/l	0.0049 - 1.18 mg/l (0.0088)
	0.009 - 24.2 mg/l	0.031 - 4.9 mg/l	0.02 - 5.16 mg/l (0.657)

Note:

* Consented MSW landfills that accepted wastes proposed for Class 1 landfills.

** Consented lined C&D landfills that accepted C&D wastes proposed for Class 2 landfills.

*** Melendez, B.A., A Study of Leachate Generated from Construction and Demolition Landfills, 1996

Leachate Collection and Removal Systems

Objective: Enable effective long term collection and removal of leachate
Minimise head of leachate on the liner

Leachate Collection System Components

The leachate collection and removal system (LCRS) is placed at the base of the landfill, above the liner system. The functions of the LCRS are to:

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

The LCRS must be designed to function throughout the operating life and after-care period of the landfill. Failure of any component can jeopardise the operation of the entire system. Hence LCRS design must be robust and conservative. The design must ensure the system is able to be maintained and rejuvenated over time, for example to mitigate clogging of collection pipes or drainage layers.

The LCRS typically consists of:

- a drainage layer constructed of either a natural granular material (graded gravel) or synthetic drainage material (e.g. geonet or geocomposite);
- perforated leachate collection pipes installed within the drainage layer to collect leachate and convey it to a collection sump;
- a protective filter layer over the drainage layer to prevent physical clogging of the drainage layer by fine material migrating downwards from the overlying waste;
- leachate monitoring points; and
- leachate collection sump(s) from which leachate can be removed.

Figure 5-4 Typical Leachate Collection System (side slope riser) and **Figure 5-5** illustrate typical leachate collection systems.

Figure 5-4 Typical Leachate Collection System (side slope riser)

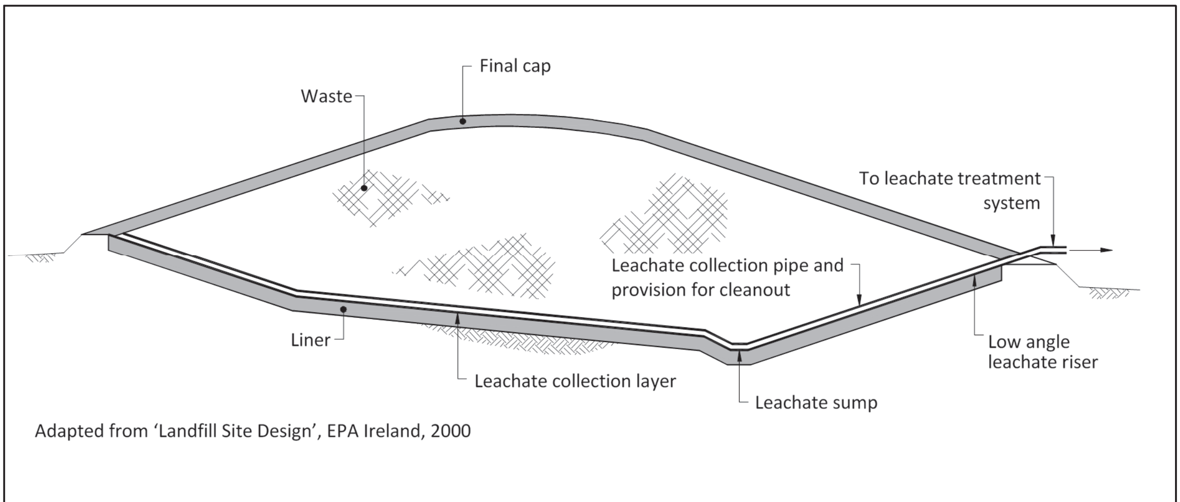


Figure 5-5 Typical Leachate Collection System (vertical riser)

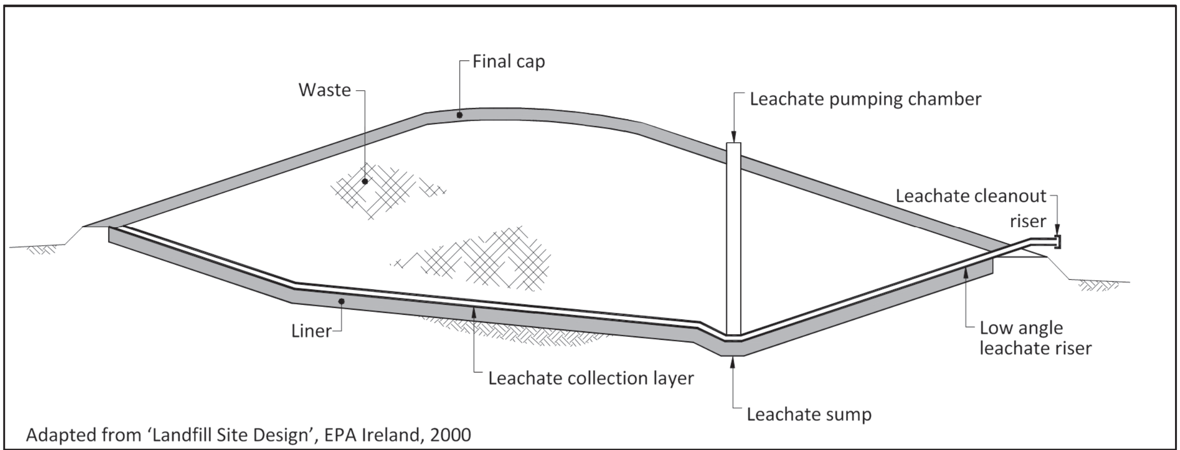


Table 5-6 summarises minimum leachate collection system requirements.

Table 5-6 Summary of Minimum Leachate Collection System Requirements

Class	1	2	3	4
Components	Drainage Media and/or Perforated Pipes	Drainage Media and/or Perforated Pipes	NA	NA
Maximum Leachate Head (mm)	300	300	NA	NA

Details of leachate collection system design are contained in **Appendix B2**.

Leachate Recirculation

Objective: Speed up the rate of waste degradation and associated landfill gas production and settlement

The potential benefits of leachate recirculation are:

- increase in the quantity and quality of landfill gas for use in energy recovery projects;
- reduction in the cost of leachate collection and treatment;
- increased rate of landfill settlement and hence potential to maximise air space; and
- potential for early stabilisation of the landfill resulting in a reduced post-closure maintenance period and associated cost.

Potential issues with implementing leachate recirculation at a landfill are:

- potential for increased leachate levels which may
  - affect the stability of waste mass
  - increase head on the liner thereby increasing liner leakage
  - result in leachate breakout from side slopes;
- increased concentration of contaminants in the leachate;
- increased potential for differential settlement; and
- increased potential for odour.

Mitigation of these concerns is addressed in **Appendix B2**.

Leachate Treatment and Disposal

Objective: Ensure leachate is treated and disposed of in an environmentally appropriate manner

Methods of leachate treatment and/or disposal include:

- Discharge to a community sewerage system, with or without pre-treatment.
- Discharge to land by spray or subsurface irrigation, with or without pre-treatment. Effects of runoff, odour from leachate storage ponds, odour and spray drift from irrigation systems, and effects on soil structure all need to be assessed.
- Discharge to natural water after treatment. Cultural considerations need to be taken into account alongside environmental effects.
- Treatment by recirculation within the landfill. Effects of increased landfill gas production, odour, potential for differential settlement; leachate build-up on the base of the landfill; decreased stability of the waste mass, and leachate breakout on surface slopes all need to be considered.
- Evaporation, for example using heat generated from the combustion of landfill gas.

At present, the dominant method of disposal is the discharge of leachate to a wastewater treatment plant, or to land.

Where discharge is to a sewer, treatment of the leachate takes place at the wastewater treatment plant. Where volumes of leachate generated are low and the landfill site is remote from an existing sewer system, tankering leachate to a wastewater treatment plant may be the most appropriate method of disposal. Because the biochemical strength of leachate is typically significantly greater than that of normal municipal wastewater, care must be taken to avoid overloading the sewage treatment plant.

With increasing pressure on wastewater treatment plant capacity, there is likely to be increased pressure on landfill operators to provide onsite treatment prior to discharge. Site-specific leachate treatment using purpose-built leachate treatment or pre-treatment plants is common internationally.

The main constituents of leachate that govern treatment are ammoniacal nitrogen, and the organic constituents.

Treatment methods can be divided into five main categories:

- land treatment and disposal;
- physical/chemical pre-treatment;
- biological treatment;
- combination of physical/chemical and biological in one system; and
- advanced treatment.

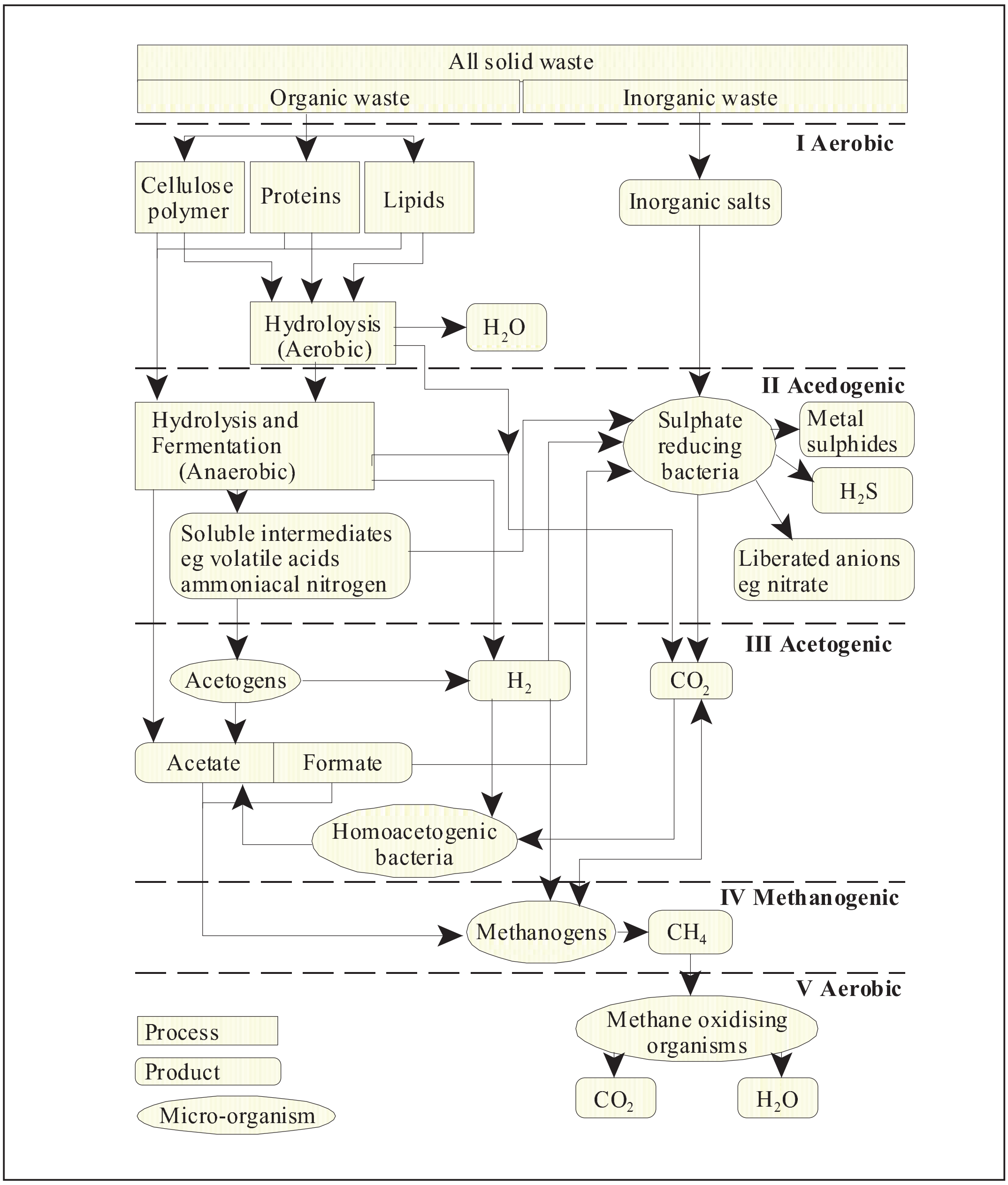
Details of leachate treatment systems are contained in **Appendix B2**.

5.9 Landfill Gas Management

Landfill Gas Generation Processes

Landfill gas is a by-product of the decomposition of waste within the landfill (Class 1 and Class 2). Different reactions occur at different times in the process of waste decomposition. See **Figure 5-6**.

Figure 5-6 Processes of Waste Decomposition



(Adapted from Environment Agency 2004, LFTGN03).

