Landfill Guidelines

Towards Sustainable Waste Management in New Zealand

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Centre for Advanced Engineering
University of Canterbury Christchurch New Zealand

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- Identify deficiencies in New Zealand's technological capability and take action to promote the addressing of these deficiencies.
- Undertake technology transfer rather than original research.

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Contact:

CAE, University of Canterbury, Private Bag 4800
Christchurch, New Zealand

Street Address:
39 Creyke Road, Christchurch 8004

Telephone: +64-3-364-2478
Fax: +64-3-364-2069

e-mail: cae@cae.canterbury.ac.nz
http://www.cae.canterbury.ac.nz

Executive Director: John P Blakeley *(to April 30, 2000)*
Dr George Hooper *(from 1 May, 2000)*
Projects Director: John L Lumsden
Publications Editor: Charles A Hendtlass

Contributors

The following companies and individuals had input into the preparation of these Landfill Guidelines.

Task Group Leader

Laurence Dolan, Woodward-Clyde (NZ) Limited

Task Group Members

Tui Gilling, Ministry for the Environment

Peter Higgs, Perry Waste Services, Landfill Operators Group

Tony Kortegast, Tonkin and Taylor Limited

Mark Milke, University of Canterbury

Tom Wetherill, SCS-Wetherill Environmental, WasteMINZ

Consultants

Individual sections and sub-sections of this document were prepared by the following consultants and individuals:

Bell Gully (Ian Cowper)

Environment and Business Group (Conway Stewart, Susie Wood)

Peter Nelson

Pattle Delamore and Associates (Alan Pattle)

SCS-Wetherill Environmental (Murray Stirling, Tom Wetherill)

Taylor Baines and Associates (James Baines, Nick Taylor)

Tonkin and Taylor Limited (Arthur Amputch, Milind Khire, Tony Kortegast)

Woodward-Clyde (NZ) Limited (Laurence Dolan, Martin Evans, Ian Jenkins, Matthew Reed, Wayne Russell)

Reviewers

Mark Drury, Woodward-Clyde

Brian Gallagher, Timaru District Council

Jim Bradley, Ian Rowden, Montgomery Watson

Jenny Chetwynd, Carla Thorn, Ministry for the Environment

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Introduction

1.1 Foreword

These Landfill Guidelines are a revision of the CAE *Landfill Engineering Guidelines*, originally published in *"Our Waste: Our Responsibility"* (1992).

Landfill siting, design, operations and monitoring have undergone major advances over the last thirty years. Awareness of the issues related to managing various categories of waste, together with growing concerns over the environmental effects of waste disposal, have seen significant improvement in the siting, design, operation and monitoring of waste disposal facilities in countries where waste disposal practices are not dictated entirely by cost.

However, current practice remains variable throughout New Zealand.

These revised guidelines have been written to:

- reinforce key components of the 1992 *Landfill Engineering Guidelines*;
- outline key issues and requirements with respect to the applicable legislation;
- provide additional guidance on siting, design and construction, with respect to new landfills and lateral expansions of existing landfills; and
- provide additional guidance on operations and monitoring at all operating landfills.

1.2 Objectives and Aims

The objectives of these Landfill Guidelines are to:

- provide the basis for siting, design, development, operation and monitoring of landfills in New Zealand in an environmentally acceptable and sustainable manner;
- provide practical guidance to landfill owners, operators and regulatory authorities in meeting their requirement to avoid, remedy or mitigate the adverse effects of landfill disposal, in accordance with the Resource Management Act (1991);
- reflect current recommended waste industry practice (both private and local authority) for key aspects of siting, design, operation and monitoring of municipal solid waste landfills, both new and extensions of existing sites, in the light of:
  - — developments in the practice of landfill siting, design, operation and monitoring;
  - — experience in the use and implementation of the 1992 *Landfill Engineering Guidelines* by landfill operators and regulatory authorities; and
  - — experience in the implementation of the Resource Management Act (1991).

In achieving these objectives these guidelines aim to:

- outline the key considerations in the siting, design operation and monitoring of landfills on a site-specific basis; and
- provide a consistent approach to landfill design and management to reduce the actual and potential effects of landfills on the environment.

These guidelines deal specifically with municipal solid waste landfills intended to accept municipal solid waste, as defined in Section 1.3 below.

Within New Zealand there are no specific and legally-binding requirements for the siting, design, operation and monitoring of landfills.

The final decision on site-specific requirements is made by the appropriate regulatory authority, or the Environment Court, under the provisions of the Resource Management Act (1991), following a site-specific assessment of effects on the environment.

Siting, designing and operating landfills, after consideration of the issues and, in accordance with recommendations contained in these guidelines, is expected to provide a reasonable assurance that the landfill site will not have significant adverse effects on the environment.

In developing and evaluating landfill proposals, landfill owners, operators and regulatory authorities need to consider in detail the resulting actual and potential effects on the environment taking into account the following:

- landfill size;

- landfill location and site characteristics;
- surrounding environment; and
- local community.

Specifics of siting, design, operations and monitoring will be determined following detailed technical, and non-technical, investigation and analysis.

Therefore, these guidelines do not eliminate the necessity for the development of site-specific requirements for investigations, design, operations and monitoring.

Figure 1.1 indicates the general issues associated with landfills and protection of the surrounding environment.

These guidelines are not intended to be a detailed technical manual, but rather a basis for landfill operators and regulatory authorities to seek detailed technical, planning and legal advice from appropriately qualified and experienced individuals and companies.

1.3 Waste Classification and Landfill Types

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

Waste Classification

Waste is classified into four general categories:

- cleanfill material (or inert waste);
- municipal solid waste;
- industrial waste; and
- hazardous waste.

Cleanfill Material (or Inert Waste)

Cleanfill material, or inert waste, is waste that does not undergo environmentally-significant physical, chemical, or biological transformations, and has no potentially hazardous content once landfilled. It must not be contaminated or mixed with any other material.

Cleanfill material is defined as:

- Material that when discharged to the environment will not pose a risk to people or the environment, and includes natural materials, such as clay, soil and rock, and other materials, such as concrete, brick or demolition products, that are free of:
  - — combustible, putrescible, degradable or leachable components;
  - — hazardous substances or materials (such as

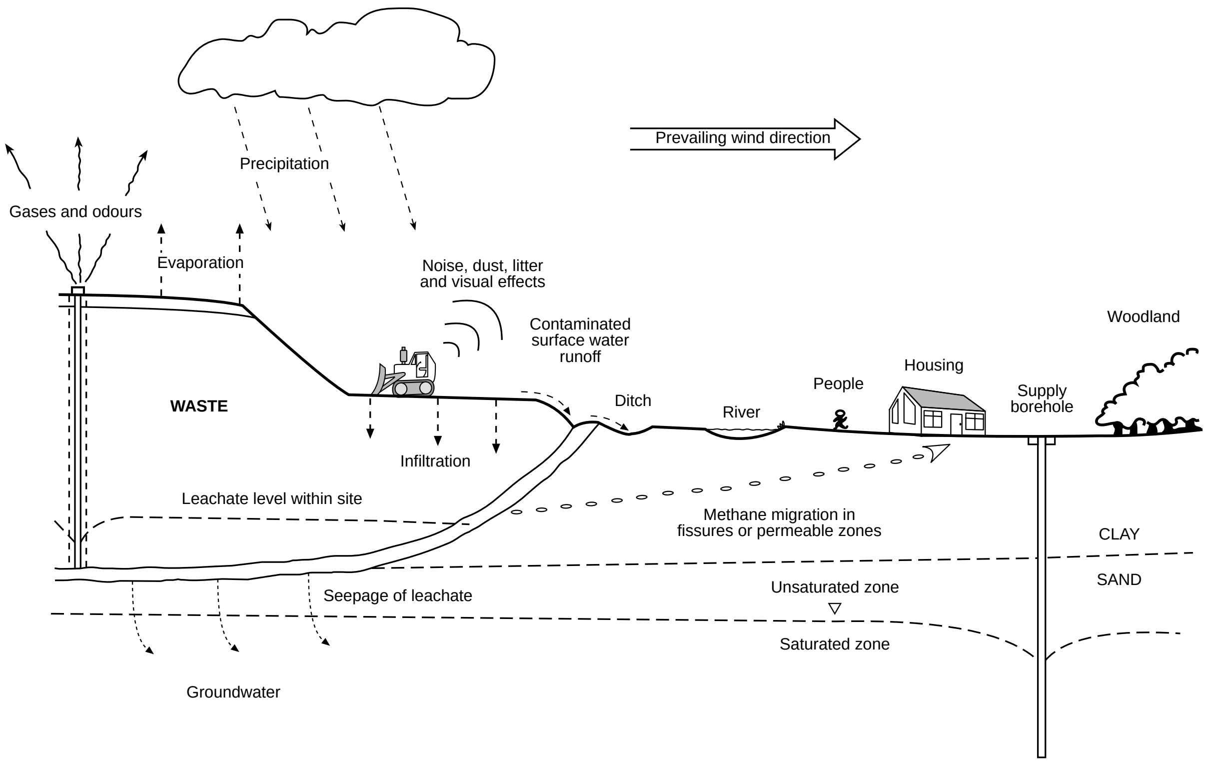


Figure 1.1: Environmental protection — Illustrations of source/receptor/pathway

(Modified Figure 3.4 from UK Department of the Environment Waste Management Paper No. 26 B (1995)) municipal solid waste) likely to create leachate by means of biological breakdown;

- — any products or materials derived from hazardous waste treatment, stabilisation or disposal practices;
- — materials such as medical and veterinary waste, asbestos, or radioactive substances that may present a risk to human health if excavated; and
- — contaminated soil and other contaminated materials.

Municipal Solid Waste

Municipal solid waste is any non-hazardous, solid waste from a combination of domestic, commercial and industrial sources. It includes putrescible waste, garden waste, uncontaminated biosolids and clinical and related waste (including contaminated waste sterilised to a standard acceptable to the Department of Health). All municipal solid waste should have an angle of repose of greater than five degrees (5˚) and have no free liquids.

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

Industrial Waste

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

Hazardous Waste

Hazardous waste is waste that poses a present or future threat to people or the environment as a result of one or more of the following characteristics:

- explosiveness;
- flammability;
- capacity to oxidise;
- corrosiveness;
- toxicity; and/or
- eco-toxicity.

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

For further discussion on hazardous waste refer to the CAE document *Management of Hazardous Waste* (2000). For recommendations on landfill waste acceptance criteria with respect to hazardous waste, refer to Section 5.6 of these guidelines.

Landfill Types

Landfills are classified into four categories:

- cleanfill;
- municipal solid waste landfill;
- industrial waste landfill; and
- hazardous waste landfill or hazardous waste containment facility.

Cleanfill

A cleanfill, or inert waste landfill, is any landfill that accepts only cleanfill material and inert wastes, including clean excavated natural materials. In general the only effective environmental controls on discharges to land and water from cleanfills relate to waste acceptance criteria.

Municipal Solid Waste Landfill (MSWL)

A municipal solid waste landfill (MSWL), also often referred to as a sanitary landfill, is any landfill that accepts municipal solid waste. A municipal solid waste landfill may also receive inert waste.

Industrial Waste Landfill (IWL)

An industrial waste landfill (IWL) is a landfill that is designed to accept predominantly industrial waste. In many cases industrial waste landfills are monofills, associated with a specific industry or industrial location (for example mining, forestry and smelting) and designed and operated in accordance with the specific wastes targeted. Design, operation and monitoring requirements may be more, or less, stringent than for municipal solid waste landfills. An industrial waste landfill may also receive municipal solid waste and inert waste, depending on design.

Hazardous Waste Landfill (HWL)

A hazardous waste landfill (HWL), or hazardous waste containment facility (HWCF) is any landfill that accepts waste formally defined as "hazardous waste" in statutory instruments, or as specifically determined through any special requirements that may be set by the Environmental Risk Management Authority (ERMA).

Siting, design, operations and monitoring requirements for landfills accepting hazardous waste will be considerably more stringent than for landfills accepting only municipal solid wastes.

For further discussion on hazardous waste landfills refer to the CAE document *Management of Hazardous Waste* (2000).

1.4 Layout of the Guidelines

These Guidelines are set out in the following sections:

- landfills and legislation;
- siting;
- design;
- operations; and
- monitoring.

Chapter 2
Landfills and Legislation

2.1 Introduction

This section provides a description of the legislative requirements with respect to landfills. It addresses the requirements in the Resource Management Act (1991) (the Act), including the following:

- requirements for designations and resource consents; and
- the resource consent application process.

Relevant case law is provided in Appendix 1.

