wasteMINZ

Technical Guidelines for Disposal to Land

Revision 3

Waste Management Institute New Zealand (WasteMINZ)

October 2022

Version	Date finalised	Written/updated by	Description of changes
1.0	April 2016	WasteMINZ	Initial version of guidelines
2.0	August 2018	WasteMINZ	Incorporated feedback from the Regional Waste and Contaminated Land Officers Forum (now the Contaminated Land and Waste Special Interest Group)
3.0	October2022	WasteMINZ	Carried out updates to Class 3 and 4 waste acceptance criteria, in addition to identifying links with the Waste Minimisation Act 2008 and waste disposal levy expansion with the Ministry for the Environment.

ISBN **978-0-473-65609-6 (PDF)**

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

Acknowledgements

These guidelines were produced with funding from the Ministry for the Environment.

These guidelines were developed in consultation with the following individuals, and would not have been possible without their time and expertise:

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
- Chris Lobb, EnviroWaste Services Ltd
- Gerry O’Neill, Ministry for the Environment
- Eric Souchon, H.G. Leach & Co. Ltd
- Walter Starke, Jacobs New Zealand Ltd

The Technical Guidelines for Disposal to Land Reference Group provided key oversight and input into this version (Revision 3) of the guidelines. We thank the following individuals for their time and expertise:

- Simon Beardmore, e3scientific
- Jonathan Caldwell, Waikato Regional Council
- Don Chittock, Fulton Hogan
- Laurence Dolan, EnviroNZ
- Nigel Donovan, Ministry for the Environment
- Simonne Eldridge, Tonkin + Taylor Ltd
- Rowan Latham, Christchurch City Council
- Graeme Proffitt, Pattle Delamore Partners
- Natalie Webster, Pattle Delamore Partners

We also extend our thanks to Environmental Protection Agency Ireland for allowing the use of figures from their Landfill Site Design Manual (2000).

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

Abbreviations

AEP	Annual exceedance probability
ASTM	American Society for Testing and Materials
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZG	Australian and New Zealand Governments
BaP TEQ	Benzo(a)pyrene toxic equivalents
BTEX	Benzene, toluene, ethylbenzene and xylenes
C&D	Construction and demolition
CAE	Centre for Advanced Engineering
COD	Chemical oxygen demand
CQA	Construction Quality Assurance
CQC	Construction Quality Control
DAF	Dilution and attenuation factor
DDT	Dichlorodiphenyltrichloroethane
DWNZ	Drinking Water Standards for New Zealand
ETS	Emissions Trading Scheme
FML	Flexible membrane liner
f_{oc}	Fraction of organic carbon
GCL	Geosynthetic clay liner
HAIL	Hazardous Activities and Industries List
HDPE	High-density polyethylene
HSNO	Hazardous Substances and New Organisms Act 1996
HSW	Health and Safety at Work Act 2015
ISM	Instantaneous surface monitoring
k	Methane generation rate constant
Kd	Soil water distribution coefficient

K_{oc}	Organic carbon water partition coefficient
kWh	Kilowatt hours
LCRS	Leachate collection and removal system
LLDPE	Linear low-density polyethylene
L_o	Methane generation potential
MAV	Maximum acceptable value
MfE	Ministry for the Environment
MoH	Ministry of Health
MSW	Municipal solid waste
NES	National Environmental Standard
NES-AQ	National Environmental Standard for Air Quality
NES-CS	National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health
NJDEP	New Jersey Department of Environmental Protection
NMOC	Non-methane organic compounds
PAH	Polycyclic aromatic hydrocarbon
PBB	polybrominated biphenyl
PCB	Polychlorinated biphenyl
PCBU	Person conducting a business or undertaking
PCT	polyterphenyl
PDP	Pattle Delamore Partners Ltd
PP	Polypropylene
QA/QC	Quality assurance/quality control
RMA	Resource Management Act 1991
SBR	sequencing batch reactor
SCS	Soil contaminant standard
SGV	Soil guideline values

SPLP	Synthetic precipitation leaching procedure
SWANA	Solid Wate Association of North America
T&T	Tonkin & Taylor Ltd
TCLP	Toxicity characteristic leaching procedure
TPH	Total petroleum hydrocarbons
USEPA	United States of America Environmental Protection Agency
VENM	Virgin excavated natural material
WAC	Waste acceptance criteria
WAP	Waste acceptance procedures
WMA	Waste Minimisation Act 2008
WMMP	Waste Management and Minimisation Plan

1. Glossary and Definitions

Aquifer	A geologic formation or layer of rock or soil that is able to hold or transmit water.
Background Level	Concentration of a contaminant accepted by regulatory authority to be the background concentration for virgin excavated natural material (VENM) within the intended catchment of the site.
Bio-accumulation	Accumulation within the tissues of living organisms.
Biosolids	The organic residue from sewage treatment processes, and the processing of organic materials.
Clean Fill	A Class 5 Clean Fill site. Accepts only clean fill material.
Clean Fill Material	VENM such as clay, soil and rock that are free of combustible, putrescible, degradable or leachable components. When discharged to the environment, clean fill material will not have a detectable effect relative to the background, and the fill site will be able to be utilised for an unrestricted purpose on closure. Future excavation into the filled materials will be unrestricted.
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-putrescible, non-hazardous C&D wastes. Waste may be generated from the construction, renovation, repair, and demolition of structures such as residential and commercial buildings, roads, and bridges.
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).
Controlled Fill	A Class 4 fill site. Accepts only controlled fill materials.
Controlled Fill Material	Predominantly natural soil and inert C&D materials; and material acceptable in Class 5 Clean Fills. The soil may have contaminant concentrations in excess of local background concentrations, but below specified criteria which limit discharges to the groundwater environment and aquatic environments, and which allow the fill site to be utilised for an unrestricted purpose on closure.
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 geomembrane material, usually high-density polyethylene (HDPE), polypropylene (PP) or poly vinyl chloride.
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 relevant regulatory authority.

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 (MSW) 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.
Inert Waste	Waste that is neither chemically nor biologically reactive i.e., waste that does not decompose, does not undergo a change in its chemical properties and does not alter the chemical properties of any other material.
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 fill site. Accepts only clean fill material, controlled fill material and managed fill material.
Managed Fill Material	Predominantly clean fill material and controlled fill material that may also contain material with contaminant concentrations in excess of controlled fill limits where site specific management controls are in place to manage discharges to the environment.
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 Ministry of Health (MoH). All MSW should have an angle of repose of greater than five degrees (5°) and have no free liquid component. It is recognised that MSW 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.
MSW Landfill	Any Class 1 Landfill that accepts MSW.
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.
SPLP Test	USEPA Test Method 1312. The synthetic precipitation leaching procedure (SPLP) test is designed to determine the mobility of both organic and inorganic contaminants present in soils, under neutral conditions. Reagent or Type 2 water (defined as water in which contaminants are not observed at or above the laboratory detection limits) is used to leach contaminants from a sample of soil.
TCLP Test	USEPA Test Method 1311. The toxicity characteristic leaching procedure (TCLP) 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) anything 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 C&D 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/fills in New Zealand:

- Centre for Advanced Engineering (CAE) Landfill Guidelines (2000); and
- A Guide to the Management of Cleanfills (Ministry for the Environment [MfE] 2002a).

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

The final decision on site-specific requirements for a landfill/fill is made by the appropriate regulatory authority, or Environment Court, under the provisions of the RMA, 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

In the context of these Guidelines ‘disposal to land’ means the final (or more than short-term) depositing of clean, managed and controlled fill materials and/or waste materials into or onto land set apart for that purpose (i.e., in a landfill or fill facility).

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

- the spreading of biosolids in a thin layer across the ground surface;
- earthworks operations involving the movement of soil that is not contaminated soil, or clean fill material within a site, including engineered fills;
- 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 contaminated soil (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 or fill facilities, or extensions of existing landfills or fill sites, including new landfill/fill 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/fill sites.

2.3 Objectives

The objectives of the Guidelines are to:

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

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, or subsequent revisions:

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

2.5 Waste Types

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

- clean fill material;
- controlled fill material;
- managed fill material;
- C&D waste;
- MSW, i.e. mixed household, commercial and industrial waste
- household waste;
- commercial waste;
- 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 and fills into five distinct types:

- Class 1 Landfill
- Class 2 C&D Landfill
- Class 3 Managed Fill
- Class 4 Controlled Fill
- Class 5 Clean Fill

Class 1 Landfill

A Class 1 Landfill is a site that accepts MSW 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 C&D Landfill

A Class 2 C&D Landfill is a site that accepts non-putrescible wastes including C&D wastes, managed fill material, controlled fill 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 C&D Landfill leachate is typically characterised by mildly acidic pH, and the presence of ammoniacal nitrogen and soluble metals, including heavy metals.

Class 2 C&D 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 C&D 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 Managed Fill

A Class 3 Managed Fill accepts materials as defined in these Guidelines. These materials comprise predominantly clean fill and controlled fill, which may also contain material with contaminant concentrations in excess of controlled fill limits. Site specific management controls are required to manage discharges to the environment. The fill material will not contain putrescible or reactive materials that when deposited may result in generation of leachate or landfill gas.

Class 3 Managed Fills should be sited in areas of appropriate geology, hydrogeology and surface hydrology. 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 surface water and groundwater.

Class 4 Controlled Fill

A Class 4 Controlled Fill accepts controlled fill materials as defined in these Guidelines. These comprise predominantly natural soil and inert C&D materials; and material acceptable in Class 5 Clean Fills. Soils may have 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 5 Clean Fill

A Class 5 Clean Fill accepts only clean fill material as defined in these Guidelines. These comprise VENM, such as clay, soil and rock that are free of combustible, putrescible, degradable or leachable components. The principal control on contaminant discharges to the environment from Class 5 Clean Fills is the WAC.

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/Fill Classes

The landfill/fill classes, and the waste types that may be accepted into each class, are summarised in **Table 2-1**, along with the key aspects relating to the management of each class of landfill/fill with respect to control of effects. For each of these landfill/fill classes, the class definition and the anticipated characteristics of the waste that will be accepted into each class of landfill/fill, along with the anticipated key contamination risks, are described in **Table 2-2**. Note that there will also be wastes that are prohibited from being disposed of to each class. This is discussed further in **Section 6.2**. A detailed list of characteristics and types of waste which should be prohibited from Class 1 to 5 landfills/fills is provided in **Appendix I**.

WAC for each class of landfill/fill are discussed in **Section 6** and are explained in greater detail in **Appendix C**.

Table 2-1 Summary of Landfill Classes

Class	**1**	**2**	**3**	**4**	**5**
Name	**Landfill**	**C&D Landfill**	**Managed Fill**	**Controlled Fill**	**Cleanfill**
Waste Types	Clean Fill Material Controlled Fill Material Managed Fill Material C&D Waste MSW including household, commercial and industrial wastes	Clean Fill Material Controlled Fill Material Managed Fill Material C&D Waste	Clean Fill Material Controlled Fill Material Managed Fill Material	Clean Fill Material Controlled Fill Material	Clean Fill Material
Control of Effects	Siting (refer to **Section 4**) WAC (refer to **Section 6**) Engineered redundancy in liner design (refer to **Section 5**) Leachate management (refer to **Section 5**) Landfill gas management (refer to **Section 5**) Operations (refer to **Section 7**) Capping (refer to **Section 5**) Monitoring (refer to **Section 8**)	Siting WAC Engineered redundancy in liner design Leachate management Landfill gas management Operations Capping Monitoring	Siting WAC Operations Capping Monitoring	Siting WAC Operations Monitoring	Siting WAC Operations Monitoring

Table 2-2 Landfill Class Rationale

Class	Name	Waste Material	Material Source	Contaminant Risk
1	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, 4 and 5. May be developed for specific industrial wastes (for example, monofills or residual waste sites).	Households, industry, institutions, construction sites, contaminated sites.	Leachate Contaminated stormwater Landfill gas Odour Dust
2	C&D Landfill	Unsorted/uncontrolled C&D material.	Construction sites, demolition material, soil from areas with significantly different chemical properties.	Leachate Contaminated stormwater Low risk of landfill gas 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 specified maximum contaminant concentrations greater than applicable local background concentrations.	Selected materials from C&D sites, earthworks and site remediation.	Contaminant mobility, risk to groundwater and surface water Dust
4	Controlled 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 and demolition sites and earthworks.	Minor risk of contaminant mobility and sediment contamination of surface water Dust
5	Clean Fill	VENM	Slips/road clearance, construction site clearance, earthworks surplus.	Sediment contamination of surface water Dust

3. Legislation

3.1 Introduction

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

Requirements in respect of the Waste Minimisation Act (WMA) 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/fills:

- Health Act 1956;
- RMA 1991;
- Health and Safety at Work (HSW) Act 2015;
- Hazardous Substances and New Organisms Act 1996;
- Local Government Act 2002;
- Climate Change Response Act 2002; and
- WMA 2008.

The key aspects of each Act, and how they are applicable to landfill/fill siting, design and operation, are outlined in **Table 3-1**.

Further information on each piece of legislation listed above as it relates to landfills/fills is provided in **Sections 3.2** and **3.3**, and in **Appendix A**.

Table 3-1 Legislation Relating to Landfills/Fills

Health Act 1956	RMA 1991	HSW Act 2015	Hazardous Substances and New Organisms Act 1996	Local Government Act 2002	Climate Change Response Act 2002	WMA 2008
Provision for waste collection and disposal by local authorities	District and Regional Plans Resource Consents National Environmental Standards (NESs)	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 minimisation and management plans (WMMPs) 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.*

3.3 Resource Management Act 1991 (RMA)

The RMA is the key piece of legislation controlling landfills, fills and other waste management facilities in New Zealand.

Detail of the processes related to obtaining resource consents under the RMA is beyond the scope of these guidelines. The following is a summary of the purpose and principles of the RMA and the related consenting 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/fills) through local policies, plans and resource consent procedures.

The RMA also provides for the development of NESs.

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

Regional 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 caused by 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.

Territorial Authorities

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

The establishment of a landfill/fill under the RMA may require several consents from a regional council and/or territorial authority. The number and type of consents required will vary depending on the class of landfill/fill, site location, and 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 or fill, its siting, and effects on the surrounding environment.

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

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 or fill.
	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.

Discharge Permit - Land

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

A single 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;
- WAC;
- design and performance of liner and leachate collection systems;
- cover systems;
- acceptance of designs;
- closure requirements;
- peer review (in some circumstances); and
- a bond or financial assurance (in some circumstances).

---

[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).

Discharge Permit - Water

Landfills/fills 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/fills generally contain conditions relating to:

- 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
- erosion control.

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

Discharge permits for discharges of contaminants onto or into land at landfills/fills, 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/fills 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 or fill is illegal as stipulated in the National Environmental Standard for Air Quality (NES-AQ).

Discharge permits for discharges of contaminants into the air from landfills/fills 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/fills 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 or fill 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 or fill 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/fills 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 new landfills or fills within a plan or proposed plan, usually a landfill/fill will require a land use consent from either a territorial authority, regional council or both.

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

- development plans;
- geotechnical stability;
- 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/fill 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/fill 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/fill project if there are roads to vest in the council or reserves to be set aside as a consequence of the landfill/fill development.

Existing Use Rights

In some circumstances landfills/fills 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 1977 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.

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/fills can only be required by a Minister of the Crown, or a regional council or territorial authority. In the case of landfills or fills, the designation procedure is not available to private organisations.

A designation for a landfill/fill provides for the use of the land as a landfill/fill. 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 and fills in their district.

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

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

National Environmental Standards (NESs)

The RMA provides for the setting of NESs.

National Environmental Standard for Air Quality (NES-AC)

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

National Environmental Standards for Assessing and Managing Contaminants in Soil to Protect Human Health (NES-CS)

The NES-CS applies to land which has been, is more likely than not to have been, or is currently, affected by contaminants in soil. Land to which the NES-CS may apply is primarily determined by establishing whether a Hazardous Activities and Industries List (HAIL) activity has taken place on the land in question. In this way, and because landfills/fills are listed on the HAIL (category G3), the NES-CS is applicable to landfill/fill sites.

The NES-CS achieves its policy objective (to regulate the development of contaminated land such that it is safe for human use) through a mix of allowing (permitting) and controlling (through resource consents) certain activities on land affected or potentially affected by soil contaminants. The NES-CS applies when the following five activities are being done on a HAIL site (such as a landfill or fill):

- removal or replacement of an underground fuel storage system and associated soil;
- soil sampling;

- soil disturbance;
- land use change; and
- subdivision of land.

The NES-CS provides a set of soil guideline values (SGVs), which are health-based trigger values (above which a risk to human health could exist, over time) for selected contaminants in soil for the protection of human health in respect of the following land uses:

- rural residential / lifestyle block 25% produce;
- residential 10% produce;
- high-density residential;
- recreation; and
- commercial / industrial outdoor worker.

These SGVs and their associated land use categories are discussed further in relation to landfill/fill WAC in **Section 6** of this Guideline.

3.4 Other Relevant Legislation

Summaries of the provisions of the following additional Acts that are relevant to the siting, design, or operation of landfills/fills are provided in **Appendix A**:

- HSW Act 2015
- Health and Safety at Work Act (Asbestos) Regulations 2016
- Hazardous Substances and New Organisms Act 1996
- Local Government Act 2002
- Climate Change Response Act 2002
- WMA 2008 (and associated regulations)
- Heritage New Zealand Pouhere Taonga Act 2014.

3.5 Other Relevant Documents

The following documents may also be relevant:

- Approved Code of Practice: Management and Removal of Asbestos 2016 (WorkSafe New Zealand 2016).
- New Zealand Guidelines for Assessing and Managing Asbestos in Soil (BRANZ 2017).
- Health and Safety Guidelines for the Solid Waste and Resource Recovery Sector (WasteMINZ 2021).

4. Siting

4.1 Introduction

Location is the key determinant of the extent to which a landfill or fill poses an environmental risk. Careful siting of a landfill/fill 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 (e.g., prevent discharges). This in turn will ensure that there are no 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 geology to limit discharges from the site, so that significant adverse effects on the surrounding environment do not occur. 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 (both surface water and groundwater), windblown litter and dust, an increase in the populations of vermin, and threats to household water supplies.

A successful landfill/fill 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/fills 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 MSW and/or industrial waste.

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

- landfill/fill siting approach;
- site selection or assessment process;

- site investigations;
- consultation; and
- landfill/fill siting criteria.

The key siting constraints for each class of landfill/fill are summarised in **Table 4-1** below, and are discussed in detail in **Section 4.4**. **Table 4-1** also provides guidance on where the differences lie for class 2, 3, 4 and 5 sites.

Table 4-1 Siting Criteria - Technical Constraints

Class	1	2	3	4	5
Type of facility	Landfill	C&D Landfill	Managed Fill	Controlled Fill	Clean Fill
Geology constraints (without site-specific additional mitigation)	High permeability soils, sand and gravels, fractured rock	High permeability soils, sand and gravels, fractured rock	High permeability soils, sand and gravels, fractured rock	High permeability fractured rock	NA
Geology and site stability constraints	Geothermal areas Karst areas Active faults	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	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	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 objective of these siting guidelines is to ensure the selection of landfill/fill sites which, to the extent practicable, provide an appropriate level of natural containment, through their inherent geological, hydrogeological and topographical characteristics. 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/fill. In addition, 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.

Therefore, an ideal siting approach includes the use of a robust selection process and siting criteria to select the most appropriate landfill/fill sites, while being commensurate with the class of landfill/fill that is proposed. Such an approach 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 (where these are required).

Where there is a difference in siting approach based on the class of landfill/fill proposed, this is detailed below.

Class 1 and Class 2 Landfills

The approach to siting Class 1 and 2 landfills must include consideration of the full range of siting criteria, with the pros and cons of each factor weighed against each other. For example, establishing a site in a location with good natural containment is 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.

Class 3 Managed Fills

For Class 3 Managed Fills a primary consideration for the siting approach is locating a site with good natural containment as this is a major technical advantage. However, the siting approach must also consider constraints related to proximity to fill material sources, existing site ownership and community considerations (which may be more focused on access, traffic, and visual amenity aspects rather than odour, litter or rodent considerations given the nature of the material that Class 3 Managed Fills accept).

Class 4 and Class 5 Fills

The siting approach for these fills does not require a significant focus on containment. While there should be no odour, litter, or rodent issues associated with these facilities, access and traffic factors, and visual amenity are likely to require consideration. The siting approach is 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

As noted in **Section 4.2**, siting considerations will include both technical factors, and community perception and values, both of which may be critical to the acceptability of a landfill/fill site.

For each of the landfill/fill classes, the following general site selection considerations are likely to apply:

Class 1 Landfills: require a comprehensive site selection process and/or assessment, taking into consideration (and giving appropriate weighting to) all landfill siting criteria. A full suite of investigations and assessments will be required.

Class 2 C&D Landfills: the site selection process should focus on areas with appropriate geology, hydrogeology and surface hydrology, and consider these in conjunction with the requirement for Class 2 C&D Landfills to have an engineered liner, and a leachate collection system; and the requirement for ongoing management and monitoring, such as groundwater and surface water monitoring. In terms of investigations, as a minimum, a site environmental assessment is required.

Class 3 Managed Fills: the site selection process should focus on areas with appropriate geology, hydrogeology and surface hydrology; and the requirement for ongoing management and monitoring such as groundwater and surface water monitoring. In terms of investigations, as a minimum, a site environmental assessment is required.

Class 4 Controlled Fills: the site selection process will likely focus on site ownership, location, and transport distance from sources of fill. However, as materials with contaminants at concentrations greater than local background may be accepted, the selection process should also consider geology, hydrogeology, and surface hydrology. Issues such as stability, surface hydrology and topography will be relevant in relation to sediment control and likely end use of the site. In terms of investigations, as a minimum an environmental site assessment should be completed.

Class 5 Clean Fills: the site selection process will generally focus on issues of practicality and commercial viability (site ownership, location and transport distance from sources of fill). Issues such as stability, surface hydrology and topography will be relevant in relation to sediment control and likely end use of the site.

The site selection process should normally include the following:

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

These aspects are detailed further below.

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, but not limited to:

- 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.

Sufficient investigations, testing and preparatory work need to be undertaken to provide the following information (commensurate with the class of landfill/fill being proposed):

- 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/fill;
- 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.

Further information about each of the investigation stages is provided below.

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/fill 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 and land-use category of site neighbours;
- access to the site and potential traffic effects, including the potential impact 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 4.4**, 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/fill options is provided in the Landfill Full Cost Accounting Guide for New Zealand (MfE 2004a).

Consultation

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

The Fourth Schedule of the RMA 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/Fill Siting Criteria

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

- identifying potential landfill/fill sites (Class 1, 2, 3, 4 and 5); and
- planning site investigations and assessing the suitability of a site for landfilling/filling.

It is unlikely that any site will meet all criteria. Therefore, the assessment of the suitability of a site for a landfill/fill 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/filling 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.

Some of the wide range of other issues to consider while selecting a landfill or fill 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 that any leachate is contained, and the migration potential of any discharges is limited (should an engineered containment system ever fail). Geology should be assessed with respect to the potential migration of leachate and 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 the 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.

If it is not possible to avoid siting a landfill/fill 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 the type and magnitude of stormwater, silt and groundwater controls, and the containment and control of leachate and landfill gas.

The key technical constraints in respect of site geology for different classes of landfills/fills are summarised in **Table 4-1**.

Materials Requirement and Balance

Soil materials are required for all stages of a landfill/fill 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 where the site is sited and how the site is developed.

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 or fill in areas overlying significant aquifers used for drinking water.

In assessing the suitability of a landfill/fill 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/fill are summarised in **Table 4-1**.

Surface Hydrology

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

It is generally undesirable to site a landfill/fill 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/fill;
- water courses and locations requiring culverts through the site and beneath the landfill/fill (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/fill, 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/fill are summarised in **Table 4-1**.

Site Stability

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

It is generally undesirable to site a landfill or fill 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).

It is noted that many of the site stability restrictions are the same as the geological restrictions discussed above.

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

- Localised subsidence areas. Differential movement could render a landfill/fill 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/fill. 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.

Engineering techniques can potentially mitigate some site stability issues. The ability to engineer a solution in response to site stability issues must be considered in relation to site specific circumstances. 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/fill are summarised in **Table 4-1**.

Environmentally Sensitive Areas

Landfills and fills should generally be located to avoid areas where sensitive natural ecosystems would be adversely affected, such as those in **Table 4-1**.

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/fill 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/fill 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/fill operator.

An assessment of the suitability of a site for a landfill or fill, 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 us at or near airports'* (2008) notes that the International Civil Aviation Organisation Bird Control and Reduction Manual recommends that [MSW 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.

Climatic Conditions

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

Rainfall

Landfills/fills 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 drainage3 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/fill 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/fills, 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/fill;
- whether the traffic can avoid residential areas;
- road safety considerations with respect to the landfill/fill entrance. Vehicles using the landfill/fill should not be required to queue on the highway;
- other transport options, for example rail.

---

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

Leachate Management

Landfill/fill siting should take into account the potential methods of leachate treatment and disposal and its effect on site neighbours. See **Section 5.7**.

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 into confined spaces such as manholes, chambers and poorly ventilated areas of buildings on or adjacent to the site;
- asphyxiation of personnel entering trenches, manholes or buildings on or near the landfill/fill site;
- odour nuisance;
- greenhouse effects of methane;
- migration in surrounding sub-strata; and
- vegetation die-off on the completed landfill/fill 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/fill siting must take account of the requirements of the NES-AQ, the potential methods of landfill gas use and disposal, and potential effects on site neighbours. See also **Section 5.8**.

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. There is a significant cross-over with the issues that must be considered when assessing compatibility with surrounding land uses, access and traffic, and cultural issues.

Community issues typically include, but are not limited to:

- design life of the landfill/fill;
- 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 4 and Class 5 fills have unrestricted future use, these sites often return to previous or similar land use, subject to site specific filling objectives and compliance with those objectives. Landfill/fill classes 1 to 3 will require appropriate aftercare and landfill/fill closure plans. These 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/fill form.

5. Design

5.1 Introduction – Design Objectives

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, and consequently the level of design, is determined by:

- the class of landfill/fill;
- the type of waste to be deposited in the landfill/fill;
- 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 and 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;
- groundwater management and control;
- surface water and stormwater management;
- leachate containment and liner systems;
- leachate management and control;
- landfill gas management;
- landfill/fill cover systems; and
- construction quality assurance (CQA) and construction quality control (CQC).

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/fill design. The designer should consider the potential environmental impact of the landfill/fill throughout its life and post closure and incorporate mitigation measures into the design appropriate to the class of landfill/fill 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.

While many of the potential risks associated with landfills/fills 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, 4 and 5 fills, the primary environmental controls are appropriate site selection and the WAC. Therefore, the design of a Class 3, 4 and 5 fill does not tend to focus on containment. Landfill features such as leachate collection, removal and treatment, low-permeability liners, gas management, and capping are also not as relevant for Classes 3, 4 and 5 because of the nature of the materials being disposed. However, Class 3 Managed Fills require an engineered capping system to minimise water ingress and provide separation between the managed fill material and end users upon closure.

Erosion and sediment control are both very important considerations for all sites. For Class 4 and 5 sites, erosion and sediment control is required to minimise the discharge of sediment to nearby surface water receptors. The sediment from these sites is unlikely to cause adverse effects due to its chemical composition, due to the WAC. For Class 3 sites the WAC have been set as a means of environmental control for the migration of contaminants to groundwater but may not be below applicable sediment quality guidelines for surface water receptors. Therefore, erosion and sediment controls are particularly important to minimise sediment discharges from Class 3 sites, as a means of controlling discharges of contaminants via this pathway.

Effective landfill/fill design will follow on from appropriate site selection, based on the appropriate level of investigation, as discussed in detail in **Section 4**.

Landfill/fill 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/fill.

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 WMA 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.

5.3 Facility Design Considerations

A selection of key facilities design considerations is discussed below.

Site Access

Access to a landfill/fill needs to be controlled to restrict the mixing of private, commercial and landfill/fill 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/fill will generate heavy vehicle movements. The standard of all roads and bridges forming part of the principal access route to the landfill/fill and their construction should be reviewed. Upgrading of roads and bridges may be required.

Access to a landfill/fill 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/fill 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/fills, 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.

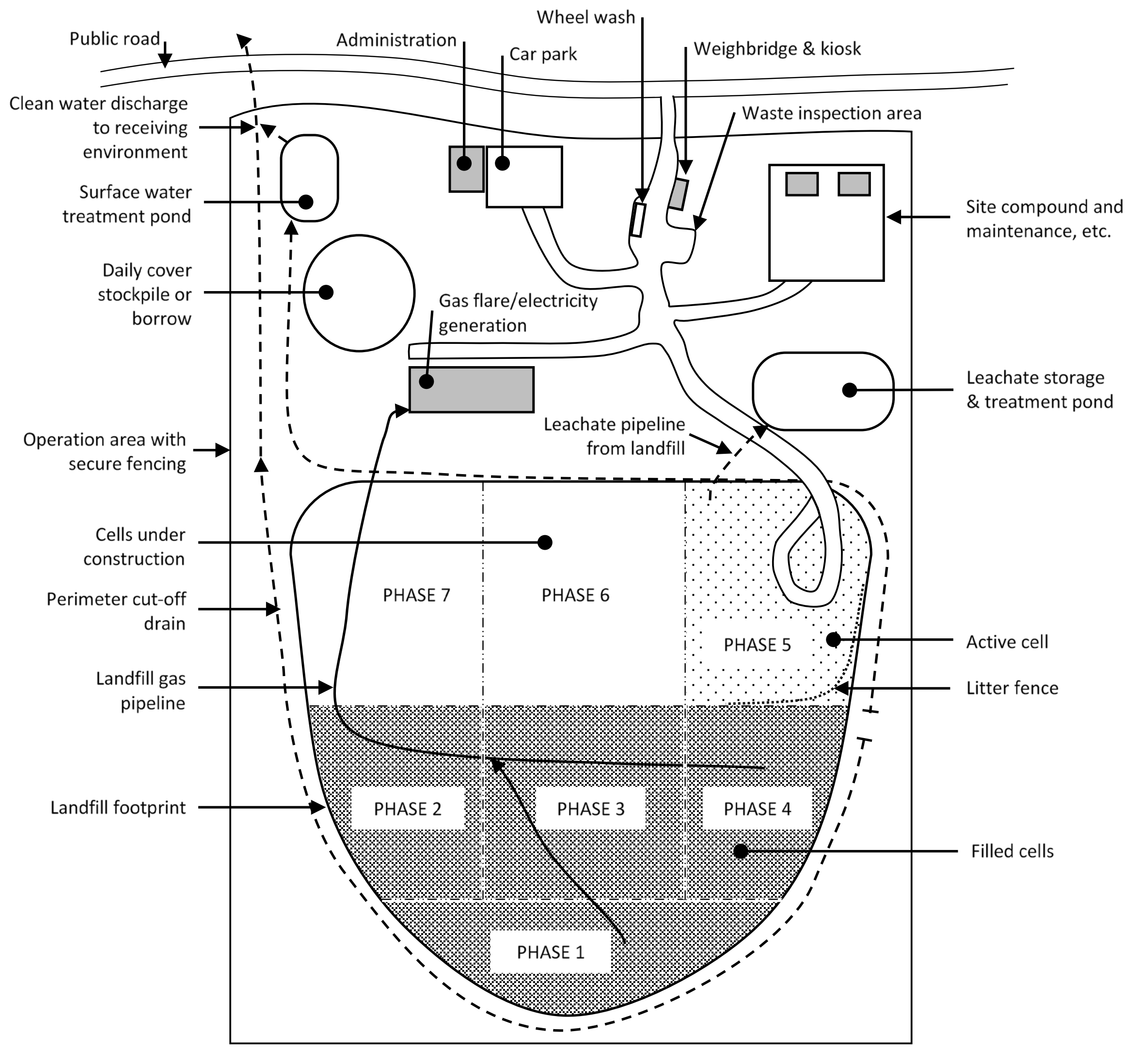
Site Facilities

The extent of the site facilities required will depend on site-specific conditions such as the size of the landfill/fill, 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/fill site is shown in **Figure 5-1.**

Figure 5-1 Typical Operational Plan for a Landfill Site



Adapted from 'Landfill Site Design', EPA Ireland, 2000

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/fill 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.

5.4 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/fill. 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 fill should preferably be above the groundwater table, with a low permeability unsaturated zone immediately below it, with a thickness of at least 2 m. Ideally the base of a lined landfill/fill 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 base grade 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 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 8**.

Table 5-1 summarises under drainage requirements for the different classes of landfill/fill.

Table 5-1 Summary of Minimum Groundwater Drainage Requirements

Class	1	2	3	4	5
Underdrains	Yes	Yes	Yes	NA	NA

5.5 Surface Water and Stormwater Management

Objectives: Maintain separation of stormwater from waste/leachate

Minimise leachate generation by preventing infiltration of surface water 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/fill area to prevent overland flow from entering the active landfill/fill 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/fill 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/fill.
- Drainage channels or drains constructed on the completed landfill/fill surface should be designed and constructed to accommodate settlement, minimise or eliminate erosion, and cope with localised design storms.
- Completed landfill/fill areas and areas of intermediate cover should be contoured to direct stormwater into drains leading away from the active filling area and working face.
- Permanent or temporary access roads should be designed to prevent them acting as stormwater channels that may direct water into the landfill/fill.

Depending on the circumstances, temporary surface water management systems typically should be designed for at least a 1-in-10 year storm (10% annual exceedance probability [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. Monitoring (including testing) of discharges from retention devices may be required, depending on the class of landfill/fill. Refer to **Section 8** for detail.