The waste decomposition process is generally acknowledged to occur in five phases:

- During **Phase 1**, the decomposable organic components of the waste undergo aerobic decomposition. Phase 1 commences just after the placement of the waste and lasts for a number of months.
- **Phase 2** commences due to the depletion of available oxygen and marks the commencement of the anaerobic stage. Phase 2 can last a number of months.
- **Phase 3** is marked by the transformation of complex materials such as cellulose, fats, proteins and carbohydrates into simple organic materials such as fulvic and acetic acids. Phase 3 can last from a number of months to a number of years.
- **Phase 4** represents the consumption of the acids developed in Phase 3 by specialised anaerobic methanogenic bacteria that convert them into methane and carbon dioxide: the principal components of landfill gas. This phase usually lasts a significant number of years.
- **Phase 5** signals the decline of landfill gas production because most of the nutrients required to sustain the methanogenic bacterial population have been depleted during previous phases. This stage typically lasts a number of years.

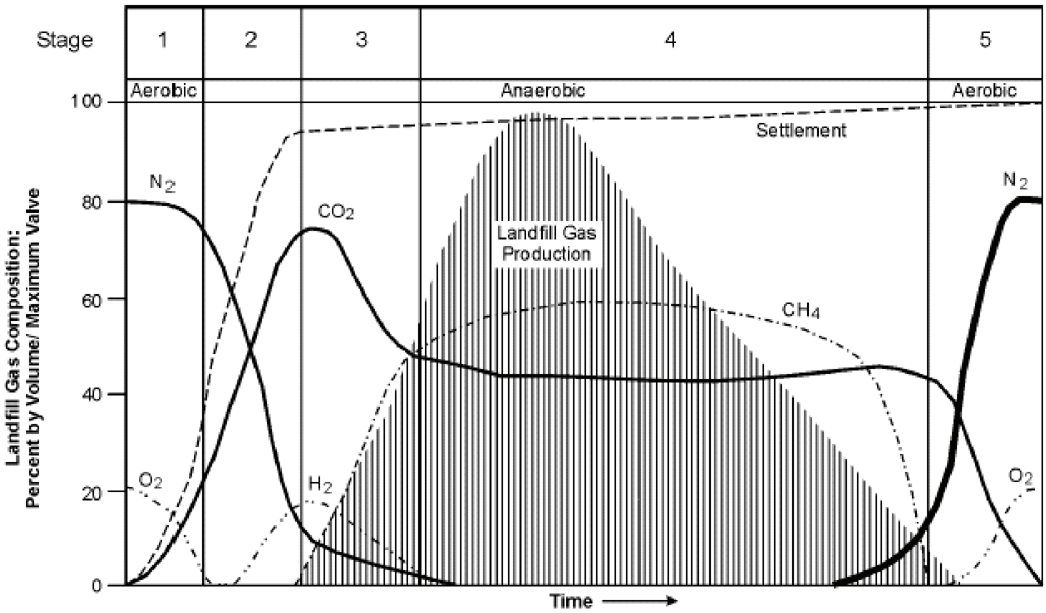
These phases of decomposition produce different by-product gases at varying rates (Farquar and Rovers (1973) original model, later modified by Rees (1980)). See **Figure 5-7**.

The production of large quantities of carbon dioxide may precede the production of methane. For this reason, detecting carbon dioxide is typically used as a means of detecting landfill gas prior to the onset of methane migration.

The composition of landfill gas changes through the various phases of waste decomposition. During the initial aerobic phase of decomposition, the landfill gas has a typical composition of 10% hydrogen and 90% carbon dioxide, and tends to be denser than air. In the anaerobic phases of decomposition, the landfill gas mixture typically comprises 60% methane and 40% carbon dioxide and consequently is slightly lighter than air. This change in gas composition can cause a change in landfill gas migration paths over time.

Details of landfill gas generation models and landfill gas system collection efficiencies are contained in **Appendix B3**.

Figure 5-7 Composition of Landfill Gas in the Decomposition Phases



(Adapted from Environment Agency 2004, LFTGN03).

Table 5-7 gives a typical composition of landfill gas.

Table 5-7 Typical Constituents Found In Landfill Gas

Component	Percent (dry volume basis)
Methane	45 - 60
Carbon Dioxide	40 - 60
Nitrogen	2 - 5
Oxygen	0.1 - 1.0
Sulphides, Disulphides, Mercaptans, etc.	0 - 1.0
Hydrogen	0 - 0.2
Carbon Monoxide	0 - 0.2
Trace Constituents	0.01 - 0.6

Source: Trace Organic Constituents in Landfill Gas, Department Civil Engineering, University of California, Davis, November, 1987

Potential Problems Associated with Landfill Gas

Potential problems associated with landfill gas include:

- risks of explosions or fires due to gas migrating and collecting in confined spaces such as manholes and chambers and in 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;
- risks to human health (on-site and off-site) and long term health effects associated with landfill gas constituents;
- odour nuisance;
- ignition of landfill gas upon release through cracks and fissures at the surface (methane fires are generally not visible in daylight);
- detrimental effects on soils and vegetation within the completed landfill and adjacent sites; and
- climate change effects due to methane.

Landfill Gas Control

Objectives: The primary objective of LFG control is to reduce the short and long term hazards associated with landfill gas (which is flammable, explosive and an asphyxiant gas).

Secondary objectives include:

- Minimising odour nuisance associated with landfill gas (due to the organic contaminants it contains)
- Minimising greenhouse gas emissions

Landfill Gas Collection and Extraction System Design

The design objectives of a landfill gas management system are to:

- minimise the risk to human health and safety;
- minimise the potential impact on air quality and the uncontrolled emissions of greenhouse gases to atmosphere;
- minimise the ingress of air into the landfill and thereby minimise the risk of fires;
- minimise the potential for landfill gas migration into services and buildings within the site boundary;
- minimise the potential for landfill gas migration beyond the site boundary;

- effectively control gas emissions;
- maximise energy recovery, where appropriate; and
- minimise the damage to soils and vegetation within restored landfill areas.

Over time, the design of landfill gas management systems has advanced considerably. This has been driven in part by recognition of the hazard potential of landfill gas, but also with recognition that landfill gas is a power resource with the potential to be harnessed. Consequently, the design of landfill gas collection wells and networks has evolved to provide not only hazard mitigation, but also the capture of landfill gas as a fuel source.

Active extraction systems typically incorporate a number of wells, a network of gas conveyance pipes and a gas blower system to generate the vacuum in the system.

Parts of abstraction systems used for gas utilisation are usually designed to recover the maximum amount of gas produced, at a methane concentration of 50% to 60%, and to move the gas through the collection system as efficiently as possible. The extraction wells focus on areas of the landfill where maximum gas generation is anticipated. However, in some cases landfill gas with lower methane concentrations can also be used for power generation or other energy recovery uses such as leachate evaporation, while also achieving the primary objective of hazard mitigation.

Abstraction systems used exclusively for hazard and environmental control are often required to be located in areas where gas quality or production rates are too low for effective utilisation. The wells used in such areas may be smaller in diameter and length and the vacuum pressure applied and the volume of gas moved through the collection system may also be less than in other areas.

At the perimeter of a landfill, a landfill gas management system must not cause the ingress of air. However, nor should it allow the migration of landfill gas off site.

Landfill gas management systems therefore need to balance the need for:

- control of lateral migration to minimise the potential for hazards, surface emissions and odour issues
- convey LFG to a flare or other destruction device or beneficial use

In the case of beneficial reuse, LFG collection is often targeted at actively collecting high quality landfill gas from the most productive areas of the landfill for subsequent beneficial reuse, such as electricity generation.

Typical details of landfill gas collection system design are contained in **Appendix B3**.

Landfill Gas Passive Venting

Passive venting systems are used where there is insufficient landfill gas being produced to result in a direct hazard, migration risk, or environmental impacts that warrant or enable flaring. Venting systems typically include vent stacks and/or gravel filled trenches. Passive systems should be designed to prevent the ingress of surface water and rain.

Landfill Gas Treatment

Landfill Gas Flare

The most commonly adopted method for the destruction of landfill gas in New Zealand is the landfill gas flare. Typically a methane concentration of at least 20% is required for a flare to be able to operate. A flare may also be used to burn excess gas, or act as a standby destruction method during periods when other landfill gas utilisation equipment (such as electricity generation units) is not operating.

There are two basic types of flare:

- enclosed; and
- open (candle).

The requirements for landfill gas flares in New Zealand are stipulated in the National Environmental Standard for Air Quality (NES). The NES requires an enclosed flare as the principal flare for landfills over a certain size. A candle flare may be used as a back-up flare only if the principal flare is not operating.

The products of combustion from the flare unit should be tested to verify that targeted destruction performance is being achieved.

Landfill Gas Utilisation

Effective landfill gas collection and treatment provides significant environmental benefit. The methane content of landfill gas (typically around 40-60% by volume) makes it a potential fuel, thereby providing potential economic benefit by way of energy production.

There are a number of potential beneficial reuse methods for landfill gas, including:

- electricity generation (in landfill gas engines used to power generators);
- combined electricity generation and use of recovered heat from the generator;

- direct use in boilers or kilns, or for other heating;
- treatment of leachate, usually by closed vessel evaporation to reduce leachate volume;
- conversion into liquefied natural gas for use as a fuel in vehicles; and
- conversion into compressed natural gas for use in domestic and commercial environments.

In New Zealand, more than 80% of current utilisation schemes use the landfill gas to generate electricity.

Details of typical landfill gas utilisation systems are contained in **Appendix B3**.

5.10 Landfill Cover Systems

Objectives: Control water ingress
Minimise landfill gas discharges
Prevent exposure of waste
Rehabilitate the site for proposed end uses

Landfill cover falls into three main categories:

- daily cover to manage
  - windblown litter
  - odour
  - vermin and birds;
- intermediate cover to
  - minimise water ingress
  - reduce air intrusion
  - reduce fugitive gas emissions
  - manage windblown litter, odour, vermin and birds
  - manage storm water
  - improve aesthetics;
- final cover to
  - control water ingress
  - reduce leachate generation
  - provide final contour and stormwater management
  - control gas migration
  - allow plant growth
  - provide physical separation between waste and plant and animal life

– provide a stable, maintainable long-term landform.

Daily Cover

Landfill daily cover is addressed in more detail with respect to landfill operations in Section 6.9.

Intermediate Cover

Intermediate cover typically consists of a compacted soil layer. The required thickness and hydraulic conductivity of the layer depends on:

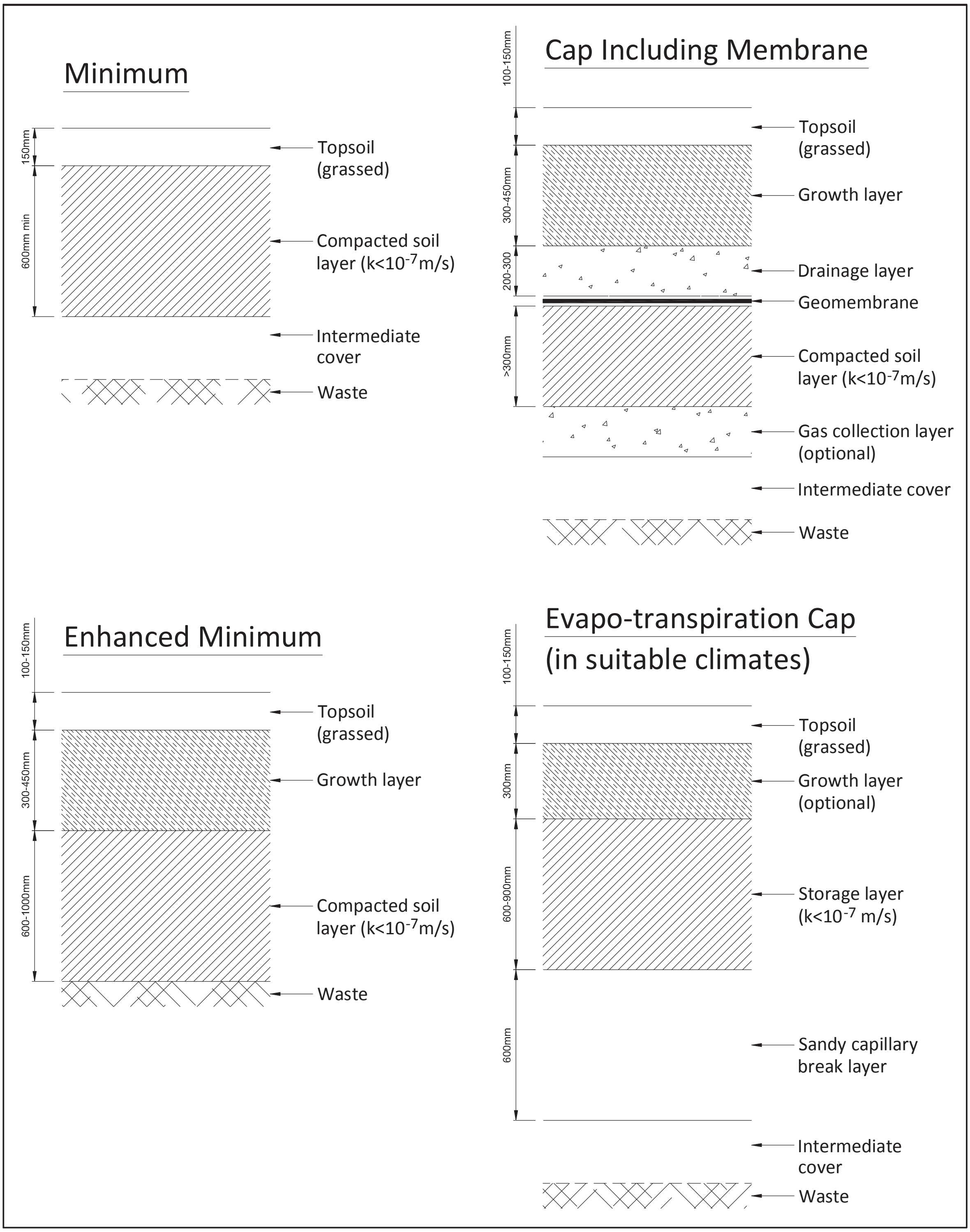
- the type of soils available on-site;
- the slope and topography of the top of the waste;
- the area of the cell; and
- the duration between the proposed placement of the final cover and the intermediate cover.