2.2 Resource Management Act (1991)

Purpose and Principles

On 1 October 1991 the Resource Management Act (1991) became the legislation controlling resource use in New Zealand. Part II of the Act sets out the purpose and principles. The purpose of the Act is:

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

The Act provides a definition of "sustainable management". Essentially, the term means communities managing resources to provide for their social, economic, and cultural well-being and for their health and safety while meeting certain environmental imperatives. The potential of natural and physical resources to meet the reasonably foreseeable needs of future generations must be sustained, the life-supporting capacity of resources must be safeguarded and adverse effects of activities on the environment must be avoided, remedied or mitigated. This last focus upon the effects of activities is a key feature of the regime introduced by the Act.

The Act also sets out a number of matters of national importance (including the preservation of the coastal environment, wetlands, lakes and rivers, the protection of outstanding natural features, landscapes and significant indigenous vegetation). Other matters to which decision-makers must have regard include the intrinsic value of ecosystems and the maintenance and enhancement of amenity values.

The Act introduces specific emphasis on the interests and resource management concerns of Maori.

Jurisdiction of Local Government

Local government functions are divided between regional councils and territorial authorities (district and city councils). Sections 30 and 31 of the Resource Management Act (1991) set out in detail the different functions of regional councils and territorial authorities.

Regional Councils

Under section 30 of the Act, the functions of regional councils include:

- the preparation, implementation and review of objectives, policies and methods to achieve integrated management of natural and physical resources of the region;
- the preparation and implementation of policies in relation to the actual or potential effects of the use, development or protection of land, which are of regional significance;
- the control of the use of water and land for soil conservation;
- the control of the discharge of contaminants;
- avoidance of natural hazards;
- maintenance of water quality;
- the prevention of adverse effects of hazardous substances; and
- activities in, or affecting, the coastal marine area.

Issues, objectives, policies and rules in relation to these resource management functions within a region are contained within its regional policy statement and regional plans.

A regional council is responsible for assessing resource consent applications for activities where its policy statement or a regional plan requires this. These can be any of the following:

- a discharge permit;

- a water permit;
- a land use consent; or
- a coastal permit.

Territorial Authorities (District and City Councils)

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 storage, use, disposal, or transportation of hazardous substances;
- the control of the subdivision of land; and
- control of noise.

2.3 Resource Consents

There are five different types of resource consent. These are:

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

A description of those consents that are particularly relevant to refuse landfills is set out below.

Discharge Permits

Under the Act, a landfill falls within the definition of "industrial or trade premises" as:

> *"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".*

Accordingly, under section 15 of the Act, no person may discharge any contaminant to air, water or land associated with the landfill unless expressly allowed by a rule in a regional plan or proposed regional plan, a resource consent, or a regulation. Regional councils are responsible for assessing applications for resource consents (discharge permits) relating to discharges to land, air and water.

Discharge to Land

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

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

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

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

Discharge to Water

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

Activities that require a discharge permit under section 15(1)(a) include discharges of clean and/or contaminated surface stormwater and groundwater from a groundwater control system. In some cases a single consent may be used for all surface water, or groundwater discharges, within a single defined catchment. In others, a separate permit may be required for each separate discharge.

The disposal of collected uncontaminated water may require a discharge permit if this is directly to water.

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

- location of discharges;

- design and integrity of structures;
- quantity of contaminants or water to be discharged;
- quality of discharges;
- monitoring of discharges; and
- scour protection.

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

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

- location of discharges;
- 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; and
- bond or financial assurance (in some circumstances).

Discharge to Air

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

Three types of discharges to air may occur:

- the emission of decomposition gases such as methane, or other greenhouse gases, and odorous compounds;
- dust; and/or
- smoke resulting from the burning of rubbish.

It is important to note that open burning in a landfill is illegal for most sites unless allowed by a regional plan. Under section 418 of the Resource Management Act, only those activities that were legal under the Clean Air Act can continue under the Resource Management Act until it is restricted by a regional plan. Open burning at landfills was banned under the Clean Air Act 1972, and is therefore illegal under the Resource Management Act 1991.

Furthermore, a variety of hazards arise when burning occurs within a landfill site, and these may present significant risks to both the health and safety of site personnel and the public. The Health and Safety in Employment Act 1992 places specific requirements on employers and those in control of a place of work, to prevent harm to employees (section 6 of the Act) and others (sections 15 and 16 of the Act) who may be affected by activities at the workplace. There would seem little doubt that fires at a landfill, whether planned or accidental, would be regarded as giving rise to a number of significant hazards, any of which may pose a risk to employees in the workplace.

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

- compliance provisions 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; and
- odour monitoring provisions (for example "sniff" panels) in some circumstances.

Water Permits

Landfills require a water permit from a regional council for the collection and control of stormwater unless it is expressly allowed by a rule in a regional plan or proposed regional plan, or a resource consent, or is an existing use under section 20 of the Act.

In practice, regional councils generally require water permits for diversion or damming of natural streams on or around the landfill site and taking of groundwater by a groundwater control system. A water permit may also be required for the diversion of stormwater around a landfill site. In some cases a single consent may be used to enable all diversions or takes within a single defined catchment. In others, a separate permit may be required for each separate diversion.

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

- location of takes, dams or diversions;
- design and integrity of structures; 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) of the Act). 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 has existing use rights.

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

Land use consents issued by territorial authorities in respect of landfills may contain conditions relating to:

- development plans;
- noise;
- roading and traffic;
- litter;
- nuisance from birds, flies and vermin;
- fencing;
- separation distances;
- site rehabilitation;
- landscaping and visual effects; and
- bond or financial assurance (in some circumstances).

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

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

- erosion; and
- silt control.

The resource consent process is outlined in more depth in Section 2.4.

Coastal Permits

In the coastal marine area (that is, below mean high water spring tide), the regional council is responsible for assessing coastal permit applications. A coastal permit would be required before a landfill could be developed in the coastal marine area (for example, in the intertidal area) or, if there is likely to be any discharge into the coastal marine area.

Subdivision Consents

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

Existing Use Rights

In some circumstances, landfills that were established some years ago may be able to claim existing use rights. Sections 10 and 20 of the Resource Management Act provide requirements that must be met if land is to continue to be used in a manner that contravenes a rule in a district plan or a proposed district plan. The first is that the land use was lawfully established before the rule became operative. This can include a land use established by a designation that has subsequently been removed.

The second requirement is that 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.

The Act also provides that:

- consents granted under the Town and Country Planning Act become land use consents (section 383); and
- water rights under the Water and Soil Conservation Act 1967, are deemed to be 'existing rights and authorities' (section 386), and become either water permits or discharge permits, expiring on either 1 October 2001 or 2026, depending upon their original duration; and
- for the numerous landfills that did not have water rights and/or land use consents at the time of enactment of the Resource Management Act 1991, no lawful consents exist.

The Suite of Typically Necessary Consents

The establishment of a landfill under the Resource Management Act 1991 may require a number of consents from a regional council and/or district/city council. The number and type of consents required, and the detail of information necessary may vary depending on the type of landfill, and its siting and surrounding environment.

The types of consent that may be necessary for a landfill, and the authorities from which they must be sought are set out in Table 2.1.

Designations

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

A designation for a landfill provides for the use of the land as a landfill. However, resource consents from the regional council will still be necessary for excavation/filling, discharges of contaminants and stormwater, and use of water.

A subdivision consent from the district/city council may still be necessary, but the presence of a designation does away with the need for a land use consent from the district council.

A notice of requirements to designate land can be publicly notified as if they were applications for resource consents and there is provision for public submission and appeal. Designations with respect to landfills generally contain conditions similar to conditions in a land use consent.

District Plans

Councils may make provision for landfills in their district plans under Clause 6, Part II, of the Second Schedule. This states that one of the matters that may be included in the district plan is:

> *"The scale, sequence, timing and relative priority of public works, goods and services including public utility networks and any provision for land used or to be used for a public work for which the territorial authority has financial responsibility."*

Any person can request a change to an operative district plan that would make provision for a landfill (section 73). This request could be for either:

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

An application for a plan change is a public process, with extensive opportunity for public submissions. Any person who has made a submission has a right to appeal the council's decision to the Environment Court.

A request for a plan change requires a considerable amount of information. Reference should be made to Part II of the First Schedule to the Act that sets out the information requirements. In general terms this includes:

- a clear definition of the change sought; and
- a description of the environmental results anticipated as a result of the change.

A description of the environmental results anticipated

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
District /City Council	Land Use Consent	Use of land for purposes of a landfill
	Subdivision Consent	This may be necessary if the project involves any amalgamation of titles, vesting of roads or reserves, or partition of the land into different ownerships

Table 2.1 Regulatory authority resource consent responsibilities

as a result of the change should be prepared in accordance with the Fourth Schedule (of the Act) and an assessment of any significant adverse effects on the environment is necessary.

Section 32 of the Act also requires that the costs and benefits of the proposed change, and the alternatives, and the need for the change, are adequately investigated and considered before the plan change is adopted. Effectively this means for a private plan change that the work must be done before the application for the change is made with the council.

The approximate time to prepare the necessary documentation to support a plan change is 6-12 months. Once the application has been lodged, the approximate minimum time to obtain a decision from the council is about 12 months.

An additional 6-12 months should be allowed for appeals to the Environment Court.

Consultation/Liaison with Consent Authorities

The appropriate regulatory authorities, be they regional, district or city councils, should be consulted at the earliest opportunity to confirm their requirements in respect of resource consent applications and to establish pre-application consultation links with staff. The advantages of this early liaison cannot be overstated.

Consultation with tangata whenua should be undertaken, and any affected parties identified and consulted.

Consultation is important to ensure the resource consent application is sufficiently clear, thorough and complete in its assessment of effects on the environment.

Enforcement Mechanisms in the Resource Management Act

The Act provides a number of enforcement mechanisms to ensure compliance with the district and regional plan requirements, designations and resource consents. There are three levels of enforcement:

- administrative enforcement, which may take the form of declarations, abatement notices, excessive noise directions and infringement offence provisions, all instigated by the relevant territorial authority or regional council;
- civil enforcement through enforcement orders, issued by the Environment Court at the instigation of a council or a member of the public; and
- offence provisions.

Administrative Enforcement

The Environment Court may issue declarations to clarify any matter concerning the Act or a plan. Declarations are usually used to clarify responsibilities or powers under the Act, or to determine the correct interpretation of a document.

Abatement notices are used to enforce compliance with the Act and various planning instruments, and to ensure that the duty to avoid adverse effects on the environment is observed. Enforcement officers appointed by local authorities can issue abatement notices. A person must comply with an abatement notice served on them within the period specified in the notice, unless they decide to appeal.

Civil Enforcement

Only the Environment Court, on application, can make enforcement orders. The potential scope of enforcement orders is wide. Orders may require a person to cease a certain activity or take positive action to remedy adverse effects on the environment. Interim enforcement orders are designed for use in emergency situations and are, in that sense, similar to injunction proceedings. If a Judge considers it necessary, the notice and hearing requirements can be dispensed with, so that interim enforcement applications may be dealt with on an *ex parte* basis where the person against whom the order is sought is not present.

Examples of what may be required in an enforcement order issued against a landfill operation include:

- cessation or prohibition of an activity that contravenes or is likely to contravene the Resource Management Act 1991, any regulations, rule in a plan, requirement, heritage order, or resource consent;
- cessation of an activity that is likely to be noxious, dangerous, offensive or objectionable, or where it has or is likely to have an adverse effect on the environment. It should be noted, however, that this remedy is not available in certain circumstances where the person is acting in pursuance of a resource consent or rule in a plan (section 219(2));
- compliance with any rules, regulations, heritage order or resource consent; and
- avoidance, remedy or mitigation of actual or likely adverse effects.

Offence Provisions

The most serious offences are punishable by a fine of up to $200,000 and a prison sentence of up to two years. For a continuing offence, a fine of up to $10,000 per day may be imposed. Any person may lay an information (the first step in a prosecution) within six months of the time when the offence first became known, or should have become known to the local authority in question. These are offences of strict liability, which means that it is not necessary to prove that the defendant intended to commit the offence.

An 'emergency' defence is available where a defendant is able to establish that an event or action was an emergency measure, that the defendant's conduct was reasonable and that following the event he or she adequately mitigated or remedied any adverse effects on the environment.

Alternatively, a defence may be made out by establishing that the event or action was beyond the defendant's control by virtue of an event such as a natural disaster, mechanical failure or sabotage. To succeed with its defence, the action or event must not have been reasonably foreseeable by the defendant, and he or she must have also adequately mitigated or remedied any adverse effects on the environment.

A defence of due diligence is available in circumstances where the defendant did not know and could not reasonably be expected to have known of the offence, or where the defendant took all reasonable steps to prevent the commission of the offence. In either case, the defendant must additionally prove that all reasonable steps were taken to remedy the effects of the offence.