In summary, surface water drainage systems for landfills/fills should contain provision for diversion, retention and testing of surface water and stormwater. Retention and testing requirements for Class 5 Clean Fills should be assessed on a site-specific basis. See **Table 5-2** for surface water and stormwater drainage requirements for each landfill/fill class.

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

Class	1	2	3	4	5
Diversion	Yes	Yes	Yes	Yes	Yes
Retention e.g., sedimentation ponds	Yes	Yes	Yes	Yes	Site Specific
Testing	Yes	Yes	Yes	Yes	Site Specific

5.6 Liner Systems

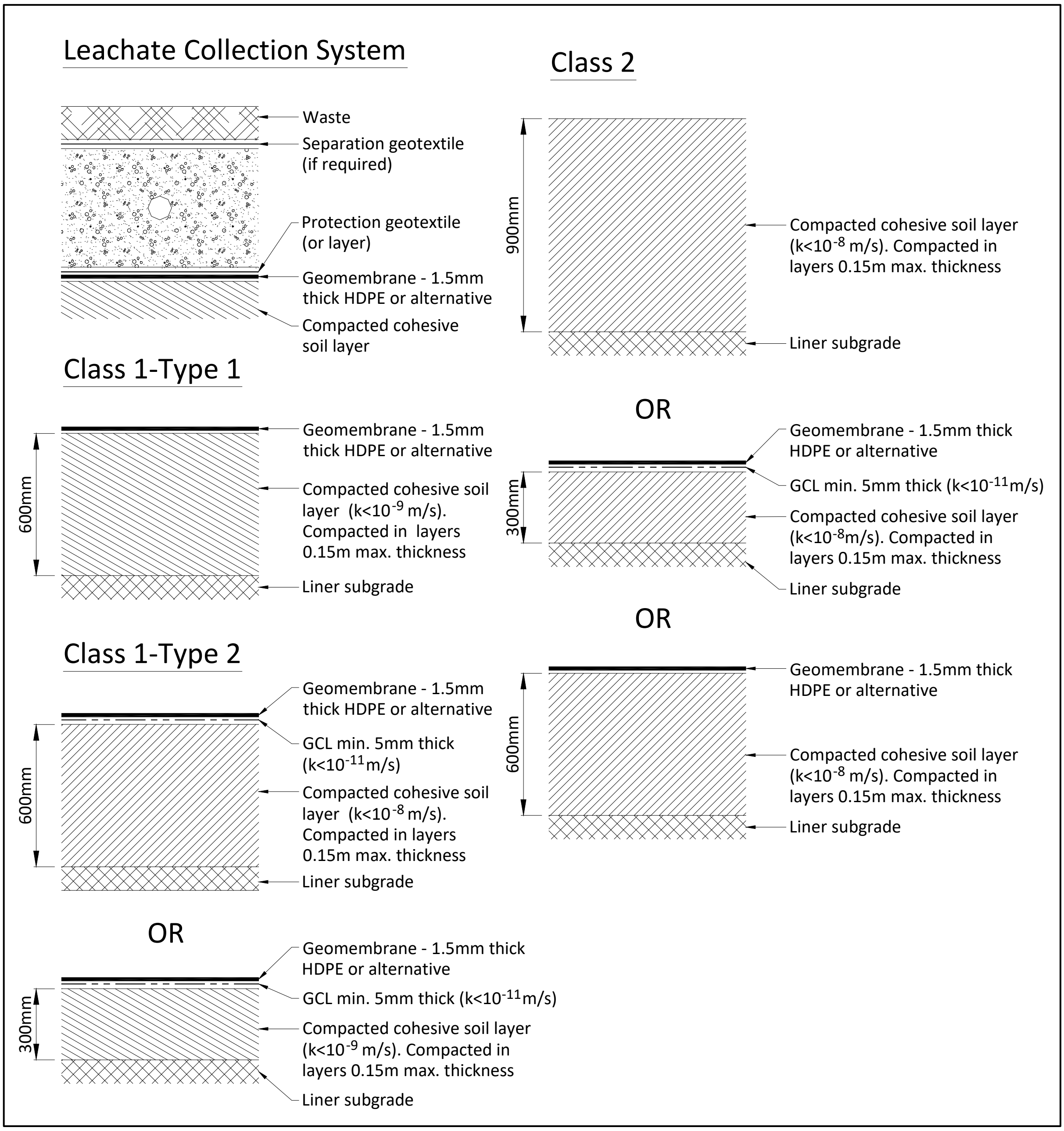
Objectives: Contain leachate for collection and treatment/disposal

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. Diagrams of the liner types are shown in **Figure 5-2**.

Figure 5-2 Liner Types



The recommended liner for each class of landfill/fill 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 FML (usually 1.5 mm thick 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 x 10^{-9} m/s, compacted in layers a maximum of 150 mm thick.

Type 2

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

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

Class 2 Liner

The following liner designs are recommended, as they have been shown to provide a suitable level of protection to the receiving environment for a Class 2 C&D 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 x 10^{-8} m/s; or
- a composite liner comprising a synthetic FML 1.5 mm thick, overlying a GCL, a minimum of 5 mm thick, with a coefficient of permeability not exceeding 1 x 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 x 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 x 10^{-8} m/s.

Class 3, 4 and 5 Liners

No engineered liner or leachate collection system is required for a Class 3, 4 or 5 fill as the environmental effects are controlled primarily by WAC.

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 B.1**.

Geosynthetic Clay Liners (GCL)

A 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 the GCL component in a landfill is to act as a hydraulic and/or gas barrier in liner and capping systems.

Additional details of GCLs are contained in **Appendix B.1**.

Geomembranes (flexible membrane liners)

FMLs or 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 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 B.1**.

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/FMLs 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 PP) depends on the waste composition and resulting leachate strength, with PP 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 B.1**.

Liner and Global Stability, Waste Settlement, and Slope

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

Details of stability, waste settlement and slope considerations as they pertain to the liner system are contained in **Appendix B.1**.

Contaminant Transport

There are two mechanisms whereby contaminants in leachate may migrate from the landfill/fill, 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 the recommended minimum liner requirements is provided in **Table 5-3.**

Table 5-3 Summary of Recommended Minimum Liner Requirements

Class	1	2	3	4	5
Minimum base grade slope	2%	2%	NA	NA	NA
Liner – compacted cohesive soils	NA	900 mm compacted cohesive soil @ < 1 x 10^{-8} m/s	NA	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	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				

5.7 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/fill through the sides or base either through defects in the liner system or by flow through its matrix;
- prevent liquid levels within the landfill/fill 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/fill include:

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

Leachate Generation Estimates

Developing reliable leachate generation estimates is an important part of the design process for landfills/fills. 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/fills).

As the landfill/fill 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 B.2**.

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/fill.

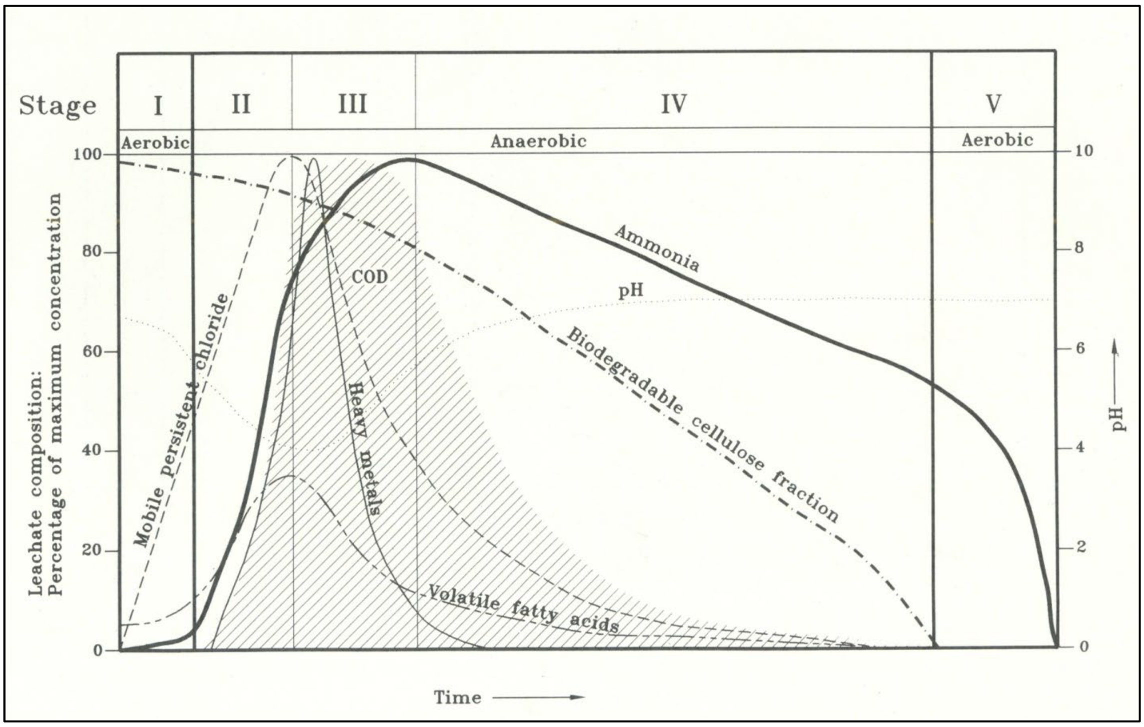
Decomposition of putrescible waste takes place through the action of microbes. It occurs in three stages.

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** 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.

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
BOD5 (mg/l)	13000	4000-40000	Na (mg/l)	1350	50-4000
COD (mg/l)	22000	6000-60000	K (mg/l)	1100	10-2500
BOD5 /COD ratio	0.58	--	Alkalinity (mg CaCO3/l)	6700	300-11500
SO4 (mg/l)	500	70-1750	NH4 (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	NO3 (mg N/l)	3	0.1-50
Mn (mg/l)	25	0.3-65	NO2 (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
BOD5 (mg/l)	180	20-550	Co (ug/l)	55	4-950
COD (mg/l)	3000	500-4500	Ni (ug/l)	200	20-2050
BOD5 /COD ratio	0.06	--	Pb (ug/l)	90	8-1020
SO4 (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

Note: * adsorbable organic halogen

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

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

Parameter	**Units**	**Class 1**[*]	**Class 2**[**]	**C&D Landfills (USA)**
pH	s.u.	5.9 – 8.5	5.9 – 8.3	6.45 – 7.60 (6.95)[***]
Conductivity	mS/m	264 – 27,900	120 – 554	
Alkalinity	mg/L	264 – 6,820	70 – 1930	38.2 – 6,520 (970)
Ammoniacal N	mg/L	3.4 – 1,440	0.86 – 99	0.1 – 170 (20.42)
TOC	mg/L	17.2 – 822	55 – 191	15 – 2,100 (306)
BOD_5	mg/L	12 – 3,867	1.4 – 38	5.7 – 920 (87.3)
COD	mg/L	84 – 5,090	15 – 610	
SO_4B	mg/L	1 – 780	360 – 1,900	11.7 – 1,700 (254)
Cl	mg/L	0.54 – 20	0.3 – 28	(2.65)
As	mg/L	45 – 2,584	18 – 200	52.7 – 262 (158)
Cr	mg/L	0.006 – 0.191	0.027 – 0.64	0.0014 – 0.046 (0.012)
Cu	mg/L	0.005 – 50.4	0.001 – 0.102	
Fe	mg/L		0.0023 – 0.3	
Pb	mg/L	1.6 – 220	0.001 – 103	0.050 – 275 (36)
Zn	mg/L	0.001 – 0.42	0.0025 – 5.5	0.02 – 5.16 (0.657)
Number of sites	--	8	2	--
Dates of sampling	--	1998 – 1999	2007 – 2012	--
Source		CAE Guidelines (2000)	Waikato Regional Council	Melendez, B.A. (1996)

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 C&D Landfills.
[***] Figure in parenthesis is the mean.

Leachate Collection and Removal Systems (LCRSs)

Objective: Enable effective long-term collection and removal of leachate

Minimise head of leachate on the liner

Leachate Collection System Components

The 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/fill; and
- control the head of leachate on the liner system to minimise the quantity of leachate leakage.

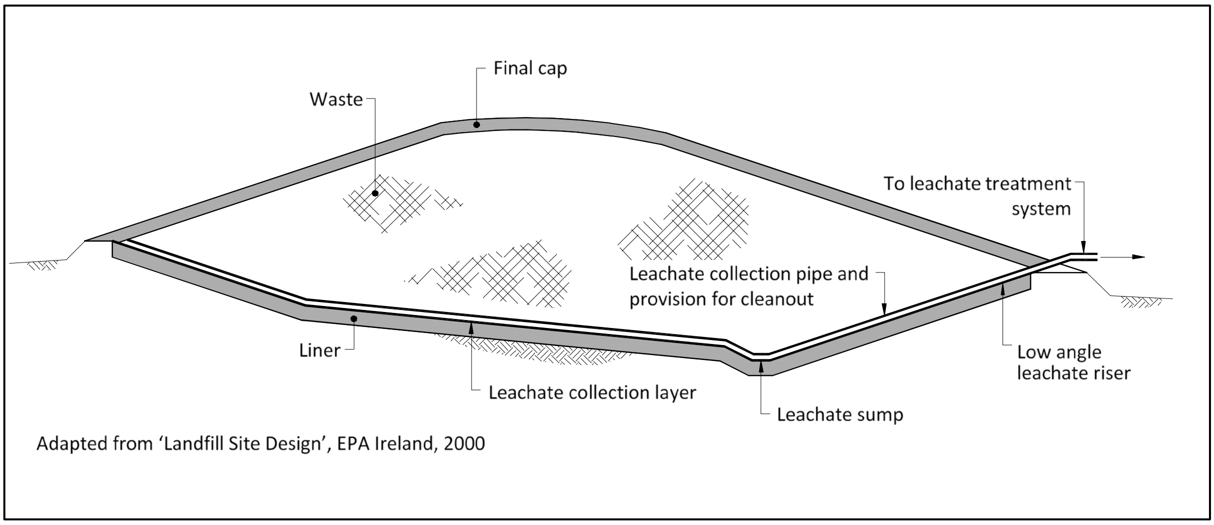
The LCRS must be designed to function throughout the operating life and after-care period of the landfill/fill. Failure of any component can jeopardise the operation of the entire system. Hence LCRS design must be robust and conservative. The design must ensure the system is able to be maintained and 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.

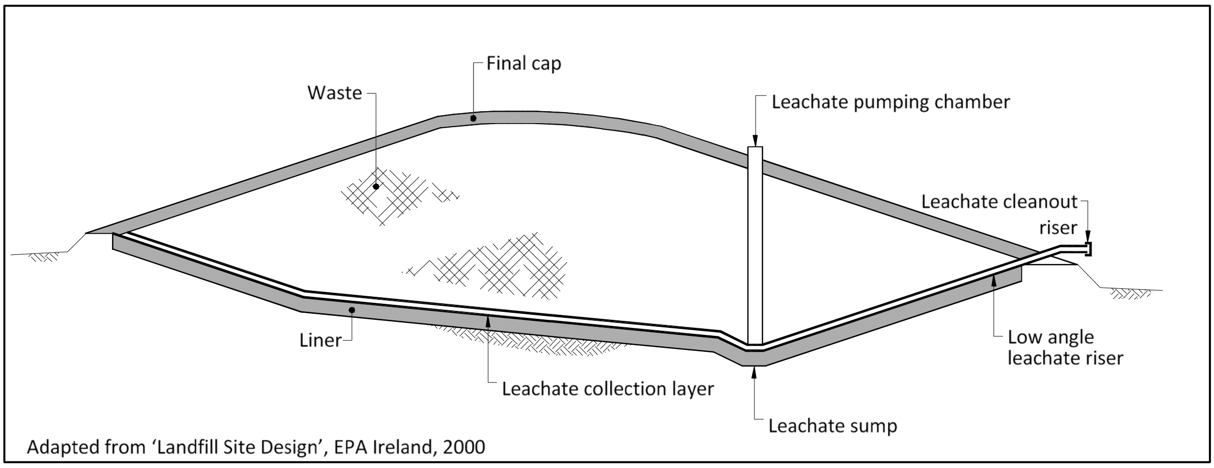
Typical leachate collection systems are illustrated in **Figure 5-4** (for a side slope riser) and **Figure 5-5** (for a vertical riser).

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



Adapted from 'Landfill Site Design', EPA Ireland, 2000

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



Adapted from 'Landfill Site Design', EPA Ireland, 2000

Table 5-6 summarises minimum leachate collection system requirements for each landfill/fill class.

Table 5-6 Summary of Minimum Leachate Collection System Requirements

Class	1	2	3	4	5
Components	Drainage Media and/or Perforated Pipes	Drainage Media and/or Perforated Pipes	NA	NA	NA
Maximum Leachate Head (mm)	300	300	NA	NA	NA

Furter details of leachate collection system design are contained in **Appendix B.2**.

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/fill settlement and hence potential to maximise air space; and
- potential for early stabilisation of the landfill/fill resulting in a reduced post-closure maintenance period and associated cost.

Potential issues with implementing leachate recirculation at a landfill/fill 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 B.2**.

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/fill. Effects of increased landfill gas production, odour, potential for differential settlement; leachate build-up on the base of the landfill/fill; 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/fill 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/fill 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 B.2**.

5.8 Landfill Gas Management

Landfill Gas Generation Processes

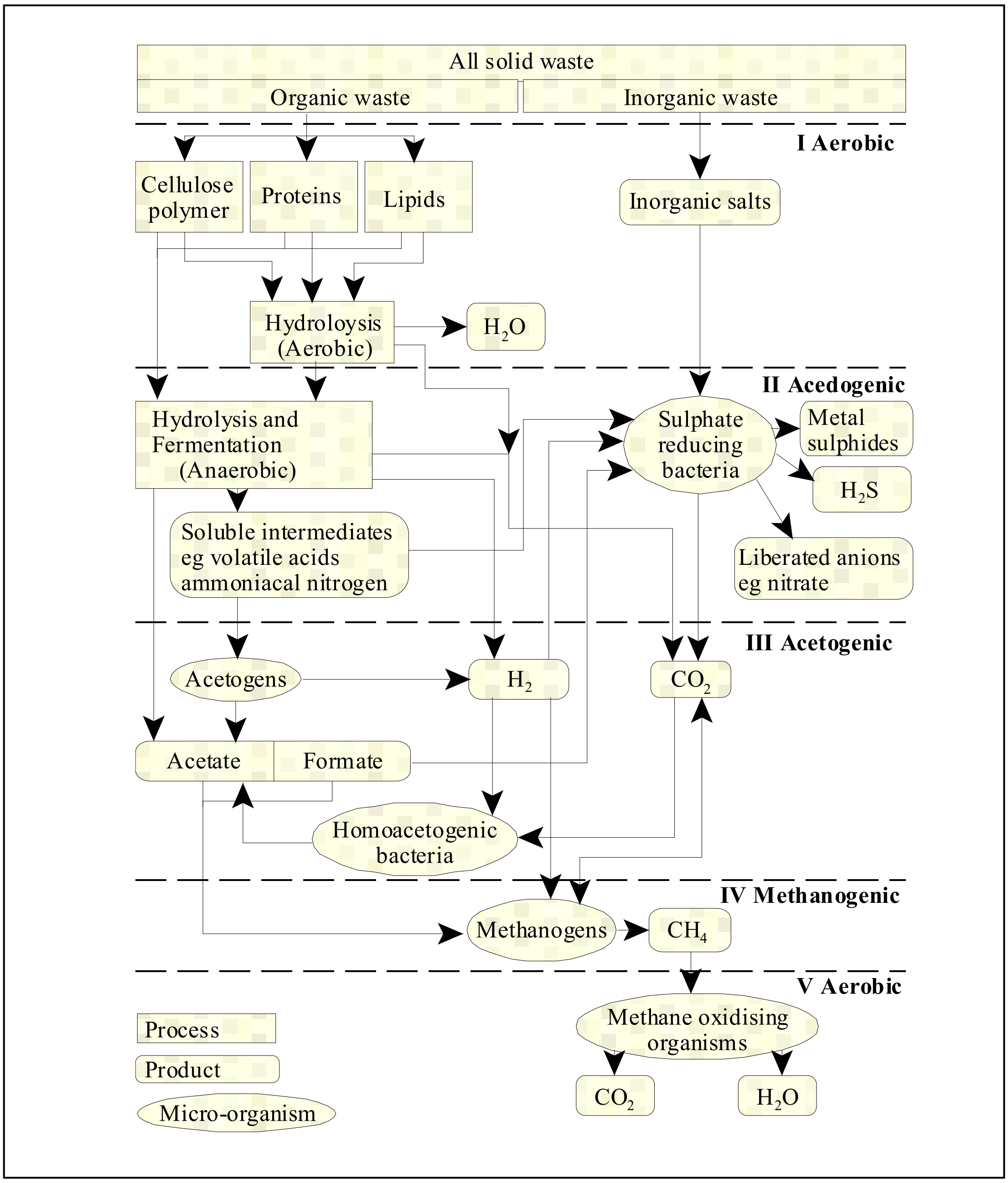
Landfill gas is a by-product of the decomposition of waste within the landfill (Class 1 and Class 2). Different reactions occur at different times in the process of waste decomposition. See **Figure 5-6**.

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.

Figure 5-6 Processes of Waste Decomposition

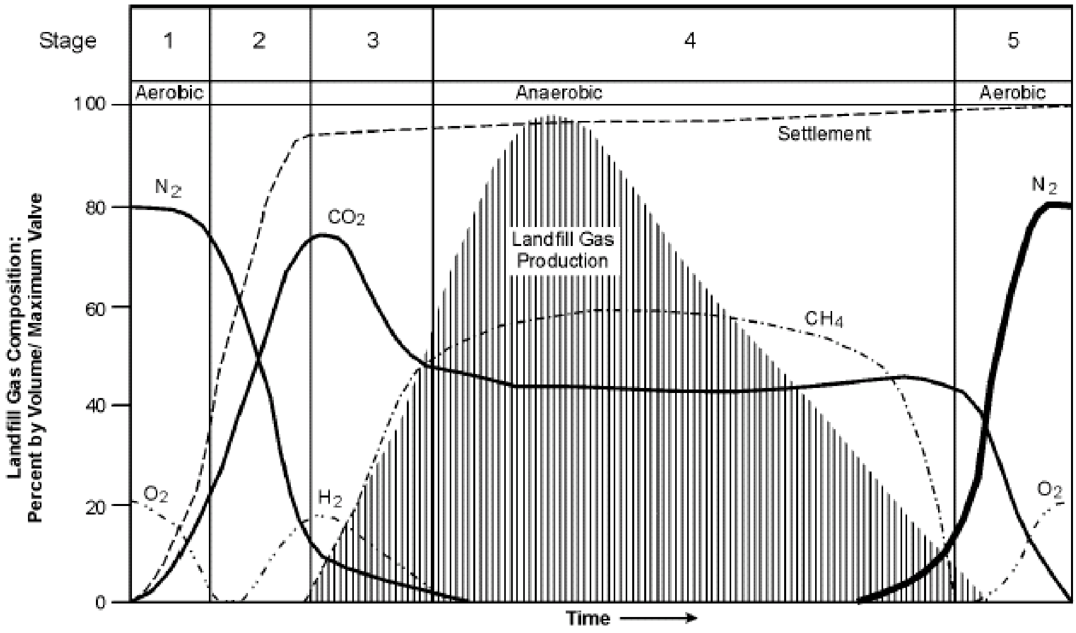


Adapted from UK Environment Agency 2004.

These phases of decomposition produce different by-product gases at varying rates (as per Farquar and Rovers (1973) original model, later modified by Rees (1980)) as shown in **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.

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



Source: Adapted from UK Environment Agency 2004.

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.

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.

Details of landfill gas generation models and landfill gas system collection efficiencies are contained in **Appendix B.3**.

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	0.001 – 0.6

Source: University of California 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 landfill gas 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. 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 landfill gas to a flare or other destruction device or beneficial use

In the case of beneficial reuse, landfill gas 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 B.3**.

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 NES-AQ. The NES-AQ 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 B.3**.

5.9 Landfill/Fill Cover Systems

Objectives: Control water ingress

Minimise landfill gas discharges

Prevent exposure of waste

Rehabilitate the site for proposed end uses

Landfill/fill 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/fill daily cover is addressed in more detail with respect to landfill/fill operations in **Section 7.9**.

Intermediate Cover

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

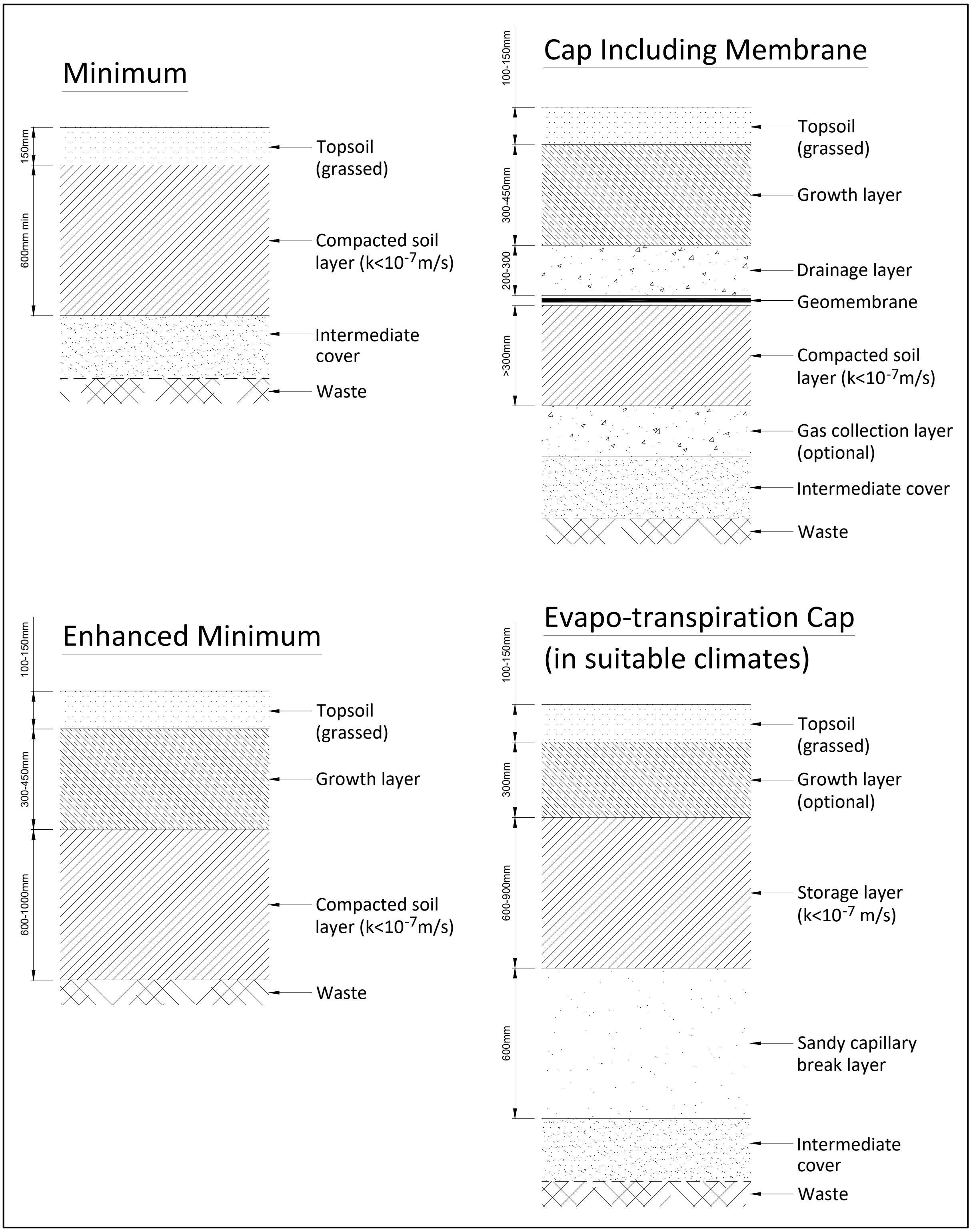
- the type of soils available on-site;
- the slope and topography of the top of the waste;
- the area of the cell; and
- the duration between the proposed placement of the final cover and the intermediate cover.

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/fill and a maximum gradient of 1V:3H is recommended to minimise erosion and post-closure care problems.
- **Effects of settlement**: Settlement may cause cracking of cover materials 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 FML (1 mm to 1.5 mm thick), or GCL 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;
    - use of a FML in final cover needs careful consideration due to the potential for cap instability on steeper slopes; and

- 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**.

Table 5-8 Minimum Recommended Final Cover Requirements

Class	1	2	3	4	5
Topsoil (mm)	150	150	150	150	150
Compacted cohesive soil (mm)	600 @ < 1 x 10^{-7} m/s	600 @ < 1 x 10^{-7} m/s	600 @ < 1 x 10^{-7} m/s	NA	NA
Subsoil layer	500	500	500	2000*	2000*
Combination of soil cover and gas dispersion layers (mm)	500mm	NA	NA	NA	NA

* WAC 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.

5.10 Construction Quality Assurance & Quality Control (QA/QC)

Objectives: Minimise defects in landfill/fill 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/fill 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 CQA plan which includes specification requirements and 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 and manufacturer's quality control documentation for all geosynthetic components (e.g., geomembranes, geotextiles, geocomposite drainage layers, geonets, geogrids, GCLs, 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 B.4**.

6. Waste Acceptance and Monitoring

6.1 Introduction

The purpose of establishing WAC is to manage wastes being disposed of at a specific landfill or fill 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/fill type, landfill/fill siting and the design of containment, leachate collection and treatment/disposal systems.

6.2 Waste Acceptance Criteria (WAC)

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/fill type, the total contaminant concentration limits for fill materials (classes 3, 4 and 5) or leachability criteria for potentially hazardous wastes (classes 1 and 2) that may be accepted.

A summary of the characteristics and types of wastes that may be acceptable for disposal in each landfill/fill class is provided in **Table 2-1** in **Section 2**.

Class 1 Landfill

WAC comprise:

- MSW; and
- for potentially hazardous leachable contaminants, maximum chemical contaminant leachability limits (TCLP) from Module 2 Hazardous Waste Guidelines – Class A (MfE 2004b).

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 MSW.

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

WAC for a Class 1 Landfill are provided in **Appendix D**. They are based on the United States Environmental Protection Agency (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 C&D Landfill

WAC comprise:

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

For Class 2 C&D Landfills, leachability testing should be completed to provide assurance that potentially hazardous waste materials meet the WAC. WAC for Class 2 C&D 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 and 4 Fills

WAC for both of these fill classes comprise:

- a list of acceptable solid materials;
- maximum incidental[4] or attached biodegradable materials (e.g., vegetation) to be no more than 2% by volume per load; and
- maximum chemical contaminant limits, which will differ depending on the fill class.

Class 3 and 4 fills have the potential to receive wastes that contain concentrations of contaminants that are above soil background levels. A class 3 fill may include engineered containment in the form of a cap upon completion of filling, however class 4 fills do not require any form of engineered containment. In both cases, the maximum chemical contaminant limits are intended to be the primary means of controlling potential adverse effects.

Testing of the materials to be disposed of, for total analyte concentrations, should be undertaken to provide assurance that waste materials meet the WAC. The total

---

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

concentration WAC represent maximum values which should not be exceeded and should be viewed as a minimum specification for Class 3 and 4 fills.

Derivation methodology information for class 3 and 4 WAC is provided in **Appendix C**.

WAC for Class 3 Managed Fills are provided in **Appendix F**; and for Class 4 Controlled Fills in **Appendix G**.

Class 5 Clean Fill

WAC comprise:

- VENM; 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 accepted by the regulatory authority to be the background concentration for VEMN within the intended catchment of the site.

When discharged to the environment, clean fill material will not have a detectable effect relative to the background, and the fill site will be able to be utilised for an unrestricted purpose (e.g., future residential development or agricultural land use) on closure.

Testing of these materials is not anticipated to be required as information should be obtained from the disposer prior to disposal to confirm that the materials meet the WAC for the fill class.

The WAC for a Class 5 Clean Fill are based on the accepted background concentrations for inorganic elements within the intended catchment of the site and provide for trace concentrations of a limited range of organic compounds. Recommended WAC for a Class 5 Clean Fill are provided in **Appendix H**.

Summary Table

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

---

[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	WAC
1	Landfill	Clean Fill Material Managed Fill Material C&D Waste MSW Household Waste Commercial Waste Industrial Waste Treated Hazardous Waste	Mixed municipal waste from residential, commercial and industrial sources, as well as: • treated hazardous wastes that meet WAC, • soils, rocks, gravel, sand, clay etc, including those that do not meet the Class 2 to 5 WAC, and • road sweepings.	Based on USEPA TCLP limits for leachable contaminants in potentially hazardous wastes. Refer **Appendix D**.
2	C&D Landfill	Clean Fill Material Managed Fill Material C&D Waste Non-putrescible Industrial Waste	As per Class 3 Managed Fill 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; • flooring products (carpet and underlay, vinyl/linoleum, cork tiles, clay tiles); • wire, wire rope, wire netting;	Based on USEPA TCLP limits for leachable contaminants in potentially hazardous wastes. Refer **Appendix E**.