Final Cover

Final cover design is largely dictated by site design as well as management provisions with respect to enhanced degradation (i.e. leachate recirculation), landfill gas management and the proposed end use for the site.

Examples of final cover designs are shown in **Figure 5-8**.

Figure 5-8 Examples of Final Cover Designs



Other issues that need to be considered when designing cover include:

- **Surface gradients:** These will be determined by the proposed final use of the site, but should be sufficient to ensure effective shedding of precipitation. A minimum gradient of 1V:20H is recommended to promote drainage of the top of the landfill and a maximum gradient of 1V:3H is recommended to minimise erosion and post-closure care problems.
- **Effects of settlement**: Settlement may cause cracking or ponding of water.
- **Vegetation cover:** For example, if the cap is to be permanently grassed then it is important to avoid creating a low permeability hard pan under a shallow layer of topsoil.

Where leachate is recirculated into the landfill to enhance waste degradation, the following issues need careful consideration with respect to cover design:

- gas production will be accelerated, and hence the potential for adverse effects from odour increased, gas escape through the cover needs to be assessed;
- settlement rates of the waste are increased so that the bulk of settlement occurs much sooner; and
- after-care requirements can potentially be reduced, and with them the potential for longer-term adverse environmental impact.

Where the final cover is designed to minimise the infiltration of water into the waste, a combination of flexible membrane liner (1 mm to 1.5 mm thick), or geosynthetic clay liner and compacted soil layer is typically used.

The following advantages and disadvantages of this approach are:

- advantages:
  - the quantity of leachate generated over time is reduced;
  - leachate treatment costs can be significantly less;
  - if leachate is pumped at the rate it is generated, leachate heads on the liner can be significantly lower; and
  - the potential for landfill gas to escape from the cover is generally very low, hence the potential for odour problems will be reduced.
- disadvantages:
  - the breakdown of materials in the landfill will be slowed;
  - leachate generation and gas production will continue for a longer period;

- gas, leachate and settlement have the potential to cause problems decades after waste placement, resulting in after-care requirements;
- The use of a flexible membrane liner (FML) in final cover needs careful consideration due to the potential for cap instability on steeper slopes; and
- The use of GCLs in cover systems, where there is the potential for significant water movement, needs careful consideration in relation to the potential for long term ion-exchange and the risk of GCL performance reduction.

Minimum recommended specifications for a final cover system are given in **Table 5-8** Minimum Recommended Final Cover Requirements

Table 5-8 Minimum Recommended Final Cover Requirements

Class	1	2	3	4
Topsoil (mm)	150	150	150	150
Compacted cohesive soil (mm)	600 @ < 1 x 10^{-7} m/s	600 @ < 1 x 10^{-7} m/s	NA	NA
Subsoil layer	500	500	2000*	2000
Combination of soil cover and gas dispersion layers (mm)	500mm	NA	NA	NA

* Waste acceptance criteria for the subsoil layer may be the same as for underlying material, provided it is compatible with final land use and does not contain solid or sharp objects that may become a hazard if exposed.

5.11 Construction Quality Assurance & Quality Control

Objectives: Minimise defects in landfill components, as received
Minimise defects in constructed liner, leachate and cover systems
Ensure that liner construction complies with design specifications
Ensure that construction complies with the manufacturer's specifications

In order to meet design requirements, and to be able to demonstrate that they have been met, a comprehensive quality management system is required, covering all aspects of landfill construction. The design documentation (including the drawings, design report and technical specification) should clearly indicate how the construction quality will be monitored and what supporting documentation is required to demonstrate compliance with specification requirements.

For many projects, this can be achieved within the standard design documentation. However, for more complex projects there may be an advantage in preparing a construction quality assurance (CQA) plan which includes specification requirements and construction quality control (CQC) procedures aimed at meeting these requirements. If these documents are separate from the technical specification associated with the design, then care must be taken to ensure the documents do not contradict each other.

Documentation collated as part of the construction process to demonstrate:

- the materials used in construction comply with the specification requirements. This will be confirmed through the supply of manufacturer's quality assurance (MQA) and manufacturer's quality control (MQC) documentation for all geosynthetic components (e.g. geomembranes, geotextiles, geocomposite drainage layers, geonets, geogrids, geosynthetic clay liners, pipes etc.); and
- the methods of construction and installation are appropriate and, as a result, the design intent is met.

Details of testing requirements for geosynthetic and soil liner components are contained in **Appendix B4**.

6. Waste Acceptance and Monitoring

6.1 Introduction

The purpose of establishing Waste Acceptance Criteria (WAC) is to manage wastes being disposed of at a specific landfill so that they are compatible with the siting, design and operation of the facility and do not lead to significant immediate or longer term adverse human health or environmental effects. WAC should be determined based on disposal objectives, landfill type, landfill siting and the design of containment, leachate collection and treatment/disposal systems.

6.2 Waste Acceptance Criteria

Development of WAC should take into account the need to reduce the potential for discharge of hazardous substances to the environment, and the need to minimise the risks, such as effects on human health and safety, associated with contaminants that may be present in waste.

WAC should comprise prescribed lists of wastes that are acceptable/not acceptable, and, depending on landfill type, the total contaminant concentration limits or leachability criteria for wastes that may be accepted.

Class 1 Landfill

Waste acceptance criteria comprise:

- municipal solid waste; and
- for potentially hazardous leachable contaminants, maximum chemical contaminant leachability limits (TCLP) from Module 2 Hazardous Waste Guidelines – Class A[4].

WAC for potentially hazardous wastes and treated hazardous wastes are based on leachability criteria to ensure that leachate does not differ from that expected from non-hazardous municipal solid waste.

For Class 1 landfills, leachability testing should be completed to provide assurance that waste materials meet the WAC.

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[4] Module 2: Hazardous Waste Guidelines, Landfill Waste Acceptance Criteria and Landfill Classification, MfE 2004

WAC for a Class 1 landfill are provided in **Appendix D**. They are based on the USEPA TCLP leaching limits.

The WAC leachability limits represent maximum values which should not be exceeded and should be viewed as a minimum treatment specification for wastes going to this class of landfill.

Class 2 Landfill

Waste acceptance criteria comprise:

- a list of acceptable materials; and
- maximum ancillary biodegradeable materials (e.g. vegetation) to be no more than 5% by volume per load; and
- maximum chemical contaminant leachability limits (TCLP) for potentially hazardous leachable contaminants.

For Class 2 landfills, leachability testing should be completed to provide assurance that waste materials meet the WAC. WAC for Class 2 landfills are provided in **Appendix E**, and are derived from the USEPA TCLP leaching limits.

The WAC leachability limits represent maximum values which should not be exceeded and should be viewed as a minimum treatment specification for wastes going to this class of landfill.

Class 3 Landfill

Waste acceptance criteria comprise:

- a list of acceptable solid materials; and
- maximum incidental or attached biodegradable materials (e.g. vegetation) to be no more than 2% by volume per load; and
- maximum chemical contaminant limits.

A Class 3 landfill does not include any form of engineered containment. Due to the nature of material received it has the potential to receive wastes that are above soil background levels. The WAC criteria for a Class 3 landfill are therefore the main means of controlling potential adverse effects.

For Class 3 landfills, total analyte concentrations should be determined to provide assurance that waste materials meet the WAC.

Recommended WAC for a Class 3 landfill are provided in **Appendix F**. The WAC total concentrations represent maximum values which should not be exceeded and should be viewed as a minimum specification for a Class 3 landfill.

Class 4 Landfill

Waste acceptance criteria comprise:

- virgin excavated natural materials (VENM), including soil, clay, gravel and rock; and
- maximum incidental inert manufactured materials (e.g. concrete, brick, tiles) to be no more than 5% by volume per load; and
- maximum incidental[5] or attached biodegradable materials (e.g. vegetation) to be no more than 2% by volume per load; and
- maximum chemical contaminant limits are local natural background soil concentrations.

Materials disposed to a Class 4 landfill should pose no significant immediate or future risk to human health or the environment.

The WAC for a Class 4 landfill should render the site suitable for unencumbered potential future land use, i.e. future residential development or agricultural land use.

The WAC for a Class 4 landfill are based on the local background concentrations for inorganic elements, and provide for trace concentrations of a limited range of organic compounds. Recommended WAC for a Class 4 landfill are provided in **Appendix G**.

It may be appropriate to establish site-specific soil background concentrations or regional acceptance criteria based on regional background soil concentrations.

Summary Table

A summary of characteristics and types of wastes that may be acceptable for disposal are summarised in **Table 6-1**.

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[5] Incidental items or materials are those present in small quantities that cannot practically be separated from the materials intended for disposal.

Table 6-1 Summary of Accepted Waste Types

Class	Common Name	Waste Description	Waste Types	Waste Acceptance Criteria
1	Municipal Solid Waste Landfill	Clean Fill Material Managed Fill Material C&D Waste Municipal Solid Waste Household Waste Commercial Waste Industrial Waste Treated Hazardous Waste	Mixed municipal waste from residential, commercial and industrial sources, as well as: • soils, rocks, gravel, sand, clay etc, including those that do not meet the Class 4, 3, or 2 WAC. • road sweepings. • asbestos (disposed in accordance with the Asbestos Regulations 1998).	Based on USEPA TCLP limits. Refer **Appendix D**.
2	Construction and Demolition Waste Landfill	Clean Fill Material Managed Fill Material C&D Waste Non-putrescible Industrial Waste	As per Class 4 and 3 landfills and also including: • plasterboard and Gibraltar board; • reinforced concrete; • untreated and treated sawn timber; • site clearance and excavation materials (including soils, clays, rocks, tree stumps); • roofing products (corrugated iron, steel, clay tiles, steel coated tiles); • fibreglass; • wallpaper, lining paper and building paper; • formica, laminex, parquet; • vehicle tyres, rubber (up to a maximum of 1% per load); • flooring products (carpet and underlay, vinyl/linoleum, cork tiles, clay tiles); • wire, wire rope, wire netting; • insulation products (fibreglass and woollen batts) excluding	Based on USEPA TCLP limits. Refer **Appendix E**.

Class	Common Name	Waste Description	Waste Types	Waste Acceptance Criteria
			asbestos products and paper products; • textiles; • softboard, hardboard, particle board, plywood, MDF, customwood; • non-recyclable glass; • roading materials and asphalt; • non-recyclable steel and aluminium fittings (cable track, spouting); • plastic materials and items associated with construction and demolition activities (including plastic bags, pipes, gutterings, building wrap); and • asbestos (disposed in accordance with the Asbestos Regulations 1998). Maximum incidental or attached biodegradable materials (e.g. vegetation) to be no more than 5% by volume per load.	
3	Managed Fill	Clean Fill Material Managed Fill Material	As per Class 4 landfills and also including: • soils, rocks, gravel, sand, clay etc. which do not meet the Class 4 WAC; • bricks, blocks and pavers; • ceramics; • concrete (exposed reinforcing removed); • road sub-base; • tiles and pipes made of clay, concrete or ceramics; and • asphalt. Maximum incidental or attached biodegradable materials (e.g. vegetation) to be no more than 2% by volume per load.	Based on maximum total concentration limits and limited organic compounds Refer **Appendix F**.
4	Clean Fill	Clean Fill Material	Non-contaminated soils, rocks, gravel, sand, clay and other natural materials.	Based on maximum total concentration limits derived from the

Class	Common Name	Waste Description	Waste Types	Waste Acceptance Criteria
			Maximum incidental inert manufactured materials (e.g. concrete, brick, tiles) to be no more than 5% by volume per load. • Maximum incidental or attached biodegradable materials (e.g. vegetation) to be no more than 2% by volume per load.	local/regional background, and limited organic compounds. Refer **Appendix G**.