2.4 Resource Consent Application Process

Resource Consent Process

"Resource consent" is an umbrella term covering five different types of consents. A resource consent permits something to be done that would otherwise be restricted by a rule in a plan. As indicated already, a resource consent includes:

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

Landfill activities are not usually provided for specifically within district or regional plans and resource consents are usually required.

When lodging applications for resource consents, an applicant must also provide an Assessment of Effects on the Environment (AEE) with respect to the proposal. This assessment is required to be in sufficient detail to enable both the consent agency and members of the public to form an appreciation of the effects of the proposal. The scope of an assessment is prescribed in the Fourth Schedule to the Act.

An AEE should also contain a description of how a landfill will be operated, to minimise any adverse effects on the environment. It may contain various management plans covering such matters as routine operations, daily cover, leachate collection and treatment, control of noise, rodent and bird pests, and landscaping. It should also include the outcome of any public consultation that has been undertaken.

Notification

A presumption in section 94 of the Act is that applications for resource consents will be publicly notified. Experience has been that most councils do in fact notify applications for resource consent in respect of landfills. Notification provides an opportunity for any member of the public to lodge a submission either in favour of or in opposition to a proposal. Submitters can also present their submissions in person at the council hearing of submissions, and subsequently take an appeal to the Environment Court if they are dissatisfied with the decision of the council.

Applications may proceed without public notification in certain circumstances. These include:

- where the consent of persons affected has been obtained in advance; and
- where any adverse effects on the environment are minor.

How Long Does the Resource Consent Process Take?

Once an application for a resource consent has been lodged, the consent authority first decides whether or not to notify the application. The timing of each process is set out below.

Notified application

- Ten working days to publicly notify the application.
- Twenty working days to receive submissions.
- Twenty-five working days after closing of submissions to hold a hearing. At least 10 working days notice must be given of the time and place of the hearing.

- Council's decision within 15 working days of the hearing.
- Appeal to the Environment Court by applicant or any submitter.

Note that under section 92 of the Act, the council may request further information from the applicant at any time up to the time of the hearing. Once such a request has been made the consent authority may postpone the notification of the application or the hearing of the application until it is satisfied that the information has been provided.

Approximate time to decision — 70 working days (allow four months).

Appeal time — an additional 6-12 months minimum.

Non-notified application

- decision made not to notify within 10 working days of receipt of all further information;
- assessment of application;
- council's decision within 20 working days of receipt of all further information;
- appeal to the Environment Court by applicant only (in respect of refusal or condition on which the consent is granted).

Note that section 92 (further information required) can apply to the non-notified process as well.

Approximate time to decision — 30 working days (six weeks).

Appeal time — an additional 6-12 months minimum, only if the applicant is not satisfied with the conditions of consent, since there will have been no submitters in opposition.

Council Hearings and Appeal Rights

If resource consents are required from both a territorial authority and a regional authority, joint hearings are often held. An applicant and any submitter may appear and present evidence. The application is usually heard by a sub-committee of elected council officers or independent commissioners. A council planner and/or technical expert(s) will attend the hearing to assist the committee where necessary. Involvement in a council hearing does not create any liability for any other party's costs; however, the applicant pays the cost of preparation for the hearing and council's costs. These costs can be significant for an applicant.

If consent is refused, or granted subject to conditions the applicant does not accept, the applicant may appeal to the Environment Court. If consent is granted, any submitter has a right of appeal. Any appeal must be lodged within 15 days of receiving the decision. Once such an appeal is lodged, it will typically take at least four months before the Environment Court sets a hearing date.

An Environment Court decision may be appealed to the High Court and Court of Appeal, but only on points of law.

The Environment Court

This court is a separate and independent judicial body established under the Act. It has jurisdiction for all appeals to decisions under the Resource Management Act.

The appeal process is a lengthy one. An appeal to the Environment Court is likely to delay a proposal by about 12 months or more.

The costs of bringing an appeal in the Environment Court are substantial and include the preparation of legal submissions and evidence from the applicant and, if necessary, technical experts, and attendance at the hearing. Costs for preparing and attending an appeal hearing escalate rapidly for appeals requiring a variety of experts to be involved.

Appeals in the Environment Court are open to award of costs. Typically, a successful party may seek costs from the other parties, and the Environment Court makes this decision.

A party may seek security for costs from another party in litigation, where there is an apprehension that that party may not have sufficient funds to meet a successful claim for costs.

Many appeals are resolved by mediation and negotiation. The Court actively encourages this approach and provides expert assistance where necessary.

Chapter 3
Landfill Siting

3.1 Introduction

Selection of appropriate sites for new landfills is fundamental to the long-term protection of the environment, both human and physical, from the potential effects of landfilling operations.

Engineered liner systems have a finite lifetime so consideration needs to be made of the ability of the underlying materials to keep discharges from the site to a level that will not cause significant adverse effects on the surrounding environment.

New landfill proposals are commonly subject to significant public debate and opposition. Traditionally, opposition has been in response to the likelihood that particular effects will impact selectively on some sections of the community.

Examples of impacts include traffic hazards, noise, unpleasant odours, windblown litter and dust, an increase in the populations of vermin and wild cats, and threats to household water supplies.

In addition, some people are philosophically opposed to the idea of continued landfilling as a means of refuse disposal.

Even though there is a national trend towards fewer, larger landfills, with consequent economies of scale, large new facilities are not more appealing to potential host communities.

The countryside of New Zealand is becoming more populated. As a result, becomes increasingly difficult to find potential landfill sites that do not pose some sort of conflict with other uses.

Opposition to new landfill sites can be expected to continue, and probably intensify in future. Opposition to a landfill proposal can be manifested by attacks on both the specifics of a proposal and the whole process of site selection.

This section addresses the following:

- landfill siting philosophy;
- strategic planning;
- site selection process; and
- landfill siting criteria.

3.2 Landfill Siting Philosophy

The philosophy behind these landfill site selection guidelines is to assist in the selection of sites that provide both a high level of containment, through their natural, geological, hydrogeological and topographical characteristics, and are located so as to cause minimum disruption to the community in the area surrounding the site.

The use of a robust site selection process and siting criteria to select the most appropriate landfill sites will help avoid or reduce potential environmental problems by reducing the potential impact on people and environmental receptors. In addition, appropriate site selection may:

- reduce reliance on engineered liner systems;
- reduce requirements for technically-based contingency and mitigation measures;
- allow more efficient and effective site management;
- result in savings in development and operating costs;
- reduce levels of public concern and opposition; and
- avoid potential delays in obtaining the necessary resource consents.

The criteria set out in this section are applicable to all municipal solid waste landfills, whether for small rural communities or large metropolitan areas. The same basic processes apply irrespective of the scale of operation.

3.3 Strategic Planning

Selection of a landfill site should ideally involve consideration of strategic waste management issues.

The need for a new landfill site usually results from either a community's solid waste management planning process, or a private company's commercial decision (or possibly a combination of the two).

Consultation undertaken during the strategic planning phase should, ideally, be linked through to appropriate stages in the site selection process to provide continuity with respect to the various individuals, groups or communities involved.

Issues to consider during the strategic planning stage include:

- size of site required to meet current and future disposal requirements;
- potential for, or likely effects of, the use of other waste management options including
  - — reduction
  - — re-use
  - — recycling
  - — composting, and
  - — incineration
- waste management plan of the district in which the landfill is to be located;
- waste management plans of the districts that the landfill will service;
- regional policy statement and applicable regional plan(s);
- location with respect to communities from which the refuse will come; and
- access to transport, either on the appropriate standard of roads or rail access.

3.4 Site Selection Process

Siting of solid waste landfills requires a careful examination and evaluation of all of the parameters that could potentially result in adverse effects on the environment.

The site selection process and criteria set out below should not be viewed as absolute. All potential locations need to be considered in the light of site-specific characteristics, which may result in some parameters being given a greater weighting than others.

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

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

Siting decisions should also be made with regard to local community issues, including needs, expectations and resources.

While landfill siting should be based primarily on technical factors, community perception and values may also be critical to the acceptability of a landfill site. Therefore, it is essential to involve the local community early in the site selection process.

The site selection process should normally include the following processes:

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

Initial Desk-top Study

A number of possible localities or sites should be identified using the following general criteria:

- geology;
- hydrogeology;
- surface hydrology;
- stability;
- topography; and
- compatibility with surrounding land use.

Information from a number of sources can be used in this process, including:

- geological maps;
- topographical maps;
- meteorological rainfall maps;
- Department of Conservation conservation management strategies;
- Historic Places Trust Register;
- district plans;
- regional plans; and
- local knowledge.

Site Investigations

Site investigations should generally follow a staged approach using:

- preliminary investigations;
- initial technical investigations;
- non-technical investigations; and
- detailed technical investigations.

Preliminary Investigations

A 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 this survey, sites should be ranked to determine a shortlist of sites for further investigation.

Care should be exercised when ranking sites as:

- design and operational techniques may elevate, or reduce, the initial status; and
- community issues may affect the status 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:

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

Non-technical Investigations

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

- location of site neighbours;
- location of any sites of cultural significance, including, rivers, streams, Marae, ancestral land, waahi tapu and other taonga (it should be noted that some of these site are not always identifiable);
- potential for nuisances associated with odour, vermin, birds and flies, noise, litter, dust and visual effects;
- access to the site and potential traffic 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 investigations.

An investigation programme should be developed on a site-specific basis. It should address the site selection criteria detailed in Section 3.5, 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 with the resource consent application process.

Economic Assessment

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

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

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

- management, administration and organisational overhead costs;
- planning and resource consent costs;
- land cost;
- development costs, including investigations, de-

sign and construction;

- operational costs;
- monitoring costs;
- closure, rehabilitation and aftercare costs; and
- potential mitigation costs.

Where incomes, other than gate charges, are expected (for example, sale of landfill gas, lease of land not used for landfilling) these should also be included.

Comparison should be made in terms of present value per unit volume, or tonnage, of landfill capacity. Sensitivity with respect to changing costs for key variables should also be checked.

The costs of transporting refuse to different landfill sites should also be taken account of when comparing sites.

Economic assessments should be repeated as the shortlisted number of sites is reduced and more information on site conditions and engineering requirements becomes available.

Additional information on full costing of landfill options is provided in the *Landfill Full Costing Guide*, MfE (1998).

Consultation

Consultation with the community is a critical component of any landfill site selection process.

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

While the decisions on the type and degree of consultation will be specific to each different proposal, the planning of the site selection process should consider the following:

- which parties should be involved in each stage of the selection process;
- the ways in which parties should be involved; and
- the roles of different parties in the process.

The use of community working parties or liaison groups can be an effective means of identifying and taking account of potential community concerns from the strategic planning stage onwards.

There are no standard requirements as to the form consultation must take. Any form of oral or written interchange that allows adequate expression and consideration of views is appropriate. There is also no standard as to the duration of the consultation. It could range from one telephone call to many meetings over a number of years. However, the following provide some useful principles and practices to be guided by:

- Ministry for the Environment practical guides to consultation, including;
  - — *Striking a Balance: A Practice Guide on Consultation and Communication for Project Advocates* (September 1999); and
  - — *Case Law on Tangata Whenua Consultation* (1999).
- The New Zealand Association for Impact Assessment, which has members with considerable experience of consultation activities.

There is a growing body of case law regarding essential principles of good consultation. The most frequently cited court judgement in New Zealand comes from the case of Wellington International Airport Ltd v Air New Zealand [1991][1] .

These principles from the Appeal Court decision provide good guidance for those planning or involved in a consultation process:

- a description of the proposal should be in its conceptual form and not yet finally decided upon;
  - — start consultation early
  - — give yourself the chance to benefit from others' suggestions
  - — don't be embarrassed by finding a fatal flaw just when you've finished the plan
- allow sufficient time for consultation;
  - — other people are busy too
  - — people need time to digest information
  - — try to accommodate interest groups' existing meeting schedules (e.g. monthly); don't impose the burden of additional meetings if this can be avoided
- make a genuine effort to consult;
  - — be proactive
  - — get out and consult
  - — don't expect people to come to you

[1] New Zealand Law Reports 671

  - think of a variety of ways to exchange information
- conduct the process in mutual good faith;
  - show that you are trying to understand how other people see the proposal
  - be open to any suggestions for alternatives or mitigation of effects
  - be prepared to offer your own suggestions unsolicited
  - cross check with others — beware of capture by the "squeeky wheel"
- provide enough information to enable the party being consulted to make intelligent and useful responses;
  - don't hold back information because you think people will react negatively to it
  - don't adopt the attitude that it's alright so long as you present relevant information at the hearing
  - the sooner people know about issues and effects, the more time there is to explore mitigation possibilities
- hold meetings, provide relevant and further information on request;
  - if you offer further information, provide it promptly
  - don't be afraid to call people's bluff — ask for evidence to back up assertions
- r e-open the consultation process if necessary;
  - be flexible and responsive to reasonable and genuine requests — but don't be spineless.