Class	Common Name	Waste Description	Waste Types	WAC
			- insulation 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 C&D activities (including plastic bags, pipes, gutterings, building wrap); and 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 Controlled Fill Material Managed Fill Material	As per Class 4 Controlled Fill.	Based on maximum inorganic and organic contaminant concentration limits. Refer **Appendix F.**
4	Controlled Fill	Clean Fill Material Controlled Fill Material	As per Class 5 Clean Fills and also including: - soils, rocks, gravel, sand, clay etc. which do not meet the Class 5 WAC; - bricks, blocks and pavers; - ceramics; - concrete (exposed reinforcing removed); - road sub-base; - tiles and pipes made of clay, concrete or ceramics; and	Based on maximum total concentration limits and limited organic compounds. Refer **Appendix G**.

Class	Common Name	Waste Description	Waste Types	WAC
			- asphalt. Maximum incidental or attached biodegradable materials (e.g., vegetation) to be no more than 2% by volume per load.	
5	Clean Fill	Clean Fill Material	Non-contaminated soils, rocks, gravel, sand, clay and other natural materials. 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.	Based on maximum total concentration limits derived from the local/regional background and limited organic compounds. Refer **Appendix H**.

Prohibited Wastes

Prohibited wastes are those which, due to their inherent characteristics, can impact on the safe operation of a landfill/fill 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 to 5 landfills/fills is provided in **Appendix I**.

6.3 Waste Acceptance Procedures (WAP)

Before a waste can be accepted at a landfill/fill 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 disposal of inappropriate materials to the landfill/fill and should have procedures that enable unacceptable wastes to be easily identified, segregated and rejected.

The following WAP should be implemented by the operator as a tiered approach. WAP should be included within the management plan for the landfill/fill.

Waste Disposal Application

Disposers should complete a formal application to deposit waste prior to becoming a user of a landfill/fill, 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/fill. 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/fill 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/fill.

For Class 5 Clean Fills, 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, 4 and 5 fills, the following key information should be obtained from the disposer to confirm that the materials meet the WAC for the fill class:

- The nature of the waste (e.g., soil, rock, etc.);
- Sources of the waste including a summary of the land use activities that have occurred on the site in the past, and / or are currently occurring;
- For Class 5 Clean Fills, confirmation that the source of the waste has not been contaminated by current or historical land use activities i.e., identified on MfE’s HAIL (MfE 2011). A summary of the HAIL is provided in **Appendix J**.
- Copies of any soil testing results completed for the waste.

- Copies of any resource consents authorising the earthworks/land disturbance held for the source of the waste.
- Confirmation that soils meet the numerical WAC criteria.

Pre-Assessment Testing

Prior to the acceptance of waste materials to Class 1, 2, 3 or 4 landfills/fills, information should be obtained from the disposer to confirm that the materials meet the WAC for the landfill/fill.

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 on potentially hazardous wastes 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 Requirements
1	Landfill	USEPA TCLP (USEPA 1996)	Required for all potentially hazardous materials at the frequency described in **Table 6-4**
2	C&D Landfill	USEPA TCLP (USEPA 1996)	Required for all potentially hazardous materials at the frequency described in **Table 6-4**
3	Managed Fill	Total analyte concentrations	Required for all materials being disposed of, at the frequency described in **Table 6-4**
4	Controlled Fill	Total analyte concentrations	Required for all materials being disposed of, at the frequency described in **Table 6-4**
5	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/fill. 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 5 Clean Fill).

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/fill. 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/fill operator to inspect, challenge, sample, test and, if necessary, reject any waste brought by the applicant to the landfill/fill 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/fill 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/fill 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/fill.

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	Landfill	Random and based on 1 in 50 loads
2	C&D Landfill	Random and based on 1 in 50 loads
3	Managed Fill	All loads
4	Controlled Fill	All loads
5	Clean Fill	Random and based on 1 in 50 loads

Verification Sampling

For Class 3, 4 and 5 fills 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 fill. Random waste samples should be collected from incoming loads. Annual waste samples should be collected from deposited waste across the fill.

Waste analysis should be completed by an accredited laboratory. Waste samples should be analysed for the following analytes as a minimum requirement:

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

The sampling rationale should be disposer-specific for random sampling of incoming loads and for annual sampling, based on the type and mass of waste that has been disposed to landfill. **Table 6-4** summarises recommended verification sampling requirements for the different classes of landfill/fill.

Table 6-4 Recommended Verification Sampling Requirements

Class	Common Name	Random Verification Sampling	Annual Verification Sampling
1	Landfill	Not applicable	Not required
2	C&D 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	Controlled Fill	Random and based on 1 sample per 500 m^3 (incoming load)	Statistically derived and based on tonnage received annually
5	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/fill 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/fill for disposal (e.g., prohibited or hazardous waste), the regulatory authority should be notified.

If the landfill/fill 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/fill 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/fills should maintain records that include information on waste accepted at the landfill/fill, 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/fill receiving wastes that require special handling procedures (for example treated hazardous waste) should record the location of those wastes when they are placed in the landfill/fill, including:

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

7. Operations

7.1 Introduction

The operating procedures employed at any landfill/fill 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/fill should be undertaken in accordance with a predetermined site management plan. This plan should cover all aspects of landfill/fill operations, with detailed descriptions of:

- site management structure and responsibilities;
- planning controls and consents;
- design parameters;
- site development and filling sequence;
- daily operating procedures;
- WAC;
- 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/fill.

The following sections detail the aspects of landfill/fill 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/fill.

Staffing requirements will vary as a function of landfill/fill class, size, types of wastes, and diversity and complexity of site operations. Landfill/fill 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/fill 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/fill operations must be performed in accordance with the requirements of the HSW 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/fills include:
    - traffic (in relation to earthworks, waste placement and compaction equipment);
    - fuel storage;
    - steep and uneven terrain;
    - vehicle rollover;
    - landfill gas;
    - 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/fill site.

Unauthorised entry to landfills/fills can lead to illegal waste dumping, exposure to landfill/fill hazards, fires, vandalism, and loss of amenity. In order to control site access, the perimeter of the landfill/fill site should be securely fenced, and the gates locked outside normal operating hours. Close control over issuing keys to the landfill/fill 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/fill 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/fill site on the surrounding community.

Visual impacts associated with the operation of landfills/fills can be minimised by following the recommended operating practices and conducting waste disposal activities behind purpose-built earth screening bunds. Landfills/fills 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/fill should utilise appropriate equipment for environmentally responsible and safe operation of the site.

Issues to consider in equipment selection include:

- Landfill/fill 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/fills 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/fill 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 fill material/waste;
- end use of the site; and
- liquid injection/recirculation requirements.

Compaction requirements for Class 3, 4 and 5 fills 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 4 and 5 fills, to prevent solid or sharp items penetrating the surface and creating a hazard.

Cover material at Class 1, 2 and 3 landfills/fills 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/fill 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 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 WAC);
    - ash (which complies with WAC);
    - 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. The depth of soil used as intermediate cover will be dependent 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/fill above the previously placed intermediate cover, when weather conditions are suitable.

Details of final cover design are addressed in **Section 5.9**.

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/fill 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/fill 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.

The main activities responsible for dust generation at landfill/fill 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 watercarts 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/fills adjacent to sensitive areas. The deposition rate from the landfill/fill 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 C&D 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 5.8**. 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/fill 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/fill 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/fill site. The noise generated during the operation of a landfill/fill 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/fill.

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/fill 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 2 m 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, 4 and 5 fills leachate is controlled by WAC. Leachate from Class 1 and 2 landfills is controlled by WAC 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/fill 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/fill 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 or from 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/fill 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/fill 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/fill 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 as a result of the decomposition of solid wastes. The quantity and the composition depends on the types of solid waste that are decomposing, as described in **Section 5.8** and **Appendix B.3**.

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 5.8**. 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 8.10**.

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/fill 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/fill, closure works should be undertaken. Generally, this is as soon as practical. Depending on the class of landfill/fill, the closure works may include:

- construction of the final cover system, including final stormwater and erosion control structures;
- revegetation of the landfill/fill 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/fill 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/fills 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/fill. The plan should take into account the class of the landfill/fill and the degree of control over the release or migration of contaminants from the landfill/fill. 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 during the aftercare period 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/fill no longer has the potential for adverse environmental effects (see **Section 8.1**). 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/fill 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 efficacy of the environmental protection and mitigation measures that are in place, and the extent of any residual environmental effects.

Monitoring requirements are usually determined prior to development and operation of a landfill/fill site. However, the monitoring programme may need to be altered or adjusted over the life of the landfill/fill and into the aftercare period, for example in response to changes or incidents at the landfill/fill site, or in response to a review of existing monitoring data over a given time period.

Landfill/Fill Processes

To properly monitor the effects of a landfill/fill, 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/fill 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/fill, 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.

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/fill surface and settlement; and
- analysis and review of monitoring data.

8.2 Objectives and Purpose of Monitoring

Monitoring of landfills/fills 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/fill monitoring programme are to:

1. Develop an understanding of the environment in which the landfill/fill is located and the engineered components of the landfill/fill.
2. Characterise the processes occurring within the landfill/fill and the interaction of these processes with the receiving environment.
3. Confirm the understanding of the interactions of the landfill/fill 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 (and the monitoring programme may need to be revised accordingly).

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/fill 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/fill 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/fill 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/fill 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 for each landfill/fill class, as shown in **Table 8-1**.

Table 8-1 Monitoring Requirements for Landfill/Fill Classes

Monitoring Requirement	Class 1	Class 2	Class 3	Class 4	Class 5
Leachate	✓	✓	✗	✗	✗
Groundwater	✓	✓	✓	✓	✗
Surface water[1]	✓	✓	✓	✗	✗
Sediment	✗	✗	✓	✓	✓
Landfill gas	✓	✓	✗	✗	✗
Settlement	✓	✓	✓	✓	✓
Meteorological conditions	✓	✓	✓	✓	✓

The extent to which each aspect of the monitoring programme will apply to each of the landfill/fill classes is discussed further in **Sections 8.5 – 8.10** below.

Monitoring focus areas are described in more detail in **Appendix K.1**.

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 (methane, carbon dioxide)
- trace organic compounds.

Monitoring parameters are described in more detail in **Appendix K.1**, which also identifies the objective (**Section 8.2**) 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/fill monitoring programmes are identified are given in **Table 8-2**.

Table 8-2 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					✓	

Parameter	Indicator	Cations/ anions	Physico-chemical	Nutrients	Trace metals	Synthetic organics
Chemical Oxygen Demand	✓		✓			
Conductivity	✓		✓			
Copper					✓	
Dissolved Reactive Phosphorous				✓		
Total Hardness			✓			
Iron		✓			✓	
Lead					✓	
Magnesium		✓				
Manganese					✓	
Nickel					✓	
Nitrate Nitrogen				✓		
pH	✓		✓			
Potassium		✓				
Sodium		✓				
Sulphate		✓				
Suspended Solids			✓			
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 (2011) 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 concern. The presence of any one of these factors, does however create the potential for contamination or an effect from 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.

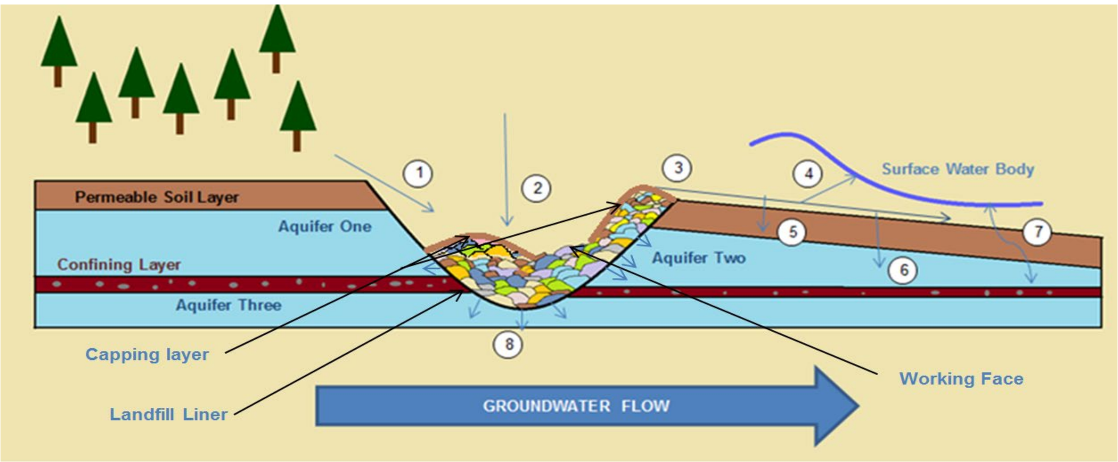
A conceptual site model can be created in any form (i.e., as a diagram, text, a flow chart, or a computer model). A good model will include all aspects of the site, including but not limited to engineering features of the landfill/fill; groundwater flow; aquifer characteristics; geology; soil types; 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 5 Clean Fill may only be required to track the movement of sediment through the site. A simple conceptual site model may be appropriate for Class 3 and 4 fills so that the groundwater and surface water system, and hence the potential migration pathways for contaminants at the site is properly understood. Landfill gas may also be required to be assessed. A Class 1 and 2 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/fill 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 parameters 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 K.1**.

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 K.1**).

A more detailed discussion of sampling and analytical requirements is contained in **Appendix K.1**.

8.5 Surface Water Monitoring (Class 1 to 5)

Purpose of Surface Water Monitoring

Landfill/fill 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/fill 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/fill 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/fill operations.
2. Comprehensive monitoring to establish any changes to the general status of surface waters once landfill/fill 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/fill operations commence or change. It is used as a benchmark for evaluating changes in surface water quality once the landfill/fill is operating.

Spatial controls are usually based on control sites. These are monitoring points at an upstream location from landfill/fill operations or in nearby, similar surface waters unaffected by landfill/fill operations. Again, data collected from such sites serves as a benchmark against which any changes in surface water quality can be evaluated.

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 Surface Water Monitoring

Locations for a surface water monitoring programme need to cover all surface water resources that could potentially become contaminated by landfill/fill operations. The key criteria when selecting monitoring stations are:

- potential sources of contamination associated with the landfill/fill 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/fills, depending on:

- Landfill/fill 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 8-3**.

An example of a surface water monitoring strategy is given in **Appendix K.3**.

Table 8-3 Surface Water Sampling Frequency

Class	1 Large[1]	1 medium[1]	1 Small[1]	2	3	4	5
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	Continuous or prior to discharge
Up-gradient	3 monthly	3 – 6 monthly	6 monthly	6 monthly	6 monthly	Site specific	NA
	Leachate indicators	Leachate indicators	Leachate indicators	Leachate indicators	Leachate indicators	Leachate indicators	
Down-gradient	3 monthly	3 – 6 monthly	6 monthly	6 monthly	6 monthly	Site specific	NA
	Leachate indicators	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.

8.6 Landfill/Fill Surface and Settlement Monitoring (Class 1 to 5)

Purpose

Landfill/fill surface monitoring facilitates:

- measurement of change in landfill/fill airspace; and
- compaction assessments.

Guidance on the frequency of monitoring via topographical surveys is presented in **Table 8-4**.

Table 8-4 Landfill/Fill Surface Monitoring Frequency

Class	1 large	1 medium	1 small	2	3	4	5
Topographical survey	6 monthly	Annually	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.

8.7 Meteorological Conditions (Class 1 to 4)

TBC.

8.8 Groundwater Monitoring (Class 1 to 4)

Purpose of Groundwater Monitoring

Groundwater can be at risk from leakage of leachate through the base of the landfill/fill and/or from ancillary activities such as mechanical workshops. In some situations, groundwater can be directly affected by landfill/fill 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/fill;
- provide pre- and post- construction baseline water quality data;
- check compliance with landfill/fill 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/fill 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/fill 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/fills to assist in the selection of well locations (Haduk 1998).

Additional information on groundwater monitoring points, design of monitoring wells and monitoring parameters is contained in **Appendix K.2**.

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/fill 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 8-5** 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.

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 and 4 fills, 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 8-5**.

Table 8-5 Groundwater Sampling Frequency

Class	1 Large[1]	1 Medium[1]	1 Small[1]	2	3	4	5
Under drain Monitoring	Continuous	1-3 monthly	3 monthly	3 monthly	TBC	NA	NA
Bore[2] -Up gradient bore	3 monthly	3 - 6 monthly	6 monthly	6 monthly	TBC	annually	NA
Bore - Landfill footprint edge bore	Min 2 wells	Min 1 well	Min 1 well	Min 1 well	Min 1 well	Min 1 well	NA
	3 monthly	3 – 6 monthly	6 monthly	6 monthly	TBC	annually	NA
Bore - Site boundary bore	Min 2 wells	Min 2 well	Min 1 well	Min 2 wells	TBC	Site specific	NA
	Dependent on g/w velocity	Dependent on g/w velocity	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.

8.9 Leachate Monitoring (Class 1 & 2)

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 8-6.**

Table 8-6 Leachate Sampling Frequency

Class	1 Large[1]	1 Medium	1 Small	2	3	4	5
Minimum frequency[2]	6 monthly	6 monthly – annual	Annual	Annual	NA	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.

8.10 Landfill Gas Monitoring (Class 1 & 2)

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 K.4.**

Surface Gas Monitoring

Several techniques exist for monitoring surface emissions from a landfill, including:

- visual inspection;
- instantaneous surface monitoring (ISM);
- integrated surface sampling;
- 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 K.4**.

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 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 8-7**.

Table 8-7 Gas Sampling Frequency

Class	1	2	3	4	5
Well heads	Weekly[1] Monthly[2]	NA	NA	NA	NA
Surface emissions	6 monthly	Annually	NA	NA	NA
Gas migration probes	6 monthly	6 monthly	NA	NA	NA

Note: [1] Where a landfill gas collection and extraction system exists.
[2] When the gas field has adjusted to a stable condition.

8.11 Analysis and Review of Monitoring Data

Purpose

The analysis and review of monitoring data should address the three main objectives for a landfill/fill monitoring programme (**Section 8.2**):

1. Develop an understanding of the environment in which the landfill/fill is located and the engineered components of the landfill/fill.
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/fill 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 8.5** to **8.10**.

General

Monitoring data from landfill/fill 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.

9. References

BRANZ. 2017. *New Zealand Guidelines for Assessing and Managing Asbestos in Soil*. Wellington.

Civil Aviation Authority (CAA). 2008. *Guidance Material for Land Use at or Near Airports.*

Centre for Advanced Engineering (CAE). 2000. *Landfill Guidelines*. Christchurch.

Coops, O., Luning, L., Oonk, H. and Weenk, A. 1995. "Validation of landfill gas formation models" In *Proceedings Sardinia 95, Fifth International Landfill Symposium, Cagliari, Italy*. 2–6 October 1995, pp. 635–646.

Department of the Environment. 1986. *Waste Management Paper* 26, Landfilling Wastes. A Technical Memorandum on the Legislation, Assessment, and Design, Development, Operation, Restoration and Disposal of Difficult Wastes to Landfill including the Control of Landfill Gas, Economics, a Bibliography, and Glossary of Terms.

E H Pechan & Associates. 1998. Emerging technologies for the management and utilization of landfill gas, Prepared for USEPA, January 1998.

Ehrig, H. J. 1989. Water and Element Balances of Landfills in *Lecture Notes in Earth Sciences: The Landfill*.

EPA Ireland, 2000, Landfill Site Design

EPA Victoria. 2010. Siting, Design, Operation, and Rehabilitation of Landfills, Publication 788.1.

Giroud, J.P., Soderman, K.L., Khire, M.V., & Badu-Tweneboah, K. 1998. New Developments in Landfill Liner Leakage Evaluation. *Proceedings of GeoEnvironment*, Atlanta, USA.

Haduk P.F. 1998. A Method for Designing Configurations of Nested Monitoring Wells Near Landfills. *Hydrogeology Journal* (1998) 6:341-348.

Knox, K. 1991. *A Review of Water Balance Methods and Their Application to Landfill in the UK*, Department of the Environment U.K. Wastes Technical Division, Research Report No. CWM--031-91.

Kodikara, J. 1996. Prediction of tension in geomembranes placed on landfill slopes, Department of Civil and Building Engineering, Victoria University of Technology, Melbourne, Vic., Australia, *Environmental Geotechnics* Balkema ISBN 90 5410 8487 Volume 1 pp 557.

Koerner, R.M. 2012. *Designing with geosynthetics*, Sixth edition, Volume 1 & 2, Xlibris Corporation.

Koerner R.M., Hsuan Y.G., Koerner G.R. and Gryger D. 2010. Ten year creep puncture study of HDPE geomembranes protected by needle punched nonwoven geotextiles. *Geotextiles and Geomembranes* 28, pp.503–513.

Lachance A.D. and M.R. Stoline. 1995. The Application of a Statistical Trend Analysis Model to Ground Water Monitoring Data from Solid Waste Landfills. *Ground Water Monitoring and Remediation*, Vol XV No 4.

Maier, T.B. 1998. Analysis of procedures for design of leachate recirculation system, *Solid Waste Association of North America (SWANA) 1998 Landfill Symposium*.

McBride G. 1998. When differences are equivalent. *Water and Atmosphere* Vol. 6 No.4. National Institute of Water and Atmospheric Research, Christchurch, New Zealand.

McKendry P. 1991. Landfill gas production – theory and practice. In *Methane: Facing the Problems symposium* Nottingham University.

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

Ministry of Business Innovation and Employment. 2011. *New Zealand Guidelines for the Management and Removal of Asbestos*. 3rd Edition.

Ministry for the Environment (MfE). 1999. *Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand*. Updated 2011. Wellington.

MfE. 2001a. *Guide to Landfill Consent Conditions.* Wellington.

MfE. 2001b. *A Guide for the Management of Closing and Closed Landfills in New Zealand*. Wellington.

MfE. 2002a. *A Guide to the Management of Cleanfills*. Wellington.

MfE. 2002b. *The New Zealand Waste Strategy: Towards Zero Waste and a Sustainable New Zealand*. Wellington.

MfE. 2004a. *Landfill Full Cost Accounting Guide for New Zealand.* Wellington.

MfE. 2004b. Module 2: Hazardous Waste Guidelines, Landfill Waste Acceptance Criteria and Landfill Classification. Wellington.

MfE. 2006. *Targets in the New Zealand Waste Strategy, 2006 Review of Progress*. Wellington.

MfE. 2009*. An Everyday Guide to the Resource Management Act* Series 2.2: Consultation for Resource Consent Applicants. Wellington.

MfE. 2011. *Hazardous Activities and Industries List* (HAIL). Wellington.

MfE. 2012. User's Guide, National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health. Wellington.

Resource Management (National Environmental Standard for Air Quality) Regulations 2004. Revised 2011.

Resource Management (National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health) Regulations 2011.

Ministry for Health (MoH). 2008. *Drinking Water Standards for New Zealand* 2005. Revised 2008. Wellington.

Nielson David M., ed, 1991. *Practical Handbook of Ground-Water Monitoring*. Lewis Publishers.

New Jersey Department of Environmental Protection. 2011. Technical Guidance for Preparation and Submission of a Conceptual Site Model.

NZ Standard 5433: 1999 – Transport of Dangerous Goods on Land.

Pierce J., LaFountain L., Huitec R. 2005. *Landfill gas generation & modelling manual of practice*, The Solid Waste Association of North America (SWANA), SWANA's Landfill Gas Management Technical Division / Landfill Gas Generation and Modeling Committee.

Reinhart, D.R. 1994. *Beneficial use of landfill gas*, University of Central Florida, September 1994.

Sanders T.G., Ward J.C., Loftis T.D., Steele T.D., Adrian D.D. and V. Yevyevich. 1983. Water quality monitoring - a systems and stochastic perspective. In: *Design of networks for monitoring water quality*. Water Resources Publications, Lyttleton.

SWANA. 1998. *Training Sanitary Landfill Operating Personnel*.

UK Environment Agency. 2002. Guidance on Landfill Gas Flaring.

UK Environment Agency. 2004. *Landfill directive LFTGN03* Guidance on the Management of Landfill Gas.

UK Environment Agency. 2005. Guidance on Sampling and Testing of Wastes to Meet Landfill Waste Acceptance Procedures, Version 1.

UK Environment Agency. 2010. Waste Acceptance at Landfills, Guidance on Waste Acceptance Procedures and Criteria, Version 1.

UK Environment Agency. 2011. *Treatment of Waste for Landfill*, Version 2.

University of California Department of Civil Engineering. 1987. *Trace Organic Constituents in Landfill Gas.*

USEPA. 1987. SW-846 Method 9095 Paint Filter Liquids Test.

USEPA. 1992. SW-846 Method 1311 Toxicity Characteristic Leaching Procedure.

USEPA. 1996. Turning a liability into an asset: A landfill gas-to-energy project development handbook, EPA 430-B-96-0004, September 1996.

Ward, R. C., Loftis, J. C. and McBride, G. B. 1990. *Design of water quality monitoring systems*. Van Nostrand Reinhold, New York.

WasteMINZ. 2021. Health and Safety Guidelines: for the Solid Wate and Rewource3 Recover Sector – parts one, two, three, four and five.

Willumsen H. 2003. Landfill gas plants – number and types worldwide, *Proceedings Sardinia 2003, Ninth International Waste Management and Landfill Symposium*, S. Margherita di Pula, Cagliari, Italy, 6 – 10 October 2003.

WorkSafe New Zealand. 2016. Approved Code of Practice: Management and Removal of Asbestos.

Appendix A Relevant Legislation

A.1 Health Act 1956

The Health Act is described in **Section 3.2**.

A.2 Resource Management Act 1991 (RMA)

The RMA is described in **Section 3.3**.

A.3 Health and Safety at Work (HSW) Act 2015

The purpose of the HSW Act 2015 is to provide a balanced framework to secure the health and safety of workers and workplaces. The Act is therefore applicable to landfills/fills in the context of these sites as workplaces (i.e., landfill/fill operation).

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). The landfill or fill operator, and any sub-contractors who may work at the landfill/fill are therefore PCBUs; and all PCBUs and workers are responsible for undertaking work at the landfill/fill in a manner that does not result in a risk to the health and safety of themselves or others.

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).*

A.4 Health and Safety at Work Act (Asbestos) Regulations 2016

The associated Health and Safety at Work Act (Asbestos) Regulations 2016 impose additional duties on PCBUs in relation to work involving asbestos which may occur at landfill or fill sites which accept asbestos-containing waste. The requirements of the regulations as they pertain to landfills/fills primarily relate to managing asbestos risks.

The regulations state that 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.

A.5 Hazardous Substances and New Organisms Act 1996

The Hazardous Substances and New Organisms (HSNO) Act 1996 controls the import, manufacture, use and disposal of manufactured chemicals that have hazardous properties. It has a role in managing the disposal of waste hazardous substances. This role was formally specified in the 2001 Hazardous Substances and New Organisms Act disposal regulations which set disposal requirements for different classes of hazardous substances.

Under the Act, disposal, in relation to a hazardous substance, means:

(i) treating the substance in such a way that it is no longer a hazardous substance; or

(ii) discharging the substance into the environment as waste; or

(iii) exporting the substance as waste from New Zealand.

The controls on disposal also cover the disposal or decontamination of containers that have been used with hazardous substances.

The HSNO Act does not specify controls for landfill/fill facilities, but rather specifies controls for disposal in relation to the hazardous substances and new organisms themselves (e.g., for any hazardous substance or new organism there will be specific requirements for the storage, handling, and disposal of that material).

A.6 Local Government Act 2002

Territorial Authorities were also given responsibilities for waste management under Part XXXI of the Local Government Act enacted in 1996. The legislation provided for the preparation of waste management plans by territorial authorities and required that they make provision for the collection and reduction, reuse, recycling, recovery, treatment, and disposal of wastes. In 2002, a new Local Government Act provided more detailed guidance about the role of local government in waste management, in particular the requirement for the preparation of waste management plans.

A.7 Climate Change Response Act 2002

The Climate Change Response Act 2002 put in place an emissions trading scheme (ETS) for methane emissions from landfills.

The Act requires landfill operators to surrender emissions units in proportion to calculated methane emissions from their landfills. Methane emissions are determined using default values or calculations based on waste composition and capture and destruction of methane (by flaring or energy production).

Emissions are accounted for in the year that the waste is received at the landfill. Emissions from closed landfills and legacy emissions from operating landfills are not included in the ETS.

A.8 Waste Minimisation Act (WMA) 2008

The WMA 2008 is New Zealand’s only waste focused legislation and is applicable to the disposal to land sector in several ways. The WMA is designed to encourage waste minimisation and reduce the quantities of waste disposed.

Facilities that dispose of waste and transfer stations likely have data reporting and levy payment obligations under the Waste Minimisation (Calculation and Payment of Waste Disposal Levy) Regulations 2009 and the Waste Minimisation (Information Requirements) Regulations 2021. The waste disposal levy is a hypothecated environmental levy that is paid on tonnage of waste in certain facilities and is shared between central government and territorial authorities to contribute to waste minimisation initiatives. In complying with these obligations, the Act and regulations set out a range of standards that must be adhered to. The MfE Waste Operations team administers a nationwide audit and enforcement function to ensure this occurs. Territorial authorities may also implement bylaws, which they are responsible for enforcing.

In addition, the WMA contains provisions setting out obligations for Territorial Authorities including how they spend their waste levy share, and what their obligations are for waste planning.

The Act requires Territorial Authorities to prepare and update WMMPs considering the following (in order of importance):

- reduction;
- reuse;
- recycling;
- recovery;
- treatment; and
- disposal.

Regulated and voluntary product stewardship and product bans may also have implications for the types of materials facilities will and should receive for disposal. Multilateral Environmental Agreements may also contain obligations that New Zealand is required to meet, and these can be relevant to the waste sector.

The WMA also established a Waste Advisory Board to provide independent advice to the Minister on waste minimisation matters.

A.9 Heritage New Zealand Pouhere Taonga Act 2014

The purpose of the Heritage New Zealand Pouhere Taonga Act 2014 is to promote the identification, protection, preservation and conservation of the historical and cultural heritage of New Zealand.

The Act controls the archaeological consenting procedure and balances heritage protection with public safety and landowners’ rights.

Under the Act a register of historic places, historic areas, wahi tapu, and wahi tapu areas is maintained.

The requirements of this act may affect landfills/fills with respect to the selection of a landfill/fill site.

Appendix B Design

B.1 Landfill Liners

Soil Liners

Design Parameters

Parameters that influence the permeability of a soil liner include:

- clay content;
- particle size distribution;
- degree of compaction (density);
- compaction method;
- moisture content; and
- post-construction condition, such as desiccation, softening etc.

Low permeability in the soil liner is typically easiest to achieve when the soil is compacted 1% to 4% wet of optimum moisture content.

Soil classification tests are used to assess the suitability of specific soil materials. **Table B-1** provides minimum criteria together with typical suitable property ranges. In addition, the deformation and swelling characteristics of the soil will need to be determined and compared with the stability assessment requirements for compressibility, swelling behaviour and shear strength.

The design should specify a range of moisture contents and corresponding soil densities (percentage compaction) that are considered appropriate to achieve the required permeability. The lower moisture content should be dictated by the permeability requirement. The upper limit may be dictated by the shear strength of the clay, because although the permeability requirement may be met, handling compaction and trafficking may become more difficult at higher moisture contents. This, in conjunction with stability considerations, determines the requirements for a minimum shear strength. Typically, an undrained shear strength of no less than 40 kPa is required.

Table B-1 Soil Classification Testing

Parameter	Test Description	Test Method
In-situ density	"Rapid"	NZS 4407:1991, Test 4.2.1 (Nuclear Densometer Direct Mode) or NZS 4407:1991, Test 4.2.2 (Nuclear Densometer Backscatter Mode) as required
	"Fully Specified"	NZS 4402:1986, Test 5.1.1, 5.1.2, 5.1.3 (Sand replacement, balloon densometer or core cutter)
Maximum dry density & overall moisture content determination	Standard Compaction	NZS 4402:1986, Test 4.1.1
	Heavy Compaction	NZS 4402:1986, Test 4.1.2
Strength	Scala Penetrometer	NZS 4402:1988, Test 6.5.2
	Pilcon Shear Vane	NZGS Guideline for handheld shear vane tests - 2001
Permeability	Laboratory Triaxial Permeability	BS 1377:1990, Part 6, Clause 6 (Permeability in a triaxial cell). Sample taken from in situ liner in accordance with NZS 4402:1986 5.1.3
Solid Density	Solid Density	NZS 4402:1986 Test 2.7.2 Solid density for medium & fine soils
Moisture Content	Moisture Content	NZS 4402:1986, Test 2.1

Note: Ensure any holes in liner from sampling or testing activities are filled with bentonite.

Construction

In situ and laboratory testing should be performed to assess the suitability of materials prior to, during and after construction.

The soil may need to be processed or conditioned before it is suitable for liner construction. Large clods will need to be broken down and stones and rocks removed. The moisture content of the soil may need to be adjusted to achieve a moisture content slightly higher than optimum.

The liner material should be constructed in a series of lifts no thicker than 150mm when compacted. The thickness of the lifts is a function of the soil characteristics, compaction equipment, firmness of the foundation material, slope angle and the anticipated effort to achieve the required permeability.

The type of compaction equipment and the number of passes of the equipment over a particular lift should be decided based on field trials. The trials should identify the construction methodology required to meet the requirements of the specification (i.e., percentage compaction, density and moisture content to achieve the stated permeability).

Each lift must be bonded well to the underlying lift to avoid lamination, and dry or-un-bonded zones of higher permeability than targeted. The surface of the lift previously compacted should be roughened prior to placement of the subsequent lift. Care should be taken during dry weather to avoid desiccation cracking and to mitigate the impacts of a dry, dusty surface. In such cases regular spraying may be required. Consideration should be given to how long the surface of the clay liner will be exposed and thus what measures are required to protect the surface. The surface of the final lift of the soil liner should be smooth prior to placement of a geomembrane, if required.