Prohibited Wastes

Prohibited wastes are those which, due to their inherent characteristics, can impact on the safe operation of a landfill and pose an unacceptable risk to people and the environment. A detailed list of characteristics and types of waste which should be prohibited from class 1, 2, 3, and 4 landfills is provided in Appendix H.

6.3 Waste Acceptance Procedures

Before a waste can be accepted at a landfill site, the operator needs to be satisfied that the waste meets the WAC. The operator should implement policies and procedures to detect and deter the inappropriate disposal of the materials to landfill and should have procedures that enable unacceptable wastes to be easily identified, segregated and rejected.

The following waste acceptance procedures (WAP) should be implemented by the operator as a tiered approach. WAP should be included within the management plan for the landfill.

Waste Disposal Application

Disposers should complete a formal application to deposit waste prior to becoming a user of a landfill, or in the case of regular deliveries, before there is a change to the nature or mass of the waste being disposed of at a landfill. The application should identify the nature and mass of the waste to be disposed, and any additional relevant information. The disposer should be required to agree not to dispose of waste of a different nature or markedly different mass except with the prior consent of the landfill operator and to attest to the veracity of the information contained within the application.

The disclosure of the nature of the waste will allow the operator to evaluate if the waste meets the WAC, and to require the generator to perform whatever tests are needed to characterise the waste. The disclosure will also provide the basis for a record of the nature and mass of the waste disposed of to the landfill.

For Class 4 landfills, the waste disposal application process is particularly important as pre-acceptance testing is not generally required. Prior to the acceptance of waste materials to a Class 3 or 4 landfills, the following key information should be obtained from the disposer to confirm that the materials meet the WAC for the landfill class:

- Sources of the waste;
- Confirmation that the source of the waste has not been contaminated by current or historical land use activities i.e., identified on the Ministry for the Environment's Hazardous Activities and Industries List (HAIL). A summary of the HAIL is provided in Appendix I.
- Copies of any soil testing results completed for the source of the waste.
- Copies of any resource consents authorising the earthworks/land disturbance held for the source of the waste.
- A signed form certifying that the soil is not contaminated.

Pre-Assessment Testing

Prior to the acceptance of waste materials to Class 1, 2 or 3 landfills, information should be obtained from the disposer to confirm that the materials meet the WAC for the landfill.

For Class 1 or 2 landfills, TCLP testing should be completed for the materials to confirm that they meet the WAC for the landfill. Testing should be completed by an accredited laboratory or other approved methodology (accepted by the regional council, unitary authority, or other appropriate statutory body). The sampling and testing programme should include samples that represent worst-case as well as average waste conditions.

The sampling rationale should be disposer-specific and based on the mass expected to be disposed to landfill. **Table 6-2** presents a summary of recommended pre-assessment testing requirements for the different classes of fill and landfill.

Table 6-2 Recommended Pre-Assessment Testing Requirements

Class	Common Name	Laboratory Sampling Method	Recommended Sampling Frequency
1	Municipal solid waste landfill	USEPA TCLP	Required for all potentially hazardous materials
2	C&D waste landfill	USEPA TCLP	Required for all potentially hazardous materials
3	Managed fill	Total analyte concentrations	Required for all soils, rocks, gravel, sand, clay etc. which do not meet the class 4 WAC
4	Clean fill	Not applicable	Not applicable – based on approval via the waste disposal application process

Assessment of Application

The operator should evaluate the completed waste disposal application and pre-assessment testing results against the specific requirements of the WAC. Wastes that meet the criteria may be admitted and disposed of in the landfill. If additional tests to better characterise the waste are required, the disposer should arrange for these tests to be performed (e.g. the completion of soil sampling to confirm that waste materials meet the WAC of a Class 4 landfill).

Wastes that do not meet the requirements of the WAC may be able to be treated so that they meet the criteria before being accepted at the landfill. However, some wastes may not be able to be accepted regardless of treatment.

Acceptance Agreement

Acceptance of a satisfactorily completed waste disposal application provides the basis of a waste acceptance agreement. The agreement should also contain details of sanctions available to the operator should the disposer breach the terms of the agreement to accept waste. It should also set out the rights of the landfill operator to inspect, challenge, sample, test and, if necessary, reject any waste brought by the applicant to the landfill for disposal.

Notification of Alternatives

If the application for disposal of waste cannot be accepted, then the operator should be required to advise the disposer of any known facilities that are able to accept the waste for storage or disposal. Alternatively, the operator should refer the disposer to the regional council or unitary authority, or other appropriate organisation for further information on suitable disposal facilities.

A similar procedure should be followed if waste is turned away from the landfill following inspection and an identified breach of the acceptance agreement. In that case, the operator should also advise the regulatory authority that the particular waste had been illegally presented.

6.4 Records, Verification, and Monitoring

Detailed records should be maintained as a mandatory requirement by the landfill operator to provide confirmation that the WAC and WAP are being followed.

Random Load Inspections

The operator should implement a programme that involves performing random load inspections of incoming waste.

This should involve detailed screening of loads to confirm the nature of the waste. The methodology should allow for selecting loads on a random basis, and the frequency of inspections should be based on the type and quantity of wastes being received and the findings from previous inspections. **Table 6-3** presents a summary of recommended random load inspection requirements for the different classes of landfill.

In the event that inspections indicate that inappropriate waste is being received at a site, then the random programme should be modified to increase the frequency of inspections.

Table 6-3 Recommended Load Inspection Requirements

Class	Common Name	Recommended Load Inspection Frequency
1	Municipal Solid Waste Landfill	Random and based on 1 in 50 loads
2	C&D Waste Landfill	Random and based on 1 in 50 loads
3	Managed Fill	All loads
4	Clean fill	Random and based on 1 in 50 loads

Verification Sampling

For Class 3 and 4 landfills which are unlined, verification sampling should be completed on both a random and annual basis to confirm that the waste materials meet the WAC for the landfill. Random waste samples should be collected from incoming loads. Annual waste samples should be collected from deposited waste across the landfill.

Waste sampling should be completed by an accredited laboratory.

Waste samples should be analysed for the following analytes:

- inorganic elements;
- total petroleum hydrocarbons (TPH);
- benzene, toluene, ethylbenzene and xylenes (BTEX);
- polycyclic aromatic hydrocarbons (PAH);
- pesticides (e.g. DDT, dieldrin); and
- semi-volatile organic compounds (SVOCs).

The sampling rationale should be disposer-specific and based on the mass expected to be disposed to landfill. **Table 6-4** summarises recommended verification sampling requirements for the different classes of landfill.

Table 6-4 Recommended Verification Sampling Requirements

Class	Common Name	Random Verification Sampling	Annual Verification Sampling
1	Municipal solid waste landfill	Not applicable	Not required
2	C&D waste landfill	Not applicable	Not required
3	Managed Fill	Random and based on 1 sample per 500 m^3 (incoming load)	Statistically derived and based on tonnage received annually
4	Clean fill	Random and based on 1 sample per 500 m^3 (incoming load)	Statistically derived and based on tonnage received annually

Supervision of the Tipping Face

Supervision of the disposal activity at the working face should be maintained at all times when wastes are received at the landfill to ensure the accountability of those depositing wastes at the site, and to identify inappropriate loads before they are covered and incorporated into the waste mass.

Notification of Regulatory Authorities

If any waste which contravenes the WAC is presented at the landfill for disposal (e.g. prohibited or hazardous waste), the regulatory authority should be notified.

If the landfill operator identifies the waste as being unacceptable while it is in the possession of the transporter, the load should be rejected and will remain the responsibility of the transporter.

If inappropriate waste is identified after unloading at the tipping face, then immediate steps should be taken to separate and secure the waste. Contingency plans for identification of the waste should be implemented immediately. If the waste is identified as unacceptable then a plan for removal or treatment needs to be actioned as quickly as practicable. Landfill users and staff must be protected from any health and safety hazards that might be caused by such waste material.

Record Keeping - Recording Waste Acceptance

Operators of all landfills should maintain records that include information on waste accepted at the landfill, load inspections, and operational activities. Information on waste acceptance should include the quantity and, where possible, classification of wastes.

Information on load inspections should include:

- the date and time wastes were received for inspection;
- sources of the wastes;
- vehicle and driver identification;
- observations made by the inspector;
- notification of violations; and
- any notifications made to a regional council, unitary authority, or other appropriate statutory body.

Information on operational activities should include records of disposal locations and training.

Record Keeping - Recording Disposal Location

An operator at a landfill receiving wastes that require special handling procedures (for example, treated hazardous waste or asbestos materials) should record the location of those wastes when they are placed in the landfill, including:

- type of waste;
- quantity of waste; and
- location of waste including depth (surveyed or identified on a landfill site plan).

7. Operations

7.1 Introduction

The operating procedures employed at any landfill site will have a significant bearing on its planned development, performance and potential effects on the environment, particularly effects on site neighbours.

This section addresses the following:

- site management plan;
- staffing and training;
- health and safety;
- site access;
- roading;
- visual impacts;
- fill material/waste placement and compaction;
- cover;
- nuisance control;
- fire prevention;
- surface water control;
- landfill gas management;
- contingency measures; and
- closure and aftercare.

7.2 Site Management Plan

Objective: Document site-specific procedures to achieve operational and environmental objectives and outcomes.

All operations at a landfill should be undertaken in accordance with a predetermined site management plan. This plan should cover all aspects of landfill operations, with detailed descriptions of:

- site management structure and responsibilities;
- planning controls and consents;
- design parameters;
- site development and filling sequence;

- daily operating procedures;
- waste acceptance criteria;
- types of equipment to be used on the site;
- monitoring requirements;
- emergency and contingency procedures;
- record keeping and reporting; and
- closure and aftercare of completed cells and the whole landfill.

The following sections detail the aspects of landfill operation which should be addressed in the site management plan and options for operating procedures.

7.3 Staffing and Training

Staffing

Objective: Adequate staffing for efficient, environmentally responsible and safe management of the landfill.

Staffing requirements will vary as a function of landfill class, size, types of wastes, and diversity and complexity of site operations. Landfill operators should provide adequate staffing to ensure that during operating hours all continuous tasks (including acceptance, compaction and covering) are completed in accordance with site management plan procedures.

Training

Objective: Familiarity of personnel with site facilities and operational requirements; and appropriate training for their specific duties.

All site personnel must be familiar with the landfill facilities, operational practices, hazards, health and safety systems, and environmental requirements.

All operational staff should be specifically trained in their site duties. At a minimum, staff training should ensure that:

- Staff who inspect or direct the placement of incoming wastes are capable of accurate data recording, and are skilled at identifying wastes that are unacceptable. These staff include supervisors, inspectors, equipment operators, and weighbridge attendants.
- Operators of compaction or earthworks equipment are skilled at undertaking all tasks required of them.

- All staff are familiar with site hazards, as well as safety practices and procedures.
- All staff are familiar with site emergency procedures.

7.4 Health and Safety

Objectives: Identification, mitigation and control of all significant site hazards.

Site staff, contractors and visitors are aware of site hazards and related health and safety requirements.

Landfill operations must be performed in accordance with the requirements of the Health and Safety at Work Act 2015, and a health and safety plan should be prepared for each site, setting out the procedures to satisfy each requirement of the Act. These requirements include, but are not necessarily limited to:

- The identification of hazards present on the site. Significant hazards at landfills include:
  - traffic (in relation to earthworks, waste placement and compaction equipment);
  - fuel storage;
  - steep and uneven terrain;
  - vehicle rollover;
  - landfill gas (LFG);
  - confined spaces;
  - sharp (injurious) or infectious waste;
  - hazardous waste; and
  - overhead power lines.
- Hazard assessment and control, including elimination of the hazard where possible, isolation where elimination is not practicable or not complete, or minimisation (including use of personal protective equipment) where elimination and isolation are not practicable.
- The provision of information concerning identified hazards, control procedures, and possible emergency occurrences to employees, contractors and visitors on the site.
- Appropriate training and supervision of employees at the site, including provision and use of safety equipment.
- Development of emergency procedures.
- Appropriate recording, investigation and reporting of accidents and incidents.