It should be noted that consultation is not:

- merely telling or presenting;
- intended to be a charade; or
- the same as negotiation.

3.5 Landfill Siting Criteria

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

- identifying potential landfill sites; and
- planning site investigations and assessing the suitability of a site for landfilling.

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

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

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

Geology

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

Areas of low permeability in-situ material are preferred. Because engineered liner systems have a finite lifetime, the ability of the underlying materials to minimise the potential for liquids to migrate out of the landfill into the environment should the liner either degrade, tear, or crack needs careful consideration.

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

- high permeability soils, sands, gravels, or substrata;
- high permeability seams or faults; and/or
- Karst geology — regions with highly soluble rocks, sinks and caverns (for example, limestone areas).

Where a landfill is developed in these geological environments, the design should incorporate a higher level of engineered leachate 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 particles (but which are workable in wet conditions) are generally the preferred soil type;

- the suitability of on-site materials for the construction of dams and drainage systems;
- potential sediment management problems, with highly erodible soils;
- existing site contamination and discharges, if present;
- suitability for on-site disposal of leachate by surface or subsurface irrigation; and
- the potential effects of failure of leachate containment and collection systems.

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

Site Stability

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

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

- areas subject to instability, except where the instability is of a shallow or surface nature that can be overcome, in perpetuity, by engineering works;
- active geological faults;
- areas of geothermal activity; and/or
- Karst terrain — regions with highly soluble rocks, sinks and caverns (for example, limestone areas).

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

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

Where there is potential seismic impact, 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.

Hydrogeology

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

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

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

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

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

Surface hydrology

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

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

- flood plains — these are generally areas which could be affected by a major (1 in 100 year) flood event;
- land that is designated as a water supply catchment or reserves for public water supply;

- gullies with significant water ingress, except where this can be controlled by engineering works without risk to the integrity of the landfill;
- water courses and locations requiring culverts through the site and beneath the landfill (if waterways are unable to be diverted); or
- estuaries, marshes and wetlands.

In assessing the suitability of a site for a landfill, the local surface hydrology needs to be considered with respect to the sensitivity of the receiving environment, including the following:

- the proximity of waterbodies or wetlands;
- the risks of pollution of waterbodies used for drinking water or aqua-culture;
- sensitive aquatic ecosystems; and
- potential for impact from cyclones and tsunamis.

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

Topography

Site topography can reduce or increase the potential for adverse effects on the environment from odour, noise, litter, and visual effects on neighbouring properties.

In considering potential landfill sites an assessment of the potential for existing topographical features to assist in minimising impacts should be made.

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

Climatic Conditions

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

Rainfall

Areas where topographical features are likely to cause higher than average rainfall are generally undesirable. Landfills in higher rainfall areas require greater attention to drainage than those in drier areas.

Sunshine

Higher sunshine areas and north facing slopes reduce infiltration by increased evaporation.

Wind

Natural shelter from winds will reduce the nuisance of windblown refuse and dust. Escarpments or valleys facing the prevailing wind should normally be avoided.

Environmentally Sensitive Areas

Landfills should generally be located to avoid areas where sensitive natural ecosystems would be adversely affected, such as:

- significant wetlands;
- inter-tidal areas;
- significant areas of native bush including the Forest Park and areas able to comply with the requirements for QEII Trust status;
- recognised wildlife habitats;
- national/regional and local parks and reserve lands (for example, cemeteries); and
- any areas where release of contaminants from the site could severely affect fish/wildlife/aquatic resources.

Other areas that should be avoided include:

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

Access and traffic

Landfill development and operations can generate significant flows of heavy vehicle traffic. Therefore site access should be as close as possible to main feeder routes. The following need to be considered when locating and determining access to landfills:

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

Compatibility with surrounding land use

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

Separation distances, or buffer areas, can be used to preserve the amenity of surrounding areas. The requirement for and extent of buffer areas should be determined on a site-specific basis. Where possible, the buffer area should be controlled by the landfill operator.

An assessment of the suitability of a site for a landfill, and/or appropriate buffer areas, 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)
  - land designated for a special purpose (for example, hospitals, schools)
- airport safety; and
- proximity to sites with cultural or historical significance.

Leachate Management

Landfill siting should take account of the potential methods of leachate treatment and disposal and its effect on site neighbours.

Methods of leachate treatment and/or disposal could include the following:

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

Landfill Gas Management

Landfill gas can give rise to adverse effects such as:

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

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

Landfill siting should take account of the potential methods of landfill gas treatment and disposal and its effect on site neighbours.

Methods of landfill gas treatment and/or disposal could include those listed below:

- Venting of landfill gas. Effects of odour and non-methane organic compounds (NMOCs) on site neighbours need to be assessed. Greenhouse gas emissions should also be assessed.
- Flaring of landfill gas. Visual (light) and noise effects of landfill gas flares need to be considered.
- On-site power generation. The effects of generator noise and backup flares need to be considered.
- On-site treatment or gas stripping prior to off-site use. The potential odour effects and effects from backup flares needs to be considered.

Community Issues

The local community will have a significant input into determining whether or not a site is suitable for development as a landfill. Many of the issues, which can be of greatest concern to the local community, may not be those identified through technical studies or investigations.

These issues, many of which are detailed above, include, but are not limited to:

- design life of the landfill;
- nuisances associated with odour, vermin, birds and flies, noise, litter, dust and visual effects;

- the potential effects of failure of containment, leachate collection or landfill gas systems;
- protection of local amenity values;
- traffic effects;
- health risks;
- cultural issues;
- heritage issues;
- loss of property values;
- long-term compliance with consent requirements; and/or
- end use of the site.

Consultation and negotiation with the community during the siting process is required to determine issues of site-specific importance, the actual, or perceived, risks and appropriate measures to avoid, remedy or mitigate adverse effects on the environment.

Chapter 4
Landfill Design

4.1 Introduction

The landfill design process is affected by the following factors:

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

Internationally, a range of legislative instruments and design guidelines are used to control landfill design. The principal ones relevant to the New Zealand context are summarised in Appendix 2.

As outlined in Chapter 1, these guidelines focus on municipal solid waste landfills.

Many of the principles involved are also relevant to the design of cleanfill sites, industrial waste landfills (including monofills), and to hazardous waste landfills, but these are beyond the scope of these guidelines. In the case of cleanfills, most regions have specific provisions for the design of such facilities included in their regional plans.

This section is intended as a guideline for landfill developers, designers and regulatory authorities. It does not attempt to repeat the wide range of design material that already exists, but focuses on key principles and applicable approaches.

Key points to note are:

- the acceptance of any design by a regulatory authority will be based on an assessment of actual and potential effects on the environment, which requires detailed technical evaluation and justification; and
- the guidelines refer to designs considered to provide a suitable level of leachate retention, thus providing a reasonable assurance of protection of the receiving environment.

These design guidelines are not prescriptive. They are intended to provide design guidance based on industry best practice and consistent with processes set out in the Resource Management Act (1991).

This section addresses the following:

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

4.2 Design Philosophy

General

The design of a landfill should ensure that biological, biochemical and physico-chemical interactions within the waste are promoted, fostering naturally-generated processes that both degrade and stabilise wastes, and ultimately render the resulting residues benign to the environment.

Enhanced degradation, and consequent reduction in the time required to stabilise wastes, can be achieved by:

- leachate recirculation;
- bioreactor design and operation; and
- aerobic landfill design and operation.

Leachate recirculation is used at some sites in New Zealand and could be implemented more in the near future, both for leachate treatment and to enhance degradation. It is discussed in Section 4.9.

A bioreactor landfill is a landfill operated for the purpose of transforming and stabilising the readily and moderately decomposable organic waste constituents within 5 to 10 years following closure by purposeful control to enhance microbiological processes. A bioreactor landfill is an extension of a leachate recirculation landfill, except that water may be added or substituted for leachate (depending on climatic conditions) and other process-enhancing strategies, such as waste shredding, pH adjustment, nutrient addition and temperature management, may be included. Bioreactor design and operation involves more intensive design, management and monitoring to carefully control waste moisture content and leachate chemistry to optimize degradation.

Aerobic landfill design and operation aims to maintain waste in an aerobic state to achieve faster degradation than would result from anaerobic breakdown.

Bioreactor and aerobic landfills have not been designed or operated in New Zealand to date. They have considerably more detailed design, operations and monitoring requirements in terms of leachate containment and recirculation and landfill gas management, than more traditional approaches.

Bioreactor and aerobic landfills are currently in the development and research stage worldwide. Bioreactor and aerobic landfills are unlikely to be developed in New Zealand in the near future and therefore guidelines for their design, operation and monitoring are considered to be beyond the scope of these guidelines.

However, it is important to continue monitoring overseas research and trials to identify aspects of bioreactor landfill design principles, which may be applicable in the New Zealand situation.

Irrespective of design philosophy, protecting groundwater and surface water from leachate contamination, and people from the adverse effects of landfill gas, remain the principal environmental performance objectives with respect to landfill design. While many of the potential risks associated with landfills can be mitigated by judicious siting, appropriate design is critical in avoiding adverse effects on the environment due to leachate and gas discharges.

International Trends in MSWL Design

International trends in MSWL design are summarised in Appendix 2. In all cases, the primary objective of the design process, or stipulated standard designs (legal requirements in some instances), is to protect the environment around the landfill. In the past, the focus has tended to be on the prevention of leachate escape and consequential effects on groundwater and surface water. However, experience in New Zealand and elsewhere over the past 10 years in particular, has indicated that other environmental issues are also very important. Such issues include odorous waste acceptance, odour and landfill gas (LFG) control, stormwater and sediment effects on surface waters, and dust management. Consideration of these issues as part of the design process has been incorporated in these guidelines.

New Zealand Landfill Design Trends

In New Zealand a number of trends (paralleling overseas practice) have emerged over the past 10 years or so in relation to MSWL design. These include:

- general improvement in design standards, particularly with regard to liner and cover systems, leachate collection and treatment, and landfill gas control at new or large sites;
- resistance to upgrading costs and consequent costs, especially for smaller sites;
- centralisation of landfill facilities and an increase in waste transfer to fewer, larger (sometimes sub-regional) facilities;
- greater recognition of the siting sensitivity attached to landfills and the need for both good design and stringent operating practices;
- adoption of overseas (often USA-based) practices for barrier system design (particularly for larger sites) in some areas;
- inadequacy of design in the absence of binding (legal) requirements for design and the relative lack of case law under the RMA in some areas;
- an increasing focus on the consequential effects associated with larger sites (e.g. local amenity and odour issues); and
- debate over the level of prescriptive design appropriate in the New Zealand context, and the adequacy of “effects-based” design in the absence of site-specific performance data.

Design Objectives

The design of a municipal solid waste landfill should provide for the following, to a degree appropriate to the landfill’s size and location:

- a leachate retention system to protect ground and surface water;
- a leachate management system;
- landfill gas control and/or monitoring;
- a surface water management system;
- site capping and rehabilitation;
- environmental monitoring; and

- site security and ancillary facilities.

In addition, management procedures should be provided to:

- track the types, quantities and sources of wastes received;
- adequately monitor the compaction of the wastes and record the position of certain special wastes burials; and
- provide quality assurance procedures for construction, operation and aftercare of the site.

4.3 Design Considerations

Landfill Siting

Location is a primary determinant of the extent to which a landfill poses an environmental risk. Judicious location of a landfill is the single most effective environmental management tool. The aim is to minimise the need for impact mitigation and ongoing management by selecting a site where natural conditions protect environmental quality and where there will not be adverse impact on existing and future development.

The hydrogeological characteristics of a site have a critical bearing on the need for, and nature of, measures to control leachate. The potential for environmental damage by leachate is more critical if the landfill is located where there is significant downstream use of surface or groundwater resources or where conditions result in significant physical or local amenity risk. Landfills can also cause a localised loss of amenity due to litter, dust, odour, noise, and vermin problems. Proximity to existing and proposed developments, the adequacy of proposed site management procedures and local climatic conditions are key issues in this regard.