Geosynthetic Clay Liners (GCL)

Bentonite swells when it comes into contact with moisture and tends to seal around a penetration. The long-term performance of a GCL is primarily driven by the mineralogy and form of the bentonite used in the GCL (e.g., natural sodium versus sodium activated calcium bentonite; powder versus granular forms; polymer enhanced and placed moisture content), the type of geotextile (e.g., woven or nonwoven) and the method of bonding (e.g., stitched, needle punched or glued). Consideration should also be given to how and when the GCL is allowed to hydrate. If the material hydrates under unconfined conditions the swelling can cause the bonding to break thereby significantly reducing the internal strength of the material. Furthermore, the bentonite can ooze through the pores of the geotextile, resulting in sliming of the surface and a corresponding reduction of the interface friction angle, thereby affecting the stability of the liner system. The advantages and disadvantages of GCLs are summarised in **Table B-2**.

Table B-2 Advantages and Disadvantages of GCLs

Advantages	Disadvantages
• Very low hydraulic conductivity when hydrated • Consistent hydraulic performance • Can be installed over a wider climate spectrum compared to a compacted cohesive soil liner • Limited thickness offers more landfill capacity • Relatively quick to install • May self-repair small punctures during handling and installation • Relatively simple on site • Easy to repair • Can be supplied to custom grades and roll lengths • Suitable for sites where a clay source is not available	• Can be punctured after installation • Possible loss of bentonite powder during installation • Thin GCL subject to puncture • Available contractors may have limited experience with handling and installation • Unreinforced GCL has relatively low internal shear strength when saturated • Less attenuation capacity than compacted cohesive soils • Requires hydration to act as a gas barrier • Susceptible to ion exchange (for GCLs with Na+ bentonite) which may impact hydraulic performance under low compressive stresses

Modified from Bouazza 2002.

The following considerations should be taken into account in the design and installation of a liner system incorporating a GCL:

- **Manufacture**: This includes the selection of the raw materials, the manufacturing of these materials into the GCL and the protection of the rolls of GCL to avoid premature hydration. Compliance testing should be performed to confirm that the material meets the specification requirements.
- **Storage and handling:** Care needs to be taken of the GCL rolls to prevent premature hydration and damage during storage and handling. Once the material reaches the site, its documentation should be checked against the specification requirements.
- **Installation**: The manufacturer's installation procedures should be adopted. The GCL must be protected immediately following placement to prevent damage and premature hydration. Installation should only be performed by an experienced installation contractor and with rigorous QA/QC procedures in place.

Internationally accepted specifications for GCLs for use in landfill applications have been produced by the Geosynthetic Research Institute and it is recommended that these standards are adopted.

Geomembranes (flexible membrane liner)

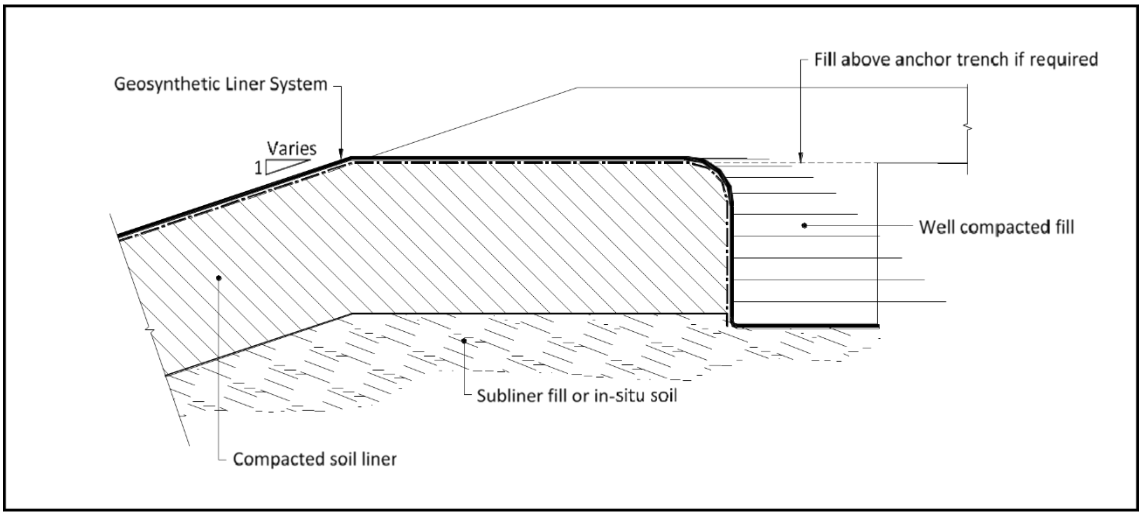
The following considerations should be taken into account in the design and installation of a liner system incorporating a geomembrane:

- **Manufacture**: This includes the selection of the specific type of geomembrane, its formulation, the manufacturing process and how texturing is applied, if required. Compliance testing should be performed to confirm that the material meets the specification requirements.
- **Storage and handling**: Care needs to be taken of the geomembrane rolls to prevent damage during storage and handling. Once the material reaches the site, its documentation should be checked against the specification requirements.
- **Installation**: The manufacturer's installation procedures should be adopted. The material should be protected during and following placement to prevent mechanical damage from construction equipment. Consideration should also be given to the temporary ballasting of the liner system to prevent wind damage. Installation should only be performed by an experienced installation contractor and with rigorous QA/QC procedures in place, including the requirements for test welds, and non-destructive and destructive testing of seams.
- **Anchor trench**: To prevent movement of the geomembrane following placement it needs to be anchored at the top of the slope. The most common form of anchor is a trench backfilled with compacted material. Other forms of anchoring include anchor beams where the geomembrane is welded to a strip of a compatible polymeric material (typically HDPE) cast into a concrete beam. Care must be taken in the design of the anchor trench to ensure that the geomembrane can preferentially pull out of the trench before the geomembrane is ruptured as a result of excessive tensile loads. A typical anchor trench is illustrated in

Figure B-1, but it is noted that anchor trench dimensions are specific to each case.

- **Liner protection**: Care should be taken until the geomembrane is covered to avoid mechanical damage. A liner protection layer should be provided on top of the geomembrane prior to placement of drainage aggregate and waste material. The design of this layer takes into account the composition of the covering material; the depth of waste material to be placed on the geomembrane; and the need to isolate the geomembrane from the risk of material migrating out of the waste mass, causing mechanical damage as the waste settles. This is typically achieved by the use of a protection geotextile, or a layer of clay or sand.

Figure B-1 Typical Anchor Trench Detail



Internationally accepted specifications for geomembranes for use in landfill applications have been produced by the Geosynthetic Research Institute and it is recommended that these standards are adopted.

Protection Geotextiles

Wilson-Fahmy et al. (1996), Narejo et al. (1996), Koerner et al. (1996) and, more recently, Koerner et al. (2010) and Koerner (2012) provide a basis for protection layer design. The design method focuses on the selection of a non-woven needle-punched geotextile protection layer with sufficient mass per unit area to provide an adequate global factor of safety against geomembrane yield. The method is based on laboratory data for 1.5 mm HDPE to develop an empirical relationship which can be adapted for other geomembrane thicknesses.

In addition to weight and strength characteristics, the need for UV stabilisation should be considered if the geotextile is to remain exposed for a period of time.

As with all geosynthetics installed in a landfill environment, the performance of geotextiles is dependant not only on their mechanical properties but also on the standard of installation. Installation should be performed by an experienced installation contractor with rigorous QA/QC procedures in place.

Liner and Global Stability

Careful consideration of the global and local stability of a landfill is required. The stresses developed in the liner system are dependent not only on the geometry of the landform, but also on the strength characteristics of the interfaces. In addition, interface friction angles between geosynthetics change, depending upon stress and hydration conditions. The assessment should therefore take into account the strength of the waste material as well as the interface friction between the components of the liner system. In particular, the stability assessment should consider the different conditions that occur during construction and at the various stages of waste filling. Consideration should be given to undertaking site-specific shear box tests to determine the interface friction characteristics.

The values adopted in the design should reflect the lower bound of possible strength behaviour and are not necessarily those used for the analysis of observed behaviour.

The tension developed within the geomembrane can be assessed by adapting conventional limit equilibrium methods developed by Koerner (2012) and supplemented by the methods introduced by Kodikara (1996). These enhanced methods can be used to determine both the conditions for stability and the conditions determining the onset of movement at a particular interface. They are also used to determine the stresses within particular liner materials prior to the onset of movement at an interface.

Waste Settlement

Waste settlement can result in down drag on the liner system. The design of a liner system should consider these forces and, in particular, the potential impact on the geomembrane.

Given modern methods of waste placement and compaction, waste will typically undergo total settlement of approximately 25% of the waste depth. Of this, about half occurs during waste placement. After placement there will be ongoing secondary compression and settlement, the rate of which is at a maximum immediately following placement. Consequently, on completion of waste filling to the top of an individual slope, some 10% to 12.5% long-term settlement is expected to ultimately occur below that level as a result of secondary compression and waste degradation.

The magnitude of the long-term settlement at an individual point within the waste mass is related to the depths of waste above and below the specific location. The greater the depths of waste above and below an individual point within the waste mass, the greater the long-term settlement at that individual point. In practice, this means that the waste settlement will be significantly greater in the waste mass directly above the base liner than adjacent to the side slope liner for the same top waste level. This is because with each successive bench and slope, the depth of waste below reduces.

Importance of Uniform Formation and Slope Heights

For the most part, the formation for a landfill should provide a reasonably regular system of slopes and benches progressing up the side slopes of the landfill. Under these circumstances any development of minor tension in the liner system and in particular the geomembrane is consistent from one area to the next, ensuring little differential stress between adjacent areas. As a result, there is no tendency for any area to be over stressed due to differences in tension across features or between different liner areas.

The sub-grade geometry should be specifically designed to avoid sudden changes in slope profile which may give rise to an uneven stress distribution within the liner system. Wherever possible, abrupt concave and convex profiles should be avoided.

B.2 Leachate Management

Leachate Generation

The factors that influence leachate generation at landfills/fills include:

- **Climate**: Leachate generation is typically directly proportional to the amount of rainfall at the site. However, the proportion is influenced by other factors such as cover practices; stormwater and groundwater diversion; humidity; and sunshine hours.
- **Topography**: On- and off-site topography affects the site’s runoff pattern and the amount of water entering and leaving the site. Landfills should be designed to limit leachate generation from areas peripheral to the site by constructing perimeter stormwater drainage systems to divert surface water “run-on” away from the site and by constructing the landfill/fill cover to promote runoff and reduce infiltration. All areas of a landfill/fill should maintain at least a two percent grade over the waste at all times to prevent ponding of surface water. This may mean constructing steeper grades (say 5%) so that suitable drainage grades remain after settlement. Unlined facilities may also be influenced by groundwater flowing into the waste material.
- **Landfill cover**: The cover at the site affects the amount of water percolating into the waste to form leachate. In general, as the permeability of the soil used for final cover increases, leachate production rates increase.
- **Vegetation**: Vegetation plays an integral part in leachate control. It limits infiltration by intercepting precipitation directly (thereby improving evaporation from the surface) and by taking up soil moisture and transpiring it back to the atmosphere. A landfill/fill with poor vegetative cover may experience erosion that cuts gullies through the cover soil and allows precipitation to flow directly into the waste.
- **Type of waste**: The type of waste, the water content of the waste and the form that it is in (bulk, shredded, etc.) affect both the composition and quantity of leachate. Wetter wastes, for example, will generate more leachate.

- **Groundwater intrusion**: If the landfill/fill is unlined, groundwater intrusion will need to be modelled separately and included in the calculation of leachate generation. If significant free water is present in the waste, then this would also need to be considered.

Leachate Generation Estimates

There are a variety of models that can be used to estimate leachate generation, from simple spreadsheets to water balance programmes. The latter incorporate weather records in data files, and a weather generator program to simulate site-specific precipitation, air temperature and solar radiation data. They also offer options for predicting leachate generation under many combinations of cover conditions.

The accuracy of model predictions can be aided by calibrating the model using actual field measurements of leachate generation at the landfill/fill, or at other landfills/fills in areas with a similar climate.

The impact of the input factors that influence leachate generation at a specific site can only be determined by calibrating the model against actual site data. However, even with a completed landfill/fill with extensive leachate data available, it may be difficult to estimate leachate volumes to better than a factor of two (Knox 1991).

Water balance calculations involving a number of different scenarios should be undertaken, taking into account:

- yearly, monthly, and daily variation in rainfall;
- variation in waste type and acceptance rate; and
- potential impact of landfilling/filling practices such as the size of the active area, and the type and timing of progressive capping.

These scenarios will help establish the sensitivity of the leachate generation rate to these parameters, and to estimate likely peak and average flows. However, actual site conditions will influence the realised generation rate, and a peak flow factor of 3 to 5 times the predicted average flow rate should be applied when designing the LCRS. The leachate drainage aggregate and pipework system should provide a high degree of redundancy in respect of flow capacity.

Leachate Collection and Removal Systems (LCRS)

Leachate Collection System Design

The LCRS should be designed to minimise the leachate head above the liner. The leachate head is a function of leachate generation, base slope, pipe spacing, hydraulic conductivity of the drainage blanket and the removal rate. The general design approach is to ensure that the design leachate head on the liner does not exceed 300mm, with appropriate allowance for the long-term performance of the leachate blanket (i.e., a conservative approach should be adopted).

Base Grade

The gradient of the landfill/fill base needs to be adequate to ensure that the leachate readily drains to the collection sumps and promotes self-cleansing to reduce the potential for blockages. A minimum gradient of 1 in 50 (2%) is recommended towards the collection sump and a minimum of 1 in 100 (1%) towards the leachate collection pipes.

Drainage Blanket

The design of the drainage blanket needs to take into account the required hydraulic conductivity, the overburden load from the waste and the protection required for the underlying geomembrane, if provided. The media should be free of fine material and comprise of a non-calcareous stone (less than 10% $CaCO_3$).

Collection Pipes

The perforated collection pipes are vulnerable to compressive strength failure and the design should consider:

- required capacity and spacing;
- pipe size and maximum slope;
- weight of waste;
- structural strength of the pipe; and
- required chemical resistance as a result of leachate quality.

It is recommended that HDPE smooth bore perforated pipes with a minimum internal diameter of 150 mm are used, laid to a self-cleansing gradient. The design needs to consider not only hydraulic capacity, but also structural strength to accommodate the weight of waste above the pipes. The spacing should be determined by the maximum leachate head allowed in the design, determined from the maximum allowable leakage rate through the liner.

The leachate head can be calculated by taking into account the quantity of leachate likely to be produced; base slope; pipe spacing; and drainage layer hydraulic conductivity; and by using either proprietary water balance models or analytical equations such as those proposed by Giroud and Houlihan (1995) and Giroud et. al. (1998). Where possible, provision should be made for cleaning the leachate pipes.

Penetrations

The collection and removal system should be designed as far as practicable to avoid any penetrations of the liner system. If penetrations are required, the penetration should be designed and constructed in a manner that allows non-destructive quality control testing of the seal between the pipe and the geomembrane.

Sumps

Sumps should be located at low points in cells to allow leachate within the cell to drain to the sump via gravity. Leachate is then pumped from the sump to a storage lagoon or treatment facility. There is an increasing trend towards the use of HDPE pipes welded to a thick base plate, rather than the more traditional concrete sumps which are prone to damage from chemical attack and from uneven loading and drag down forces associated with waste settlement. The minimum diameter should be 300 mm to facilitate pump access.

Sumps can be inclined or vertical depending on the configuration of the landfill/fill side slope. See **Figure B-2** and **Figure B-3**.

Figure B-2 Inclined Leachate Collection Sump and Riser Going up the Side Slope

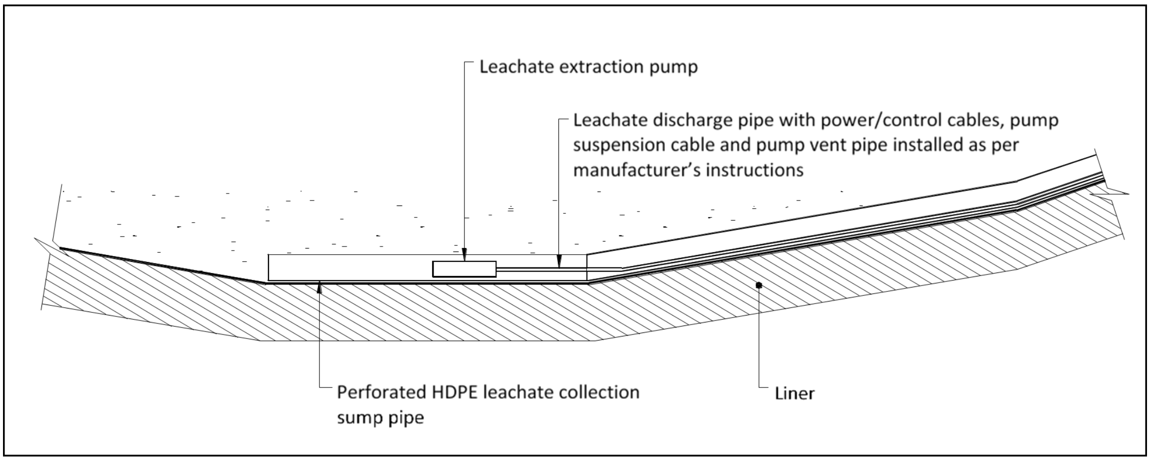
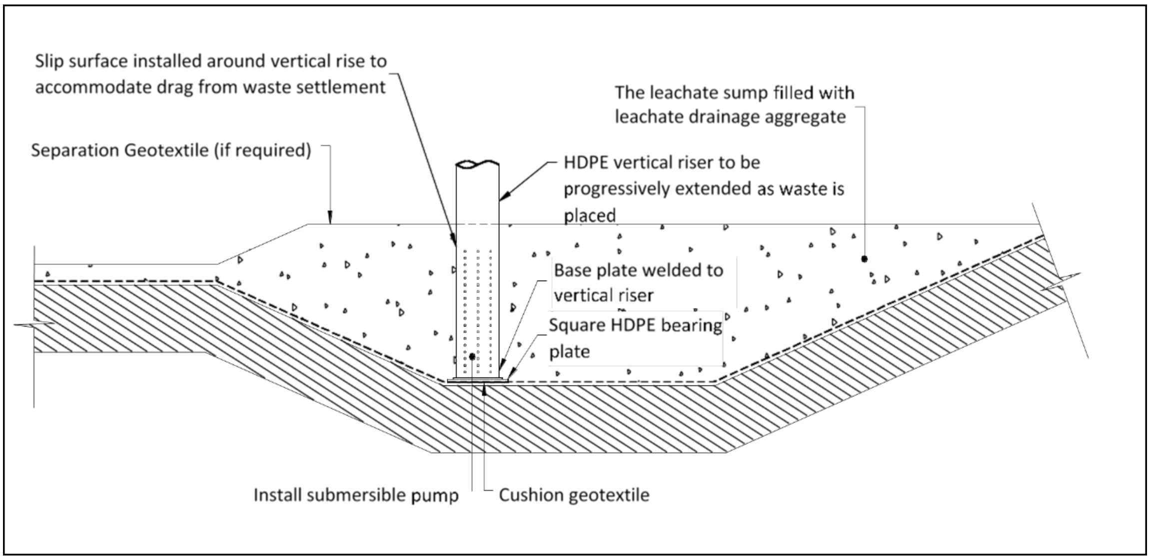


Figure B-3 General Arrangement of a Leachate Pumping Chamber



An inclined sump is not suitable for steep slopes or slopes with intermediate benches. The low angle riser system is less prone to damage from the filling process and uneven loading associated with waste settlement. Vertical sumps should be surrounded by a permeable drainage media rather than waste to assist with the vertical percolation of leachate to the chamber. Vertical sumps can be progressively raised as filling progresses, thereby providing access.

Pumps

Pumps for leachate removal need to be sized for the maximum generation rate and have the required hydraulic head. Hydraulic, pneumatic and submersible pumps are typically used. They need to be able to handle variability in flow and chemical composition as well as some particulates.

Maintenance

The collection and removal system needs to be maintainable throughout the operating life and post closure phase of the landfill/fill. This can be achieved by including rodding, jetting and CCTV access points in the design of the system.

Methane levels in pumping chambers and collection pipes should be monitored and venting should be provided where necessary. All pumps should be intrinsically safe, whilst any monitoring equipment should not be able to cause sparks within any enclosed spaces.

Leachate Recirculation

There are some concerns about implementing leachate recirculation at a landfill/fill as follows:

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

In order to mitigate these concerns, the following precautions should be taken:

- leachate recirculation should only occur where there is an appropriate liner and leachate collection systems in place;
- monitoring is required to determine the level of leachate within the waste and the contaminant levels within the leachate; and
- landfill/fill operators should be trained in the operational requirements of the leachate recirculation system.

One method which addresses the above concerns aims to match the rate at which leachate is recirculated into the waste with the absorptive capacity of the existing and incoming waste mass. The method is based on an approach developed by Geosyntec Consultants (Maier 1998).

In areas of low to moderate rainfall, the in-situ waste in a landfill/fill is capable of absorbing and storing significant amounts of additional moisture (i.e., the moisture content of the waste mass is typically less than its field capacity[6]). This storage volume can be used to reduce the amount of leachate which needs to be treated by other means.

The recirculation system is therefore designed to wet the waste to its field capacity moisture content (on average throughout the entire waste mass), thereby wetting the waste mass uniformly without increasing pore pressures which could lead to instability of the waste mass. The approach is referred to as the "one-and-a-half" approach where the first pass is the initial drainage of leachate (“one” pass), and the re-injection constitutes the “half”. In practice, the waste cannot be wetted entirely or uniformly, and some areas will remain permanently below field capacity. However, the objective is to wet as much of the waste mass as possible to levels approaching field capacity.

The factors which affect the rate, frequency and volume of leachate recirculation that can be maintained are:

- the leachate storage capacity of the waste;
- the potential for development of increased pore pressures within the waste mass;
- the rate at which the leachate will percolate into the waste mass; and
- the availability of areas where recirculation trench construction is practical.

Overall, the rate at which the leachate is recirculated into the waste mass must be compatible with the actual absorption capacity of the waste.

Leachate can be recirculated into the waste mass in trenches constructed progressively as the waste mass is placed, or in trenches excavated into intermediate and final cap areas.

The waste absorption capacity for a leachate recirculation trench can be determined by considering the dimensions of the trench and the volume of waste available to absorb leachate. For a layered trench system which is constructed in lifts, the waste volume is taken as the thickness of waste between trenches, rather than the total thickness of waste beneath a trench, as it is assumed that the waste below lower trenches has already been wetted to its field capacity by leachate injection into the lower trench.

Leachate is batch pumped into the trench until it reaches capacity and then allowed to dissipate through the waste mass.

Leachate Treatment and Disposal

The volume and strength of leachate produced at landfill/fill sites is subject to seasonal variations. Wide fluctuations in flow and concentration can be minimised by balancing leachate flow, either by storing leachate within waste already deposited, or by using a

---

[6] The maximum amount of moisture that can be retained by waste subject to drainage by gravity.

lagoon, so reducing the required treatment capacity by removing peak loadings. However, concentrations of components in leachate also change with its age. Treatment strategies need to adapt to changes in leachate volumes and strengths both during the filling stage of the landfill/fill and after its completion.

The method and degree of leachate treatment necessary will be site specific and dependent on the type of waste deposited, any expected variation in flow, the strength of toxic components and the nature of the receiving environment.

Table B-3 provides a summary of leachate treatment methods and objectives.

Table B-3 Leachate Treatment Methods and Objectives

Treatment Objective	Main Treatment Options
Removal of degradable organics (BOD)	Aerobic biological • Aerated lagoon / extended aeration • Activated sludge • Sequencing batch reactor (SBR) Anaerobic biological • Upflow anaerobic sludge bed
Removal of ammonia	Aerobic biological • Aerated lagoon / extended aeration • Activated sludge • SBR Physico-chemical • Air stripping of ammonia
Denitrification	Anoxic biological SBR
Removal of non-degradable organics and colour	Lime/coagulant addition Activated carbon Reverse osmosis Chemical oxidation
Removal of hazardous trace organics	Activated carbon Reverse osmosis Chemical oxidation
Removal of methane	Air stripping Aerobic biological (limited)
Removal of dissolved iron and heavy metals and suspended solids	Lime/coagulant addition, aeration

Treatment Objective	Main Treatment Options
Final polishing	Wetlands Sand filtration
Volume reduction	Reverse osmosis Evaporation

Modified from Hjelmar et al. (1995)

Land Treatment and Disposal

Spray irrigation or subsurface irrigation of treated leachate are effective disposal methods where suitable land areas and soil types are available.

Spraying treated leachate onto land can significantly reduce its volume, due to evapotranspiration. Additionally, as the leachate percolates through vegetated soils, opportunities are provided for microbial degradation of organic components, removal of inorganic ions by precipitation or ion exchange, and the possibility of rapid uptake by plants of constituents such as nitrate (from soil bacteria oxidation of ammonia).

Intermittent spraying throughout each day will provide more effective treatment than a single daily application. Transpiration by vegetation will account for a substantial proportion of the total loss. The issues to be considered with respect to spray irrigation are:

- **hydraulic loading rate** for its potential to cause excess leaching and surface ponding;
- **total dissolved solids** for its potential to affect vegetation growth;
- **sodium** for its potential to change soil structure and reduce soil infiltration;
- **nitrogen loading rate** for its potential to leach into groundwater, and surface waters; and
- **colour** which does not tend to be of concern on pasture but can turn trees and shrubs brown/black.

Little information is available on the long-term effects of spraying leachate onto land. The spraying of leachates containing metals or persistent organic compounds is not recommended because of their accumulation in soils and plant material.

Physical/Chemical Pre-treatment

Physical/chemical pre-treatment methods are typically used for leachates with lower biodegradable organic carbon, such as leachates from low organic facilities or older/closed landfills/fills, or as a polishing step for biologically treated leachate.

Common technologies include:

- air stripping of methane;
- air stripping of ammonia; and
- flocculation / sedimentation.

Biological Treatment

The most common treatment for leachates with high concentration of degradable carbon, ammonia or both is biological treatment, as this is typically the most reliable and economic treatment process. Biological treatment methods occur under either aerobic or anaerobic conditions or a combination of the two.

Common technologies include:

- activated sludge;
- SBRs;
- rotating biological contactor;
- anaerobic treatment; and
- biological nitrogen removal.

Physical/Chemical and Biological Treatment

Compact systems for the treatment of concentrated wastewaters are becoming increasingly more available. Common technologies include:

- a membrane bioreactor (combination of biological and membrane technology);
- powdered activated carbon (biological); and
- filtration.

Tertiary Treatment Methods

Internationally, additional treatment methods are used for the tertiary treatment of leachate prior to discharge to surface waters. These methods include:

- activated carbon adsorption;
- reverse osmosis;
- chemical oxidation;
- evaporation; and
- reed bed treatment.

B.3 Landfill Gas Management

Landfill Gas Generation Models

The rate at which landfill gas is generated declines with time and this is often represented as an exponential decay. The rate of the decay over time is strongly influenced by temperature within the landfill, moisture content, availability of nutrients and pH.

The generation of landfill gas is a complicated biological process that is affected by many factors including waste composition; waste placement history (age and depth of waste, use of cover and capping); moisture content; pH; temperature; and maintenance of the anaerobic environment within the landfill. Landfill gas control technology is relatively new and actual data from landfills that is both accurate and representative of the many underlying factors affecting generation is limited. Therefore, generation models are based on theory, relatively short-term data extrapolated over time, small-scale laboratory experiments, experience, or a combination of these. As a result, prudent engineering suggests that a degree of conservativism be included within the design of the gas management system.

First-Order Model

The most widely used landfill gas prediction model is the first-order model. The simplest approach is the single stage first-order decay model, which assumes that waste degradation parameters are constant over the analysis period. The model requires two input parameters:

- methane generation potential (L_o) in m^3/tonne;
- methane generation rate constant (k) in 1/yr.

These parameters are discussed in more detail below.

The model assumes that the gas production rate is at its peak upon initial waste placement, after a negligible lag time during which anaerobic conditions are established in the landfill. The gas production rate is then assumed to decrease exponentially (i.e., first-order decay) as the organic fraction of the landfill waste decreases. It can be refined further by dividing the landfill into smaller sub-masses to account for different ages of the waste accumulated over time. A convenient sub-mass for computational purposes is the amount of waste accumulated in one year. The total methane generation from the entire landfill (the sum of each sub-mass contribution) is at its peak upon landfill closure if a constant annual acceptance rate is assumed.

Alternative Landfill Gas Generation Models

Compound First-Order Model

Assuming that the waste degradation parameters are constant over the analysis period is valid if the composition of the waste does not vary significantly over time. However, a more complex analysis maybe required if:

- the proportion of inert material within the waste stream is expected to change significantly over time (causing a change in L_o over time); or
- the relative fraction of slower versus more rapidly degrading waste is expected to change significantly over time (causing a change in k over time).

Under such conditions a compound first order decay model can be used which differentiates between the rapidly degrading and slowly degrading waste.

In a compound analysis, the waste is separated into rapidly degrading and slowly degrading waste. Separate analysis is run for each waste stream with corresponding L_o and k values. The predicted landfill gas generation per year from the individual streams are summed to obtain the total landfill gas prediction for the combined waste stream.

Coops et al (1995) undertook a study of 21 Dutch landfills in 1993 and 1994 and compared measured emissions with estimates from a first-order decay model. The study concluded that the results from compound models gave only slightly better correlation with recorded values. However, selection of waste fractions and rate constants for the compound model can be time consuming and involve uncertainty. Consequently, single phase first order decay models are commonly used in the US (Pierce et. al. 2005), UK (UK Environment Agency 2004) and Europe (Coops et. al. 1995).

Zero Order Model

The first-order model assumes that, for a given quantity of waste, landfill gas production is directly proportional to the amount of waste that can degrade to form landfill gas. Each year some of the waste material degrades and forms landfill gas. In the following year, less waste is available to degrade and consequently less landfill gas is generated.

By contrast, the zero-order model assumes that although the landfill gas production is directly proportional to the amount of degradable waste available, it is limited by other factors. Landfill gas production is assumed to rapidly increase to a maximum and then stay at a constant until almost all the degradable waste is consumed. At this point, the availability of degradable material becomes more important, and the landfill gas generation rapidly decreases to zero. The landfill gas generation curve from a zero-order model therefore shows production reaching and maintaining an extended plateau compared with a curve from a first-order decay model which reaches a peak and immediately starts to decline.

Proponents of the zero-order model typically argue that environmental conditions in a landfill (such as pH, temperature and moisture) prevent unconstrained degradation of all available degradable waste.

The key parameters input into the zero-order model are also L_o and k. However, the k or rate factor is fundamentally different from the k in the first order model. In the zero-order model, it represents the fraction of ultimate production released in a given year.

The zero-order model has not been extensively used internationally or in New Zealand. Selections of appropriate k values are thus problematic, as there is insufficient data against which to calibrate the model. The zero-order model is therefore not considered further.

Methane Generation Potential (L_o)

The theoretical maximum yield of landfill gas from a tonne of MSW is dependent upon waste composition. However, an estimate based upon balanced stoichiometric equations for a mixture of paper waste and food waste probably provides an upper limit of the potential yield. See **Table B-4** (McKendry 1991). In practice, the gas yield is considerably less than this.

Table B-4 Methane Yield form Municipal Waste

Condition or Location	Methane Generation Potential (m^3/tonne)	Landfill Gas Yield (50% methane) (m^3/tonne)
Theoretical maximum (balanced stoichiometric equations)	230 to 270	460 to 540
US EPA default values	100 to 170	200 to 340
Typical New Zealand landfills	100 to 230	200 to 460

Some researchers have reported “obtainable L_o” which accounts for the nutrient availability, pH, and moisture content within the landfill. The researchers point out that “obtainable L_o” is less than the theoretical L_o. Even though waste may have a high cellulose content, if the landfill conditions are not hospitable to the methanogens, the potential methane generation capacity of the waste may never be reached. The “obtainable L_o” is approximated from overall biodegradability of "typical" composite waste or individual waste components, assuming a conversion efficiency based on landfill conditions.

The MfE (2001) suggests that typical values of L_o used in New Zealand range from 100 to 230 m^3/tonne.

The maximum “obtainable L_o” for typical New Zealand waste streams is 170 m^3/tonne for a 100% organic waste stream.

Methane Generation Rate Constant (k)

The methane generation rate constant, *k*, determines how quickly the methane generation rate decreases, once it reaches the peak rate after waste has been placed. The higher the value of k, the faster the methane generation rate from each sub-mass decreases over time.

The value of k is a function of the following major factors:

- waste moisture content;
- availability of the nutrients for methanogens;
- pH; and
- temperature.

In general, increasing moisture content increases the rate of methane generation up to a moisture level of 60 percent, above which the generation rate does not increase. A pH of 6.6 to 7.4 is thought to be optimal for methanogens. Some studies suggest buffering to moderate the effects of volatile acids and other acid products, which tend to depress the pH below the optimal pH.

Temperature affects microbial activity within the landfill, which in turn affects the temperature of the landfill. Warm landfill temperatures favour methane production and methane production may also reflect seasonal temperature fluctuation in cold climates where the landfill is shallow and sensitive to ambient temperatures.