The health and safety plan will apply to all employees, subcontractors and visitors at the site. Attention must also be paid to ensuring that any contractors engaged on the site and site visitors are fully conversant with site hazards and the health and safety requirements.

7.5 Site Access

Objective: Prevent unauthorised access to the landfill site.

Unauthorised entry to landfills can lead to illegal waste dumping, exposure to landfill hazards, fires, vandalism, and loss of amenity. In order to control site access, the perimeter of the landfill site should be securely fenced and the gates locked outside normal operating hours. Close control over issuing keys to the landfill should be maintained to ensure public health is adequately safeguarded and the operational procedures are complied with at all times. All incoming vehicles should report to the weighbridge or reception office before proceeding further to waste tipping or working areas.

7.6 Roading and Traffic Management

Objectives: Minimise nuisances due to traffic movement.
Ensure traffic moves around the site safely.

Roads at landfill sites provide access to the site generally, as well as to the working face, special facilities (such as 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, the weighbridge and wash-down facility) should ideally be sealed to a good standard.

Internal access roads beyond the entrance facilities should be aligned with easy gradients and should, wherever practicable, follow perimeter routes on good founding to minimise reconstruction and relocation as filling progresses. Any access road that will be in service for six months or longer should be sealed. Access across the waste itself, where required should be constructed using appropriate road materials to suit the site conditions.

7.7 Visual Impacts

Objective: Minimise the visual impact of the landfill site on the surrounding community.

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 placing shade-cloth screening or screening vegetation at specific locations around the property.

Planting around the perimeter of the site should be commenced at the earliest opportunity, utilising fast-growing varieties of vegetation in order to establish both a visual barrier and some degree of wind protection to site operations.

7.8 Waste Placement and Compaction

Objectives: Maximise site life
Stabilise fill material/waste mass
Minimise vermin, vectors and the spread of litter

Equipment Selection

A landfill should utilise appropriate equipment for environmentally responsible and safe operation of the site.

Issues to consider in equipment selection include:

- landfill class;
- daily fill material/waste input quantity;
- types of fill material/waste;
- density/compaction requirements;
- cover requirements including the type of cover; and
- operator comfort and safety.

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

Waste Placement

Objective: Ensure access is available for disposal in all weather conditions.
Minimise the size of the working face.

Landfills should be developed progressively in cells based on a pre-determined plan. Typically the working face will be opened each day by stripping back daily cover.

Depending on site conditions and landfill development configuration, it may be necessary to have an alternative area available in which a working face can be opened in response to specific conditions, such as high winds or heavy rain.

The width of the working face should be as narrow as possible, to minimise the area of exposed waste. However, there needs to be sufficient room to permit vehicles to manoeuvre and unload quickly and safely. A balance is required in determining the working area and should consider the number of incoming vehicles, the need to minimise stormwater infiltration, cover requirements and nuisances such as litter.

Waste Compaction

The degree of compaction required will be determined after taking into account:

- type of fillmaterial/waste;
- end use of the site; and
- liquid injection/recirculation requirements.

Compaction requirements for Class 3 and 4 landfills will be dictated by the size of the facility, waste depth, and stability and engineering requirements for the end use of the site.

For class 1 and 2 landfills the amount of landfill space and land used to dispose of waste can be minimised by compaction. Compaction also improves the stability of the waste mass and minimises the formation of voids that can encourage vermin, or result in fires or excess generation of leachate.

Waste should be placed and compacted to ensure that unconfined faces are stable and capable of retaining cover material.

If liquid injection or leachate recirculation is proposed to enhance degradation and increase landfill gas production, this may require careful placement and reduced compactive effort for lower permeability wastes.

Bulky waste items require special measures in their placement. Such items should be crushed by 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 waste, due to the risk of liner damage. Similarly, bulky items should not be placed in the final lift since they may pierce the cap following waste settlement.

7.9 Cover

In general a final cover layer including a two metre layer of subsoil is recommended for Class 3 and 4 landfills, to prevent solid or sharp items penetrating the surface and creating a hazard.

Cover material at Class 1 and 2 landfills is used to achieve a range of operational and environmental objectives including:

- limiting run-on and infiltration of surface water;
- minimising risk of fire;
- minimising emission of landfill gas;
- suppressing site odour;
- reducing fly attraction and propagation;
- reducing bird and rodent attraction; and
- decreasing litter generation.

Three types of cover are used:

- daily;
- intermediate; and
- final.

Daily Cover

Objective: Minimise odours, vermin, vectors and the spread of litter.

Daily cover may be soil or other materials and should be applied after the waste has been placed, compacted, and formed to the proper grade.

If low permeability soils are used it will be necessary to either remove or penetrate the daily cover prior to subsequent waste placement to avoid perched water tables, especially if liquid injection or leachate recirculation is proposed.

Daily cover should be sloped to promote surface water runoff.

Daily Cover Options

Options for daily cover materials include natural soils such as:

- Soils or clays stockpiled from cut operations during landfill construction;
- Soils or clays imported and stockpiled for use as cover; and
- Incoming inert waste materials suitable for stockpiling and use as daily cover.

In addition there are a number of (non-soil) Alternative Daily Cover (ADC) options, including:

- Low quality compost, mulch or shredded green waste imported for use as cover;
- Manufactured cover materials, including:
  - spray-on pulp or foam;
  - geosynthetic blankets;
  - small weave netting; and
  - heavy duty reusable plastic sheets or tarpaulins; and
- Materials accepted for disposal that may also be suitable for use as cover in some circumstances, including:
  - sawdust;
  - contaminated soil (which complies with waste acceptance criteria);
  - ash (which complies with waste acceptance criteria);
  - stabilised sludge; and
  - paper pulp.

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

- availability of material;
- ease of material handling;
- climatic conditions (for example high permeability materials may be suitable in areas with low rainfall or during dry periods);
- odour or dust nuisance potential;
- potential contaminants within the material;
- potential effect on site stability; and
- potential to create perched water tables.

Intermediate Cover

Objective: Minimise water ingress and odour in areas subject to significant delay in further waste placement.

Intermediate cover is used to close off a cell that will not receive additional lifts of waste or final cover for some time and the depth of soil used as intermediate cover will be depend on:

- the length of time until cells will be re-opened;

- types of waste material;
- requirements to minimise leachate production; and
- requirements for landfill gas capture and odour minimisation.

Intermediate cover surfaces that will remain exposed for a period exceeding three months should be temporarily grassed using conventional methods, or by hydro-seeding.

When waste is placed over an area where an intermediate cover has been applied, it is important to ensure that the cover is adequately penetrated or removed to render the surface permeable to gas and leachate.

Final Cover

Objectives: Minimise water ingress.
Rehabilitate the site surface as appropriate for the planned end use.

Final site capping and revegetation should ensure that the completed surface provides an appropriate barrier to surface water infiltration in accordance with the design philosophy; controls emissions to water and air; promotes sound land management and conservation; prevents hazards; and protects amenity. A simple final cover system generally includes (from bottom to top):

- intermediate soil cover (if already in place);
- a low permeability layer; and
- a topsoil layer.

In addition, a final cover system can also include a granular gas drainage blanket, or a geosynthetic membrane below a subsoil drainage layer, as well as other components. The final cover generally 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 addressed in Section 4.10.

Vegetation on the final cover should be established immediately following completion of the cover.

The achievement of design objectives for the site depends on final cover being installed in accordance with design requirements. Ongoing monitoring and maintenance of final cover following placement is also necessary to remedy the effects of settlement, cracking or vegetation die-off.

7.10 Nuisance Control

Objective: Minimise the impact of the landfill on surrounding land, roads and neighbours.

Litter

Objective: Prevent litter migration beyond the site boundary.

Uncontrolled litter can contribute significantly to the loss of amenity experienced at a landfill site. A basic operating procedure is for all litter outside of the tipping area to be retrieved on a regular basis. In some cases this may be a continuous daily operation.

Litter can be controlled through:

- minimising the area of the working face;
- prompt compaction of waste;
- use of daily cover;
- use of litter nets and fences; and
- use of an alternative, sheltered tipping face during windy conditions.

Litter control nets and fences should be erected around the perimeter of the area being filled. Relocatable barrier-type fences can also be placed immediately adjacent to the active working face, as required. Nets and fences should be inspected and cleared regularly, on a daily basis or more often if needed.

Contingency plans should be in place to deal with extreme events that have the potential to create a litter nuisance on surrounding properties.

Dust

Objective: Prevent dust nuisance beyond the site boundary.

Dust can be a particular problem at Class 3 and 4 landfills.

The main activities responsible for dust generation at landfill sites are:

- disturbance of dried soils on access roads as a result of wind or traffic movements;

- earthworks, such as the placing of cover material during dry periods; and
- filling and compaction of dry dust-generating wastes.

In order to minimise dust emissions, permanent access roads between the site boundary and entrance facilities (including reception areas, the weighbridge and wash-down facility) should be sealed to a good standard. Both sealed and unsealed roads may require the use of water-carts and/or mechanical road sweepers, during dry periods. If roads have speed controls and are properly maintained, dust problems will be kept to a minimum.

Dust-generating wastes should be considered a "special" or difficult disposal. The waste generator or transporter should be required to dampen down the load before delivery to the site and specific controls may also be required at the working face (water sprays or waste pit).

Dust controls should minimise pollutants leaving the site as airborne dust, reduce stormwater sediment load, and protect local amenity. Where monitored the generally expected maximum level for dust deposition is 4 gm/m^2 per month as an annual mean for total solids, but the limit could be lower for landfills adjacent to sensitive areas. The deposition rate from the landfill should not be exceeded outside the site boundary.

Odour

Objective: Prevent offensive or objectionable odours beyond the site boundary.

Odour is a particular potential problem at Class 1 and 2 landfills. While Class 2 landfills are not expected to receive putrescible wastes, the production of hydrogen sulphide (due to the reduction of sulphate in plasterboard gypsum) can result in nuisance odour at these sites.

The main sources of odour at a Class 1 landfill site are:

- inadequately covered waste at the working face;
- tipping of odorous loads of putrescible waste;
- excavations into old waste;
- leachate; and
- landfill gas.

The landfill operator should adopt appropriate housekeeping practices to prevent the production of odours. The size of the working face should be kept to a minimum, and the use of daily cover and immediate attention to odorous waste loads will minimise the generation of odours from daily operations.

Odour from incoming waste loads should also be minimised by requiring the generators of odorous waste to deliver prior to putrefaction or, if appropriate, to treat the waste to combat odours before delivery. Loads not complying with these requirements should be refused entry and returned for treatment.

Application of deodorant chemicals by spray near the working face, or in areas of excavation in old waste, can also be used to control odours. In general excavations into old waste should be kept to a minimum and should be subject to specific controls and operating procedures aimed at controlling odour.

Odours caused by emission of landfill gas from wells and pipework and from the working face and landfill surface can be significant and should be minimised through regular inspections and maintenance, and timely cover system construction and maintenance.

Odours originating from the generation of landfill gas can be controlled by the development and operation of a landfill gas collection and destruction system. Landfill gas collection system design is addressed in Section 4.9. The landfill gas collection system should be operated in accordance with design objectives.

Damage to the landfill gas collection system by machinery during operations should be repaired immediately to avoid point sources of gas discharge and related odour.

Release of volatile organic compounds from leachate is another potential odour source and should be considered in the design of systems for leachate storage, treatment and disposal.

The installation of an on-site meteorological station which monitors wind speed, wind direction, and temperature enables correlation of any odour complaints with weather conditions and site activities.

Birds

Objective: Minimise bird numbers at the landfill site.

Birds, particularly gulls, can be attracted to Class 1 landfill sites in large numbers for water, food, nesting or roosting. The birds may transfer pathogens to drinking water collection or storage areas and crops, as well as depositing excreta and food scraps. Birds can also present a hazard if the landfill is located near an airfield.

Birds should be discouraged from the landfill site from its establishment so behavioural traits do not become established. In addition, sudden imposed control on access by birds to landfilled waste can lead to birds seeking alternative food sources. This can impact on other bird species, including endangered native species, whose eggs can become a food source for landfill birds.

Nesting at the site can be minimised by examining the nesting patterns and requirements of undesirable birds and designing controls accordingly. For example, nesting can be controlled for certain species by adhering to mowing and maintenance schedules.

The following measures can be adopted to minimise the attraction of birds to the landfill:

- good litter control;
- minimising the uncovered working face (denying the food source);
- prompt and thorough compaction of waste;
- covering waste at the end of each day;
- special handling of highly organic waste; and
- minimising areas of exposed earthworks and related 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;
- use of mobile high wires;
- special kites, including realistic models of the birds' natural predators;
- sonic bird scaring devices;
- shooting of species not protected by law; and
- anti-roosting strips on buildings.

Birds can become accustomed to one particular control method, so bird control techniques should be varied.