Investigations and Site Characterisation

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

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

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

- characterisation of the geological, hydrogeological and geotechnical conditions at the site;
- specific data on site soil properties, including, for relevant materials, where a soil liner is involved:
    - — index tests, water content, Atterberg limits, grain size and solid density;
    - — compaction characteristics (generally the New Zealand Heavy compaction test should be used);
    - — permeability determined at optimum water content or wetter to simulate soil remoulding at field target water content (testing should be pressure permeability in a triaxial cell using tap water as the permeate, or leachate if conditions warrant); and
    - — soil security tests, pinhole dispersion, Emerson crumb test, and, where appropriate, tests on stabilised soils appropriate to the materials and site location;
- definition and characterisation of surface waters, including receiving waters;
- 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.

Access

Public Access or Not?

Landfilling operations should, ideally, exclude public access to the working face.

There are significant disadvantages in allowing public access to the working area of a landfill. These disadvantages include:

- lack of control on placing of refuse;
- the need to provide vehicle control, larger refuse discharging areas, and better roading to the working face;
- having a larger (wider) tipping face open, with the consequences of more litter control problems, greater rodent and bird problems, increased stormwater infiltration, greater fire risk and more cover material required;
- public health risk, particularly from special wastes and scavenging; and
- additional transportation costs to the community.

A transfer station or reception facility should be established, either at the landfill (remote from the tipping face) or at some other location closer to the centre of refuse generation.

The distance of the landfill from the centre of refuse generation will influence the economics of providing a transfer station there, or a reception facility at the landfill site.

Access to the landfill by larger-volume refuse contractors should be allowed by special arrangement, but only where it is more economical than accepting this material at a transfer station.

External Access

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

Access to a landfill should be planned in such a way that it creates minimal hindrance to existing road users. Access should, where possible, be on sealed roads to reduce dust and mud nuisance, reduce maintenance and facilitate cleaning.

Careful consideration should be given to the requirements of the road control authority, that is, Transit New Zealand or the territorial local authority.

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 facility, laid out so that queuing vehicles do not back up on public roads.

The appearance of the accessway is important as this will influence the users' perception and, hence, behaviour in the landfill area.

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

At larger landfills, where internal roads should either be permanent or have a substantial service period, roads should be sealed, particularly if on steep gradients. Temporary access roads should be constructed to an all-weather standard.

If a special reception area is available to the public, particular care will be required in the design, layout and operation of traffic control systems. Unloading areas should provide, separately, for both small and large vehicles.

Site Facilities

Site Entrance Notification

Signs should be provided to ensure all users are made aware of the following:

- access restrictions;
- days and hours of opening;
- acceptable (or prohibited) wastes;
- materials accepted for recycling;
- disposal charges;
- documentation that must accompany any waste load;
- level of control and inspection of wastes to be undertaken;
- name and emergency contact number of the facility operator; and
- name of the facility owner.

Directional signage should be provided to assist smooth traffic flow to the reception facilities, weighbridge, payment booth, recycling compound and unloading areas, as appropriate.

All signs, should give information in a concise, easy-to-read and attractive manner.

Weighbridge

Accurate data on the quantity of waste disposed of in the landfill is important for operational control, future development of the site and long-term planning. The most accurate way of obtaining the required data is to weigh incoming refuse.

A weighbridge provides the most equitable method for assessing charges to users, particularly commercial users. It can also assist in determining in-place densities of the filling area for landfill control purposes.

The importance of data for deriving waste quantities now means that weighbridges may be justified even for landfills for relatively small communities.

Charging Booth

A booth should be provided for the gathering of fees or coupons and the recording of user data to enable invoicing of frequent, large-volume users.

Important aspects to consider for the booth are:

- siting;

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

- security for the cash and the cashier; and
- accounting procedures.

Operational Facilities

The nature and extent of facilities related to the operational needs of the landfill will, to some extent, depend on the size of the operation.

Facilities that would normally be required include:

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

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

Services

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

Water should be available in adequate quantity for fire-fighting. Piped (domestic) supplies may be supplemented for this purpose by making provision for water to be pumped from on-site ponds.

Hazardous Waste Reception and Storage Compound

Consideration may need to be given to the reception and storage of small quantities of hazardous materials (for example, used oil), particularly if there is no other facility for hazardous waste treatment or disposal within a reasonable distance.

Important features of a hazardous waste storage compound are:

- secure and lockable;
- bunded, sealed floor to contain spills;
- completely covered, including walls, but well ventilated; and
- good access for the handling of drums.

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

Wheel Wash Facilities

Wheel wash facilities should be provided where soil type will cause a major off-site nuisance, such as tracking mud on to public roads. Typical problem soils are clays and sensitive silts. Adequate internal roading constructed with good metal or seal can eliminate the need for wheel wash facilities.

Wash water should be tested for contamination and drained to sedimentation ponds prior to discharge. If contaminated, wash water may need to be disposed of to the leachate disposal system.

Fencing and Gate

Landfills should be fully fenced along all site boundaries to ensure the safety of the general public and prevent unauthorised entry and disposal.

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

Landscaping

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

In some cases there could be advantages in contouring the perimeter of the site to provide screening by earth mounds, and these could also be planted. Earth banks or bunds can also provide effective noise barriers.

Final Use and Final Landform

Key aspects of landfill design are the determination of the final landform, the method of final reinstatement and final uses for the site.

The most common final uses for completed landfills are:

- passive recreation (gardens, parks, golf courses); and

- controlled farming (agriculture or horticulture).

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

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

The end use options and final landform should be canvassed during the initial site selection, public consultation and resource consent processes. The plan of the final landform contours should be prepared as part of the design process prior to consent applications.

The final filling levels should be carefully controlled in accordance with this plan.

Site Capacity

Having determined the final shape of the completed landfill relative to the initial contours, the total volume able to be contained on the site can be calculated.

An estimate of the compacted density of the refuse that will be achieved on the site, and of the compacted volume of daily, intermediate and final cover required over the life of the site, must be made in order to estimate the total refuse tonnage that can be accommodated.

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

To make an allowance for daily cover, a waste to daily cover volume of between 4:1 and 5:1 can be expected. Intermediate and final cover volumes can be estimated from their thickness.

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

Assuming the refuse stream to the site can be quantified (making due allowance for predicted changes over the life of the facility), the likely lifespan of the facility can then be predicted.

The appropriate range of design densities for compacted refuse will depend on the compaction plant available, effort applied (as in earth compaction), and operation methods adopted. For example, where a refuse landfill is operated by contract, a payment system that rewards the achievement of high densities and penalises the non-achievement of target densities, is more likely to consistently achieve the waste density adopted for design purposes.

Staging of Site Development

Much of New Zealand is subject to relatively high rainfall and short duration, high intensity rainfall events. These factors make it important that measures are taken to reduce rainfall infiltration into the landfilled refuse, and control leachate production.

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

A development programme for the proposed landfill should be prepared, using a series of plans that show the areas and sequencing of the landfill operation. These should outline the measures required at each stage for leachate collection, treatment and disposal, stormwater drainage and silt control, cover material source, and access roading, and how these will be provided throughout the life of the site.

Figure 4.1 shows a typical operational plan for a landfill site.

Cells

One method of landfilling involves placing wastes within pre-bunded areas to form cells. This method can be used on medium-sized to large landfills, and encourages progressive filling and restoration.

Cells can vary in size depending on:

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

Daily cells may be constructed within a larger cell if filling rates are high. Using the cell method allows surface water accumulating in prepared landfill areas to be treated as stormwater, prior to coming into

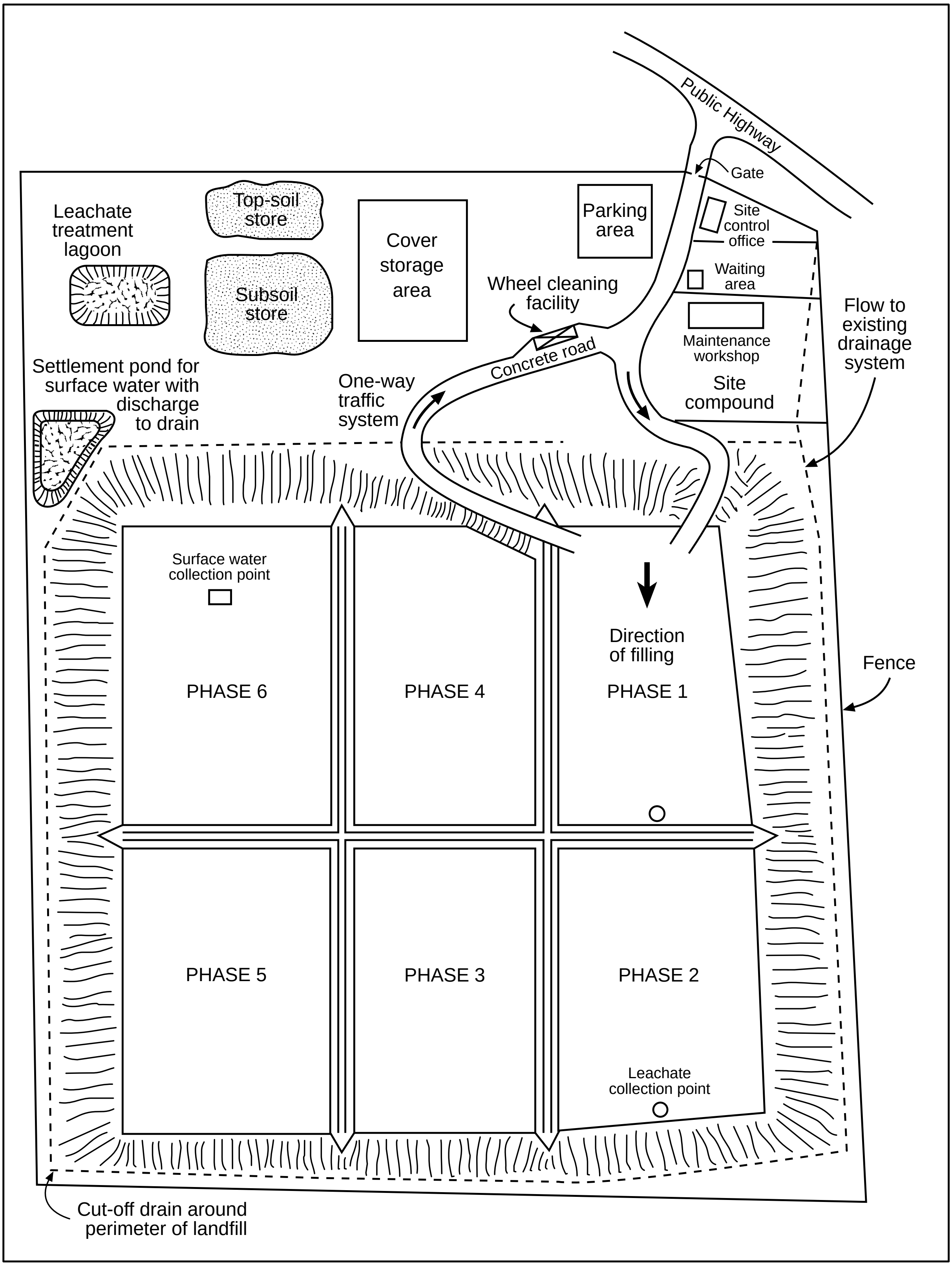


Figure 4.1: Typical operational plan for landfill site

(Figure 5.16B From UK Department of the Environment Waste Management Paper No. 26 (1986))

contact with refuse and also minimises leachate production. Cells constructed within the landfill should be built from a suitably inert and free-draining material to avoid stratified layers within the landfill.

If the cell method of landfilling is used, the design balance between lost landfill space versus cell size should be considered. Cell walls should exceed refuse height during filling, and hydraulic lift must be considered in sites prone to varying groundwater tables.

Cell walls may be constructed in low permeability material to retain leachate if this is consistent with the design of the leachate collection and removal system. It is important that cell wall construction is carried out with suitable structural stability to ensure the continued retention of waste and in such a way that the wall may, if required, be removed when the adjoining cell is constructed. Care should be taken to ensure that leachate breakout does not occur through the wall.

4.4 Groundwater Management and Control

General

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

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

Site investigations should clearly determine groundwater flows in the area of the site and the maximum range of groundwater levels.

Normally the landfill liner system should be located above the groundwater table with an unsaturated zone immediately below the liner. Stringent management is required for groundwater seepages from either the sides or base of landfills located in excavations below the groundwater table. In such cases it is necessary to relieve hydrostatic pressures that may otherwise cause uplift forces on the landfill liner and hence potential instability or rupture.

The protection of groundwater from the impact of landfill leachate is covered in Section 4.6.

Groundwater Drainage

In situations where the landfill is located below the water table, an under drainage system should be provided to intercept groundwater seepages and to control groundwater levels beneath the landfill area. A gravity drainage system is preferred for all long-term requirements.