Values of k obtained from available literature, laboratory simulator results, industry experts, and back-calculations from measured gas generations rates range from 0.03 to 0.21. The USEPA suggests 0.04 1/yr for moderate climates and 0.02 1/yr for dry climates (less than 635 mm rainfall per year). See **Table B-5**.

Table B-5 Typical Methane Generation Rate Constant Values

Location	**Condition**	**Methane generation rate constant, *k* (1/year)**
Range in international literature		0.03 to 0.21
USA EPA default AP-42	Dry climate	0.02
USA EPA default AP-42	Moderate climate	0.04
USA EPA default NSPS/EG	Dry climate	0.02
USA EPA default NSPS/EG	Moderate climate	0.05
Typical New Zealand landfills		0.036 to 0.15

MfE (2001) suggests that typical values of k used in New Zealand range from 0.036 1/year to 0.15 1/year and typically a maximum value of 1/year is adopted even for wet landfills (high rainfall areas and poor landfill cover).

Pierce et. al. (2005) proposes a correlation between rainfall and k based on research undertaken in the US. The resulting empirical relationship is given by:

$k = 0.016\, e^{0.040r}$ where r is the average annual rainfall.

Landfill Gas Collection Efficiency and Fluctuations

Determining the potential rate at which landfill gas can be captured from a gas field and used is as important as the estimation of the gas generation rate. The gas capture rate is a percentage of the generation rate and is a function not only of the effectiveness of the abstraction system, but also of factors such as the original landfilling methods, depth of waste, leachate saturation levels and cap permeability.

To maximise the recovery of the available gas, the abstraction system should be comprehensive and flexible. Consequently, an optimal design will balance the maximisation of the extraction of methane-rich landfill gas against the risk of inducing the ingress of air into the waste mass. It will also enable operators to readily adjust the suction applied to each gas extraction well.

The overall collection efficiency of the landfill gas management system is determined by the percentage coverage of the system at any one time multiplied by the anticipated collection efficiency of the system.

The USEPA estimates that the collection efficiency for a typical comprehensive landfill gas collection system ranges from 60% to 85%. Recent research led by industry in the US suggests that the collection efficiency could be as high as 90 to 95% (Sullivan 2009).

Landfill Gas Control

A number of factors affect the number of extraction wells and their locations. However, the primary considerations are:

- well radius of influence and spacing;
- phasing of landfill development; and
- landfill geometry.

The spacing of well locations is determined by the expected radius of influence for each well. This radius is heavily influenced by the nature of the waste and the vacuum pressure applied. In operation, gas flows can be regulated by adjusting the vacuum pressure. Well spacing may range from approximately 50 m to 100 m, depending on the radius of influence for each well.

The base of an extraction well should be typically targeted at least 5 m above the base of the landfill. However, if there is some uncertainty about the level of the base of the landfill, or where supplementary wells are provided between deep wells, the base level of the well should be raised to avoid the risk of penetrating the liner system.

Experience from New Zealand and overseas has shown that the minimum criteria for landfill gas well fields used to optimise landfill gas extraction and meet environmental control requirements are as follows:

- well spacing 50 to 70 m; and
- wells placed no greater than 30 m from the edge of the waste mass.

As landfill gas generation predictions are not exact, design should provide conservatism by adopting the following design gas flows:

- **Pipework & extraction equipment**: The maximum landfill gas generation throughout the design life of the pipework system.
- **Utilisation equipment**: The maximum collected landfill gas throughout the design life of the landfill gas management system.

Active Collection Wells

The principle underlying the active collection system is to provide a series of deep extraction wells in the body of the waste mass for the collection of landfill gas over a wide area. In addition, a series of shallow extraction wells around the perimeter control the migration of landfill gas close to the surface of the landfill. The design of the active system is intended to collect the majority of the landfill gas containing at least 50 percent methane — a typical minimum percentage required when landfill gas is utilised in the generation of electricity.

The vertical wells can be supplemented by a series of horizontal collectors which can be progressively installed as the waste is placed.

If a well field is developed in parallel with filling operations, the arrangement of the active wells and their ability to capture landfill gas is influenced by a number of factors, including:

- **Access for waste placement**: The wells are typically developed in parallel with the waste placement and need to be suitably placed and spaced to enable waste placement.
- **Proximity to the tipping area**: To reduce the potential for odour issues, the wells need to be sited as close as possible to the tipping area; however, if an individual well is too close to an open area, then there will be a tendency to draw in air and the vacuum applied at the well will need to be adjusted accordingly.
- **Capping on platforms and side slopes**: The permeability of a temporary soil cap on platforms and side slopes not currently receiving waste would permit air ingress if high vacuum pressures were applied to an extraction well. Thus, during operation of the landfill only relatively low vacuums can be applied to a number of wells thus reducing the collection efficiency. This may necessitate closer well spacing.

The design of the extraction system needs to be sufficiently flexible to allow the field to be developed in a modular fashion and for areas to be disconnected and quickly reconnected to suit operational activities.

If the well field is retrospectively drilled into the waste mass on completion of filling, the primary factors influencing well placement are:

- **Location of any special or liquid wastes**: The wells are located to ensure, as far as practicable, that they do not pass through localised areas of special wastes or liquid waste which might affect well performance.
- **Irregular base formation information**: For older sites there is often limited information of the exact base formation of the landfill. Care must be taken not to compromise the liner system when drilling gas wells, with wells being carefully positioned and targeted to depths at least 5 m above the base liner level.
- **Depth constraints**: Typically, the maximum depth a well can be retrospectively drilled into an existing waste mass is in the order of 30 m, which may not be the full depth of the waste column. For deep landfills, consideration should be given to whether well installation should be a combination of retrospective drilling and progressive installation.

Active Extraction Vacuum

Active extraction systems can be characterised by the magnitude of the vacuum that is applied at the wellheads. The vacuum that is applied to a wellhead, amongst other factors, influences the flow of gas that can be extracted and the radius of influence of a well. To meet the requirements for gas collection and environmental protection, a combination of deep wells with high vacuum and shallow systems with low vacuum is adopted, as follows:

- **high vacuum (greater than 100mm of water, or 10 millibar)**: generally applied to large diameter wells installed in the area of waste above which there is a competent cap;
- **low vacuum (less than 100mm of water, or 10 millibar)**: used where the cap is permeable and where the risk of air ingress into the waste mass must be minimised, and also where leachate levels are high, and a comparatively thin layer of gas-producing waste exists.

The regulating valve at the well head is used to control the vacuum applied at an individual well.

Active System Flexibility

Flexibility is required in an active system to accommodate variations that occur through the waste mass, changes in landfill gas generation rates and operational constraints. For these reasons, the design of the active landfill gas extraction system incorporates considerable flexibility.

Extraction Well Design

The design of an extraction well needs to accommodate a number of factors:

- the required radius of influence to generate the design gas flow;
- potential air ingress through the cap;
- flow and pressure loss of gas coming from the waste into the well pipe riser;
- flow and pressure of gas up the well pipe riser;
- structural integrity of the well pipe riser;
- construction of the well bore and its stability during construction;
- the progressive extension of the well vertically as the waste mass increases in height; and
- consolidation settlement of the waste mass and down-drag forces.

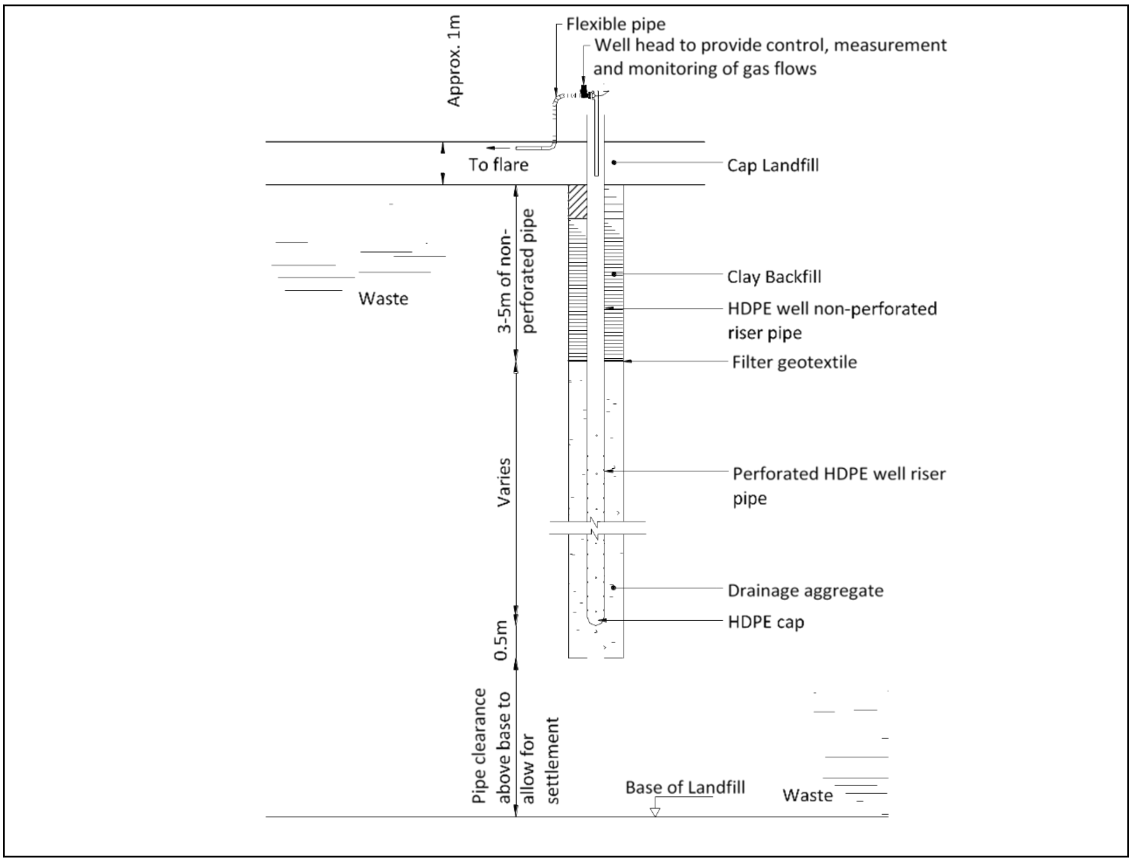
For deep wells, the stability of the open bore during construction is of prime importance. Larger bores are more stable in construction than small bore wells, and the construction of the well can be undertaken without damage to the well structure. For this reason, a large bore size is typically adopted for deep wells. This large diameter also permits a larger radius of influence and will induce a greater gas flow.

Extraction wells installed during filling need to be progressively extended vertically upwards as the waste mass increases in height. This is typically achieved by the use of a steel slip casing (typically 5 to 7 m long) which is progressively lifted as the well is extended. The top of the well casing is typically kept 1 to 3m above the waste surface to provide some protection to the wellhead whilst enabling access for maintenance and field balancing.

A waste depth of at least 10 m is necessary for the operation of a gas well. The base of the well should be a minimum of 5 m above the base of the landfill and the upper 2 to 5 m of the well riser should be non-perforated to prevent air entrainment. Therefore, a well installed in 10 m of waste has a minimum of 3 m of perforated length to draw gas from.

Typical design features of a gas well are provided in **Figure B-4**.

Figure B-4 Typical Landfill Gas Well Design



Air Ingress

The extraction wells will be located either adjacent to active filling areas, in areas with a temporary soil cap, or in areas with a final soil cap. Care must be taken in all of these areas to prevent air ingress, and thus the general arrangement of wells is important. Of particular importance is the design of an individual well, such that the length of plain pipe in the uppermost section of the well is sufficient to prevent air ingress through the cap. The air ingress criterion is taken to be 2% of the gas flow extraction for a well, and the intrinsic permeability of the cap is based upon the hydraulic permeability of the soil cap.

In the final condition the permeability of the soil cap should be low enough to enable individual wells to operate with a high degree of efficiency at a vacuum pressure of 10 mbar provided the perforated section of the well riser is terminated approximately 2 to 5 m below the final surface.

However, in the interim condition, the depth of interim cover may not be sufficient to minimise air intrusion. The quality of gas at individual wells will need to be monitored closely to detect if air intrusion becomes too great. Notwithstanding this, the perforated well riser will need to be temporarily terminated a minimum of 2 m below the interim ground surface. The non-perforated section will need to be replaced with perforated pipe as the well is extended progressively up through the waste mass.

Well Riser Structure

The structure of the well riser pipes needs to ensure the long-term operation of the extraction wells. It has been extensively demonstrated in gas wells elsewhere that insufficient strength in the wells can lead to buckling of the wells which prevents their operation.

HDPE pipes are manufactured using standards for resins that vary depending upon the country of origin. The different resins result in a different elastic modulus for different pipes, and thus the structural integrity of a pipe with the same standard dimension ratio can vary substantially. The two resins typically adopted are PE100 and PE80. The PE100 material provides a high elastic modulus, allowing pipes of smaller wall thickness to be used to achieve the same structural integrity. The use of these pipes provides a more economical design than a pipe manufactured from PE80. It should also be noted that the carbon black content varies depending on the standard the pipe is manufactured to. Carbon black content is extremely important for UV resistance which is particularly relevant for the pipes laid above ground. The carbon black content of pipes manufactured to American Society for Testing and Materials (ASTM) standards is higher than those manufactured to European standards. Consequently, it is recommended that pipes manufactured to ASTM standards are used.

The design of the well structure needs to take account of the loss of strength of the pipe wall that arises from its perforations. Excessive perforations can lead to pipe collapse. For this reason, it is imperative that slotted pipes are not used for gas extraction wells, and that the perforation pattern adopted provides sufficient strength in the pipe wall without being detrimental to the gas flow capacity of the well.

Wellhead

The design of the wellhead needs to consider:

- safety;
- access requirements;
- settlement of waste;
- control facilities;
- drainage;
- protection from surface water;
- gas seals through the cap; and
- construction.

Wellhead chamber designs and materials vary, but fall into one of two general types:

- **Open chambers:** These are used where there is no public access. They are shallow in depth to prevent landfill gas collecting and large enough to allow the operators to stand and work within the chamber.
- **Closed chambers:** These are typically used where the public has or may have authorised or unauthorised access. The chambers are small enough to prevent a person entering and have lockable covers.

During landfill operations, there is no need for chambers and the well heads will be left proud of the interim waste surface. In the long term, if public access to the completed landfill surface is allowed, consideration should be given to whether chambers are necessary.

Wellhead Control Equipment

The wellhead is the transition between the gas well and the gas header system network. The wellhead incorporates various equipment and ports to:

- control the extraction of gas from the well by means of a valve;
- measure the gas flow from the well;
- measure the suction pressure and temperature at the well;
- allow for sampling; and
- allow for leachate level monitoring within the well.

Prefabricated wellhead units are a simple, reliable option.

Flow Monitoring

Gas flow at the wellhead can be monitored using a pitot tube device. The diameter of the wellhead needs to be sufficiently small that the gas flow velocity can be measured by the pitot tube device. Consideration should be given to the potential maximum gas flow rate at the well and the potential rate of decline in the gas flow rate as the gas generation rate declines after closure of the landfill.

Some proprietary wellheads allow monitoring with specifically compatible monitoring equipment (e.g., GEM500 monitor and Landtec wellheads). The accuracy of such monitoring is considered greater than less sophisticated methods.

Allowance for Settlement

Wherever gas wells are established, the potential settlement is high due to the depth of waste. The gas wells tend to remain stationary within the waste mass whilst the surrounding ground surface settles. Thus, over time, the gas well pipe rises higher above the surrounding ground. The design should allow for this by providing flexible hose connections to the gas header, which can accommodate minor settlement. However, as settlement progresses, the wellhead assembly may need to be removed and the well pipe cut down. An alternative is to allow for slip joints within the vertical pipe string.

Extraction Network

The design of the system of header pipes and other ancillaries for the extraction network is based on:

- redundancy in the ability to collect gas from areas of the site;
- efficiency in the balancing of the field;
- condensate management;
- ease of installation and maintenance; and
- standardising pipe sizes.

Header pipes and pipe networks can be constructed either above ground or below the final ground surface. There are benefits and disadvantages in either approach. Factors which should be taken into account in the assessment of whether to lay pipes above or below ground include:

- **Hot weather**: Exposed header systems may be subject to extremes of pipe expansion with heating and cooling between day and night or between seasons.
- **Maintenance**: It is beneficial to have wellheads above ground for ease of maintenance.
- **Settlement**: Landfill settlement and differential settlement of the landfill can cause structural damage to the piping in the form of sags and breaks; consequently, a collector header that is not buried is easier to repair.
- **Vandalism**: Exposed headers are more vulnerable to potential vandalism.
- **Visual impact**: Exposed headers may constitute an eyesore.
- **Generation of condensate**: Condensate can significantly reduce the capacity of the extraction pipework if it is not properly drained. Condensate sumps should be provided at all low points and landfill gas and condensate should flow in the same direction wherever possible.

The size of each pipe section is optimised to provide a maximum flow velocity in each of the pipes of 15 m/s at the design flow and a typical average velocity of 10 m/s. The pressure loss along each section of pipe is a function of the flow, the pipe diameter and length, and the ancillary components in the pipeline (for example, valves and branches). The pressure loss in each section can be estimated using a number of different formulae (e.g., the Darcy Weisbach formula, the Moody diagram that accounts for the viscosity of the landfill gas, and Reynolds number of the flow in the friction loss equation) or figures provided by manufacturers.

Pipeline

The material used in the extraction pipes should be HDPE. HDPE is resistant to chemical attack from condensate, provides sufficient strength to require no further support when buried and is flexible to accommodate settlement. The strength and wall thickness of the pipes should be commensurate with the loadings to which they will be subject. The design of these pipes depends upon the strength of the base resin, as determined by the manufacturer’s standards.

Butt fusion welded joints are generally preferred over electro fusion couplings as they simplify the disconnection, relocation, and reconnection of pipework. Electro fusion couplings require careful support to protect them from settlement and operational activities.

Isolation and Road Crossing Valves

Valves are typically provided in various locations within the gas extraction network to provide control of the gas field and allow for flexibility in the operation of the field to:

- provide isolation or control of sectors of the network;
- control the vacuum pressure at each well head; and
- provide for isolation of all road crossings.

Condensate Management

Condensation of water vapour in the landfill gas occurs when it exits the warm environment of the landfill and progresses through the relatively cool environment of the gas collection pipework, resulting in condensate being collected in gas pipes. If this condensate is allowed to accumulate, it can inhibit the free flow of the gas through the system. The condensate generation calculation assumes that the gas is fully saturated at the wellhead and the proportion of water vapour that condenses is dependent upon the difference in temperature between the waste mass and ambient air temperature.

To control the condensate that will arise in the gas collection system, the system should include condensate traps. Condensate traps are designed to allow condensate to percolate back into the waste mass without the need for active control. Condensate will naturally flow to the lowest point of the ring main. Therefore, condensate traps should be constructed:

- at key points around the ring main as necessary; and
- at the lowest point in the collection network before the final pipework to the flare.

Condensate traps generally do not remove all of the water vapour in the gas. Therefore, to ensure that water vapour in the gas does not damage the blower system and other systems downstream, a knockout pot is typically installed prior to the blower. A knockout pot uses the principle of drawing the gas through a container of large volume; as the gas expands through the container, the temperature of the gas drops and the water vapour condenses. For the design of the knockout pot, the volume of condensate to be removed is assumed to be the total amount of water vapour potentially in the landfill gas (i.e., discounting any effect of condensate traps).

Landfill Gas Utilisation

It takes approximately 500 m^3 per hour of landfill gas to generate 1 megawatt of electricity and it takes a waste acceptance rate of 50,000 to 75,000 tonnes per annum to reliably generate 500 m^3 of gas per hour.

An average New Zealand household uses approximately 7,800 kilowatt hours (kWh) of electricity per year. A 1-megawatt landfill gas powered generator can potentially produce 7,800,000 kWh in a year and therefore provide electricity for approximately 1000 households.

The three principal factors which affect viability of the beneficial reuse of landfill gas at a particular waste facility are:

- energy value;
- landfill gas quantity; and
- landfill gas quality.

Key factors that should be considered during the design of the utilisation plant include:

- composition of the raw gas extracted/used from the landfill;
- level and type of pre-treatment or conditioning applied to the gas prior to its supply to the combustion equipment (e.g., water removal and filtration);
- type of combustion equipment used (e.g., internal combustion engines with wet or dry manifolds, gas turbines, etc.);
- temperature of combustion;
- set-up and maintenance of the combustion equipment; and
- fuel to air ratio applied during combustion (which will affect the amount of excess air, if any, available and hence the completeness of oxidation reactions).

The value of the energy is affected by the project type, which may include:

- sale of electricity to a grid or landfill gas to a natural gas network;
- on-site utilisation to meet electricity requirements for a flare station, leachate or groundwater treatment plant and on-site facilities such as office complexes, maintenance garages etc.; or
- off-site utilisation such as electricity supply direct to specific electricity users or transportation of landfill gas to remote electricity generation or utilisation plants.

Electricity Generation Technologies

Established technologies for the generation of electricity from landfill gas include:

- reciprocating engines;
- combustion turbines; and
- steam cycle power plants.

Recent emerging technologies include:

- micro turbines;
- fuel cells; and

- Stirling cycle engines.

Landfill Gas Pre treatment

Most utilisation technologies require some form of pre-treatment of the landfill gas. Typically, this is in the form of cooling and filtering to remove moisture and impurities.

However, if there is significant hydrogen sulphide concentration in the landfill gas it needs to be removed to reduce corrosivity. Furthermore, siloxane treatment is becoming increasingly common to avoid fouling of the utilisation equipment.

Additional levels of primary treatment/supplementary processing should be introduced when the gas is to be used as a fuel. These can include:

- filtration;
- drying (or ‘conditioning’);
- higher pressure boosting;
- after-cooling; and
- gas composition adjustment.

Heat Recovery

Heat recovery from a landfill gas utilisation plant can be an additional source of revenue. The heat can be used for on-site requirements such as in leachate treatment or office heating. Alternatively, it can be sent off site as either hot water or steam; however, it is only viable if there is a local end user.

B.4 Construction Quality Assurance & Quality Control (QA/QC)

Geosynthetic Testing Requirements

The Geosynthetic Institute is a membership-based organisation in the United States, whose members include international facility owners; designers; consultants; quality assurance and control organisations; testing laboratories; resin and additive suppliers; manufacturers; manufacturers’ representatives; installation contractors; and federal and state governmental agencies.

The documents available on their website[7] include internationally recognised specifications for geosynthetics. The specifications cover the majority of geosynthetics used in landfills/fills and provide information on material properties and testing regimes. It is recommended that these specifications form the basis of specification and design development.

---

[7] https://geosynthetic-institute.org/specifications.htm

Consideration should be given to whether independent testing of the manufacturer's data is required.

Soils Testing Requirements

QA/QC is required for soil materials, used in the construction of landfill/fill liners and capping layers, to confirm:

- the materials meet the specification requirements;
- the required compaction is achieved; and
- the final surface is smooth enough to prevent mechanical damage to the geomembrane, if one is required.

Testing and inspection are therefore required at source, during placement, and on completion as outlined in **Table B-6**.

Table B-6 Soil Testing Requirements (table to be adjusted for NZ conditions)

Parameter	Test Frequency[1]
In-situ density[2] ("Rapid")	Consider the following: • Rate of testing based on waste and fill material placement from each borrow area. The rate for a borrow may reduce over time depending on consistency of results. Typically, one set for every 200- 500 m^3 of waste or fill material placed. • Maximum number per day. • Maximum horizontal distance between test locations. • Maximum vertical separation between tests.
In-situ density ("Fully Specified")	As required to provide confidence that the "rapid method" is giving reliable results. Refer to NZS4407:1991.
Strength (shear vane or scala penetrometer test as appropriate)	Consider the following: • Rate of testing based on waste or fill material placement, typically 1 set per 200 m^3 of fill placed. • Maximum horizontal distance between test locations. • Maximum vertical separation between tests.
Moisture content	1 per in-situ density test
Maximum dry density and overall moisture content determination	Consider the following: • Initial test prior to fill placement. • Rate of testing based on waste or fill material placement from each borrow area or waste or fill material type. Typically, 1 test per 10,000 m^3 for a particular borrow source or waste or fill material type.

Parameter	Test Frequency[1]
Permeability (Laboratory Triaxial Test)	Consider the following: • Rate of testing based on waste or fill material placement from each borrow area. Typically, 1 test per 500-1000 m^3. The rate for a borrow may reduce over time depending on confidence from results. • Typically, would require at least 1 test per week
Solid density	Consider the following: • Initial testing prior to waste or fill material placement. • Rate of testing based on waste or fill material placement from each borrow area or waste or fill material type. Typically, 1 test per 10,000 m^3 for a particular borrow source or waste or fill material type.

Notes: [1] The test frequency depends on the size of the project and anticipated filling rate.
[2] When in-situ density "rapid" tests area carried out, a set shall comprise 2 No. measurements using the same probe hole but oriented at 90 to each other.
3 An even spread of test locations, both vertically and horizontally, is required through all landfill/fill areas. A "landfill/fill area" in this case is defined as the area or zone of continuous waste or fill material placed on a particular working day.

B.5 References

Bouazza, A. 2002. Geosynthetic clay liners. *Geotextiles & Geomembranes*, Vol. 20, No1, pp. 3-17.

Coops, O., Luning, L., Oonk, H. and Weenk, A. 1995. Validation of landfill gas formation models. *Proceedings of the Fifth International Landfill Symposium*, Sardinia, Italy, October 1995, pp. 635–646.

Giroud, J.P., & Houlihan, M.F. 1995. Design of Leachate Collection Layers, *Proceedings of the Fifth International Landfill Symposium*, Sardinia, Italy, October 1995, Vol. 2, pp. 613-640.

Giroud, J.P., Soderman, K.L., Khire, M.V., & Badu-Tweneboah, K. 1998. New Developments in Landfill Liner Leakage Evaluation. *Proceedings of GeoEnvironment*, Atlanta, USA.

Knox, K. 1991. *A Review of Water Balance Methods and Their Application to Landfills in the UK*. Department of the Environment U.K. Wastes Technical Division, Research Report No. CWM--031-91.

Kodikara, J. 1996. Prediction of tension in geomembranes placed on landfill slopes. Department of Civil and Building Engineering, Victoria University of Technology, Melbourne, Vic., Australia, *Environmental Geotechnics* Balkema ISBN 90 5410 8487 Volume 1 pp 557

Koerner, R.M. 2012. *Designing with geosynthetics*, Sixth edition, Volume 1 & 2, Xlibris Corporation.

Koerner R.M., Hsuan Y.G., Koerner G.R. and Gryger D. 2010. Ten year creep puncture study of HDPE geomembranes protected by needle punched nonwoven geotextiles. *Geotextiles and Geomembranes,* Vol 28, pp. 503–513.

Koerner, R.M., Wilson-Fahmy, R.F. and Narejo, D., 1996, Puncture Protection of Geomembranes Part III: Examples, *Geosynthetics International*, Vol. 3, No. 5, pp. 655-675.

Maier, T.B. 1998. Analysis of procedures for design of leachate recirculation systems, *SWANA 1998 Landfill Symposium*.

McKendry, P. 1991. Landfill gas production – theory and practice. *Methane: Facing the Problems Symposium*, Nottingham University

MfE. 2001. A Guide for the Management of Closing and Closed Landfills in New Zealand.

New Zealand Standard NZS 4407:1991. Methods of Sampling and Testing road Aggregates.

Narejo, D., Koerner, R.M. and Wilson-Fahmy, R.F., 1996, "Puncture Protection of Geomembranes Part II: Experimental", *Geosynthetics International*, Vol. 3, No. 5, pp. 629-653.

E H Pechan & Associates. 1998. Emerging technologies for the management and utilization of landfill gas. Prepared for USEPA, January 1998.

Pierce, J., LaFountain, L., and R. Huitec. 2005. *Landfill gas generation & modelling manual of practice*. The Solid Waste Association of North America (SWANA), SWANA's Landfill Gas Management Technical Division / Landfill Gas Generation and Modeling Committee.

Reinhart, D. R. 1994. *Beneficial use of landfill gas*. University of Central Florida, September 1994.

Spokas, K. et. al. 2006. Methane Mass Balance at Three Landfill Sites: What is the Efficiency of Capture by Gas Collection Systems? in Waste Management, Vol. 26, Issue 5, 2006, pp. 516–525.

Sullivan, P. 2009. Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills., prepared for Solid Waste Industry for Climate Solutions, Version 2.2, Revised January, 2009.

UK Environment Agency. 2002. Guidance on Landfill Gas Flaring.

UK Environment Agency. 2004. LFTGN03, Guidance on the Management of Landfill Gas.

USEPA. 1996. Turning a liability into an asset: A landfill gas-to-energy project development handbook. EPA 430-B-96-0004, September 1996.

Willumsen, H. 2003. Landfill gas plants – number and types worldwide. *Proceedings Sardinia 2003*, Ninth International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy, 6 – 10 October 2003.

Wilson-Fahmy, R.F., Narejo, D. and Koerner, R.M., 1996, "Puncture Protection of Geomembranes Part I: Theory", *Geosynthetics International*, Vol. 3, No. 5, pp. 605-628.

Appendix C Derivation of Waste Acceptance Criteria (WAC)

C.1 Philosophy and Basis for WAC Development

WAC are developed to provide confidence that materials placed within a facility do not result in an unacceptable adverse effect on human health or environmental receptors. Potential exposure to constituents from the material via any viable exposure route needs to be considered when determining potential effects.

A conceptual site model is considered for each class of landfill/fill, and this provides the basis for a generic exposure assessment, pathways and scenarios (**Table C-1**). Based on the exposure pathways and scenarios, dilution and attenuation factors are developed. This enables the back calculation of WAC from existing guidelines for receptors, such as drinking water standards or aquatic criteria for receiving waters. Multiple pathways are considered in the conceptual site model with the limiting pathway controlling the WAC to be adopted. A minimum threshold for WAC based on the soil background levels is taken to ensure WAC are pragmatic.

In developing WAC for Class 4 and 5 fills, the precautionary principle of not creating contaminated sites is inherent within the methodology adopted. Similarly, the WAC are developed on the basis that Class 4 and 5 fills should not present an unacceptable risk for unrestricted future land use. Where a future land use is already constrained for a site, the WAC that are based on a human health pathway may consider a less sensitive exposure scenario. The limiting pathway should still determine the WAC adopted.

C.2 WAC Development

WAC can be expressed as either total concentrations or leachable concentrations (or both).

Typically, Class 1 and 2 landfills have a level of engineered containment that provides controls in respect of leachate, landfill gas, runoff or direct exposure to a waste material. For landfills that have a level of engineered containment (Class 1 and 2) the adoption of leachability-based criteria for potentially hazardous wastes is therefore considered appropriate.

For less contaminated or inert wastes (Class 3, 4 and 5 fills) with limited or no engineered containment, the WAC are the primary control on potential effects from the fill or waste material. A more conservative approach of adopting total concentration-based WAC is therefore adopted. Total concentrations refer to laboratory analysed samples with an extraction method accredited as providing the total recoverable concentration.

C.3 Exposure Assessment

The exposure scenarios and pathways for contaminants contained within a landfill or fill depend on the type of site.

WAC have been developed based on existing guideline values except for Class 3 and 4 fills for which criteria were calculated based on the pathways appropriate to the class, and the limiting pathway for each contaminant chosen.

The selection of guideline values is based on a generic exposure assessment. A tabulated depiction of these is shown for each landfill/fill class in **Table C-1**. The table summarises the following five elements that are required to make up an exposure pathway:

- **Contaminant source or release**. The waste is the source which could release contaminants into various media.
- **Environmental fate and transport**. Once released to the environment, contaminants move through and across different media.
- **Exposure point or area**. The specific point where people or environmental receptors might come into contact with a contaminated medium.
- **Exposure route.** The means by which people physically contact environmental contamination at the exposure point (e.g., by inhalation, ingestion, or dermal contact).
- **Potentially exposed populations**. Both people and ecological receptors.
- **Erosion or runoff**. Release of waste directly to the environment is controlled by operational and engineering controls such as daily cover and stormwater treatment and is verified by monitoring. These pathways are considered incomplete.
- **Leaching to groundwater or seepage**. This pathway is mitigated by engineered controls, such as liners and leachate collection systems, but is a primary pathway for exposure to contaminants from waste either as groundwater use or seepage to surface water. These pathways are therefore assessed on the basis of Australian and New Zealand Environment and Conservation Council (ANZECC) criteria or Drinking Water Standards.
- **Landfill gas migration** both onsite and offsite is potentially a complete pathway. For the offsite pathways, indoor and outdoor air are both potential pathways. The onsite exposure during operations is controlled by management plans and assessment above. Onsite exposure post closure will have institutional controls in terms of constraints on future land use and a post closure management plan, which will control the indoor and maintenance and excavation worker exposure pathways. Only the onsite outdoor air exposure pathway is therefore considered complete post closure.