Flies

Objective: Minimise fly numbers at the landfill site.

Flies may become a problem during the summer months, particularly when there are delays between collection and deposition of waste. Eggs laid in putrescible waste may hatch over this period. Flies are capable of transmitting salmonella and other food-borne diseases through mechanical transmission.

Prompt and good compaction and application of cover are essential to the control of flies. This eliminates food, shelter and breeding areas. In bad cases of fly infestation the application of insecticides may be necessary.

Vermin

Objective: Minimise vermin numbers at the landfill site.

Vermin such as mice and rats can spread disease, cause property destruction and contaminate food. They are difficult to eliminate once a colony is established. Rat populations often occur because they are brought to site in loads, or migrate to the site from surrounding bush.

The most satisfactory way to counter rat infestation is by prompt and good compaction and application of cover soil. It may also be appropriate to arrange a system of regular visits and precautionary action by a pest control contractor.

Measures that can be adopted to minimise the attraction of vermin to the 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; and
- use of poison bait.

Noise

Objective: Ensure noise from landfill operations is kept to levels that do not create a nuisance in the surrounding environment.

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

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

Noise attenuation measures can include buffer zones, physical acoustic barriers such as earth bunds and acoustic treatment of equipment. Good bund design will limit noise from the site. 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 minimise noise. Particular attention should also be paid to the design of items such as speed humps and vibration grids to prevent noise generation. Effective noise control can also be accomplished by restricting hours of operation to align with adjacent land use.

7.11 Fire Prevention

Objectives: Prevent landfill fires.
Rapidly extinguish any fires that might occur.

Landfill fires can cause health effects due to people being exposed to pollutant emissions from burning waste smoke. This is due to the low burning temperature and incomplete oxidation of the burning waste. In addition, landfill fires can create physical hazard risks for landfill personnel and users, such as burns, explosions, subsidence, and exposure to hazardous materials.

Once started, landfill fires can be difficult to extinguish so fire prevention is the primary objective.

Landfill fires can generally be attributed to one of the following factors:

- delivery and burial of undetected burning material;
- delivery of highly flammable materials;
- combination of reactive materials within the landfill;
- spontaneous combustion through aerobic decomposition;
- malicious intent by site trespassers;
- cigarette smoking; and
- flammable debris contacting hot parts of equipment.

The adoption of good waste acceptance and site management practices should minimise the risk of fire from any of these factors.

Landfill fires can generally be classified as either surface fires or deep-seated fires. Surface fires are fires in recently deposited waste in the landfill working face. Deep-seated fires are found at depth in material deposited months or years previously.

Surface Fires

Surface fires can be started by any of the causes listed above. Every effort should be made to extinguish the fire before it becomes established. The best way to control and extinguish a surface fire is to douse it with large volumes of water, or to smother it with large volumes of wet or damp soil.

Deep-seated Fires

Deep-seated fires are usually started by spontaneous combustion through aerobic decomposition. Ensuring that waste is placed in a well-compacted state should prevent the occurrence of deep-seated internal fires. However, care should also be taken to ensure that the interior of the landfill is maintained in an oxygen-depleted state. In particular, an active landfill gas extraction system in the vicinity of the working face or areas with only intermediate cover can result in high oxygen levels in the waste and the establishment of aerobic conditions. The resulting temperature rise can lead to combustion within the landfill. Increased temperatures at gas extraction points may indicate that aerobic conditions are developing.

The area of a deep-seated fire should be identified, and surcharged with large volumes of clay or similar material. This minimises the number of outlets for gases to escape and reduces the entry of air to the fire. The area should be checked daily for heat, smoke, cracking, and subsidence. Landfill gas extraction should be stopped in the vicinity of the fire, but wells should be checked for temperature and carbon monoxide. Landfill gas vents and extraction wells should be sealed to prevent the escape of combustion gases and the entry of oxygen. If practical, the area of the fire can be isolated by deep trenches backfilled with clay.

Large deep-seated fires require specific investigation and management, often involving extensive excavation (overhauling) of waste as well as other measures.

Management Provisions

Good landfill management practices should minimise the potential for fires. These practices should include:

- fire breaks constructed around landfill cells;
- prohibition on all forms of deliberate burning;
- no smoking on site;
- screening of wastes;
- close control of waste deposition; and
- good compaction and cover.

Fire-fighting equipment should be maintained on-site. Operations staff should be trained in the use of such equipment and in techniques for dealing with surface fires and deep-seated fires. The Fire Service should be consulted regarding training and establishment of fire-fighting procedures.

Equipment available on site should include:

- an adequate permanent water supply that can be delivered to any area of the landfill;
- fire extinguishers; and
- protective clothing and breathing gear.

In addition, at larger landfills equipment should include:

- a water cart fitted with a high pressure hose system; and
- specialist chemical spill agents and foams.

7.12 Water Control

Objectives: Manage leachate generation and disposal.
Prevent contamination of surface water on and around the landfill.

Leachate

Leachate Generation

The control of leachate is fundamental to the protection of both surface and ground water quality.

Surface water should be controlled to prevent its ingress into the landfill and the consequent formation of leachate. Groundwater seepage is another potential contributor to the formation of leachate. Control of groundwater is primarily dependent on the design and construction of the landfill liner system, and its location in relation to groundwater level. Ideally the base of any liner system should be at least 2m above long term groundwater level.

Prohibition of the disposal of bulk liquid wastes should also be implemented to control waste that may become a source of leachate. Liquid waste refers to any waste material that is determined to contain free liquids. This is usually defined by SW-846 (USEPA, 1987) Method 9095B – Paint Filter Liquids Test. One common waste stream that that may contain a significant quantity of liquid is sewage sludge.

Leachate Control

At Class 3 and 4 landfills leachate is controlled by waste acceptance criteria. Leachate from Class 1 and 2 landfills is controlled by waste acceptance criteria and leachate collection, treatment and disposal systems.

Leachate management systems should be fully operable prior to the disposal of waste in a particular area. A regular programme of preventative maintenance for leachate management systems should be required. Typical items that should be addressed include:

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

To improve the flow of leachate within the waste mass and to prevent locally perched leachate levels, daily or intermediate cover should be removed or perforated prior to continued filling.

Monitoring

Because of the complex biochemical processes that occur 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. Changes in leachate composition can assist in identifying problems such as overloading with a particular type of waste.

Stormwater

Stormwater Control

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

Surface water from outside any areas of exposed earthworks should be diverted around the perimeter of the works. Surface water from the within the area of exposed landfill earthworks should be treated in silt retention systems prior to discharge in accordance with resource consent 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. All surface water that comes into contact with waste should be treated as leachate.

A regular programme of preventative maintenance for stormwater control systems should be undertaken. Items that should typically be addressed include:

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

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

Landfill washouts (areas of local erosion of waste and/or cover) can occur during periods of high intensity rainfall. Remedial work should be undertaken as soon as practicable to minimise any adverse environmental effects. If not repaired, relatively minor washouts can result in a release of waste, leachate and gas, and promote landfill instability. Depending on the severity of the washout, proper repair and reinstatement may involve substantial effort.

Monitoring

Because of the potential for environmental effects associated with stormwater management, monitoring is essential to confirm that the stormwater control system is behaving in the ways predicted by the site design.

7.13 Landfill Gas Management

Objectives: Ensure landfill gas is managed in accordance with site design objectives.

Minimise the hazard associated with landfill gas.

Ensure that landfill gas is managed to meet environmental and health and safety objectives.

Landfill Gas Generation

Landfill gas is produced at Class 1 and 2 landfills when solid wastes decompose. The quantity and the composition depends on the types of solid waste that are decomposing. Methane (CH_4) and carbon dioxide ($C0_2$) are the major constituents of landfill gas. Other trace gases are also present and some may impart odour. Hydrogen sulphide may be generated at a landfill that contains a large amount of sulphate, such as from gypsum board. Non-methane organic compounds (NMOCs) are also present and may impact on air quality when emitted through the cover or vent systems.

Landfill Gas Control

A landfill gas control system can have a number of 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; and
- greenhouse gas emission control, to reduce methane discharge to the atmosphere.

Landfill gas control system design is addressed in Section 4.9. Landfill operations should be consistent with the design and environmental objectives of the landfill gas control system.

Care should be taken to ensure that no unintentional landfill gas migration pathways (for example service trenches) result in uncontrolled gas release or migration. In addition, the effect of changes in atmospheric pressure on gas migration patterns should be taken into account. A rapid drop in atmospheric pressure can result in a spike in landfill gas generation.

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

A regular programme 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 periodic inspection. Service personnel should normally be available on an on-call basis in the event of a system malfunction.

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. Landfill gas monitoring is addressed in Section 7.8.

7.14 Contingency Management

Objective: Ensure that potential incidents resulting in risk or hazard are identified and planned for.

Contingency planning should form part of the site management plan. Potential incidents that need to be considered and planned for include:

- deposition of unauthorised waste;
- fuel spills;
- landfill fire;
- equipment breakdown;
- power outage;
- offensive and objectionable odours beyond the site boundary;
- failure of the leachate collection system;

- failure of the landfill gas control system;
- waste slumping or slips;
- high winds;
- earthquakes and other natural hazards; and
- intruders.

7.15 Closure and After-care

Objectives: Ensure that the landfill is completed in accordance with design principles and its proposed end use.

Ensure ongoing management of final cover and leachate, stormwater and landfill gas control systems.

Closure

Upon completion of waste disposal operations in part of a landfill, closure works should be undertaken. Generally this is as soon as practical. Depending on the class of landfill, the closure works may include:

- construction of the final cover system, including final stormwater and erosion control structures;
- revegetation of the landfill cap; and
- construction of the final landfill gas and leachate control structures.

The aim of these works is to provide for the continued decomposition of the disposed wastes in a safe and environmentally sound landfill structure. Site capping and revegetation should ensure that the final surface provides a barrier to migration of water into the waste and controls discharges of landfill gas and leachate. It should also promote sound land management and conservation, prevent hazards and protect amenity.

During the closure process, operations personnel will be required to maintain leachate, stormwater and landfill gas control systems while the final cover system is under construction. Additional care will be required to maintain surface water standards during the earthworks associated with final cover construction. Monitoring should continue during the closure works.

After-care

The natural processes within landfills continue to produce leachate and gas that require environmental management for many years after landfilling ceases. Operations to support environmental management should be undertaken in the post-closure period.

Post-closure operations should follow the direction of a closure plan prepared to reassess the provisions made during the development of the landfill. The plan should take into account the class of the landfill and the degree of control over the release or migration of contaminants from the landfill. The plan should specify:

- the steps to be taken in stabilising the site and the time frame required;
- the requirements for all leachate, landfill gas, and stormwater control systems and monitoring and reporting practices to be maintained during the after-care period;
- contact arrangements for adjacent property owners to maintain communications with operations personnel; and
- contingency measures in case of natural hazards.

Site operations would typically include:

- leachate collection and disposal;
- landfill gas control;
- monitoring of site integrity;
- repairs to the final cover system;
- maintenance and control of vegetation;
- stormwater and sediment control; and
- monitoring of groundwater, surface water and landfill gas.

Monitoring for environmental effects and site integrity should be continued until the landfill no longer has the potential for adverse environmental effects (see Section 7.1). Remedial actions should also be completed as required, based on periodic post-closure inspections.

8. Monitoring

8.1 Introduction

Monitoring Philosophy

Monitoring is the collection and assessment of environmental and discharge information gathered at and around a landfill site to determine baseline environmental conditions before development, and then effects on the environment during site development, operation and aftercare. Monitoring provides information for engineering design, obtaining regulatory consents, measuring performance of systems and assessing effects on the environment.

Monitoring is not an environmental mitigation measure. It provides information on the degree to which environmental protection and mitigation measures are being effective, and the extent of any residual environmental effects.

Monitoring requirements are usually determined prior to development and operation of a landfill site.

Landfill Processes

To properly monitor the effects of a landfill, a good understanding of the processes that generate contaminants, and their potential pathways from production to sensitive receivers, is required.

The physical, chemical and biological breakdown of waste within a Class 1 or Class 2 landfill produces leachate and landfill gas.

Leachate, if it discharges through the base of a landfill, can contaminate groundwater, and from there potentially contaminate surface water. Leachate that seeps from capped areas 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. It also contains greenhouse gases.

Landfill operation can also result in areas of bare earth, while vegetative cover is being re-established. Sediment runoff from these areas can impact upon surface water.

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 – 50 years for a Class 1 landfill.

Structure of Section

This section addresses the following:

- objectives and purpose of monitoring;
- scope of the monitoring programme;
- conceptual site models;
- developing a monitoring programme;
- leachate monitoring;
- groundwater monitoring;
- surface water monitoring;
- landfill gas monitoring;
- landfill surface and settlement; and
- analysis and review of monitoring data.