Design of an under drainage system should consider the following:

- pipes designed to allow inspection and maintenance and to carry the maximum probable flow;
- 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
- protection of pipes to ensure risk of 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 clogging and possible deterioration. In addition, it is preferable to design the under drainage system to enable use of closed circuit television (CCTV) and remote control hydro-jetting equipment for inspection and cleaning of pipework.

Groundwater drainage discharge flowrate and quality should be regularly monitored to detect any leachate contamination. This is discussed in Section 6.4.

4.5 Surface Water and Stormwater Management

General

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

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

Surface Water and Stormwater Control

The surface water management objectives listed above may be achieved by the following control measures.

- Interception drains surrounding the active fill area to prevent overland flow from entering the active fill area should be provided.

- Rainfall falling on the active fill area should be collected and managed as leachate via the leachate collection, treatment and disposal system.
- Rainfall run-off from slopes outside and above the landfill should be intercepted and diverted to watercourses. These diversion drains/channels may require invert protection to prevent scour and/or lining to prevent leakage into the landfill.
- Drainage channels or drains constructed on the completed landfill surface should be designed and constructed to accommodate settlement, minimise or eliminate erosion, and cope with localised design storms.
- Completed 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.

Surface Water Discharges

Water discharged from any of the above sources to surface water courses must be disposed in accordance with the discharge permit(s), which may stipulate both quality and quantity limits.

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

Sedimentation ponds should be developed prior to discharge of surface waters to natural stream or river flows. The ponds and traps should be designed to ensure easy maintenance and cleaning.

4.6 Leachate Generation and Characteristics

Leachate Characteristics

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

Decomposition of the putrescible waste takes place by the action of microbes. It occurs in three stages. In the first stage, degradable waste is attacked by aerobic organisms, resulting in production of organic compounds, carbon dioxide and water. Heat is generated and the aerobic organisms multiply.

The second stage commences when all the oxygen is consumed or displaced by carbon dioxide. Aerobic organisms, which thrived when oxygen was available, die off. The degradation process is then taken over by facultative organisms that can thrive in either the presence or absence of oxygen. These organisms can break down the large organic molecules present in food, paper and similar waste into more simple compounds such as hydrogen, ammonia, water, carbon dioxide and organic acids. 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 anaerobic, or methanogenic phase) methane-forming organisms multiply and break down organic acids to form methane gas and other products. The water soluble degradation products from these biological processes, together with other soluble components in the waste, are present in leachate. In addition, pH changes and acid formation may mobilise metals and increase their content in the leachate. Table 4.1 shows the changes in leachate composition that occur as a landfill proceeds through the various phases of decomposition.

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

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

Household waste is reasonably consistent in composition over all landfill sites, as is the resulting leachate. Leachate composition at sites accepting predominantly industrial waste is much more variable.

The composition of leachates is generally in the form of a clear liquid which turns black and odorous upon contact with air. The rate of generation of leachate is closely linked to the water balance within the landfill, but even in very dry landfills there is enough moisture to generate small quantities of leachate.

Parameters with differences between acetic and methanogenic phase			Parameters for which no differences between phases could be observed		
Acetic phase	**Average**	**Range**		**Average**	**Range**
PH	6.1	4.5-7.5	Cl (mg/l)	2100	100-5000
BOD_5 (mg/l)	13000	4000-40000	Na (mg/l)	1350	50-4000
COD (mg/l)	22000	6000-60000	K (mg/l)	1100	10-2500
BOD_5 /COD	0.58	--	Alkalinity (mg $CaCO_3$/l)	6700	300-11500
SO_4 (mg/l)	500	70-1750	NH_4 (mg N/l)	750	30-3000
Ca (mg/l)	1200	10-2500	OrgN (mg N/l)	600	10-4250
Mg (mg/l)	470	50-1150	Total N (mg N/l)	1250	50-5000
Fe (mg/l)	780	20-2100	NO_3 (mg N/l)	3	0.1-50
Mn (mg/l)	25	0.3-65	NO_2 (mg N/l)	0.5	0-25
Zn (mg/l)	5	0.1-120	Total P (mg P.l)	6	0.1-30
			AOX (ug/Cl/l)*	2000	320-3500
Methanogenic phase			As (ug/l)	160	5-1600
pH	8	7.5-9	Cd (ug/l)	6	.5-140
BOD_5 (mg/l)	180	20-550	Co (ug/l)	55	4-950
COD (mg/l)	3000	500-4500	Ni (ug/l)	200	20-2050
BOD_5 /COD	0.06	--	Pb (ug/l)	90	8-1020
SO_4 (mg/l)	80	10-420	Cr (ug/l)	300	30-1600
Ca (mg/l)	60	20-600	Cu (ug/l)	80	4-1400
Mg (mg/l)	180	40-350	Hg (ug/l)	10	0.2-50
Fe (mg/l)	15	3-280			
Mn (mg/l)	0.7	0.03-45	* adsorbable organic halogen		
Zn (mg/l)	0.6	0.03-4			

Table 4.1: Changes in leachate composition in different stages of a landfill
(Source: Ehrig, H. J., "Water and Element Balances of Landfills" in Lecture Notes in *Earth Sciences: The Landfill*, 1989)

In order to determine leachate composition, leachate analysis needs to be undertaken at regular intervals.

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

Leachate Characteristics at New Zealand Landfills

The leachate characteristics for a number of New Zealand landfills are listed in Table 4.2.

This data reflects the differences in the monitoring conditions set for each landfill. For example, at the Horotiu Landfill, leachate from 14 cells is required to be monitored. The low concentrations given for Horotiu are from a cell closed for more than 10 years and the high concentrations are from a currently operating cell. At the Rosedale Rd Landfill, the high leachate concentrations are from a currently operating cell and the low concentrations are composite leachate from the whole site prior to sewer discharge. The highs and lows at Redruth, Redvale and Southern Landfills represent the maximum and minimum levels in the range of results obtained for leachate collected from the same location over time.

Factors Affecting Leachate Generation

The factors that influence leachate generation at landfills include:

- **Climate**: Climate at the site significantly influences the leachate generation rate. All other factors being equal, a site located in an area of high precipitation can be expected to generate more leachate.
- **Topography**: Topography affects the site's runoff

		Horotiu 1999[1]		Redvale 1999[2]		Redruth 1999[3]		York Valley 1998[4]	Omarunui 1998[5]	Southern 1998-99[6]		Rosedale Rd 1998[7]		Greenmount 1998[7]
Parameter	units	low	high	low	high	low	high			low	high	low	high	
Alkalinity	mg/l	264	6820	*	*	1200	3800	1860	3500	*	*	1260	4723	*
Aluminium	mg/l	0.046	4.1	0.16	3.17	0.05	7.9	*	0.06	0.019	190	*	*	*
Ammoniacal nitrogen	mg/l	67.1	1440	50	285	0.13	400	290	428	3.4	47	178.4	766	684
Arsenic	mg/l	0.006	0.18	0.008	0.07	0.004	0.17	0.14	0.019	0.013	0.055	0.0073	0.0845	0.191
Boron	mg/l	0.54	19	3.4	20.1	1.1	5.8	7.2	10	0.61	1.1	2.1	7.9	8.06
Biological oxygen demand	mg/l	14	166	50	3867	14	>220	530	100	12	40	<23	220	230
Cadmium	mg/l	<0.001	<0.001	0.0004	0.01	<0.006	<0.05	0.003	0.0008	0.0003	0.001	<0.005	<0.005	<0.005
Calcium	mg/l	85	380	64	620	36	370	*	95	*	*	69	86	92.5
Chloride	mg/l	74.9	1450	45	758	690	7300	410	2584	130	283	294	1024	867
Chromium	mg/l	0.012	0.12	0.03	50.4	<0.05	0.11	0.08	0.1	0.005	0.16	0.015	0.218	0.13
Chemical oxygen demand	mg/l	213	1950	84	5090	*	*	1200	1260	109	136	*	*	1040
Conductivity	S/cm	1905	15650	2300	24300	308	2546	*	11450	15130	27900	3280	11310	9290
Dissolved reactive phosphorus	mg/l	0.012	6.54	0.03	0.32	*	*	*	*	0.1	0.1	0.04	*	*
Iron	mg/l	3.7	32	1.6	198	3.5	14	178	2	15	220	8.2	7.57	2.87
Lead	mg/l	0.001	0.014	0.007	0.17	0.089	*	0.02	<0.01	0.001	0.42	<0.02	<0.02	0.09
Magnesium	mg/l	20	200	81	175	10	690	*	140	*	*	36.5	82	87.5
Manganese	mg/l	0.67	4	0.45	5.5	0.49	5.2	4.6	0.55	10	12	*	*	0.894
Nickel	mg/l	0.012	0.14	0.05	19.5	0.019	0.037	0.03	0.35	0.001	0.14	0.034	0.093	0.124
Nitrate nitrogen	mg/l	0.003	0.12	0.01	1.1	<0.01	0.017	0.06	2.1	0.01	0.09	*	*	*
pH	pH Units	5.9	7.4	6.3	8.2	6.5	7.7	*	8.5	6.2	6.5	*	*	7.5
Potassium	mg/l	80	740	204	358	7.2	380	150	720	*	*	131.2	540	306
Silica	mg/l	12	36	*	*	*	*	*	*	*	*	*	*	*
Sodium	mg/l	57	970	500	755	20	4250	290	1360	*	*	222	812	780
Sulphate	mg/l	1	499	7	45	22	780	32	23	*	*	18.5	53.1	84.7
Suspended solids	mg/l	*	*	1860	48	50	110	*	*	*	*	*	*	*
Total Kjeldhal nitrogen	mg/l	70.5	1370	*	*	*	*	*	*	*	*	186	793	*
Total oganic carbon	mg/l	87.3	822	*	*	17.2	640	*	378	*	*	*	*	*
Total hardness	mg/l	*	*	2270	627	150	3760	*	*	*	*	172.5	215	231.3
Total phenols	mg/l	*	*	*	*	*	*	*	0.0046	*	*	*	*	*
Volatile acids	mg/l	*	*	*	*	<4	672	*	0.32	*	*	*	*	*
Zinc	mg/l	0.015	0.8	0.13	24.2	0.1	1	1.6	0.6	0.009	1.1	0.145	0.158	0.233
Total VOC**	mg/l	0.22	0.87	0.003	23.4	0.10	0.15	*	<LOD	*	*	*	*	0.11
Total SVOC**	mg/l	0.06	0.15	0.0006	8.7	<LOD	<LOD	*	<LOD	*	*	*	*	0.004

Metals analyses are for total metals * not reported ** excluding LOD values (LOD = Limit of Detection)
Source: 1 - Hamilton City Council, 2 - Waste Management NZ Ltd, 3 - Timaru District Council, 4 - Nelson City Council, 5 - Hastings District Council, 6 - Wellington City Council , 7 - Envirowaste Services Ltd

Table 4.2: Leachate characteristics at selected New Zealand landfills

pattern and the amount of water entering and leaving the site. Landfills should be designed to limit leachate generation from areas peripheral to the site by constructing perimeter stormwater drainage systems to divert surface water "run-on" away from the site and by constructing the landfill cover to promote runoff and reduce infiltration. All areas of a landfill should maintain at least two percent grade over the waste at all times to prevent ponding of surface water.

- **Landfill Cover**: Landfill cover at the site affects the amount of water percolating into the landfill to 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 with poor vegetative cover may experience erosion that cuts gullies through the cover soil and allows precipitation to flow directly into the landfilled waste.
- **Type of waste**: The type of waste, the water content of the waste and the form that it is in (bulk, shredded, etc.) affect both the composition and quantity of leachate. Wetter wastes, for example, will generate more leachate.

Predicting Leachate Production Rates

Sound landfill design requires calculation of expected leachate production. The amount of leachate generated will affect operating costs if leachate collection and treatment are provided. The amount of leachate formed also affects the potential for liner leakage and hence the potential for groundwater contamination. It also affects the cost of post-closure care.