Table C-1 Exposure Pathway Assessment

All Classes of Landfills and Fills						Class 1&2		Class 3		Class 4		Class 5	
Exposure path	**Contaminant source**	**Release/ transport/ media**	**Exposure point**	**Exposure route**	**Receptor - operational**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**
1.1	Waste	Direct contact/soil	Onsite	Ingestion	Human health – workers	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC/IC	Incomplete IC	Incomplete IC	NA	NA
1.2	Waste	Direct contact/soil	Onsite	Ingestion	Human health – public	NA	Incomplete EC	Incomplete EC/IC	Incomplete EC/IC	NA	Assessed - any land use human health	NA	NA
1.3	Waste	Direct contact/soil	Onsite	Dermal contact	Human health - Workers	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC/IC	NA	NA
1.4	Waste	Direct contact/soil	Onsite	Dermal contact	Human health - public	NA	Incomplete EC	Incomplete EC/IC	Incomplete EC/IC	NA	Assessed - rural residential/ lifestyle, residential	NA	NA
1.5	Waste	Direct contact/soil	Onsite	Ingestion	Wildlife	Incomplete EC	Incomplete EC	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC	Incomplete EC	NA	NA
2.1	Waste	Volatilisation or wind/air or dust	Onsite	Inhalation	Human health - workers	Assessed commercial industrial land use	Incomplete EC	Incomplete EC/IC	Incomplete EC/IC	Assessed outdoor air	Assessed outdoor & indoor air	NA	NA

All Classes of Landfills and Fills						Class 1&2		Class 3		Class 4		Class 5	
Exposure path	Contaminant source	Release/ transport/ media	Exposure point	Exposure route	Receptor - operational	Assessment - operational	Assessment - post closure	Assessment - operational	Assessment - post closure	Assessment - operational	Assessment - post closure	Assessment - operational	Assessment - post closure
2.2	Waste	Volatilisation or wind/air or dust	Offsite	Inhalation	Human health - residential	Incomplete EC	Incomplete EC	Incomplete EC/IC	Incomplete EC/IC	Assessed outdoor & indoor air	Assessed outdoor & indoor air	NA	NA
3.1	Waste	Erosion or runoff/ dissolved or suspended sediment	Offsite	Ingestion	Aquatic ecosystems	Incomplete EC	Incomplete EC	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC	Incomplete EC	Incomplete EC	Incomplete EC
3.2	Waste	Erosion or runoff/ dissolved or suspended sediment	Offsite	Dermal contact	Human health – public Contact recreation	Incomplete EC	Incomplete EC	Incomplete EC/IC	Incomplete EC/IC	Not applicable	Incomplete EC	Not applicable	Incomplete EC
3.3	Waste	Erosion or runoff/ dissolved or suspended sediment	Onsite	Ingestion	Human health - workers	Incomplete EC	Incomplete EC	Incomplete EC/IC	Incomplete EC/IC	Incomplete IC	Incomplete EC	Incomplete IC	Incomplete EC
4.1	Waste	Leaching/ groundwater / seepage	Offsite	go to 3.1 to 3.3									

All Classes of Landfills and Fills						Class 1&2		Class 3		Class 4		Class 5	
Exposure path	**Contaminant source**	**Release/ transport/ media**	**Exposure point**	**Exposure route**	**Receptor - operational**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**
4.2	Waste	Leaching/ groundwater / seepage	Onsite	Ingestion	Human health - workers	Incomplete EC	Incomplete EC	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC/IC	NA	NA
4.3	Waste	Leaching/ groundwater / seepage	Onsite	Dermal contact	Human health - workers	Incomplete EC	Incomplete EC	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC/IC	Incomplete EC/IC	NA	NA
4.4	Waste	Leaching/ groundwater / seepage	Offsite	Ingestion	Aquatic ecosystems	Assessed - ANZECC	Assessed - ANZECC	Assessed - ANZECC	Assessed - ANZECC	Assessed - ANZECC	Assessed - ANZECC	NA	NA
5.1	Waste	Leaching/ groundwater / GW wells	Offsite	Ingestion	Human health - drinking water	Assessed - GW use	Assessed - GW use	Assessed - GW use	Assessed - GW use	Assessed - GW use	Assessed - GW use	NA	NA
5.2	Waste	Leaching/ groundwater / GW wells	Offsite	Dermal contact	Human health - drinking water	Assessed - GW use	Assessed - GW use	Assessed - GW use	Assessed - GW use	Assessed - GW use	Assessed - GW use	NA	NA
6.1	Waste	Landfill gas/ air subsurface	Offsite	Inhalation	Human health - residential	Assessed outdoor & indoor air	Assessed outdoor & indoor air	NA	NA	NA	NA	NA	NA
6.2	Waste	Landfill gas/ air subsurface	Offsite	Explosion	Human health - residential	Incomplete EC/IC	Incomplete EC/IC	NA	NA	NA	NA	NA	NA

All Classes of Landfills and Fills						Class 1&2		Class 3		Class 4		Class 5	
Exposure path	**Contaminant source**	**Release/ transport/ media**	**Exposure point**	**Exposure route**	**Receptor - operational**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**
6.3	Waste	Landfill gas/ air subsurface	Onsite	Inhalation	Human health - recreation	NA	Assessed outdoor air	NA	NA	NA	NA	NA	NA
6.4	Waste	Landfill gas/ air subsurface	Onsite	Inhalation	Human health - workers Indoor air	Incomplete EC/IC	Incomplete EC/IC	NA	NA	NA	NA	NA	NA
6.5	Waste	Landfill gas/ air subsurface	Onsite	Explosion	Human health - workers Outdoor air	Incomplete EC/IC	Incomplete EC/IC	NA	NA	NA	NA	NA	NA

Note: Assessed = pathway assessed against standard or guideline scenario specified; EC = engineered controls; IC = institutional controls; incomplete = incomplete exposure pathway/scenario.

Class 1 and 2 Landfills

For landfills with engineered containment (Class 1 and 2) the exposure scenarios and pathways in **Table C-1** were evaluated as follows:

- Direct contact with waste. These exposure scenarios/pathways are generally considered incomplete. The placement of final cover, institutional controls in the form of a site management plan, including measures for maintenance of cover post closure, and limitations on future land use, will eliminate these pathways.
- Inhalation of volatiles. Migration of volatile constituents through the landfill cover is a potential pathway. Many sites will have engineered controls in place that would remove or mitigate these pathways post closure, such as gas collection systems. Consideration is given to workplace exposure standards for volatiles when the site is operating.

Class 3 Managed Fill

Class 3 has no engineering containment but engineered runoff controls exist both during the operational and post-closure phases. Post-closure capping prevents contact with waste. The exposure scenarios evaluated were:

- Leaching to groundwater or seepage. This pathway is a primary pathway for exposure to contaminants from waste, either as groundwater use or seepage to surface water. These pathways are therefore assessed.
- All other pathways are either not applicable (e.g., no landfill gas generation) or controlled by engineered or institutional controls.

Class 4 Controlled Fill

For fills without engineered containment (such as Class 4) the exposure scenarios and pathways were evaluated as follows:

- Direct contact with waste. These exposure scenarios/pathways would - generally be incomplete during operation of the site but are potentially complete post closure. The placement of final cover, institutional controls in the form of a site management plan, including measures for maintenance of cover post closure, and limitations on future land use could eliminate these pathways. Ecological receptors are expected to be controlled during operations and, with the establishment of vegetative topsoil cover post closure, these pathways are considered incomplete post closure.
- Inhalation of volatiles. Migration of volatile constituents through the fill cover is a potential pathway. Consideration is given to workplace exposure standards for volatiles when the site is operating and outdoor and indoor air post closure.
- Erosion or runoff. Release of waste directly to the environment is a potential pathway during operations. Cover placement and closure management controls would prevent waste release and make this pathway incomplete post closure.

- Leaching to groundwater or seepage. This pathway is a primary pathway for exposure to contaminants from waste, either as groundwater use or seepage to surface water. These pathways are therefore assessed.
- Landfill gas migration. Given the absence of significant organic material in this class of fill these pathways are not evaluated.

Class 5 Clean Fill

WAC for these fills are not risk based, but reflective of natural background conditions at the site. For fills without engineered containment (such as Class 5) and unrestricted operation there is only a single pathway that needs to be considered, that of non-contaminated sediment being transported to an aquatic environment. However, this will be managed through engineered controls and therefore should be incomplete.

C.4 Exposure Scenarios

The exposure assessment identifies complete exposure pathways and assessment criteria that should be considered. For the assessment criteria identified it is necessary to select an exposure scenario within existing guidelines, in respect of environmental and/or human health protection, that most closely approximates this exposure assessment. For a number of exposure pathways this is dictated by land use. The following assumptions have been made in respect of potential future land use:

- Class 1 and 2 landfills - operational – “commercial industrial worker outdoor”.
- Class 1 and 2 landfills – post closure – the lesser of "recreational/parkland” and “commercial industrial outdoor”.
- Class 3 Managed Fills - the potential future land use is assumed to be restricted, in which case it will be the lowest of the values protective of users of groundwater and aquatic receptors in nearby streams.
- Class 4 Controlled Fills - the potential future land use is assumed to be unrestricted, in which case it will be the lowest of the values protective of ecological receptors in the fill, people exposed to the fill, users of groundwater and aquatic receptors in nearby streams.
- Class 5 Clean Fills - the potential future land use is assumed to be unrestricted and therefore only virgin excavated material with natural concentrations of trace contaminants will the accepted. Acceptance criteria have not been set; rather compliance is achieved by demonstrating the soil or rock being disposed of is in its natural condition.

In some cases for Classes 3 and 4, the limiting value may be lower than local background, because for some geological conditions background concentrations are significantly higher than typical background concentrations for most geological conditions. Examples are zinc and nickel. In these cases, the limiting exposure pathway value has been adopted as the WAC but if local background at the fill site is higher for a trace contaminant, then the local background becomes the acceptance criterion.

Where a pathway is limiting in terms of the WAC, and has limited applicability, consideration needs to be given to deriving a site-specific exposure scenario. The *Contaminated Land Management Guideline No. 2* (MfE 2011a) is applied where New Zealand guidelines values are not provided for a parameter.

C.5 Leachability Based Criteria

There are a number of leaching tests which can be used to determine the rate at which constituents leach from waste. The USEPA TCLP criteria (40 CFR §261.24) are leachability-based criteria that are widely used in New Zealand as the basis for landfill/fill WAC. The USEPA TCLP test is a relatively straight forward method that provides a leachability that is applicable to the conditions present within MSW.

Where decomposing organic material is not present, the TCLP tests may provide an overly conservative indication of leaching rate for trace elements. A relatively small component of organic material can lead to the development of anaerobic conditions but is unlikely to lead to the presence of organic acids and the leaching conditions simulated by the TCLP test.

C.6 Derivation of Leaching Criteria

WAC for Class 1 Landfills are generally based on a dilution and attenuation factor. The USEPA adopts a dilution and attenuation factor of 100 times the drinking water limits. The appropriate dilution and attenuation factor will be subject to a number of variables including the following:

- the density, effective porosity and permeability of the placed waste or fill material which influences the solid to liquid ratio and leaching rate and thereby the leachate concentration;
- the design of the landfill cover, which influences the rate of rainfall infiltration;
- the design of the landfill liner, drainage layer and leachate collection system and hence the rate of leakage and attenuation through the liner; and
- the hydrogeology, groundwater regime and proximity to the receiving environment for the site and the resulting dilution and mobility of contaminants in leachate.

The above factors are highly site specific and need to be considered if developing a dilution and attenuation factor for a site. The dilution and attenuation factor of 100 is generally considered appropriate for a Class 1 Landfill with site specific conditions that fall within the following general ranges:

- waste with a placed permeability of between 1×10^{-3} and 1×10^{-7} m/s, a placed density of 0.7 to 1.6 t/m^3 and an effective porosity between 0.1 and 0.5;
- a landfill cover with a permeability of between 1×10^{-6} and 1×10^{-9} m/s;
- a leachate discharge (liner leakage) to ground of between 10 and 5000 litres per hectare per day;

- a site located within 100 m of the receiving environment or a sensitive receptor; and
- sites where there is not a sustained inward hydraulic gradient and the hydraulic conductivity of the primary pathways for leachate migration is in excess of 1 x 10^{-5} m/s.

C.7 Recommended WAC

Class 1 - Landfills

The USEPA TCLP criteria (USEPA 1997) are recommended as WAC for Class 1 Landfills.

It is acknowledged that the USEPA criteria are based on US drinking water standards which are higher than Drinking Water Standards for New Zealand (DWSNZ) and therefore have lower concentrations than New Zealand. Adopting the USEPA WAC is effectively assuming a higher dilution and attenuation factor (DAF) for constituents where the DWSNZ is more onerous. The design criteria for a Class 1 Landfill will generally offer a higher level of hydraulic containment, where GCL or FML are included in the liner design over the compacted clay liner originally prescribed by USEPA Subtitle D regulations (USEPA 1997). Adopting the USEPA TCLP criteria as they stand, which is effectively adopting a higher DAF, is therefore considered reasonable.

Leachate data for landfill sites where the TCLP criteria have been utilised for waste acceptance have shown they are effective, but not overly precautionary, at controlling the concentrations of constituents in leachate.

Class 2 C&D Landfills

The USEPA TCLP tests are recommended as a means of determining leachable concentrations for Class 2 C&D Landfills. Threshold minimum total concentrations are provided to indicate the waste concentrations at which TCLP testing should be undertaken.

The design criteria for Class 2 C&D Landfills allows for containment to consist of only compacted soil to a hydraulic conductivity 1 x 10^{-8} m/s with no GCL or FML. This liner configuration will not offer the same level of containment for volatile organic compounds as with a Class 1 Landfill. In terms of the mass flux of contaminants through the liner the compacted soil component of the liner controls the difference in the level of containment. These differences in containment will generally result in an increase between 5 and 10 times the mass flux of contaminant discharge through the liner.

Criteria for Class 2 C&D Landfills are based on the USEPA dilution and attenuation factor approach. In deriving WAC, consideration has been given to the following:

- differing level of containment relative to a Class 1 site as noted above;
- nature of the waste received at a Class 2 site will by definition have less organic material (<5%) and hence less concentrated organic acids that result from biodegradation of waste; and

- organic constituents in waste will have less partitioning onto the waste solids given the lower general organic matter content.

A dilution and attenuation factor of 20 is therefore adopted to derive WAC for Class 2 C&D Landfills for inorganic constituents (this equates to USEPA TCLP criteria for a Class 1 site divided by 5).

A dilution and attenuation factor of 10 is therefore adopted to derive WAC for Class 2 C&D Landfills for organic constituents (this equates to the USEPA TCLP criteria for Class 1 Landfills divided by 10).

Class 3 – Managed Fills

WAC for Class 3 Managed Fills are based on total concentrations for the set of commonly encountered contaminants selected as being appropriate for disposal on Class 3 fills. The set of contaminants is shown in **Table C-2**. Total concentration analysis is preferable over the leaching criteria used for Class 1 and 2 landfills as it is simpler and more economical.

A Class 3 Managed Fill is similar to a Class 4 Controlled Fill (see below) in the type of waste it can receive (mainly waste soil or rock) and does not have any form of engineered containment at its base, however, the Class 3 Managed Fill only needs to consider protection of the groundwater drinking-water and aquatic environment protection pathways. Accordingly, waste soil with concentrations that are elevated above background and typically greater than would be acceptable at a Class 4 Controlled Fill are acceptable in a Class 3 Managed Fill. The exception is when one of the drinking-water or aquatic protection pathways are limiting for Class 4, in which case the Class 3 and Class 4 criterion for such contaminants are the same.

As the Class 3 (and some Class 4) criteria are based on water phase concentrations in either a drinking-water source or an aquatic environment, it is necessary to convert these to soil phase limits to arrive at total concentration WAC. The following assumptions are adopted to provide this conversion:

- The groundwater use and aquatic environment receptors are located at the down-gradient boundary of the fill.
- The WAC is the soil concentration that will create a leachate concentration in the soil porewater from rain falling on the soil that, after migrating to the point of compliance, will not exceed the chosen groundwater concentration limit or aquatic ecosystem protection values.
- The allowable leachate concentrations within the fill are estimated by multiplying the chosen groundwater concentration or aquatic ecosystem protection value by a DAF. The limiting leachate concentration is the lowest value from these calculations.
- The groundwater concentration limit is the maximum acceptable value (MAV) from the DWSNZ 2005 (Revised 2018) (MoH 2018) on the assumption groundwater is being used for human consumption. Where a drinking-water

standard is not available but a tolerable daily intake for the contaminant is available, the equivalent of a MAV is calculated in the same way as the DWSNZ MAVs.

- Aquatic protection values are, unless otherwise stated, the 95% species protection values from the internet-based Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Australian and New Zealand Governments [ANZG] 2018) which supersedes the old ANZECC (2000) water quality guidelines.
- A DAF of 20 has been adopted as representative of the dilution of leaching porewater that will occur as the porewater/leachate travels to the groundwater abstraction point at the down-gradient boundary of the site. This is based on a USEPA (1996) weight of evidence finding that this value is conservative for a range of site conditions.
- A further DAF of 5, given a total DAF of 100, is assumed to be the minimum that would occur in groundwater discharging to a freshwater receiving environment, to account for dilution within a small stream.
- For organic compounds, the WAC is then estimated from the allowable porewater concentration using a relationship between porewater and soil concentration provided by literature values of partition coefficients for the compounds (soil organic carbon partition coefficient or K_{oc}).
- For the inorganic compounds, the WAC has been estimated from the porewater concentration using a large dataset of SPLP testing results.
- It is acknowledged that the method and associated assumptions have many limitations, but the derived generic WAC values are intended to be conservative. It may be appropriate to evaluate site conditions on a site-specific basis when less conservative values are required.

The detail of the derivations is given in Pattle Delamore Partners Ltd (PDP) final report to MfE (PDP 2021). That report is based on several technical memoranda prepared for MfE and submitted to the WasteMINZ/MfE Technical Guidelines for Disposal to Land Reference Group for discussion and decisions. The final report (PDP 2021) varies slightly from some of the derivations in the technical memoranda as a result of consultation with and decisions made by the Reference Group.

Organic contaminants

As noted, for organic contaminants the derivation relies on organic carbon-water partition coefficients (K_{oc}) from the literature. A K_{oc} value can be converted to a soil water distribution (or partition) coefficient (Kd), by multiplying by the fraction of organic carbon (f_{oc}) in the soil. By definition, Kd is the ratio of the solid phase (the waste soil) to the dissolved phase (the leachate) of a substance. If the maximum allowable leachate concentration is known, the maximum allowable soil concentration, or WAC, can be calculated using the Kd value.

The derived values are shown in **Table C-2**. In the calculations:

- The fraction of organic carbon is 1%, which is considered a reasonably conservative value for most soils. Soils with greater organic carbon will leach less and vice versa. While some sandy and other granular soils may have f_{oc} less than 1%, it is expected that, on average, soils will have f_{oc} greater than 1%.
- K_{oc} values have been taken from a database of the properties of thousands of different chemicals maintained by the USEPA. This is considered to be an up-to-date, authoritative source for all the K_{oc} values. The database has both measured and theoretically calculated K_{oc} values. Average measured values from the database were used.
- The DWSNZ provide MAVs for all the organic contaminants except the two TPH fractions that are considered. Similarly, 95% ANZG (2018) values also exist for all the organic substances except TPH. A different derivation method was therefore adopted for the TPH fractions, which is described further below.

For TPH, in the absence of drinking-water MAVs and aquatic protection guidelines, a different approach using surrogate hydrocarbon compounds for which these values do exist, was employed. This is based on selecting a TPH WAC that would ensure the WAC for the surrogates are unlikely to be exceeded and assumes TPH and the surrogate concentrations have some sort of relationship in hydrocarbon contaminated soils. The selected surrogates were the BTEX compounds for C7-C9 TPH, all of which have WAC, and naphthalene for the C10-C14 TPH fraction.

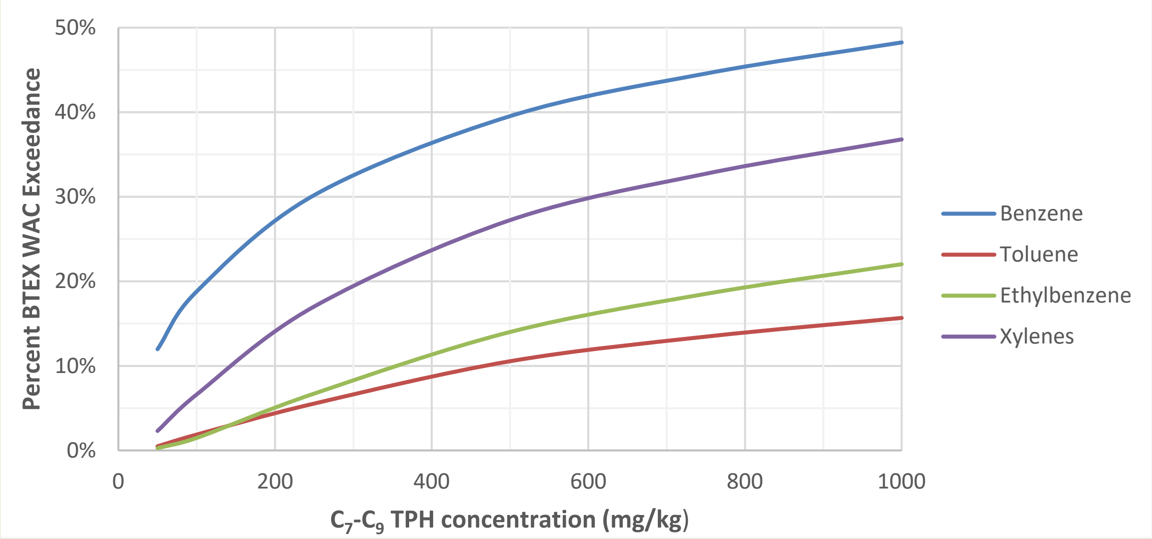
There is no Class 3 WAC for naphthalene, but it is a PAH that is frequently found in hydrocarbon-contaminated soil. To enable naphthalene to be used as a surrogate for the mid-range TPH, a notional WAC was derived in the same way as the other organic WAC. The detail is provided in PDP (2021)

For the C7–C9 TPH faction, a large, anonymised dataset of BTEX and TPH results for the same samples was obtained from a laboratory that holds a large part of the New Zealand market for analysis of hydrocarbon-contaminated soils. This dataset was used to plot each of the four BTEX results against the C7-C9 TPH results to see how the WAC for each of the four compounds compared with the C7-C9 concentration. There were no obvious relationships between the individual BTEX compounds and the light TPH fraction concentrations. This prevents an easy selection of a TPH value that would ensure the individual BTEX WAC are not exceeded.

A trial approach was adopted to see what percentage of the dataset exceeded the toluene WAC for a given trial TPH WAC. The results of this analysis are graphed below.

A trial approach was adopted to see what percentage of the dataset exceeded the toluene WAC for a given trial TPH WAC. This was repeated for each of the BTEX compounds. The results of this analysis are tabulated and graphed below.

Figure C-1 Plot of Percent BTEX WAC Exceedance versus TPH Concentration



For a given TPH value the WAC for benzene and total xylenes are exceeded more frequently than toluene and ethylbenzene. For benzene, even at a TPH concentration of 50 mg/kg, approximately 12% of samples will contain benzene at concentrations which exceed the benzene WAC (0.11 mg/kg). To avoid an impractically low C7-C9 WAC and taking into account that both benzene and toluene will volatilise and biodegrade quickly, a Class 3 TPH WAC of 200 mg/kg was selected as a good compromise across the BTEX compounds. The details are contained in PDP (2021).

A similar approach was taken for C10-C14 TPH using naphthalene (C10) as the proxy. As an intermediate step this required deriving a notional naphthalene WAC. A 95% aquatic protection value exists for naphthalene, but a New Zealand drinking-water standard does not exist and no value could be found from any other jurisdiction. Instead, a range of notional drinking-water guidelines were calculated using the World Health Organization methodology (World Health Organisation 2017), which the MoH follows with some variations, and a range of tolerable daily intakes from authoritative sources. The drinking-water pathway proved not be limiting, with the calculated notional 15 mg/kg for the aquatic protection pathway.

A large dataset of TPH and PAH sample results was obtained from the same laboratory that supplied the BTEX data set. In a similar manner to the C7-C9 TPH assessment, trial C10-C14 TPH values were compared with the naphthalene results. This resulted in the selection of 600 mg/kg, for which approximately 4% of the sample result dataset exceeds the notional naphthalene WAC. This proportion of exceedances is considered acceptable given that not all soil in a controlled fill would have hydrocarbon contamination and therefore, on average, C10-C14 leachate concentrations would be significantly lower than the derivation assumes. Again, the detail of the derivation may be found in PDP (2021).

Inorganic contaminants

Derivations for the suite of inorganic contaminants (a common suite of heavy metals and metalloids found on contaminated land) did not rely on partition coefficients (Kd values) to relate soil concentrations to porewater concentrations, as were used for most of the organic compounds. This is Kd values for such contaminants can vary by several orders of magnitude, depending on such things as soil pH, organic carbon content, the chemical form of the contaminant and the soil mineralogy, which makes choosing representative values very difficult. Instead, derivations were based on a dataset of SPLP and total recoverable concentration test result pairs. The SPLP test, which has been developed by the USEPA to simulate the leaching by rainfall, is assumed to give a conservative estimate of the leachate produced by a particular soil.

The dataset is of soil samples most likely obtained from contaminated sites that were being assessed for redevelopment. It was assumed the samples represent the range of soil that might be disposed of to a Class 3 or 4 fill from such sites.

Target SPLP values were firstly derived for each contaminant (see **Table C-2**) in the same manner as for the organic compounds, taking the lowest of the drinking-water or aquatic protection values after multiplying the water standards/guidelines for each contaminant by the respective DAFs. The SPLP versus total recoverable concentration datasets for each contaminant were then used to obtain the total recoverable concentration equivalent to each of the target SPLP concentrations. The total recoverable concentration then becomes the acceptance criterion (WAC) for the contaminant.

The datasets ranged from in excess of 1200 data points to about 300 datapoints, the larger datasets being for the more commonly encountered contaminants (e.g., arsenic and lead) and consisted of up to ten years of data from the two laboratories in New Zealand which perform the bulk of this work. While SPLP testing is not performed as commonly as TCLP, the data are considered the most representative available in New Zealand for the leachability of the metals and metalloids for which WAC were required.

For most of the contaminants there were a few high SPLP results for low total recoverable concentrations, meaning that it was not possible to have all SPLP results below some acceptance criterion without the acceptance value being unreasonably low (often close to or even below typical background concentrations). A trial approach was therefore adopted, similar to that for the TPH derivations, selecting a total concentration as a trial WAC value and calculating the percentage of SPLP results in the dataset that complied with the trial WAC but exceeded the target SPLP value. This was repeated for a range of potential WAC, up to about 3% SPLP results exceeding the target. Detail is provided in PDP (2021).

A decision-making hierarchy was used to select the WAC, including:

1. The WAC must be above the background concentration.
2. The WAC should preferably be above the MfE (2011c) residential soil contaminant standard (SCS) on the basis that residential development will be the source of much waste soil and avoiding excessive SPLP testing for this common source is preferable.
3. As a matter of judgement, where percentages exceeding the SPLP could be calculated, a WAC in the range 2 to 3% of the dataset exceeding the SPLP target should be chosen as giving reasonable values while ensuring adequate protection of the environment.

4. The WAC should not exceed the 95th percentile and preferably not exceed the 90th percentile, of the particular dataset.

Some of the contaminants have low leachability with all SPLP test results being below the SPLP targets. In these cases, a WAC was set following the hierarchy, but also considering concentrations likely to be found in soil in real-world contaminated sites. The Reference Group made the final decisions.

In the cases of nickel and zinc, for which the datasets showed low leachability, the WAC values were chosen to be approximately the same as higher than typical background concentrations found in some geological conditions. This is to allow disposal to Class 3 Managed Fill from contaminated sites that could have such background concentrations.

The resultant WAC for all the contaminants are shown in **Table C-2** as total concentration values in mg/kg.

Table C-2 Class 3 Managed Fill Exposure Scenarios

Contaminant	K_{oc} [1] (L/kg)	Target Leachate Concentrations[2] (mg/L)		Adopted WAC to give Target Leachate (mg/kg)	Limiting pathway
		Groundwater DWSNZ x 20	Aquatic ANZG x 100		
Arsenic	-	0.2	1.3	140	Drinking-water
Cadmium	-	0.08	0.02	10	Low leachability - professional judgement
Chromium	-	1	0.1	150	Aquatic protection
Copper	-	1	0.14	280	Aquatic protection
Lead	-	40	0.34	460	Drinking-water
Mercury	-	0.2	0.06	3	Low leachability - professional judgement
Nickel	-	0.14	1.1	320	Low leachability - professional judgement
Zinc	-	1.6	0.8	1,200	Aquatic protection/professional
TPH C7 – C9[3]	-	-	-	200	BTEX used as proxies
TPH C10 – C14[4]	-	-	-	600	Naphthalene used as proxy - aquatic
Benzene	83	0.2	95	0.11	Drinking-water
Ethylbenzene	1100	6	8	10	Drinking-water
Toluene	302	16	18	19	Drinking-water
Total Xylene	240 [5]	12	21	25	Drinking-water
Benzo(a)pyrene (e.q.)	389,000	0.014	0.02	125	Drinking-water
Dieldrin	21,380	0.0008	0.001	0.10	Drinking-water
Total DDT[6]	2,630,000	0.02	0.001	2.0	Aquatic protection

Notes:
[1] Unless otherwise noted, from USEPA 2020.
[2] Target (lowest) SPLP target shown in bold.
[3] Not calculated using K_{oc} value. Used the BTEX compounds as proxy and TPH - BTEX relationships (PDP 2021)
[4] Not calculated using K_{oc} value. Used naphthalene as proxy and TPH naphthalene relationship (PDP 2021)
[5] Mean value for o-, m- and p-isomers
[6] Total DDT is the six o,p'- and p,p'- isomers of DDT, DDD and DDE

Class 4 Controlled Fills

WAC for Class 4 Controlled Fills are based on total concentrations.

A Class 4 Controlled Fill 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. WAC should therefore be developed for total concentrations that limit the potential for significant adverse effects. These criteria need to be developed in terms of maximum allowable concentrations.

Table C-3 shows the exposure pathways that are limiting based on the exposure assessment outlined above and the resultant criteria. Given the uncertainty inherent within the derivation of guideline values it is proposed that the default national soil background values should be adopted as the minimum concentration at which pragmatic WAC can be established. However, where the next lowest criterion is greater than soil background (i.e., one of soil ecology protection, human health protection for agricultural or rural residential use, drinking-water protection or protection of an aquatic environment) then that is the adopted acceptance criterion.

In evaluating WAC for Class 4 Controlled Fills the ecological receptor values developed by Landcare Research (Landcare 2019) have been employed with the exception of nickel and mercury, for which only older values are available (Cavanagh 2006). No ecological values are available for the BTEX compounds and dieldrin. Where ecological values are limiting and if the local background concentration is greater than the ecological limits, then the local background concentration should be the WAC.

For organic constituents the WAC are based on exposure assessment outlined above. If site-specific criteria are derived, consideration should be given to all the relevant exposure pathways based on **Section C.3** and potential future land uses.

These values are presented as guidance only and should not be adopted over values derived by a site-specific risk assessment that considers all relevant exposure pathways and scenarios.

Table C-3 Class 4 Controlled Fill Exposure Scenarios

	Receptor/ Exposure Scenario					Adopted	Limiting pathway/guideline
	Human health		Ecological receptor	Leaching to Water (Only value for limiting pathway shown)			
	NES rural residential / lifestyle 25% produce	Oil industry agricultural use	Landcare (2019) & Cavanagh (2006)	Groundwater (DWSNZ)	Aquatic Protection (ANZG 2018)		
Arsenic	17	NGV	20	140	-	17	Human health (MfE 2011c) Rural Residential 25% produce
Cadmium	0.8	NGV	1.5	10 (judgement - not calculated)		0.8	Human health (MfE 2011c) Rural Residential 25% produce
Chromium	290	NGV	300	-	150	150	Aquatic (ANZG 2018)
Copper	>10,000	NGV	220	-	280	220	Ecological (Landcare 2019)
Lead	160	NGV	30	460	-	160	Human health (MfE 2011c) Rural Residential 25% produce
Mercury	200	NGV	0.7	3 (judgement – not calculated)		0.7	Ecological (Cavanagh 2006)
Nickel	NGV	NGV	35	32 (judgement – not calculated)		35 or background if higher	Ecological (Cavanagh 2006)
Zinc	NGV	NGV	190	1200 (judgement – not calculated)		190 or background if higher	Ecological (Landcare 2019)
TPH C7 – C9	NGV	120	110	-	600	110	Ecological (Landcare 2019)
TPH C10 – C14	NGV	58	70	NGV	NGV	58	Human health (MfE 2011b)
Benzene	NGV	1.1	NGV	0.11	-	0.11	Human health -DWSNZ

	Receptor/ Exposure Scenario						
	Human health		**Ecological receptor**	**Leaching to Water (Only value for limiting pathway shown)**		**Adopted**	**Limiting pathway/guideline**
	NES rural residential / lifestyle 25% produce	**Oil industry agricultural use**	**Landcare (2019) & Cavanagh (2006)**	**Groundwater (DWSNZ)**	**Aquatic Protection (ANZG 2018)**		
Ethylbenzene	NGV	59	NGV	10	-	10	Human health - DWSNZ
Total Xylene	NGV	59	NGV	25	-	25	Human health –DWSNZ
Benzo(a)pyrene (equivalent*)	6.0	(Superseded by NES)	2.8	54	NGV	2.8	Ecological (Landcare 2018)
Dieldrin	1.1	NGV	NGV	0.2	NGV	0.1	Human health - DWSNZ
Total DDTs	45.0	NGV	1.8	526	26	2	Ecological (Cavanagh 2006)

Class 5 Clean Fills

WAC for Class 5 Clean Fills are based on total concentrations.

Materials placed within a Class 5 Clean Fill are effectively inert and the regional soil background levels for trace elements should be adopted as the basis for acceptance of materials for these sites.