8.2 Objectives and Purpose of Monitoring

Monitoring of landfills is necessary to confirm that they are performing as expected, in accordance with design, operational practices and regulatory requirements, and that discharges are not resulting in, or likely to result in, adverse effects on the environment.

The three main objectives for any landfill monitoring programme are to:

1. Develop an understanding of the environment in which the landfill is located and the engineered components of the landfill.
2. Characterise the processes occurring within the landfill and the interaction of these processes with the receiving environment.
3. Confirm the understanding of the interactions of the landfill with the environment and determine whether any environmental effects are occurring. If the results of the monitoring programme are not consistent with the understanding of the system, then this understanding needs to be revisited.

A conceptual site model is one of the best tools for implementing these objectives and designing an appropriate site-specific monitoring programme.

The primary focus areas for a landfill monitoring programme are leachate, stormwater, groundwater, surface water, and landfill gas. Each of these is monitored for different purposes, using different techniques.

In order to ensure that landfill monitoring meets its objectives, these need to be clearly articulated. Each individual component of the monitoring programme should have a clearly defined purpose.

To define the purpose of any monitoring programme, it is important to start with the questions that need to be answered by the programme. Examples include:

- What constituents are present in the leachate produced?
- Has leachate quality changed over time?
- Is groundwater being impacted by leachate?
- How widespread is this impact?
- Is leachate having an impact on surface water?
- Is stormwater and therefore sediment having an impact on surface water?
- Is the landfill producing potentially hazardous gas?
- Where are the areas at risk?

8.3 Scope of Monitoring

Monitoring requirements need to be developed on a site-specific basis, taking into account:

- landfill size and class;
- geological, hydrogeological and hydrological characteristics at and around the site; and
- proximity to, and sensitivity of surrounding environments.

Monitoring

The monitoring programme will generally focus on the following:

- leachate;
- stormwater;
- gas;
- groundwater;
- surface water;
- sediment; and

- ecosystems.

Monitoring focus areas are described in more detail in **Appendix J1**.

Parameters Analysed

The selection of parameters for analysis should be guided by the purpose of the monitoring. Parameters fall into a number of groups, including:

- leachate indicators such as;
  - cations/anions
  - nutrients;
  - trace metals;
  - organic compounds.

- landfill gas constituents such as:
  - physical parameters (temperature, pressure)
  - primary organic compounds (CH_4, CO_2)
  - trace organic compounds.

Monitoring parameters are described in more detail in **Appendix J1**, which also identifies the objective (Section 7.2) that each group of parameters is typically associated with.

A single parameter may fall into several groups. The groups in which leachate and water monitoring parameters typically associated with landfill monitoring programmes are identified are given in **Table 8-1**.

Table 8-1 Leachate and Water Monitoring Parameters

Parameter	Indicator	Cations/anions	Physico-chemical	Nutrients	Trace metals	Synthetic organics
Water Level			✓			
Alkalinity			✓			
Aluminium					✓	
Ammoniacal Nitrogen	✓			✓		
Arsenic					✓	
Biological Oxygen Demand			✓			
Boron	✓	✓			✓	
Cadmium					✓	
Calcium		✓				
Chloride	✓	✓				
Chromium					✓	
Chemical Oxygen Demand	✓		✓			
Conductivity	✓		✓			
Copper					✓	
Dissolved Reactive Phosphorous				✓		
Total Hardness			✓			
Iron		✓			✓	
Lead					✓	
Magnesium		✓				
Manganese					✓	
Nickel					✓	
Nitrate Nitrogen				✓		
pH	✓		✓			
Potassium		✓				
Sodium		✓				
Sulphate		✓				
Suspended Solids			✓			

Parameter	Indicator	Cations/anions	Physico-chemical	Nutrients	Trace metals	Synthetic organics
Silica		✓				
Temperature			✓			
Total Kjeldahl Nitrogen				✓		
Total Organic Carbon			✓			
Turbidity			✓			
Zinc					✓	
Total Phenols						✓
Volatile Acids						✓
Volatile Organic Compounds						✓
Semi-volatile Organic Compounds						✓

8.4 Conceptual Site Models

Design of Monitoring Programmes

A conceptual site model is one of the best tools for designing a monitoring programme. The New Jersey Department of Environmental Protection (NJDEP) 2011[6] defines a conceptual site model as:

> 'a written and/or illustrative representation of the physical, chemical and biological processes that control the transport, migration and actual/potential impacts of contamination (in soil, air, groundwater, surface water and/or sediments) to human and/or ecological receptors'.

A conceptual site model is used to design a monitoring programme which addresses all potential exposure pathways. An exposure pathway is made up of three components, the **source**, the **pathway** and the **receptor**. If any one of these three components is not present then the pathway is considered incomplete and contamination is not usually a

[6] New Jersey Department of Environmental Protection (2011) Technical Guidance for Preparation and Submission of a Conceptual Site Model

concern. The presence of any one of these factors, does however create the potential for contamination and this potential should be noted.

The scope of the model depends upon the complexity and sensitivity of the system. The deeper the understanding of the system provided by the conceptual site model, the more robust a monitoring programme will be.

A conceptual site model can be created in any form (i.e. as a diagram, text, a flow chart, or a computer model). A good model will include all aspects of the site, including but not limited to engineering features of the landfill; groundwater flow; aquifer characteristics; geology; soil types; and local surface water systems. The model should note any significant natural areas including conservation land and endangered native species.

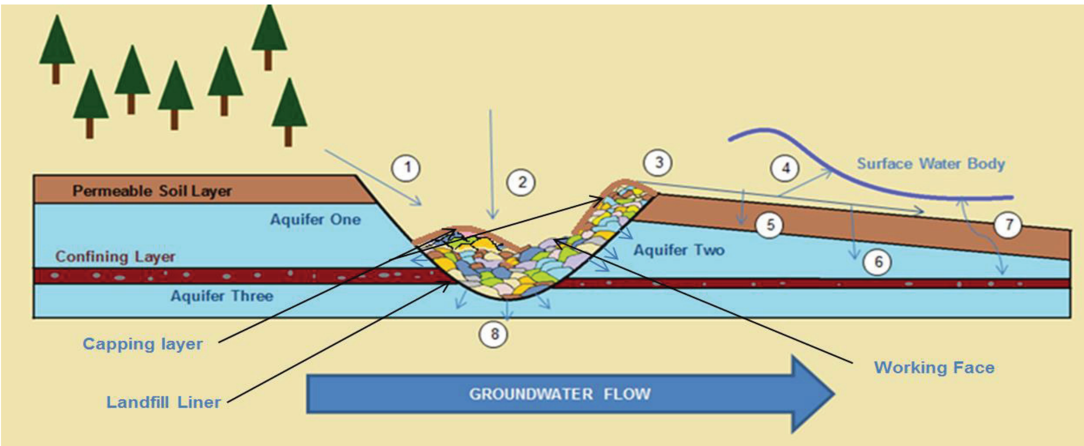
Without a sound conceptual site model, the design and resultant interpretation of the results of the monitoring programme may not appropriately reflect the actual conditions at the site.

The detail and complexity of the model should be appropriate to the size and risks associated with the site, as well as the complexity of the surrounding environment.

A conceptual site model for a Class 4 landfill may only be required to track the movement of sediment through the site. A simple conceptual site model may be appropriate for Class 2 and 3 landfills; it would be expected that leachate should be modelled as well as sediment contamination. Landfill gas may also be required to be assessed. A Class 1 landfill would require a more detailed conceptual site model that considers risks and pathways for stormwater, sediment, leachate and landfill gas.

Figure 8-1 shows an example of a simple leachate conceptual site model.

Figure 8-1 Example of a Simple Leachate Conceptual Site Model



1. Runoff from the adjacent plantation forest into the landfill
2. Rainfall into the waste percolates through and creates leachate
3. Leachate seep flows down the slope away from the landfill
4. Leachate seep flows into a local surface water body reducing water quality
5. Leachate leaching into the permeable soil layer
6. Leachate leaching through the soil layer to groundwater
7. Recharge and discharge of water between the surface water body and the stream
8. Potential for breaches in the landfill liner, which would result in leachate leaching into groundwater.

In this example, two monitoring bores should be located on the plantation forest side of the landfill (upstream) to characterise background levels of contaminants. One bore should be screened in Aquifer One the other in Aquifer Three.

Downstream at least two bores should be monitored: one screening Aquifer Two the other Aquifer Three. It may be helpful to have further bores at increasing distance from the landfill to track the progression of any contamination.

Surface water quality should also be monitored from the local surface water body as this water body could potentially be impacted through overland flow as well as indirectly by contaminated groundwater.

For example, a simple site with groundwater flow in one direction may only require an upstream monitoring bore which would provide background levels of contaminants and one or two downstream bores. A complex site may require bore locations to be decided based on preferential flow paths or multiple aquifers. Local use of groundwater and risk of contamination should be used to determine the frequency of monitoring required.

Surface water monitoring may not be appropriate or possible if no surface water is located within the area. At sites where the risk of contamination is low, a visual check for sheens, odours, scums or stressed vegetation may be sufficient to ensure the landfill is not having an impact. At large Class 1 landfills this visual check should be combined with regular water quality testing.

Developing a Monitoring Programme

Once a conceptual site model(s) has been developed, it can then be used to develop a monitoring programme. This monitoring programme need not include all of the focus areas mentioned above; what is included should be decided based on the risks associated with the site. The conceptual model should be used as a guide to determine the number of monitoring locations required and where these should be sited.

The conceptual site models should be continually updated as new information is gathered about the site. The monitoring programme should be reassessed regularly to ensure that it accurately reflects the findings, monitoring data gathered and remains appropriate for the site.

Trigger Levels

Trigger levels consist of specified numerical values or narrative descriptors for the protection of groundwater and surface water resources. If a trigger level is reached or exceeded, response by the landfill operator is required.

Trigger levels can be set in two ways:

- Expected typical concentrations. Exceedance of this trigger level indicates that there has been a change in monitored concentrations. Such exceedances should trigger further investigations. This type of trigger value should be derived from historical data on water quality for the site, or for an equivalent site. If a sufficient baseline data set is available, trigger levels for individual parametres can be set at either three standard deviations from the mean, which relates approximately to the 95% confidence level, or at the median/maximum concentration plus a pre-agreed margin.
- Concentration above which adverse environmental effects may occur. This type of trigger will be based on available and appropriate guidelines relevant to the sensitive receivers that are present at the site. Exceedance of this trigger level indicates that adverse environmental effects may occur and remediation measures may be required.

Additional details on the setting of trigger levels, are contained in **Appendix J1**.

Detection Limits

The detection limit is a function of the analytical protocol used by the laboratory to perform the analysis. For most analysis, the detection limit is determined by the protocol used and the nature of the sample itself. However, for some parameters, a number of detection limits may be available, with analysis to lower detection levels generally costing more. This applies particularly to trace metals, synthetic organics and some other parameters.

For parameters where different detection limits are available, the detection limits should be set as part of a sampling plan and be based on the following:

- the likely concentration range of the parameter in the sample;
- the trigger level(s) against which the sample will be assessed; and
- practical limitations of the sampling and analysis process.

Detection limits should be set in consultation with the laboratory to ensure that the objectives of the sampling plan can be met. A detection limit 10 times or more below the applicable trigger level will provide clear indication of any adverse trends.

Sampling and Analytical Requirements

The collection of representative samples and the subsequent unbiased analysis of results can present considerable challenges for monitoring programmes.

During collection and handling, a water sample may be subjected to several different environments and ambient conditions before it is analysed. Programmes 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.

Factors that need to be taken into account in developing a monitoring programme include:

- sample replication;
- sampling methods and equipment;
- sample collection protocols;
- field filtering;
- collection and recording of field data;
- sample storage and transport;
- sample analysis protocols; and
- QA/QC requirements (see **Appendix J1**).

A more detailed discussion of sampling and analytical requirements is contained in **Appendix J1**.

8.5 Leachate Monitoring

Purpose of Leachate Monitoring

The quantity, composition and strength of leachate produced and collected from a Class 1 or 2 landfill depends on a number of factors, including:

- the composition of landfilled waste;
- the rate of infiltration of rainwater and surface water;
- whether the landfill recirculates leachate; and
- (possibly) the rate of infiltration of groundwater.

Leachate monitoring should be undertaken at any landfill where leachate is collected in order 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); and
- refine groundwater and surface water monitoring programmes.

Monitoring should include:

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

Monitoring Locations

In order 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.

Monitoring Parameters and Frequency

In general, leachate should be monitored regularly for a full range of parameters appropriate to the types of waste 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 programmes, particularly if leachate contamination is already evident.