Predicting leachate generation quantities requires water balance calculations. The issues to consider in developing a site water balance are illustrated in Figure 4.2. A water balance equation is presented below.

$$L_0 = P - SRO - ET - DS$$

where

L_0 = leachate production (m^3/year)

P = precipitation (m^3/year)

SRO = surface runoff (m^3/year)

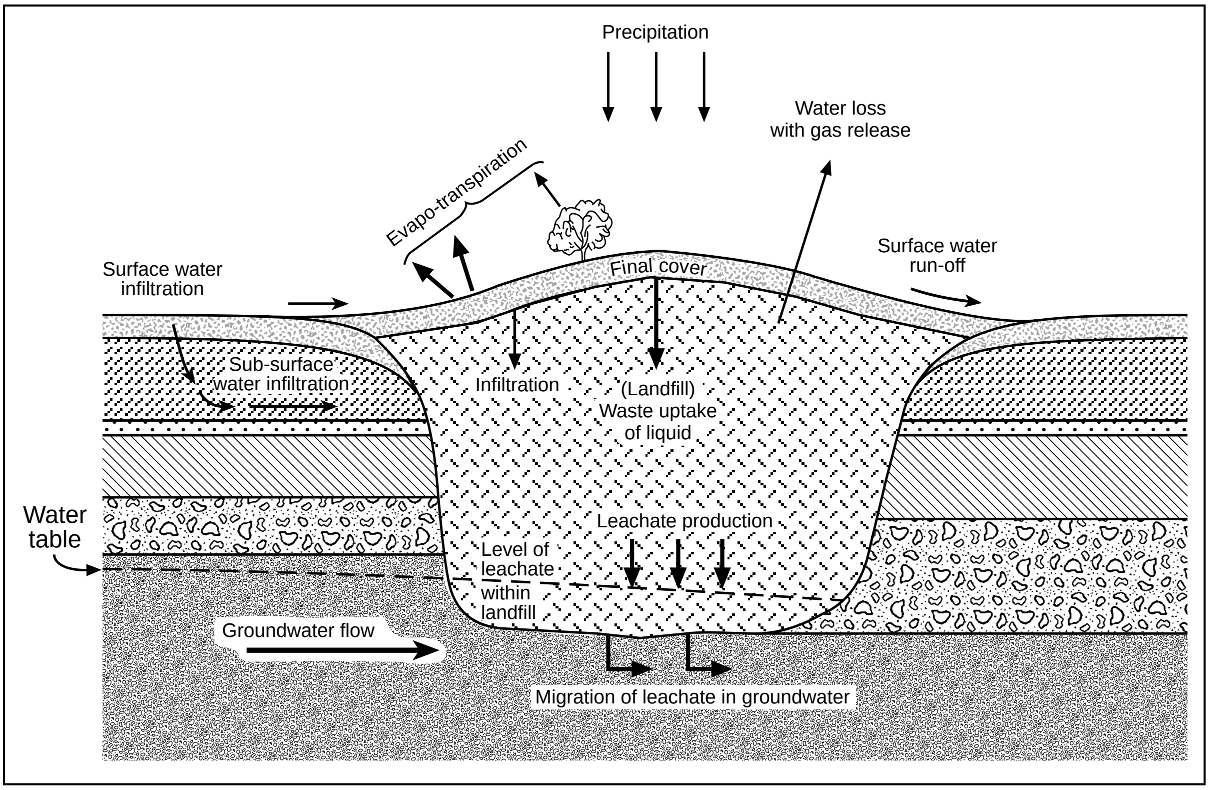


Figure 4.2 Landfill water balance issues

(Figure 3.3 from UK Department of the Environment Waste Management Paper No. 26 (1986))

ET = evapotranspiration (m^3/year)

DS = change in leachate storage of the waste (m^3/year)

The equation estimates the amount of water from rain or melting snow that will percolate through the landfill cover. Over time, the volume of percolating water will nearly equal the volume of leachate produced. There may be a lag between the time percolating water enters the fill material and the time leachate emanates continuously from the base of the fill. During this lag period the landfilled wastes increase in moisture content until their field capacity is reached (field capacity is defined as the moisture content of the waste above which downward flow of moisture will occur under the influence of gravity). Some leachate will be generated intermittently (almost immediately in wet climates), because of water channelling through the wastes. However, once field capacity is achieved, leachate production should be more consistent.

The USEPA, in co-operation with the Army Corps of Engineers Waterways Experiment Laboratory, has prepared a computer program, Hydrologic Evaluation of Landfill Performance (HELP), to calculate the water balance of landfills. The HELP model version 3.0 has weather records in data files and a weather generator program to generate site-specific precipitation, air temperature and solar radiation data and offers options for predicting leachate generation under many combinations of cover conditions.

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

4.7 Leachate Retention and Liner Systems

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

- a leachate retention (or liner) system; and
- a leachate collection system.

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

These guidelines, while recognising the statutory requirements for site-specific, effects-based design, also incorporate designs shown to provide a suitable level of leachate retention at sites with a good level of natural retention, selected in accordance with the site selection criteria in Chapter 3.

In preparing a leachate retention system design, a site-specific assessment of effects on the environment must be prepared to characterise the site and local environment, identify environmental receptors and evaluate the potential risks due to the landfill. This assessment will need to address:

- geology;
- hydrogeology;
- surface hydrology;
- stability; and
- environmentally sensitive areas.

In order to obtain sufficient information to assess actual and potential effects that could result from the use of a design, specific investigations and studies should include:

- sufficient surface and subsurface investigations, by mapping, test pitting, drilling and monitoring to;
  - — develop geological cross-sections for materials beneath the site
  - — determine depth to water table and seasonal water table fluctuations
  - — confirm the existence of groundwater divides
  - — measure hydraulic conductivities of materials beneath the site
  - — determine rate and direction of groundwater flow, both vertical and horizontal
  - — identify potential preferential flowpaths for leachate and groundwater movement
  - — determine the dispersion characteristics of the aquifer
  - — locate aquifer recharge and discharge areas, seeps and springs
  - — determine baseline groundwater and surface water quality
  - — determine distance to and sensitivity of groundwater and surface water receptors or users

— determine stability of materials underlying the landfill site

- an assessment of likely quantity and quality of leachate produced;
- an assessment of potential effects of failure of leachate retention and collection systems; and
- an initial evaluation of potential contingency measures to remediate the effects of retention system failure.

It is important to note that an engineered liner system is not a perfectly impermeable barrier, and over time it will allow relatively minor amounts of leachate into the underlying soil and groundwater system. The liner needs to be designed to ensure that the quantity of leachate leakage and its concentration do not pose a risk to the environment. Design needs to take into account the combination of liner hydraulic and chemical diffusion and attenuation performance.

Leachate discharges from a landfill will potentially occur over a period of time in excess of 30-50 years following closure, with the leachate varying in strength over time. It is difficult to predict the rate and quantity of leachate discharges, both over time and in response to various events that could result in liner failure, and the likely effects of these discharges. Therefore, a degree of redundancy is required in any liner design.

The following three liner designs, illustrated in Figure 4.3, are recommended, 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.

(a) A single liner comprising 900 mm of clay or other low permeability soils compacted in layers a maximum of 150 mm thick, to achieve a coefficient of permeability not exceeding 1×10^{-9} m/sec;

(b) A composite liner comprising a synthetic flexible membrane, 1.5 mm thick, overlying 600 mm of clay with a coefficient of permeability not exceeding 1×10^{-9} m/sec;

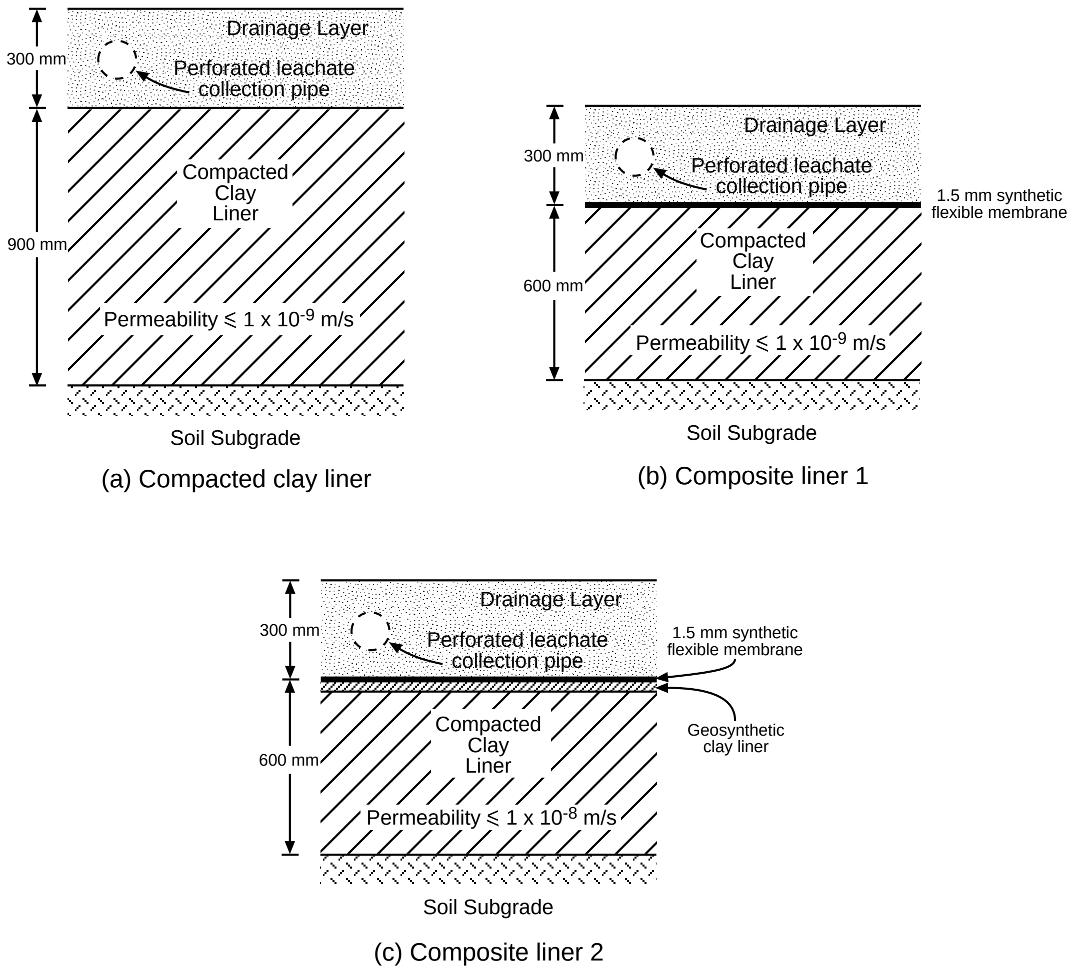


Figure 4.3 Recommended liner designs

(c) A composite liner comprising a synthetic flexible membrane 1.5 mm thick, overlying a geosynthetic clay liner (GCL), a minimum of 5 mm thick, with a coefficient of permeability not exceeding 1×10^{-11} m/s, overlying a 600 mm thick compacted sub-base layer with a coefficient of permeability not exceeding 1×10^{-8} m/s.

However, other designs could be suitable at some sites, after taking into account one or more of the following factors:

- landfill size;
- favourable geological and natural containment characteristics;
- unfavourable geological or hydrogeological characteristics; and/or
- proximity to, and sensitivity of, surrounding environments.

In considering alternative design requirements a quantitative evaluation of retention system leakage and a quantitative assessment of effects on the receiving environment, including a quantitative assessment of leachate migration and attenuation should be undertaken. This is likely to require significantly more investigation and consent documentation than would be necessary for the recommended designs, and include:

- an assessment of the quantity of leachate leakage through the retention system, by both advection and diffusion;
- leachate attenuation tests on materials underlying the site, using leachate similar to that expected at the site;
- an assessment of likely leachate concentration in groundwater at the site boundary or receiving environment; and
- an assessment of the effects of leachate contamination on the receptor environment(s).

Where groundwater resources, with existing or potential users, exist within 1000 metres of the landfill, then a risk analysis should be undertaken to confirm the adequacy of design.

Where the containment is based on natural site characteristics, an engineered barrier layer comprising one of the following should be used to reduce the potential for leakage due to inconsistencies in the natural site materials:

- re-compaction of site soils to achieve a minimum 300 mm thick layer of demonstrated permeability of $< 1 \times 10^{-9}$ m/s, suitably protected from damage or desiccation; and
- an FML barrier, suitably protected from damage, over prepared in-situ low permeability soils.

The permeability of less than 1×10^{-9} m/s, recommended for the clay liner component of the first two designs, is aimed at ensuring that overall installed liner permeability is not great enough to result in significant leakage, when scale, construction and post-construction effects are allowed for. Permeability of liner materials should be determined using pressure permeability methods (such as in a triaxial cell) and using New Zealand heavy compaction to simulate field compaction of liner materials.

In all cases the emphasis must be on adequately demonstrating that the design will avoid potential adverse effects and not result in long-term environmental degradation.

It should be noted that, due to the long-term potential for discharges from landfills, a lack of monitored or observed adverse effects from an existing landfill site is not in itself sufficient justification for a lateral expansion using past design practices, without additional investigations on areas proposed for expansion. The potential for cumulative effects from old and new areas of a site also needs to be considered with respect to lateral expansions.

Liner Construction Issues

Low permeability soils are often used for the construction of landfill liners and, where they are available in-situ, they provide a cost-effective solution. They are often used in conjunction with synthetic flexible membranes.