Soil background concentrations are region specific. Where region specific values are not available, soil background concentrations from other regions should NOT be adopted. As a default, national background soil levels numbers are provided where region specific values are not available. These national background soil levels should only be adopted when region specific values are not available. The national background levels are taken as the 99th percentile of the available dataset.

The presence of synthetic organic compounds, which are not naturally occurring and result from anthropogenic sources, are common in natural soils. These synthetic organic compounds can be present at detectable concentrations that do not present a risk to the receiving environment or influence the potential future land use. WAC should therefore provide for the presence of these compounds up to concentrations where there is negligible potential for significant adverse effects as a result of direct contact with the waste or fill material or groundwater in contact with the waste or fill material.

WAC for anthropogenic synthetic organic compounds should only be provided for the most common of these compounds. More persistent, potentially toxic or mobile synthetic organic compound should not be accepted at Class 5 Clean Fills.

WAC are therefore recommended only for the following synthetic organic compounds:

- TPH;
- BTEX;
- PAH; and
- pesticides (DDT).

Waste or fill material containing detectable organic constituents not included in the above list should not be accepted at Class 5 Clean Fills.

For TPH and BTEX, the WAC are conservatively based on the MfE *Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand* (MfE 2011b), known as the ‘Oil Industry Guidelines’, for an agricultural land use “all pathways”. TPH criteria for C_{10}-C_{14} are based on a PAH surrogate, specifically naphthalene, with produce consumption as the limiting pathway.

With respect to DDT, the NES for Assessing and Managing Contaminants in Soil to Protect Human Health Regulations 2011 does not consider ecological receptors. Using the MfE *Contaminated Land Management Guidelines No. 2 - Hierarchy and Application in New Zealand of Environmental Guideline Values* (MfE 2011a) hierarchy, the international risk-based criteria adopted for DDT are those in the Canadian Soil Quality Guidelines for the

Protection of Environmental and Human Health (CCME 1999) ecological receptor pathway for agricultural use.

PAHs as represented by benzo(a)pyrene toxic equivalents (BaP TEQ), are considered ubiquitous as they are a product of incomplete combustion. They are particularly prominent in urban soils due to anthropogenic sources, such as gasoline and diesel exhaust. This is widely recognised internationally and has led to comprehensive studies to identify background levels (DEFRA 2012 and NJDEP 2002). Similarly, there are data for areas within New Zealand that confirm the presence of background levels of PAH's including:

- Background concentrations of PAHs in Christchurch urban soils - Environment Canterbury Report No. R07/19 (Tonkin & Taylor 2007) which determines a BaP TEQ 95% upper confidence limit value of 0.922 mg/kg with a maximum of 4.278 mg/kg.
- Determination of Common Pollutant Background Soils Concentrations for Wellington Region (URS 2003) which determines a BaP (Note: not TEQ values) maximum values across all soil types of 0.33 mg/kg.

Unpublished investigations have also been completed in the Auckland and Waikato regions. The 95th percentile for BaP TEQ in schools and parks within the Waikato region was 4.2 mg/kg.

Based on the available information, an interim value in the absence national soil background values of 2 mg/kg BaP TEQ is proposed as a background level for urban soils where a region's specific value is not available.

Table C-4 summarises the basis for selection of guideline values.

Region specific soil background levels are available for the following regions:

- Auckland
- Waikato
- Wellington
- Canterbury

Table C-4 Class 5 Clean Fill Exposure Scenarios

	Receptor/ Exposure Scenario				
Class 5	**Soil background**	**Human health**	**Ecological receptor**	**Groundwater**	**Aquatic**
Arsenic	Adopted	Not applicable	Not applicable	Not applicable	Not applicable
Cadmium	Adopted	Not applicable	Not applicable	Not applicable	Not applicable
Chromium	Adopted	Not applicable	Not applicable	Not applicable	Not applicable
Copper	Adopted	Not applicable	Not applicable	Not applicable	Not applicable
Lead	Adopted	Not applicable	Not applicable	Not applicable	Not applicable
Mercury	Adopted	Not applicable	Not applicable	Not applicable	Not applicable
Nickel	Adopted	Not applicable	Not applicable	Not applicable	Not applicable
Zinc	Adopted	Not applicable	Not applicable	Not applicable	Not applicable
TPH C7 – C9	Not applicable	MfE Oil agricultural all pathways	NGV	Not limiting	Not limiting
TPH C10 – C14	Not applicable	MfE Oil agricultural all pathways	NGV	Not limiting	Not limiting
Benzene	Not applicable	Not limiting	NGV	MfE Oil GW protection	Not limiting
Ethylbenzene	Not applicable	Not limiting	NGV	MfE Oil GW protection	Not limiting
Toluene	Not applicable	Not limiting	NGV	MfE Oil GW protection	Not limiting
Total Xylene	Not applicable	Not limiting	NGV	MfE Oil GW protection	Not limiting
Benzo(a)pyrene (equivalent*)	Not applicable	Not limiting	CCME	Not limiting	Not limiting
Total DDT	Not applicable	Not limiting	CCME	Not limiting	Not limiting

Note: MfE Oil = *Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand* (MfE 2011b)

C.8 Site Specific WAC

Class 1 - Landfills

WAC for Class 1 Landfills are leachability criteria applied to waste materials.

Wastes that do not comply with the WAC for a Class 1 Landfill should be considered potentially hazardous. Potentially hazardous wastes should be treated to a level which meets the site's WAC. Treatment in this context is intended to include treatment, which recover, breakdown or remove contaminants and methods such as encapsulation, stabilization or blending which reduce leachability of the contaminant to meet WAC.

The derivation of site-specific criteria is not considered appropriate for Class 1 Landfills.

Class 2 C&D Landfills

WAC for Class 2 C&D Landfills are leachability-based criteria.

Wastes that do not comply with the WAC for a Class 2 C&D Landfill should not be accepted without further management. The waste acceptance requirements of any resource consent conditions for a site must be considered in determining the proposed management. The following options are provided as possible approaches for management of these waste materials:

- Wastes should be sent to a Class 1 Landfill if they comply with Class 1 Landfill WAC.
- Waste should be treated to a level which meets the site's WAC. Treatment in this context is intended to include recovery, breakdown or removal of a contaminant and stabilisation or blending to reduce leachability of the contaminant to meet WAC.

Derivation of site-specific criteria at Class 2 C&D Landfills should only be undertaken by a suitably qualified hydrogeologist with experience in contaminant transport and should consider the following:

- Assess all pathways for potential exposure to contaminants within the waste, leachate, air and gas including health and safety risks to site operators in handling the waste and implications on leachate treatability for the site.
- Assess all phases that the contaminant may be present in the waste, such as non-aqueous phase liquids, and assess the potential implications of these phases on the engineered containment of the site (FML and GCL components).
- Derivation of site-specific dilution attenuation factors should NOT assume attenuation or dilution by the total waste mass, ONLY the engineered components of the containment and the underlying geology.
- Derivation of site-specific dilution attenuation factors for leaching from the waste should assume receptors are located at the downgradient extent of the footprint for the fill site.

- Site specific WAC should include limitations on the amount of waste containing the contaminants as a percentage of the total waste stream received at the site. This should typically not exceed 2% of the waste stream.

Class 3 and 4 Fills

WAC for Class 3 and 4 fills should generally be applied as a maximum total concentration (mg/kg) not to be exceeded in any material received at the site. A statistical basis for compliance with WAC may be developed by the site operator. This statistical basis should provide a high level of confidence (99 percentile or higher) that waste complies with the acceptance criteria.

Site specific criteria should be considered for Class 3 and 4 fills if there are site specific factors that will effectively mitigate the potential for significant adverse effects. Specific situations where derivation of site-specific criteria for Class 4 Controlled Fills could be considered are:

- WAC for Class 4 Controlled Fills that are based on the human health exposure pathway may vary based on the land use at the site if it is already constrained. The philosophy with WAC derivation is that possible future land uses are not limited. In the case of urban areas where land has a current commercial industrial use, it is conceivable that the land use could change to more sensitive residential use. It is however unlikely to become agricultural land. The least restrictive land use that should be considered for Class 4 Controlled Fill WAC is therefore residential (10% produce).
- WAC for waste material, within the fill mass, that when placed will not be in direct contact with the water table, or within 2 m of the finished fill surface could consider a revised exposure scenario with respect to human health. However, the groundwater and aquatic pathways in **Table C-3** must be considered as they may be limiting.
- WAC based on leaching pathways may vary if the nearest groundwater supply well or aquatic environment is well away from the fill and/or the geological conditions below the fill are such as to limit migration of contaminants in groundwater. This would include fine-grained soils (silts and clays) with low hydraulic conductivity.

Class 5 Clean Fills

WAC for Class 5 Clean Fills should be applied as a maximum total concentration not to be exceeded in any material received at the site.

There should be no provision for site specific assessment at Class 5 Clean Fills other than to determine region specific soil background for the site.

C.9 References

Australian and New Zealand Environment and Conservation Council (ANZECC). 2000. *Guidelines for Fresh and Marine Water Quality*.

Australian and New Zealand Governments (ANZG). 2018. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.*

Cavanagh J. 2006. *Development of Soil Guideline Values Protective of Ecological Receptors in the Auckland Region:* Parts 1 and 2 Landcare Research Contract Reports LC0506/065 and LC0506/179, Prepared for Auckland Regional Council.

Department for Environment, Food & Rural Affairs (DEFRA). 2012. British Geological Survey Part 2A, *Environmental Protection Act Technical Guidance Sheet (TGS) on normal levels of contaminants in English Soils*, July.

Landcare. 2019. *Updated Development of soil guideline values for the protection of ecological receptors (eco-SGVs*). Contract Report: LC3509 prepared for Gisborne District Council, Envirolink Tools Grant: C09X1402, Landcare Research Limited, June 2019.

MoH. 2018. *Drinking Water Standards for New Zealand 2005* (Revised 2018), Ministry of Health, Wellington.

MfE. 2011a. *Contaminated Land Management Guidelines No. 2 - Hierarchy and Application in New Zealand of Environmental Guideline Values* (2003, Revised 2011), Wellington.

MfE. 2011b. *Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand* (1999, revised 2011), Wellington.

MfE. 2011c. *Methodology for Deriving Standards for Contaminants in Soil to Protect Human Health*, Wellington.

New Jersey Department of Environmental Protection (NJDEP). 2002. Characterisation of Ambient Levels of Selected Metals and CPAH's in New Jersey Soils.

PDP. 2021. *Derivation of Class 3 and 4 Landfill Waste Acceptance Criteria*. Report prepared for the Ministry for the Environment, Pattle Delamore Partners Limited, Wellington, June 2021.

Tonkin & Taylor. 2007. "Background Concentrations of Polycyclic Aromatic Hydrocarbons in Christchurch Urban Soils" Report No. R07/19 for Environment Canterbury.

URS New Zealand. 2003. Determination of Common Pollutant Background Soils Concentrations for Wellington Region.

USEPA. 1996. *Soil Screening Guidance: Technical Background Document*, Second Edition. EPA/540/R-95/128, May.

USEPA. 1997. *Identification and Listing of Hazardous Waste* Title 40, Part 261, Code of Federal Regulations. 40 CFR §261.24.

USEPA. 2020. “CompTox Chemistry Dashboard”. Accessed June 2020. https://comptox.epa.gov/dashboard

World Health Organization. 2017. Guidelines for drinking-water quality: fourth edition incorporating the first addendum, Geneva.

Appendix D Class 1 Landfill Waste Acceptance Criteria (WAC)

For Class 1 Landfills, leachability testing should be completed to provide assurance that waste materials meet the following recommended WAC. The WAC leachability limits represent maximum values which should not be exceeded and should be viewed as a minimum treatment specification for a landfill.

If the following limits are exceeded by a leachate extract of the waste with respect to any of the listed constituents, then the material is not suitable for disposal to the facility.

Table D-1 Class 1 WAC for Inorganic and Organic Elements

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Source
Inorganics			
Aluminium	mg/L	40	Module 2: Hazardous Waste Guidelines (MfE 2004)
Antimony	mg/L	0.6	Module 2: Hazardous Waste Guidelines (MfE 2004)
Arsenic	mg/L	5	USEPA Chapter 40 CFR
Barium	mg/L	100	USEPA Chapter 40 CFR
Beryllium	mg/L	10	Module 2: Hazardous Waste Guidelines (MfE 2004)
Boron	mg/L	20	Module 2: Hazardous Waste Guidelines (MfE 2004)
Cadmium	mg/L	1	USEPA Chapter 40 CFR
Chromium	mg/L	5	USEPA Chapter 40 CFR
Copper	mg/L	5	Module 2: Hazardous Waste Guidelines (MfE 2004)
Cyanides	mg/L	50	USEPA Chapter 40 CFR
Fluoride	mg/L	200	Module 2: Hazardous Waste Guidelines (MfE 2004)
Lead	mg/L	5	USEPA Chapter 40 CFR
Lithium	mg/L	20	Module 2: Hazardous Waste Guidelines (MfE 2004)
Mercury	mg/L	0.2	USEPA Chapter 40 CFR
Molybdenum	mg/L	10	Module 2: Hazardous Waste Guidelines (MfE 2004)

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Source
Nickel	mg/L	10	Module 2: Hazardous Waste Guidelines (MfE 2004)
Selenium	mg/L	1	USEPA Chapter 40 CFR
Silver	mg/L	5	USEPA Chapter 40 CFR
Sulphides	mg/L	50	USEPA Chapter 40 CFR
Tin	mg/L	1000	Module 2: Hazardous Waste Guidelines (MfE 2004)
Vanadium	mg/L	2	Module 2: Hazardous Waste Guidelines (MfE 2004)
Zinc	mg/L	10	Module 2: Hazardous Waste Guidelines (MfE 2004)
Organics			
1,1,1 Trichloroethane	mg/L	200	Module 2: Hazardous Waste Guidelines (MfE 2004)
1,1,2 Trichloroethane	mg/L	500	Module 2: Hazardous Waste Guidelines (MfE 2004)
1,1,2,2 Tetrachloroethane	mg/L	50	Module 2: Hazardous Waste Guidelines (MfE 2004)
1,1-Dichloroethylene	mg/L	0.7	USEPA Chapter 40 CFR
1,2 Dibromo-3-chloropropane	mg/L	0.2	Module 2: Hazardous Waste Guidelines (MfE 2004)
1,2 Dichlorobenzene	mg/L	0.2	Module 2: Hazardous Waste Guidelines (MfE 2004)
1,2 Dichloroethene	mg/L	10	Module 2: Hazardous Waste Guidelines (MfE 2004)
1,2 Dichloropropane	mg/L	1	Module 2: Hazardous Waste Guidelines (MfE 2004)
1,2-Dichloroethane	mg/L	0.5	USEPA Chapter 40 CFR
1,3 Dichloropropene	mg/L	2	Module 2: Hazardous Waste Guidelines (MfE 2004)
1,4-Dichlorobenzene	mg/L	7.5	USEPA Chapter 40 CFR
2 Chlorophenol	mg/L	0.05	Module 2: Hazardous Waste Guidelines (MfE 2004)
2,4 Dichlorophenol	mg/L	0.05	Module 2: Hazardous Waste Guidelines (MfE 2004)
2,4,5-Trichlorophenol	mg/L	400	USEPA Chapter 40 CFR

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Source
2,4,5-Trichlorophenoxypropionic acid	mg/L	1	USEPA Chapter 40 CFR
2,4,6-Trichlorophenol	mg/L	2	USEPA Chapter 40 CFR
2,4-Dichlorophenoxyacetic acid	mg/L	10	USEPA Chapter 40 CFR
2,4-Dinitrotoluene	mg/L	0.13	USEPA Chapter 40 CFR
Aniline	mg/L	0.2	Module 2: Hazardous Waste Guidelines (MfE 2004)
Benzene	mg/L	0.5	USEPA Chapter 40 CFR
Bromodichloromethane	mg/L	1	Module 2: Hazardous Waste Guidelines (MfE 2004)
Bromoform	mg/L	10	Module 2: Hazardous Waste Guidelines (MfE 2004)
Carbon disulphide	mg/L	3	Module 2: Hazardous Waste Guidelines (MfE 2004)
Carbon Tetrachloride	mg/L	0.5	USEPA Chapter 40 CFR
Chlordane	mg/L	0.03	USEPA Chapter 40 CFR
Chlorobenzene	mg/L	100	USEPA Chapter 40 CFR
Chloroform	mg/L	6	USEPA Chapter 40 CFR
Dibromochloromethane	mg/L	10	Module 2: Hazardous Waste Guidelines (MfE 2004)
Dichloromethane	mg/L	2	Module 2: Hazardous Waste Guidelines (MfE 2004)
Diethylphthalate	mg/L	100	Module 2: Hazardous Waste Guidelines (MfE 2004)
Dimethylphthalate	mg/L	400	Module 2: Hazardous Waste Guidelines (MfE 2004)
Endrin	mg/L	0.02	USEPA Chapter 40 CFR
Ethyl benzene	mg/L	50	Module 2: Hazardous Waste Guidelines (MfE 2004)
Heptachlor	mg/L	0.008	USEPA Chapter 40 CFR
Hexachloro – 1,3-butadiene	mg/L	0.5	USEPA Chapter 40 CFR
Hexachlorobenzene	mg/L	0.13	USEPA Chapter 40 CFR
Hexachloroethane	mg/L	3	USEPA Chapter 40 CFR

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Source
Lindane	mg/L	0.4	USEPA Chapter 40 CFR
m-Cresol	mg/L	200	USEPA Chapter 40 CFR
Methoxychlor	mg/L	10	USEPA Chapter 40 CFR
Methyl ethyl ketone	mg/L	200	USEPA Chapter 40 CFR
Naphthalene	mg/L	10	Module 2: Hazardous Waste Guidelines (MfE 2004)
Nitrobenzene	mg/L	2	USEPA Chapter 40 CFR
o-Cresol	mg/L	200	USEPA Chapter 40 CFR
p-Cresol	mg/L	200	USEPA Chapter 40 CFR
Pentachlorophenol	mg/L	100	USEPA Chapter 40 CFR
Phenol	mg/L	40	Module 2: Hazardous Waste Guidelines (MfE 2004)
Polychlorinated biphenyls	mg/L	50	USEPA Chapter 40 CFR
Pyridine	mg/L	5	USEPA Chapter 40 CFR
Tetrachloroethylene	mg/L	0.7	USEPA Chapter 40 CFR
Toluene	mg/L	100	Module 2: Hazardous Waste Guidelines (MfE 2004)
Total cresol	mg/L	200	USEPA Chapter 40 CFR
Total halogenated compounds	mg/L	1000	USEPA Chapter 40 CFR
Total synthetic non-halogenated compounds	mg/L	10000	USEPA Chapter 40 CFR
Toxaphene	mg/L	0.5	USEPA Chapter 40 CFR
Tributyltin oxide	mg/L	3	Module 2: Hazardous Waste Guidelines (MfE 2004)
Trichloroethylene	mg/L	0.7	USEPA Chapter 40 CFR
Vinyl chloride	mg/L	0.2	USEPA Chapter 40 CFR
Xylene (m,o,p)	mg/L	100	Module 2: Hazardous Waste Guidelines (MfE 2004)

Appendix E Class 2 C&D Landfill Waste Acceptance Criteria (WAC)

For Class 2 C&D Landfills, leachability testing should be completed to provide assurance that waste materials meet the following recommended WAC. The WAC leachability limits represent maximum values which should not be exceeded and should be viewed as a minimum treatment specification for a landfill. The total concentration is the threshold level at which TCLP testing should be required. Total concentrations below this level cannot exceed the TCLP criteria.

If the following limits are exceeded by a leachate extract of the waste with respect to any of the listed constituents, then the material is not suitable for disposal to the facility.

Table E-1 Class 2 C&D Landfill WAC for Inorganic and Organic Elements[8]

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Unit	Total concentration above which TCLP tests required
Inorganics				
Aluminium	mg/L	4	mg/kg	80
Antimony	mg/L	0.06	mg/kg	1.2
Arsenic	mg/L	1	mg/kg	20
Barium	mg/L	20	mg/kg	400
Beryllium	mg/L	1	mg/kg	20
Boron	mg/L	2	mg/kg	40
Cadmium	mg/L	0.2	mg/kg	4
Chromium	mg/L	1	mg/kg	20
Copper	mg/L	0.5	mg/kg	10
Cyanides	mg/L	10	mg/kg	NA
Fluoride	mg/L	20	mg/kg	400
Lead	mg/L	1	mg/kg	20
Lithium	mg/L	2	mg/kg	40
Mercury	mg/L	0.04	mg/kg	0.8
Molybdenum	mg/L	1	mg/kg	20

---

[8] Module 2: Hazardous Waste Guidelines (MfE, 2004)

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Unit	Total concentration above which TCLP tests required
Nickel	mg/L	1	mg/kg	20
Selenium	mg/L	0.2	mg/kg	40
Silver	mg/L	1	mg/kg	20
Sulfides	mg/L	10	mg/kg	NA
Tin	mg/L	100	mg/kg	2000
Vanadium	mg/L	0.2	mg/kg	4
Zinc	mg/L	1	mg/kg	20
Organic Compounds				
1,1,2 Trichloroethane	mg/L	50	mg/kg	1000
1,1,2,2 Tetrachloroethane	mg/L	5	mg/kg	100
1,1-Dichloroethylene	mg/L	0.07	mg/kg	1.4
1,2 Dibromo-3- chloropropane	mg/L	0.02	mg/kg	0.4
1,2 Dichlorobenzene	mg/L	0.02	mg/kg	0.4
1,2 Dichloroethene	mg/L	1	mg/kg	20
1,2 Dichloropropane	mg/L	0.1	mg/kg	2
1,2-Dichloroethane	mg/L	0.05	mg/kg	1
1,3 Dichloropropene	mg/L	0.2	mg/kg	4
1,4-Dichlorobenzene	mg/L	0.75	mg/kg	15
2 Chlorophenol	mg/L	0.005	mg/kg	0.1
2,4 Dichlorophenol	mg/L	0.005	mg/kg	0.1
2,4,5-Trichlorophenol	mg/L	40	mg/kg	800
2,4,5-Trichlorophenoxy-propionic acid	mg/L	0.1	mg/kg	2
2,4,6-Trichlorophenol	mg/L	0.2	mg/kg	4
2,4-Dichlorophenoxyacetic acid	mg/L	1	mg/kg	20
2,4-Dinitrotoluene	mg/L	0.013	mg/kg	0.26
Aniline	mg/L	0.02	mg/kg	0.4
Benzene	mg/L	0.05	mg/kg	1
Bromodichloromethane	mg/L	0.1	mg/kg	2
Bromoform	mg/L	1	mg/kg	20
Carbon disulphide	mg/L	0.3	mg/kg	6

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Unit	Total concentration above which TCLP tests required
Carbon Tetrachloride	mg/L	0.05	mg/kg	1
Chlordane	mg/L	0.003	mg/kg	0.06
Chlorobenzene	mg/L	10	mg/kg	200
Chloroform	mg/L	0.6	mg/kg	12
Dibromochloromethane	mg/L	1	mg/kg	20
Dichloromethane	mg/L	0.2	mg/kg	4
Diethylphthalate	mg/L	10	mg/kg	200
Dimethylphthalate	mg/L	40	mg/kg	800
Endrin	mg/L	0.002	mg/kg	0.04
Ethyl benzene	mg/L	5	mg/kg	100
Heptachlor	mg/L	0.0008	mg/kg	0.016
Hexachloro – 1,3- Butadiene	mg/L	0.05	mg/kg	1
Hexachlorobenzene	mg/L	0.013	mg/kg	0.26
Hexachloroethane	mg/L	0.3	mg/kg	6
Lindane	mg/L	0.08	mg/kg	1.6
m-Cresol	mg/L	20	mg/kg	400
Methoxychlor	mg/L	1	mg/kg	20
Methyl ethyl ketone	mg/L	20	mg/kg	400
Naphthalene	mg/L	1	mg/kg	20
Nitrobenzene	mg/L	0.2	mg/kg	4
o-Cresol	mg/L	20	mg/kg	400
p-Cresol	mg/L	20	mg/kg	400
Pentachlorophenol	mg/L	10	mg/kg	200
Phenol	mg/L	4	mg/kg	80
Polychlorinated biphenyls	mg/L	5	mg/kg	NA
Pyridine	mg/L	0.5	mg/kg	10
Tetrachloroethylene	mg/L	0.07	mg/kg	1.4
Toluene	mg/L	10	mg/kg	200
Total cresol	mg/L	20	mg/kg	400
Total halogenated compounds	mg/L	100	mg/kg	NA
Total synthetic non-halogenated compounds	mg/L	1000	mg/kg	NA

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Unit	Total concentration above which TCLP tests required
Toxaphene	mg/L	0.05	mg/kg	1
Tributyltin oxide	mg/L	0.3	mg/kg	6
Trichloroethylene	mg/L	0.07	mg/kg	1.4
Vinyl chloride	mg/L	0.02	mg/kg	0.4
Xylene (m,o,p)	mg/L	10	mg/kg	200

Note: NA = not applicable

Appendix F Class 3 Managed Fill Waste Acceptance Criteria (WAC)

Table F-1 Class 3 Managed Fill WAC for Inorganic and Organic Elements

Contaminant of concern	Unit	Maximum allowable total concentration
Arsenic	mg/kg	140[a]
Cadmium	mg/kg	10[b]
Chromium	mg/kg	150[c]
Copper	mg/kg	280[c]
Lead	mg/kg	460[a]
Mercury	mg/kg	3[b]
Nickel	mg/kg	320[b]
Zinc	mg/kg	1,200[b]
TPH C7 – C9	mg/kg	200[d]
TPH C10 – C14	mg/kg	600[d]
Benzene	mg/kg	0.11[c]
Ethylbenzene	mg/kg	10[c]
Toluene	mg/kg	19[c]
Total Xylene	mg/kg	25[c]
Benzo(a)pyrene* (equivalent*)	mg/kg	125[a]
Dieldrin	mg/kg	0.10[a]
Total DDTs**	mg/kg	2.0[c]

Notes: * For benzo(a)pyrene, the equivalent BaP concentration is calculated as the sum of each of the detected concentrations of nine carcinogenic PAHs (benzo(a)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and indeno(1,2,3-cd) pyrene), multiplied by their respective potency equivalency factors.

** Sum of six o,p'- and p,p'- isomers of DDT, DDD and DDE

[a] Drinking-water pathway limiting using DWSNZ (2018)

[b] Not calculated – professional judgement

[c] Aquatic protection pathway limiting using ANZG (2018) Guidelines for Fresh and Marine Water Quality.

[d] Aquatic pathway limiting using proxy compounds.

Appendix G Class 4 Controlled Fill Waste Acceptance Criteria (WAC)

Table G-1 Class 4 Controlled Fill WAC for Inorganic and Organic Elements

Contaminant of concern	Unit	Maximum allowable total concentration
Arsenic	mg/kg	17[a]
Cadmium	mg/kg	0.8[a]
Chromium	mg/kg	150[b]
Copper	mg/kg	220[c]
Lead	mg/kg	160[c]
Inorganic Mercury	mg/kg	0.7[d]
Nickel	mg/kg	35[d]
Zinc	mg/kg	190[c]
TPH C7 – C9	mg/kg	110[d]
TPH C10 – C14	mg/kg	58[e]
Benzene	mg/kg	0.11[f]
Ethylbenzene	mg/kg	10[f]
Toluene	mg/kg	19[f]
Total Xylene	mg/kg	25[f]
Benzo(a)pyrene (equivalent*)	mg/kg	2.8[c]
Dieldrin	mg/kg	0.1[f]
Total DDTs**	mg/kg	2

Note: * For benzo(a)pyrene, the equivalent BaP concentration is calculated as the sum of each of the detected concentrations of nine carcinogenic PAHs (benzo(a)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and indeno(1,2,3-cd) pyrene), multiplied by their respective potency equivalency factors.

** Sum of six o,p'- and p,p'- isomers of DDT, DDD and DDE

[a] From MfE (2011c) Table ES1 Summary of soil contaminant standards – SCSs(health) – for inorganic substances, rural residential/lifestyle block 25 % produce.

[b] Aquatic protection pathway limiting using ANZG (2018) Guidelines for Fresh and Marine Water Quality.

[c] Based on Landcare (2019) ecological receptor values

[d] Based on J Cavanagh (2006) ecological receptor values.

[e] Derived from MfE (2011b) Table 4.13 Tier 1 soil acceptance criteria for TPH, agricultural use, all pathways.

[f] Groundwater as drinking-water pathway limiting using DWSNZ (2018) MAV values.

Appendix H Class 5 Clean Fill Waste Acceptance Criteria (WAC)

Table H-1 Class 5 - Examples of Regional Background Concentrations for Key Inorganic Elements

Contaminant of concern	Unit (total recoverable)	Default National Soil Background	Auckland Council		Greater Wellington				
			Non-volcanic soil type	Volcanic soil type	Sand soil type	Greywacke soil type	Hutt alluvium soil type	Wairarapa alluvium soil type	Mudstone/ siltstone soil type
Arsenic	mg/kg	17[a]	12	12	7	7	7	7	4
Boron	mg/kg	NA	45	260	2.1	2.2	1.6	2.7	2.6
Cadmium	mg/kg	0.65[a]	0.65	0.65	0.1	0.1	0.2	0.2	0.2
Chromium	mg/kg	NA	55	125	12	16	18	21	15
Copper	mg/kg	NA	45	90	10	25	19	19	19
Lead	mg/kg	NA	65	65	180	78.6	73.3	34	38.1
Mercury	mg/kg	NA	0.45	0.45	0.1	0.2	2.6	0.1	0.1
Nickel	mg/kg	NA	35	320	9	13	14	21	13
Zinc	mg/kg	NA	180	1160	79	105	201	121	72

Note: NA – Not available

[a] MfE Methodology for Deriving Standards for Contaminants in Soil to Protect Human Health (2011) Appendix 6 Natural Background Topsoil Datasets for Arsenic and Cadmium

Table H-2 Class 5 WAC for Organic Elements

Contaminant of concern	Unit	Maximum allowable total
TPH C7 – C9	mg/kg	110
TPH C10 – C14	mg/kg	58[a]
Benzene	mg/kg	0.0054[b]
Ethylbenzene	mg/kg	1.1[b]
Toluene	mg/kg	1.0[b]
Total Xylene	mg/kg	0.61[b]
Benzo(a)pyrene	mg/kg	Interim = 2[c]
Total DDT	mg/kg	0.7[d]

Notes: * For benzo(a)pyrene, the equivalent BaP concentration is calculated as the sum of each of the detected concentrations of nine carcinogenic PAHs (benzo(a)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and indeno(1,2,3-cd) pyrene), multiplied by their respective potency equivalency factors.

[a] Derived from MfE Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand 1999, revised 2011. Table 4.15 Tier 1 soil acceptance criteria for TPH, residential use, 'all pathways' agricultural use.

[b] Derived from MfE Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand 1999, revised 2011. Table 4.2 Soil acceptance criteria for protection of groundwater quality (clay).

[c] TBD National soil background to be determined.

[d] USEPA (2006) ecological receptors.

Appendix I Prohibited Wastes

Numbering and terminology used are generally consistent with the ANZECC classification system and refer in the first instance to untreated wastes. As the system contains both waste types and constituents, more than one category may be applicable to a particular waste and therefore all categories need to be checked to determine whether landfill disposal may be appropriate.