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

- requirements for the management of leachate treatment/disposal systems;
- groundwater level fluctuations; and
- rate of leachate migration or groundwater flow.

Guidance on sampling frequency is presented in **Table 8-2.**

Table 8-2 Leachate Sampling Frequency

Class	1 Large[1]	1 Medium	1 Small	2	3	4
Minimum frequency[2]	6 monthly	6 monthly - annual	Annual	Annual	NA	NA

Note:

NA: not applicable

1 Large landfill: > 50,000 tonnes per annum; medium landfill: between 10,000 and 50,000 tonnes per annum; small landfill: < 10,000 tonnes per annum.

2 Per discrete landfill cell/stage.

8.6 Groundwater Monitoring

Purpose of Groundwater Monitoring

Groundwater can be at risk from leakage of leachate through the base of the landfill and/or from ancillary activities such as mechanical workshops. In some situations, groundwater can be directly affected by landfill construction activities. Groundwater monitoring seeks to identify actual or potential effects on the groundwater. In particular to:

- 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; and
- identify any need for mitigation and/or remediation.

Objectives of Groundwater Monitoring

The key objective of monitoring is to achieve reliable, long term information about the behaviour of groundwater at a site and the effects of the landfill on it. However, obtaining reliable and pertinent information on groundwater behaviour and characteristics requires an understanding of the site's hydrogeological conditions, including aquifer configuration and characteristics and groundwater flow direction. Due to the high cost of typical groundwater investigation programmes, investigation and monitoring objectives are often integrated so that boreholes can serve both purposes.

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; and
- characterisation of the interactions of leachate components with groundwater, including migration pathways and attenuating effects likely in the groundwater system.

Groundwater Drainage Discharge Monitoring

At sites where a groundwater drainage system is installed beneath the liner, groundwater discharge flow rate and quality need to be monitored regularly to detect leachate contamination that may result from liner leakage or failure.

In the first instance, monitoring could be for a stable indicator prevalent in leachate, such as conductivity, chloride and ammoniacal nitrogen. If contamination is indicated then more detailed analysis is required to determine the extent of contamination.

Determining Numbers and Locations of Monitoring Points

Appropriate positioning of monitoring points in a groundwater monitoring network is a key aspect of any monitoring programme. Selection of well locations needs to consider the potential pathways and travel rates for the migration of contaminants. Complex hydrogeology normally requires a larger number of wells than does 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[7].

Additional information on groundwater monitoring points, design of monitoring wells and monitoring parameters is contained in **Appendix J2**.

Monitoring Frequency and Timing

Key factors that influence frequency and timing of monitoring include those used to determine well location (discussed above), as well as:

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

As a result, a monitoring programme normally has a tiered structure. Each tier defines a suite of monitoring parameters, their timing (e.g. short term or seasonal versus contingency) and frequency. Most tiered systems will contain at least the following basic elements:

- a baseline or pre-existing conditions tier.
- an indicator tier that tracks short term behaviour.
- a comprehensive tier that tracks long term changes. Sometimes this tier is split into two parts to allow more costly analyses to be made on a less frequent basis.
- A contingency tier that is implemented following abnormal results from the indicator tier. Generally, this tier results in the comprehensive tier being undertaken on a more frequent basis while the cause of the abnormality is investigated and remedied.

The tiered system in **Table 8-3** shows measurements being taken and their frequency. Actual 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.

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[7] Haduk PF, 1998: A Method for Designing Configurations of Nested Monitoring Wells Near Landfills. Hydrogeology Journal (1998) 6:341-348

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 also consider seasonal groundwater behaviour. Co-ordination with the surface water monitoring programme 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 Class 1, 2 landfill sites, it is recommended that groundwater monitoring be undertaken at least twice a year, to coincide with high and low groundwater levels.

For Class 3 landfills, groundwater monitoring requirements should be determined on a site-specific basis, taking into account fill size, hydrogeology and downgradient receptors.

Guidance on groundwater sampling frequency is presented in **Table 8-3**.

Table 8-3 Groundwater Sampling Frequency

Class	1 Large[1]	1 Medium	1 Small	2	3	4
Under drain Monitoring	Continuous	1-3 monthly	3 monthly	3 monthly	NA	NA
Bore[2] -Up gradient bore	3 monthly	3 - 6 monthly	6 monthly	6 monthly	annually	NA
Bore - Landfill footprint edge bore	Min 2 wells	Min 1 well	Min 1 well	Min 1 well	Min 1 well	NA
	3 monthly	3 – 6 monthly	6 monthly	6 monthly	annually	NA
Bore - Site boundary bore	Min 2 wells	Min 2 well	Min 1 well	Min 2 wells	Site specific	NA
	Dependent on g/w velocity	Dependent on g/w velocity	Dependent on g/w velocity	Dependent on g/w velocity		NA

Note:

min = minimum; g/w = groundwater; NA = not applicable

1 Large landfill: > 50,000 tonnes per annum; Medium landfill: between 10,000 and 50,000 tonnes per annum; Small landfill: < 10,000 tonnes per annum.

2 Typically, a minimum of 3 bores is required in total to establish groundwater flow direction. In some situations it may be able to be reliably inferred from other observations e.g. topography.

8.7 Surface Water Monitoring

Purpose of Surface Water Monitoring

Landfill operations give rise to a range of adverse environmental effects and pose a risk to surface water quality and aquatic biota. Surface water monitoring is used to:

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

Leachate and sediment runoff pose the primary risks of contamination of surface waters due to:

- sub-surface migration of leachate as a result of steady state liner seepage or an accidental breach/failure of the landfill liner;
- discharge of sediment from the landfill as a result of earthworks or structural failure;
- surface leachate break-outs or spills;
- surface spills of hazardous substances; and
- other activities with the potential to contaminate surface waters, for example discharge of vehicle or machinery wash water.

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

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

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

Controls for Surface Water Monitoring

Surface water monitoring programmes need to be carefully designed to enable the reliable collection of information that is specific to the site, while being cost-effective.

The design of a surface water monitoring programme should be based on statistical considerations. These take into account the variability and accuracy of the data collected and their ability to identify change and non-compliances.

Collection of baseline data provides temporal control and documents surface water quality before landfill operations commence or change. It is 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 monitoring points at an upstream location from landfill operations or in nearby, similar surface waters unaffected by landfill operations. Again, data collected from such sites serves as a benchmark against which any changes in surface water quality can be evaluated.

Quality assurance and quality control (QA/QC) measures are important to ensure surface water monitoring data is accurate and reliable.

Design of Surface Water Monitoring Programmes

Key considerations in the design of surface monitoring programmes are:

- historical ecological studies which may give an indication of the expected aquatic biota;
- flow rate and flow rate variability;
- selection of suitable monitoring points;
- selection of suitable monitoring parameters;
- monitoring frequency;
- sampling requirements;
- analytical detection limits;
- analysis and review of monitoring data; and
- trigger levels.

Determining Locations for Water Monitoring

Locations for a surface water monitoring programme need to cover all surface water resources that could potentially become contaminated by landfill operations. The key criteria when selecting monitoring stations are:

- 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; and
- site accessibility.

Monitoring Frequency and Timing

The requirements for the frequency and timing of surface water monitoring vary between landfills, depending on:

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

Guidance on surface water sampling frequency is presented in **Table 8-4**.

Table 8-4 Surface Water Sampling Frequency

Class	1 Large[1]	1 medium	1 Small	2	3	4
Sediment ponds[2]	Continuous or prior to discharge	Continuous or prior to discharge	Site specific	Continuous or prior to discharge	Continuous or prior to discharge	Continuous or prior to discharge
Up-gradient	3 monthly	3 – 6 monthly	6 monthly	6 monthly	Site specific	NA
	Leachate indicators	Leachate indicators	Leachate indicators	Leachate indicators	Leachate indicators	
Down-gradient	3 monthly	3 – 6 monthly	6 monthly	6 monthly	Site specific	NA
	Leachate indicators	Leachate indicators	Leachate indicators	Leachate indicators	Leachate indicators	

Note:
1 Large landfill: > 50,000 tonnes per annum; medium landfill: between 10,000 and 50,000 tonnes per annum; small landfill: < 10,000 tonnes per annum.
2 A decision on discrete vs. continuous sampling and testing should take into account landfill size and environmental sensitivity.

An example of a surface water monitoring strategy is given in **Appendix J3**.

8.8 Landfill Gas Monitoring

Purpose of Landfill Gas Monitoring

Monitoring of landfill gas is undertaken to enable effective management of on-site and off-site risks. On landfills operating active gas extraction systems, the surface and sub-surface monitoring results also provide supplementary information on the effectiveness 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 potential migration pathways;
- assess risks to neighbouring properties; and
- assess the fire risk potential of the landfill gas, both within and outside the waste.

Characteristics Affecting Monitoring Requirements

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

- landfill size;
- waste type and age;
- surrounding land use;
- site geology and groundwater conditions;
- preferential flow paths e.g. service trenches;
- landfill gas control measures in place; and
- results from previous monitoring.

Subsurface Gas Monitoring

Where developments such as houses are located within 250 metres of a landfill site, or the underlying geology makes landfill gas migration a possibility, landfill gas should be monitored using probes installed 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 is occurring at depth. Incremental depth measurement of landfill gas species (CO_2, CH_4, H_2S and O_2) can also be used to assess the methane oxidation efficacy of cover soils.

Additional details of subsurface gas monitoring procedures are contained in **Appendix J4.**

Surface Gas Monitoring

Several techniques exist for monitoring surface emissions from a landfill, including:

- visual inspection;
- instantaneous surface monitoring (ISM);
- integrated surface sampling (ISS);
- ambient air sampling;
- flux box testing; and
- portable accumulation chamber surveys.

It is likely that a combination of these techniques may be required.

Where surface emissions may present a risk at a site, or have the potential to 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 landfill gas extraction, ISM results can also provide useful information for optimising the effectiveness of the extraction system and capping maintenance.

Additional details of surface gas monitoring procedures and monitoring in buildings on or around a landfill site are contained in **Appendix J4**.

Landfill Gas Control System Monitoring

Where landfill gas is actively collected (extracted) and flared or used for electricity generation or as an alternative energy source, monitoring of the system is necessary to ensure:

- air is not drawn into the landfill as a result of system vacuum or well location, hence 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 sufficient control to enable areas of the site to be isolated or gas extraction rates adjusted; and
- 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); and
- carbon monoxide (as an indicator of landfill fire).

Monitoring should be frequent and ideally should occur weekly. However, monthly monitoring is commonly adopted once a gas field has been “tuned” (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 NMOC emissions.

Flares

Two types of flare are commonly used: candle (open) flares and ground (enclosed) flares. Ground flares provide a significantly higher level of gas combustion control capability. Both types of flare 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; and
- 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 for the incoming gas. Combustion temperature is also monitored and facilities for high temperature gas sampling are usually available.

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

Guidance on gas sampling frequency is presented in **Table 8-5**.

Table 8-5 Gas Sampling Frequency

Class	1	2	3	4
Well heads	Weekly[1] Monthly[2]	NA	NA	NA
Surface emissions	6 monthly	Annually	NA	NA
Gas migration probes	6 monthly	6 monthly	NA	NA

Note:

1 Where a landfill gas collection and extraction system exists.

2 When the gas field has adjusted to a stable condition.

8.9 Landfill Surface and Settlement Monitoring

Purpose

Landfill surface monitoring facilitates:

- measurement of change in landfill airspace; and
- compaction assessments.

Guidance on the frequency of monitoring via topographical surveys is presented in **Table 8-6**.

Table 8-6 Landfill Surface Monitoring Frequency

Class	1 large	1 medium	1 small	2	3	4
Topographical survey	6 monthly	Annually	Annually	Annually	Annually	NA

Note: Large landfill: > 50,000 tonnes per annum; medium landfill: between 10,000 and 50,000 tonnes per annum; small landfill: < 10,000 tonnes per annum.

8.10 Analysis and Review of Monitoring Data

Purpose

The analysis and review of monitoring data should address the three main objectives for a landfill monitoring programme (Section 7.2):

1. Develop an understanding of the environment in which the landfill is located and the engineered components of the landfill.
2. Characterise the processes occurring within the landfill and the interaction of these processes with the receiving environment.
3. Confirm the understanding of the interactions of the landfill with the environment and determine whether any environmental effects are occurring. If the results of the monitoring programme are not consistent with the understanding of the system, then this understanding needs to be revisited.

Account needs to be taken of the purpose of monitoring for each focus area addressed in Sections 7.5 to 7.9.

General

Monitoring data from landfill sites need 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 resource consent requirements;
- provide information for reporting to regulatory authorities;
- review QA/QC information;
- process and store data (preferably using computer software); and
- prepare monitoring reports.

Analysis 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; and
- the form and ease of interpretation of the results.

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