I.1 Waste Prohibited at All Landfills/Fills (Class 1, 2, 3, 4 or 5)

Table I-1 Prohibited Waste Characteristics

Waste code	Waste description
H1	Explosives
H2	Gases
H3	Flammable liquids
H4.1	Flammable solids
H4.2	Substances or wastes liable to spontaneous combustion
H5.1	Oxidising substances
H5.2	Organic peroxides
H6.2	Infectious substances
H7	Radioactive materials
H8	Corrosives
H10	Liberation of toxic gases in contact with air or water
H13	Capable, by any means after disposal, of yielding another material i.e., leachate which possesses any of the above characteristics

Table I-2 Waste Types which may Exhibit the above Characteristics

Waste code	Waste description
Cyanides, surface treatment and heat treatment	
A100	Cyanide containing waste from treatment of metals
A110	Cyanide containing waste
A120	Complexed cyanides
A130	Other cyanides

Waste code	Waste description
Acids	
B100	Sulfuric acid
B110	Hydrochloric acid
B120	Nitric acid
B130	Phosphoric acid
B140	Chromic acid
B150	Hydrofluoric acid
B160	Sulfuric/hydrochloric acid mixtures
B170	Other mixed acids
B180	Organic acids
Alkalis	
C100	Caustic soda, potash, alkaline cleaners
C110	Ammonium hydroxide
C140	Other (hazardous substances must be specified)
Inorganic chemicals	
D100	Metal carbonyls
D120	Mercury
D280	Alkali metals
D330	Sulphur
Reactive chemicals	
E100	Oxidising agents
E110	Reducing agents
E120	Explosives
E130	Highly reactive chemicals
Paints, lacquers, varnishes, inks, dyes, pigments, adhesives	
F200	Uncured adhesives or resins
Organic solvents	
G100	Ethers
G110	Non-halogenated (FP>61°C), n.o.s
G130	Halogenated (FP>61°C), n.o.s
G140	Halogenated (FP>61°C), n.o.s
G150	Halogenated n.o.s

Waste code	Waste description
G160	Wastes from the production and formulation of organic solvents
G180	Others (hazardous substances must be specified)
Pesticides	
H100	Inorganic, organometallic pesticides
H110	Organophosphorus pesticides
H180	Organic wood preserving compounds
H120	Nitrogen-containing pesticides
H130	Halogen-containing pesticides
H140	Sulphur-containing pesticides
H150	Mixed pesticide residues
H160	Copper-chrome-arsenic
H170	Other inorganic wood preserving compounds
Oils, hydrocarbons, emulsions	
J100	Waste mineral oils unfit for their original intended use (lubricating, hydraulic)
J110	Waste hydrocarbons
J120	Waste oils/water, hydrocarbon/water mixtures, emulsions (mainly oil and or hydrocarbons, i.e., >50%)
J130	Waste oils/water, hydrocarbon/water mixtures, emulsions (mainly water, i.e., >50%)
J140	Transformer fluids (excluding polychlorinated biphenyls [PCBs])
J150	Other (cutting, soluble oils)
J160	Tars and tarry residues (including tarry residues arising from refining)
Putrescible, organic wastes	
K100	Liquid animal effluent (poultry and fish processing)
K150	Liquid vegetable oils and derivatives
K170	Liquid animal oils and derivatives
K180	Abattoir effluent
K200	Food processing effluent
Industrial washwaters, effluents	
L100	Truck, machinery washwaters with or without detergents
L101	Car wash waters with or without detergents
L120	Cooling tower washwater
L130	Fire wastewaters

Waste code	Waste description
L140	Textile effluent
L150	Other industrial plant washdown water
Organic chemicals	
M100	PCBs and/or polyterphenyl (PCTs) and/or polybrominated biphenyls (PBBs)
M110	Equipment containing PCBs and/or PCTs and/or PBBs
M120	Solvents and materials contaminated with PCBs and/or PCTs and/or PBBs
M150	Phenols, phenol derivatives including chlorophenols
M160	Halogenated compounds n.o.s.
M170	Any congener of poly-chlorinated dibenzofuran
M180	Any congener of poly-chlorinated dibenzo-p- dioxin
M210	Organic cyanides
M250	Liquid surfactants and detergents
Chemical and pharmaceutical wastes	
R100	Infectious substances
R110	Pathogenic substances
R130	Cytotoxic substances
Miscellaneous	
T100	Waste chemical substances arising from research and development or teaching activities, which are not identified

I.2 Waste Possibly Suitable for Class 1 Landfill Disposal – Solids and Sludges

Table I-3 Characteristics of Wastes Possibly Suitable for Class 1 Landfill Disposal

Waste code	Waste description
H6.1	Poisonous substances
H11	Toxic substances (chromic or delayed effects)
H12	Eco-toxic

Table I-4 Waste Types which may Exhibit the Characteristics of Wastes Possibly Suitable for Class 1 Landfill Disposal

Waste code	Waste description
Alkalis	
C120	Waste lime and cement
C130	Lime/caustic neutralised wastes containing metallic constituents
Inorganic chemicals	
D110	Inorganic fluoride compounds
D120	Mercury compounds
D121	Equipment and articles containing mercury
D130	Arsenic, arsenic compounds
D140	Chromium, chromium compounds
D141	Tannery wastes containing chromium
D150	Cadmium, cadmium compounds
D160	Beryllium, beryllium compounds
D170	Antimony, antimony compounds
D180	Thallium, thallium compounds
D190	Copper compounds
D200	Cobalt, cobalt compounds
D210	Nickel, nickel compounds
D220	Lead, lead compounds
D230	Zinc compounds
D240	Selenium, selenium compounds
D250	Tellurium, tellurium compounds
D260	Silver compounds
D261	Photographic waste containing silver
D270	Vanadium, vanadium compounds
D280	Alkali metal containing compounds
D290	Barium, barium compounds
D310	Boron, boron compounds
D320	Inorganic non-metallic phosphorus compounds
D330	Inorganic sulphur containing compounds
D340	Other inorganic compounds and complexes

Waste code	Waste description
Putrescible, organic wastes	
K100	Animal residues (poultry and fish processing wastes)
K101	Scallop processing residues
K120	Grease interceptor trap waste – domestic
K130	Bacterial sludge (septic tank)
K132	Sewage sludge and residues
K140	Tannery wastes not containing chromium
K150	Vegetable oil derivatives
K160	Vegetable wastes
K170	Animal oil derivatives (e.g., tallow)
K180	Abattoir residues
K190	Wool scouring wastes
Organic Chemicals	
M130	Non-halogenated (non-solvent) n.o.s.
M140	Heterocyclic organic compounds
M190	Organic phosphorus compounds
M200	Organic sulphur compounds
M220	Organic isocyanates
M230	Amines and other nitrogen compounds (aliphatic)
M240	Amines and other nitrogen compounds (aromatic)
M260	Highly odorous (e.g., mercaptans, acrylate)
M270	Methacrylate compounds
M280	Other
Solid/sludge requiring special handling	
N100	Drums which have contained hazardous substances (and which have been triple rinsed)
N110	Containers and bags which have contained hazardous substances (hazardous substances must be specified)
N120	Contaminated soils (hazardous substances must be specified)
N130	Spent catalysts (contaminants must be specified)
N140	Fire debris
N150	Fly ash
N160	Encapsulated wastes

Waste code	Waste description
N170	Chemically fixed wastes
N180	Solidified or polymerised wastes
N190	Ion-exchange column residues
N200	Industrial waste treatment sludges and residues n.o.s.
N210	Residues from pollution control operations
N220	Asbestos (refer to the Management and Removal of Asbestos Approved Code of Practice, WorkSafe New Zealand 2016)
N230	Synthetic mineral fibres
Clinical and pharmaceutical wastes	
R120	Pharmaceutical and residues
R140	Wastes from the production and preparation of pharmaceutical
Miscellaneous	
T120	Scrubber sludge
T130	Photographic chemicals which do not contain silver
T140	Inert sludges/slurries (e.g., clay, ceramic suspensions)
T150	Used tyres/tyre wastes
T190	Other (hazardous substances must be specified)

Appendix J Hazardous Activities and Industries List

A. Chemical manufacture, application and bulk storage

1. Agrichemicals including commercial premises used by spray contractors for filling, storing or washing out tanks for agrichemical application
2. Chemical manufacture, formulation or bulk storage
3. Commercial analytical laboratory sites
4. Corrosives including formulation or bulk storage
5. Dry-cleaning plants including dry-cleaning premises or the bulk storage of dry-cleaning solvents
6. Fertiliser manufacture or bulk storage
7. Gasworks including the manufacture of gas from coal or oil feedstocks
8. Livestock dip or spray race operations
9. Paint manufacture or formulation (excluding retail paint stores)
10. Persistent pesticide bulk storage or use including sport turfs, market gardens, orchards, glass houses or spray sheds
11. Pest control including the premises of commercial pest control operators or any authorities that carry out pest control where bulk storage or preparation of pesticide occurs, including preparation of poisoned baits or filling or washing of tanks for pesticide application
12. Pesticide manufacture (including animal poisons, insecticides, fungicides or herbicides) including the commercial manufacturing, blending, mixing or formulating of pesticides
13. Petroleum or petrochemical industries including a petroleum depot, terminal, blending plant or refinery, or facilities for recovery, reprocessing or recycling petroleum-based materials, or bulk storage of petroleum or petrochemicals above or below ground
14. Pharmaceutical manufacture including the commercial manufacture, blending, mixing or formulation of pharmaceuticals, including animal remedies or the manufacturing of illicit drugs with the potential for environmental discharges
15. Printing including commercial printing using metal type, inks, dyes, or solvents (excluding photocopy shops)
16. Skin or wool processing including a tannery or fellmongery, or any other commercial facility for hide curing, drying, scouring or finishing or storing wool or leather products
17. Storage tanks or drums for fuel, chemicals or liquid waste
18. Wood treatment or preservation including the commercial use of anti-sapstain chemicals during milling, or bulk storage of treated timber outside

B. Electrical and electronic works, power generation and transmission

1. Batteries including the commercial assembling, disassembling, manufacturing or recycling of batteries (but excluding retail battery stores)

2. Electrical transformers including the manufacturing, repairing or disposing of electrical transformers or other heavy electrical equipment
3. Electronics including the commercial manufacturing, reconditioning or recycling of computers, televisions and other electronic devices
4. Power stations, substations or switchyards

C. **Explosives and ordinances production, storage and use**

1. Explosive or ordinance production, maintenance, dismantling, disposal, bulk storage or re-packaging
2. Gun clubs or rifle ranges, including clay targets clubs that use lead munitions outdoors
3. Training areas set aside exclusively or primarily for the detonation of explosive ammunition

D. **Metal extraction, refining and reprocessing, storage and use**

1. Abrasive blasting including abrasive blast cleaning (excluding cleaning carried out in fully enclosed booths) or the disposal of abrasive blasting material
2. Foundry operations including the commercial production of metal products by injecting or pouring molten metal into moulds
3. Metal treatment or coating including polishing, anodising, galvanising, pickling, electroplating, or heat treatment or finishing using cyanide compounds
4. Metalliferous ore processing including the chemical or physical extraction of metals, including smelting, refining, fusing or refining metals
5. Engineering workshops with metal fabrication

E. **Mineral extraction, refining and reprocessing, storage and use**

1. Asbestos products manufacture or disposal including sites with buildings containing asbestos products known to be in a deteriorated condition
2. Asphalt or bitumen manufacture or bulk storage (excluding single-use sites used by a mobile asphalt plant)
3. Cement or lime manufacture using a kiln including the storage of wastes from the manufacturing process
4. Commercial concrete manufacture or commercial cement storage
5. Coal or coke yards
6. Hydrocarbon exploration or production including well sites or flare pits
7. Mining industries (excluding gravel extraction) including exposure of faces or release of groundwater containing hazardous contaminants, or the storage of hazardous wastes including waste dumps or dam tailings

F. **Vehicle refuelling, service and repair**

1. Airports including fuel storage, workshops, washdown areas, or fire practice areas
2. Brake lining manufacturers, repairers or recyclers
3. Engine reconditioning workshops
4. Motor vehicle workshops
5. Port activities including dry docks or marine vessel maintenance facilities

6. Railway yards including goods-handling yards, workshops, refuelling facilities or maintenance areas
7. Service stations including retail or commercial refuelling facilities
8. Transport depots or yards including areas used for refuelling or the bulk storage of hazardous substances

G. **Cemeteries and waste recycling, treatment and disposal**

1. Cemeteries
2. Drum or tank reconditioning or recycling
3. Landfill sites
4. Scrap yards including automotive dismantling, wrecking or scrap metal yards
5. Waste disposal to land (excluding where biosolids have been used as soil conditioners)
6. Waste recycling or waste or wastewater treatment

H. **Any land that has been subject to the migration of hazardous substances from adjacent land in sufficient quantity that it could be a risk to human health or the environment**

I. **Any other land that has been subject to the intentional or accidental release of a hazardous substance in sufficient quantity that it could be a risk to human health or the environment**

Appendix K Landfill Monitoring

K.1 Scope of Monitoring

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

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

This section discusses the various aspects of the monitoring programmes and the scope of monitoring required.

Monitoring

The monitoring programme will generally involve the following focus areas, with the detail of monitoring dependent upon the class and size of the landfill/fill and the surrounding environment.

- **Leachate**. Understanding the character of the leachate will enable the appropriate interpretation of potential risks which the discharge of the leachate may have on the receiving environment. Certain parameters are generally present in leachate, but the relative concentrations of these parameters will vary depending on the nature of the waste and the age of the landfill/fill. In a landfill/fill with an engineered liner and leachate collection system, the leachate can generally be sampled directly. This is the most appropriate location at which to test for trace toxicants, as they will be present here at the highest concentrations and hence are more likely to be detected in the leachate itself. In landfills/fills without such systems, the leachate may need to be sampled via bores, after it has mixed with the underlying groundwater.
- **Stormwater**. Stormwater is rainfall which has fallen onto the landfill/fill and is shed. Generally, stormwater that falls on the active areas of the landfill/fill and hence is potentially contaminated by waste is managed with the leachate. Rainfall on peripheral and closed areas of the landfill/fill is generally considered to be uncontaminated but may contain sediment which requires management. An understanding of the stormwater catchment area of each landfill/fill site activity will identify the nature of the potential contamination which should be monitored. It should be noted that leachate seeps can result in the stormwater network receiving leachate, and the potential for this to occur should be assessed.
- **Gas**. Landfills receiving organic waste produce landfill gas, which may constitute a hazard and can migrate off site. This migration of gas and its spatial pattern and concentration will need to be monitored. Larger landfills may have a landfill gas

collection system, via which the composition of the gas can be monitored. However, the migration of the gas needs to be monitored through other means as discussed in **Section 8.10**.

- **Groundwater**. Leakage from a fully engineered lined landfill/fill may occur, resulting in a discharge into groundwater to some extent. In a fully engineered landfill/fill with a leachate collection system, the extent of this discharge will be minimal, whereas in unlined landfills/fills, the leachate will be discharging into the ground or groundwater under the site. In the first instance, monitoring is to verify that leachate is being adequately contained and is not escaping into the underlying aquifer(s). In the latter case, monitoring is focused towards determining the extent of the leachate plume and whether any sensitive receivers are being impacted. The extent of the groundwater bore network needed to meet these objectives depends upon the nature of the hydrogeology and the sensitivity of the use of the aquifer.
- **Surface water**. If there is a surface water body in the vicinity of the landfill/fill, then monitoring of it should be considered. However, the potential route for contamination should be carefully assessed. Leachate seepage from the landfill/fill surface, or failure of above ground leachate pipes or storage facilities, may result in leachate discharge to the stormwater management system. Otherwise, if the surface water and groundwater are not connected, then there is minimal potential for leachate contamination to be transmitted to the surface water and any impact is probably restricted to sediment impacts from stormwater discharges, with monitoring targeted appropriately.
- **Sediment**. Contaminants which are associated with particulates may accumulate in the sediments of an impacted surface water body. Therefore, if the landfill/fill could potentially discharge contaminants into a surface water body, then monitoring of the sediment in depositional areas of the water body may indicate any accumulation of contaminants, particularly trace metals and synthetic organic constituents.
- **Ecosystem monitoring**. Whilst chemical monitoring can indicate the potential for a discharge to have an impact on an ecosystem, monitoring of the ecosystem itself provides a direct measure of any impact. This can include monitoring of the speciation and abundance of elements of the ecosystem, for example benthic organisms, macroinvertebrates, and periphyton. Standard methodologies have been developed for the monitoring of these aspects. The receiving environment should be assessed to determine whether appropriate ecosystem indicators are present to which these methodologies can be reliably applied. This monitoring will indicate the general status of the ecosystem, which is generally inherently highly variable. Careful design of the programme is required if analysis of effects specifically from the landfill/fill are required.

Parameters Analysed

The selection of the parameters for analysis should be guided by the purpose of the monitoring as clearly delineated by the defining questions (**Section 7.2**). Parameters fall into a number of groups which are used for different purposes. The broad objective (that each group of parameters would typically be associated with) is identified in section 7.2 of the guidelines. Parameters include:

- **Leachate Indicators**. Leachate typically contains elevated concentrations of a number of parameters, primarily chemical oxygen demand (COD), conductivity and ammoniacal nitrogen. Should consistent sampling indicate elevated levels of these three parameters, leachate is likely present. Generally, an elevated concentration of a single parameter is not sufficient to indicate leachate contamination but elevation of a number of them provides a useful indication. This parameter group is useful for groundwater or surface water where the purpose is to determine if leachate is present and the degree to which contamination is occurring. It can also indicate the extent to which the waste in the landfill/fill has decomposed and what stage that landfill/fill is at. [Objective 2].
- **Physico-chemical Parameters**. These parameters, such as temperature, conductivity and pH, indicate the general condition of the water sample. They determine the general characteristics of the water sample and can be used to indicate the source of the water (e.g., does it contain any leachate). These parameters can affect the way in which the results are interpreted, especially the potential toxicity of the sample. [Objective 3]
- **Cation/Anion**. These are the major cations and anions in the water sample. These characteristics can be used to determine if samples from different locations have been collected from the same aquifer or water source, as water from the same source will have similar cation/anion characteristics. Analysis for these parameters can be useful to clarify that samples are being collected from the same aquifer, and also the degree of connectivity between groundwater and surface water. [Objective 1 and 3].
- **Nutrients**. The primary nutrients of concern are nitrogen (N) and phosphorus (P), and, to a lesser extent, potassium (K). Leachate is a significant source of N in the form of ammoniacal N, and can contain P. Therefore, a landfill/fill can contribute to the general nutrient balance in a catchment. N and P can exist in a variety of forms and can change between these forms in the environment. Therefore, if nutrients are a concern in the receiving environment, analysis for the range of forms may be appropriate, especially if there are a number of background sources of nutrients. [Objective 1 and 3].
- **Trace Metals**. Leachate can contain trace metals, which can be toxic at higher concentrations. Any discharge of leachate can thus increase the concentration of these metals in the receiving environment. However, when deciding which parameters to analyse and in interpreting the results, it should be noted a number of these metals are present naturally in the environment (for example aluminium is present in a number of clays). Therefore, elevated metal concentrations may not necessarily be due to leachate, especially if the primary leachate indicators are not elevated. [Objective 2].
- **Synthetic Organics**. Dependent upon the nature of the waste in the landfill/fill, leachate can contain synthetic organic contaminants such as pesticides, herbicides, plasticisers etc. Generally, these are present at low concentrations,

even in the leachate, and are less than the detection limits. Monitoring for these parameters should focus upon the leachate to determine their presence, as they are unlikely to be detected in groundwater except in a concentrated plume. [Objective 2].

- **Landfill Gas Constituents**. Typically, CO_2, CH_4, H_2S and O_2 in the landfill gas collection system and in migration monitoring wells.

A single parameter may fall into a number of these groups.

Trigger Values

As outlined in **Section 8.4** of the Guidelines, trigger levels consist of specified numerical values or narrative descriptors for the protection of groundwater and surface water resources that require response by the landfill/fill operator.

Trigger values would typically not be set for all parameters that are monitored but would be determined for a suite of parameters that will act as the indicators for the site.

Different trigger values would be set for the different components of the monitoring programme. For example, different trigger values could be set for groundwater than for surface water. Significantly different values will be set for leachate and stormwater, as these are potential contaminant discharges prior to mixing. Appropriate trigger values for environmental effects should be set based on the receptors identified for a certain site. If the surrounding land use includes provision of drinking water for surface and groundwater, human health indicators should be considered. The New Zealand Drinking Water Standards (MoH 2018) provide guideline values for human health.

Guideline values which protect ecosystem health should be sourced from ANZG (2018). These guidelines include a wide variety of guidance for various uses of the water, including ecosystem protection, both for general stressors and toxicity; stock water; irrigation; and other primary industrial uses.

The ANZG (2018) provide values for 80%, 90%, 95% and 99% protection levels. The level of modification of the surrounding environment will determine the protection level used. A 99% protection level is appropriate for highly pristine, unmodified ecosystems, while 80% protection level is appropriate for highly modified environments with little ecological significance or value (again not often used). The most common guideline level used is 95% protection level which is suitable for modified ecosystems.

For sites which are used for contact recreation, reference should be made to the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MfE, 2003).

The location at which the trigger values are imposed should be considered carefully and should be as close as possible to either edge of the area within the allowed mixing zone, or at or just upstream of the site of the sensitive receiver. They should be assessed across all sites. An assessment of the background (upstream or upgradient) concentrations should also be made.

To be able to evaluate compliance of monitoring data with surface water performance standards or trigger levels, it is necessary to specify what an exceedance is. The statistical function that will be used to determine compliance needs to be clearly defined and should be consistent with the derivation of the trigger value.

Examples of this are:

- for continuous (i.e., half-hourly) measurements of turbidity and conductivity, compliance with trigger levels can be assessed by using running averages calculated over 12 successive measurements (i.e., 6 hours total);
- for fortnightly monitoring data, compliance can be assessed using running averages over three successive sampling occasions. Also, non-compliance can be deemed to have occurred if more than one of the three data points exceeds the trigger level; and
- for quarterly and annual monitoring data, compliance with trigger levels can be assessed using individual data points.

There are two types of errors inherent in any monitoring programme which must be taken into account in the design of the programme. These two error types, Type I and Type II, are:

> *'The situation where we conclude that an important change has happened when, in fact it has not, is technically referred to as a Type I error. Conversely, many indicators are very variable naturally and intensive sampling may be essential to detect ecologically important changes in the indicator. If the sampling intensity is too small and the important change is missed, then a Type II error is committed' (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, 2000, pp. 3.1-21).*

When designing a monitoring programme, these two error types should be considered and an explicit acceptance of the extent to which these two errors will occur should be made. This will enable the selection of appropriate programme design.

Detection Limits

Detection limits are considered in **Section 8.4** of the Guidelines.

Sampling and Analytical Requirements

As outlined in **Section 8.4** of the Guidelines, the collection of representative samples and the achievement of a subsequent unbiased analysis of results can present considerable challenges for monitoring programmes.

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

- **Sample replication**. The number (replicates) of samples to be collected at any time needs to be specified. The collection of replicates allows an understanding of the inherent variability in the water body. Ideally, the number of samples is determined by an acceptable level of uncertainty specified at the 95% confidence level. However, due to the high costs incurred by replication, this guideline is seldom achieved. Rather, the approach taken to reduce the uncertainty of monitoring data is to average them over time or space.
- **Sampling Methods and Equipment**. In general, the fewer disturbances that a sample receives before capture in a sample bottle, the more likely it is to retain its integrity. The sampling methods should be selected to achieve the minimum of sample disturbance and should be standardised such that variability in the results between sites is not introduced through different sample collection methods. Also, access to the various sites should be considered, especially if pumps and associated batteries or generators are required to collect the sample.
- **Sample Collection Protocols**. Care should be taken to ensure that the sample as collected is as representative as possible of the water body from which it is collected. For groundwater sample collection, the well should be purged of stagnant water before taking a sample. Normal practice is to purge three to five well volumes and monitor key indicators to determine that the sample extracted has stabilised. The procedures given in A National Protocol for State of the Environment Groundwater Sampling in New Zealand (MfE 2006)11 provide useful guidance. However, for wells which do not recharge rapidly, an alternative approach of draining the well, then sampling from the water which refills the well, may have to be employed. Micro-purging12 is an alternative method, usually undertaken at pumping rates of less than 1 L/min, that can avoid highly turbid samples (and the need for pre-filtering) and large purge volumes.
- **Field Filtering**. Whether to undertake field filtering should be carefully considered, with the relative risks of field contamination of the sample weighed against the potential for the partitioning of the parameters to change during transport to the laboratory. In some cases, laboratory pre- filtering may be more practical if samples are highly turbid and transit time to the laboratory is short.
- **Collection and recording of field data**. Ambient conditions in the water body sampled (i.e., aquifer, surface water, leachate pond etc.) should be recorded through visual observations, field measurements, sample collection and analytical testing. Standard field sheets should be used to ensure that all required information is collected. Adequate photographic evidence should be collected to adequately describe the conditions under which each sample is collected; the general conditions of the site; and any specific issues which may affect the interpretation of the results. There are a number of references which may be used for this purpose, including APHA (2012), Hellawell (1978), Metcalfe-Smith (1992) and Standards Association of Australia, (1987). A full range of references is provided in ANZECC (2000). Protocols should be passed on to external contractors involved in the monitoring programme.

- **Sample Storage and Transport**. The use of laboratory supplied bottles and transport containers is usually the most secure and quality assured sample holding method. A comprehensive chain of custody procedure is required to ensure that samples are received and analysed as required.
- **Sample Analysis Protocols**. Selection of analysis methods needs to consider factors including likely parameter concentrations, detection limits, regulatory requirements, and cost. More details of analytical methods can be found in Standard Methods (APHA, 2012). The portion of the sample that should be analysed needs to be identified (the dissolved, acid soluble or total digestible portion). This applies to metals but also to other parameters which may be affected by solids in the sample, such as COD and total nutrients. The ability to collect a clean sample free from sediment, along with the manner in which trigger values were derived, will impact upon which portion of the sample is analysed.
- **QA/QC Requirements**. QA/QC requirements vary depending on elements of the monitoring programme. Some standardisation is possible but specific plans are required for each site. All QA/QC protocols and results should be documented in a manner that enables them to pass regulatory authority scrutiny. Approximately 10 to 15% of the sampling effort should be devoted to QA/QC (ANZECC, 2000). Plans should cover:
  - cleaning and decontamination of sampling equipment;
  - maintenance and calibration of instrumentation;
  - requirements for field blanks, bottle blanks, and replicate samples;
  - laboratory safeguards including reagent blanks, duplicates and reference materials;
  - requirements for independent certification of the laboratory test method;
  - checks by independent third parties;
  - checking of analysis results by comparison with previous measurements; and
  - chain of custody requirements.

K.2 Groundwater Monitoring

Determining Number and Location of Monitoring Points

As outlined in **Section 8.8** of the Guidelines, appropriate positioning of monitoring points in a groundwater monitoring network is a key aspect of any monitoring programme.

Sensitivity of the surrounding environment is an important factor in monitoring well network selection. In shallow aquifers with a water table where the environmental risk is low, a basic monitoring well system could comprise one well hydraulically up-gradient and at least two wells hydraulically down-gradient of the landfill/fill.

For large scale landfill/fill facilities, 20 to 50 monitoring/investigation wells may be required. As a minimum for landfill/fill sites which cover only a small area, it is recommended that at least one up-gradient and two down-gradient groundwater monitoring wells (possibly screened at different depths) be installed. A monitoring network of three wells will only be sufficient in limited circumstances; and the suitability of such a network would have to be established via appropriate investigation of the hydrogeological conditions at the site location.

Key factors for selecting well sites include:

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

Pathways for movement of contaminants can be affected by:

- background concentrations of contaminants;
- aquifer numbers and characteristics;
- locations of recharge and discharge areas;
- location of any pumping influences such as local wells;
- nature of the unsaturated zone;
- presence of perched aquifers;
- fractured or porous aquifers;
- soil and geological characteristics;
- geological formation boundaries;
- bedding and tilting of strata;
- geological faults;
- groundwater divides;
- seasonal and short-term climatic influences; and
- preferential pathways.

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

- Hydraulic conductivity, *K*
    - Very slow K < 10-8m/s
    - Slow 10-6 > K > 10-4 m/s
    - Medium 10-4 > K > 10-6 m/s
    - Rapid K > 10-4 m/s
- Effective porosity
- Hydraulic gradient
- Soil/rock/leachate species interaction as given by the Distribution Coefficient, *Kd*
    - Very mobile Kd < 1 ml/g
    - Mobile 1 < Kd > 100 ml/g
    - Immobile Kd > 100 ml/g

Design Requirements for Monitoring Wells

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

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

Well design should cover:

- **Screen Length and Position**. Screens are normally 1 m to 3 m long. Longer screens lose detection sensitivity to vertically variable water quality and provide only a gross measure of contamination. Screens should be positioned on main flow pathways and intersect the water table, where immiscible floating contaminants such as petrol, and some solvents are likely to be found, if present.
- **Casing and Screen Materials**. Common practice is to use PVC materials due to their chemical and corrosion resistance. Stainless steel is also suitable. Joints should use mechanical connections without the use of glues which can affect the sample integrity.
- **Casing Diameter**. 50 mm diameter casing meets common sampling and construction objectives. Special sampling tools are available for smaller diameters.
- **Drilling and Construction Limitations**. Drilling methods need to be appropriate for the target zone(s) and soil/rock type, along with secure emplacement and

sealing of screen sections. Wells should be developed following construction to remove drilling fluid contaminants, clean the well and to remove fines from around screens.

- **Filter Pack and Annular Seals for Screened Zones**. Filter materials selected for packing screens should be nonreactive to the groundwater environment. Geotextile sheaths can be appropriate for fine grained formation materials but are susceptible to clogging and no data on the adsorption of organics and other compounds is available. Annular seals using cement should not be used in screen zones to avoid leached residues from the cement impacting water quality.
- **Surface Completion**. Security of the well head from surface water ingress and external damage are prime design considerations.
- **QA/QC Procedures**. Specifications for monitoring well construction need to cover quality requirements for materials, methods and testing to ensure satisfactory performance of the completed well.

Monitoring Parameters

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

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

Generally, contaminants that move in groundwater systems are in a dissolved form. Unless the strata contain large openings, as sometimes occurs in fractured rock or dissolved cavity aquifers (for example, karst limestone aquifers), entrained solids in fluid contaminants are filtered in the first layers of soil. However, some contaminants (such as petroleum products) may be in pure liquid form beneath or floating on the water table. Others, such as some metals, may move by intermittently changing between solid and dissolved phases. In cavity flow systems, contaminants can move by attachment to colloids or very fine sediment.

The main focus is normally on parameters that are soluble in the ambient groundwater at the site.

K.3 Surface Water Monitoring

Table K-1 provides an example of a surface water monitoring strategy. The strategy applied for each site will be dependent on the site, location of filled area relative to surface water receptors, and the landfill/fill class, among other factors.

Table K-1 Example Surface Water Monitoring Strategy

Monitoring tier	Frequency	Description of parameters
Baseline	Monthly to quarterly monitoring of general water and sediment quality and biological parameters	Establishes the status of existing surface water resources at selected monitoring stations before commencement or a change in landfill/fill operations.
Indicator	Continuous record of flow	Automatic flow meter installed at one or more stations to record catchment and landfill/fill runoff and identify the need for flow-related controls.
	Continuous record of conductivity	Automatic meter installed at one or more stations to pick up any escapes of leachate to surface waters.
	Continuous record of turbidity	Automatic meter installed above and/or below stormwater ponds to check treatment efficiency and measure compliance.
	Daily visual inspections	Visual inspection of stormwater control systems and surface waters downstream of landfill/fill.
	Fortnightly water quality sampling	Short list of parameters aimed at checking general water quality and picking up leachate contaminants.
	Contingency	Long list of parameters to be sampled only when indicator monitoring data indicates regulatory exceedance.
Comprehensive	Quarterly sampling	Long list of parameters checking general water quality and a wide range of possible contaminants (same parameters used as for baseline monitoring).
	Yearly sampling	Selected parameters including organic screening tests, sediment and biological sampling, WET tests (optional).

K.4 Landfill Gas Monitoring

Subsurface Gas Monitoring

For any landfill where gas generation may occur e.g., in Class 1 and 2 landfills, monitoring of landfill gas should be undertaken using installed probes around the site boundary.

Permanent monitoring probes should consist of a length of pipe made from an inert material, such as PVC, with a perforated section over the required sampling length. The pipe is usually installed in a gravel pack and appropriately sealed over the upper 1 m. A sampling point should be installed in the capped top of the probe to enable measurement of landfill gas without having to open the sampling probe. Probe depths should generally be at least 3 m, although deeper probes may be required in areas of low groundwater tables, where deep unsaturated permeable layers/fissures exist, or where waste depths are high and water levels low.

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

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

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

The probe should remain sealed between monitoring periods. Opening of the probe cap (to obtain water table levels etc.) should only be done at the completion of a monitoring procedure.

The number and locations of monitoring probes depends on site-specific factors (see **Section 8.10**). Probe spacing and depths will be site specific and should be determined only after a detailed review of site conditions.

Monitoring Frequency

Probe monitoring frequencies will vary depending on site circumstances. Where site conditions change (e.g., extraction rates, surrounding land use, or water table), or in response to unexpected or out-of-the-ordinary results during routine monitoring, the frequency of monitoring should be increased until gas concentrations are found to stabilise.

As a minimum, monitoring of each probe should be carried out six monthly until probe gas concentrations have stabilised below 1% by volume methane and 1.5% by volume carbon dioxide.

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

Surface Gas Monitoring

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

- **Visual inspection**. Although not adequate in itself as a means of monitoring, visual inspection can provide useful information as to potential areas of elevated landfill gas emissions. Key indicators are areas of distressed vegetation, capping cracking, discernible landfill gas odours and gas bubbles in puddles after periods of rain. Findings from a visual inspection should be confirmed using ISM.
- **ISM**. An ISM is conducted over a prescribed or random walk pattern across a site using a flame ionisation detector. Methane is sampled via a wand with a funnelled inlet held 50mm to 100mm above the ground surface. Site conditions should be dry and wind velocities less than 15 km/hr on average. During the monitoring the technician makes recordings at regular intervals and includes any areas of elevated emission levels.
- **Integrated surface sampling**. Integrated surface sampling is similar to instantaneous surface monitoring with the exception that gas collected during the walk pattern is pumped to a non-contaminating sample bag. The methane reading in the bag can then be measured, giving an average concentration over the walk pattern. Trace constituents can also be measured from the gas sample. Extreme care is required using this system in order to obtain representative results.
- **Ambient air sampling**. Ambient air up-wind and down-wind of a site is collected via integrated ambient air samplers into non-contaminating bags. This form of sampling is usually focused on measuring total non-methane hydrocarbons and trace pollutants and is likely to be required only in exceptional and specific circumstances.
- **Flux box testing**. Flux boxes are containers (typically drums cut lengthways) with the open end embedded approximately 2 cm into the landfill surface. A small hole is formed in the side of the container to allow venting. A flux box testing programme requires a specific design to ensure that a dependable outcome is achieved.
- **Portable accumulation chamber surveys**. Accumulation chamber surveys can be used to measure the flux (rate) of CO_2, CH_4 or H_2S at the land surface at a given point. The method is non-invasive and through measurement of sufficient points, can be used to assess the total emissions from a site as well as to represent the spatial pattern in landfill gas flux across the surface (Rissmann et. al. 2011). An accumulation chamber survey requires a specific design and employs multivariate statistical methods, such as stochastic simulation, to provide a measure of the uncertainty of the emission rate.

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

Monitoring in Buildings

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

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

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