The design and construction of an engineered liner must be undertaken with an extensive quality assurance and quality control (QA/QC) programme, complemented by a well-defined materials testing programme.

Permeability specifications for clay liners are based on in-situ field permeability measurements.

In-situ testing of the permeability of the installed liner is not straightforward. Therefore, proof testing is best undertaken by monitoring dry density and water content of the installed liner and correlating this data to the laboratory-measured permeability data obtained by testing the clay compacted at various water contents along the compaction curve.

Soil liner material may originate at the site or be hauled from a nearby borrow area. Soil additives, such as bentonite (montmorillonitic clay), may also be introduced to decrease the hydraulic conductivity of the liner material.

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

The joining or seaming of synthetic flexible membranes is critical as the seams are the most likely source of failure. Under the site-specific QA/QC plan, the joints or seams should be tested for any potential defects.

The strength and stability of basement materials must be adequate to ensure the integrity of the liner for as long as is required to ensure protection of the environment.

Liner stability against slope failure also needs to be considered, along with construction practicalities, particularly at the boundaries of segmented construction phases for large landfills.

Penetrations and appurtenances need special care in all liner systems to ensure no leakage path is created. These should be avoided if at all possible.

Section 4.13 addresses QA/QC tests and testing frequencies for liner construction.

4.8 Leachate Collection and Removal Systems

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

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

The design and effectiveness of a leachate collection and removal system is site-specific and depends on the design of the liner and the leachate collection pipes. General shape of the site, phase shapes, and overall slope and topography affect the layouts of the liner and pipe network systems.

A typical leachate collection and removal system should include the following components:

- a high-permeability drainage layer constructed of either natural granular materials (sands and gravels) or a synthetic drainage material (Geonet). The drainage layer is generally placed directly on the liner;
- perforated leachate collection pipes and/or boulder drains within the high-permeability drainage layer to collect the leachate and carry it rapidly to a collection sump;
- sump(s) at low points within the system from where leachate can be collected; and
- graded filter layers, as appropriate, over the high-permeability drainage layer and collection pipes and/or boulder drains to prevent physical clogging of the material.

The design and construction of the collection system needs to be undertaken with great care to ensure that the system remains operable throughout the life and after-care period of the landfill. Failure of a component could render the whole system useless.

The collection system should be designed to ensure that a minimum depth of leachate is retained over the landfill liner. This depth can be calculated by taking into account the quantity of leachate likely to be produced, bottom slope, pipe spacing and drainage layer hydraulic conductivity, by using the HELP model (referred to in Section 4.6), or using analytical equations proposed by Giroud and Houlihan in the paper *Design of Leachate Collection Layers* (1995). The target maximum depth for leachate on the liner should not exceed 300 millimetres.

The gradient of the collection system needs to be adequate to ensure that the leachate readily drains to the collection sumps. A minimum gradient of 1 in 50 (2 percent) is recommended.

Reliance on small diameter perforated pipes should be avoided to prevent clogging of the perforations. A minimum diameter of 150 mm is recommended.

Piping design needs to consider not only hydraulic capacity, but also structural strength to accommodate the weight of refuse above them. Spacing should be determined by the maximum leachate head allowed in the design.

Allowance should be made for additional lining protection beneath leachate collection pipes and sumps as these areas have the potential for the highest leachate heads.

4.9 Leachate Recirculation

Leachate recirculation has been shown to offer significant benefits in reducing the strength of leachate in terms of BOD and some metal ion concentrations.

The other benefits of leachate recirculation include:

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

Generally, leachate should only be recirculated in the landfills that are designed and equipped with a liner and leachate collection system constructed for a target 300 mm depth of leachate over the liner.

Leachate recirculation systems require design to address potential problems associated with:

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

Leachate recirculation should be provided for as soon as it is practicable to do so. Leachate produced from more recent areas of the landfill should be collected and discharged to areas containing aged refuse. Discharge is generally via a subsoil perforated pipe over a length of trench constructed just below the surface of the fill and remote from the leachate collection system, to maximise the percolation distance. Recirculated leachate should not be sprayed onto the surface of old areas of the landfill as problems of contaminated surface runoff and odour could result.

Rates of recirculation should be carefully monitored and controlled to ensure that areas of refuse do not become saturated, as this could result in surface outbreaks, and could potentially jeopardise the slope stability of the landfill. Rates and areas of recirculation should be carefully chosen and will invariably require seasonal adjustment to maintain optimum landfill performance.

4.10 Leachate Treatment and Disposal

Leachate collected from landfill drainage systems needs to be pre-treated and/or disposed of carefully, to reduce the risk of pollution.

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;
- discharge to natural water following treatment;
- treatment by recirculation within the landfill; and
- evaporation using heat generated from the combustion of landfill gas.

At present, the dominant method of disposal is the discharge of leachate to a sewer, land or watercourse.

Where discharge is to a sewer, treatment of the leachate takes place at the sewage treatment plant. Where volumes of leachate generated are low, tankering leachate to a sewage plant may be the most appropriate method of disposal. Since leachate strengths are significantly greater than normal municipal waste waters, care shall be taken to avoid overloading the sewage treatment plant. Studies have shown that sewage treatment plant operation has been disrupted when leachate exceeds 2 percent of the hydraulic loading.

A further option for off-site treatment is at a specialised hazardous or toxic waste centre, where leachate from landfills in the region is accepted.

The volume and strength of leachate produced at landfill sites is subject to large seasonal variations. Wide fluctuations in flow and concentration can be minimised by balancing leachate flow, either by storage within already deposited waste or by using a lagoon, so reducing the required treatment capacity by removing the peak loadings. However, concentrations of components in leachate also change with its age. Treatment strategies must therefore adapt to changes in leachate volumes and strengths both during the filling stage of the landfill and after its completion.

Leachate, particularly that from recently placed wastes, contains high concentrations of readily biodegradable material (principally organic acids) which is amenable to biological treatment. Leachate from wastes that have been deposited for a longer time is generally lower in organic content, less readily biodegradable and may contain relatively high concentrations of ammonia or iron. Thus, leachate from aged waste may require a combination of processes for effective treatment.

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, strength of toxic components and the nature of the receiving environment.

On-site Treatment Technologies

Technologies for on-site treatment of leachates include:

- biological anaerobic or aerobic systems;
- chemical oxidation and reduction;
- precipitation;
- air stripping; and
- carbon adsorption.

The selection of a treatment process should be based on leachate quality, laboratory evaluation studies and, where possible, on pilot-scale studies. Where no leachate data exist, such as at the design stage for a new landfill, an alternative approach is required. In this situation leachate quality may be predicted from leachate generation calculations, experience at other sites, and leaching tests for typical industrial and other wastes expected to be received.

Land Treatment and Disposal

Spray irrigation, or subsurface irrigation, of treated leachate is an effective disposal method where suitable land areas and soil types are available. Department of Health guidelines on waste irrigation recommend that only pre-treated effluent be irrigated. Subject to site-specific requirements, oxidation ponds with minimum detention of 30 days or, alternatively, two-stage aerated lagoons with a minimum total detention of 10 days, may be appropriate.

Spraying of treated leachate onto land can result in a significant reduction in 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 evaporation than a single daily application. Transpiration by vegetation will account for a substantial proportion of the total loss. The possibility of spreading harmful pathogens by spraying leachate needs to be considered, but evidence to date suggests that this is not a problem provided appropriately treated leachate is applied and the operation is properly managed.

Little information is available on the long-term effects of continual spraying of 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. In this respect, reference should be made to publications on the application of sewage sludge to land.

4.11 Landfill Gas Management

General

In general terms, landfill gas will be produced in almost all landfills. Gas is produced as an end product of biological decomposition. Although mainly methane and carbon dioxide, it may also contain other gases, including volatile organic compounds. Table 4.3 gives a typical composition of landfill gas. In the early aerobic decomposition phase, the gas is predominantly carbon dioxide. In the later anaerobic decomposition phase, the gas has a relatively high methane content. Methane may be generated in commercial quantities.

Potential Problems Associated With Landfill Gas

Potential problems as a result of landfill gas include:

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

Landfill Gas Production

The rate of gas production can be controlled to a large extent by the adoption of appropriate landfill management techniques. Site design may require that gas production be either encouraged or minimised, depending on whether or not the gas is to be utilised. Where accelerated stabilisation is an objective, a substantially greater rate of gas production will result. The

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

Table 4.3 : Typical constituents found In landfill gas

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

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

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

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

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

Landfill Gas Control

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

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

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

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

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

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

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

Migration Control and Monitoring

It is important to detect possible gas migration from the site towards sensitive areas. Purpose-designed gas monitoring boreholes should be installed between the site and sensitive property boundaries and regular monitoring should be undertaken. Landfill gas monitoring is discussed in more detail in Section 6.7.

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

No single form of gas migration control may be adequate to protect sensitive adjacent property. Thus, in addition to an on-site gas collection system, other measures, such as the use of low-permeability barriers between the site and the adjacent strata, may be necessary. Because of differences in the viscosity of liquids and gas, clay and bentonite clay barriers are orders of magnitude less effective at restricting the flow of gas than that of leachate. Hence the designer may need to consider whether the proposed leachate retention liner/barrier is adequate for gas control or whether a higher specification liner using a synthetic flexible membrane is required for gas control purposes.

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

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

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

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

Examples of passive landfill gas venting systems are shown in Figures 4.4 and 4.5.

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

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

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

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

An example of a gas extraction well for use in active systems is shown in Figure 4.6.

It may also be possible to collect gas using leachate recirculation trenches.

Landfill Gas Disposal

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

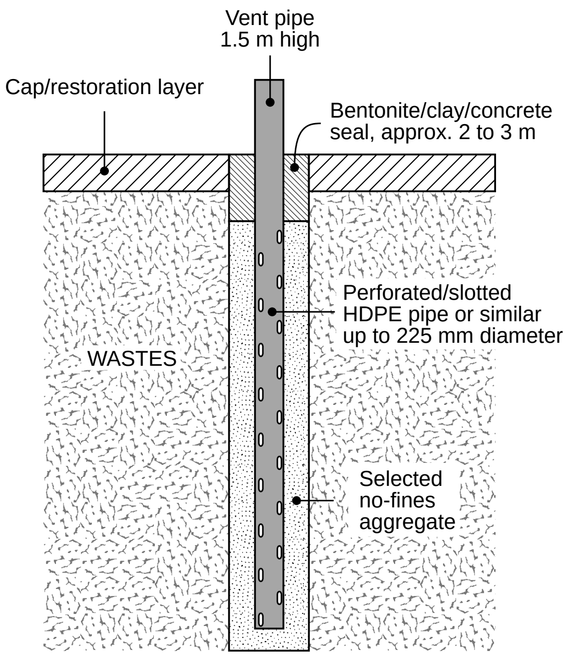


Figure 4.4 Example of passive landfill gas venting well

(Figure 8.2 from UK Department of the Environment Waste Management Paper No 27 (1991))

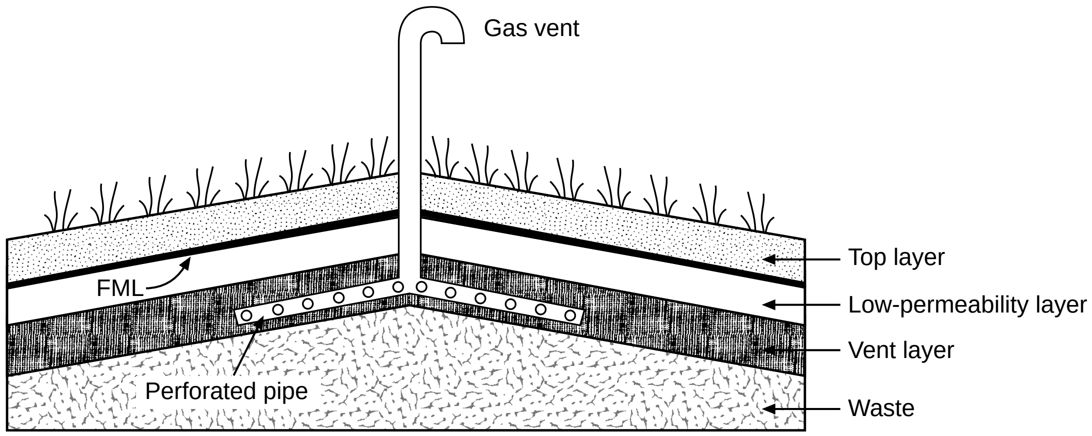


Figure 4.5 Example of passive landfill gas venting system
(Figure 3-4 from USEPA Solid Waste Disposal Facility Criteria Technical Manual (1993))

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

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

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

4.12 Landfill Cover Systems

Landfill covers fall into three categories having different functions:

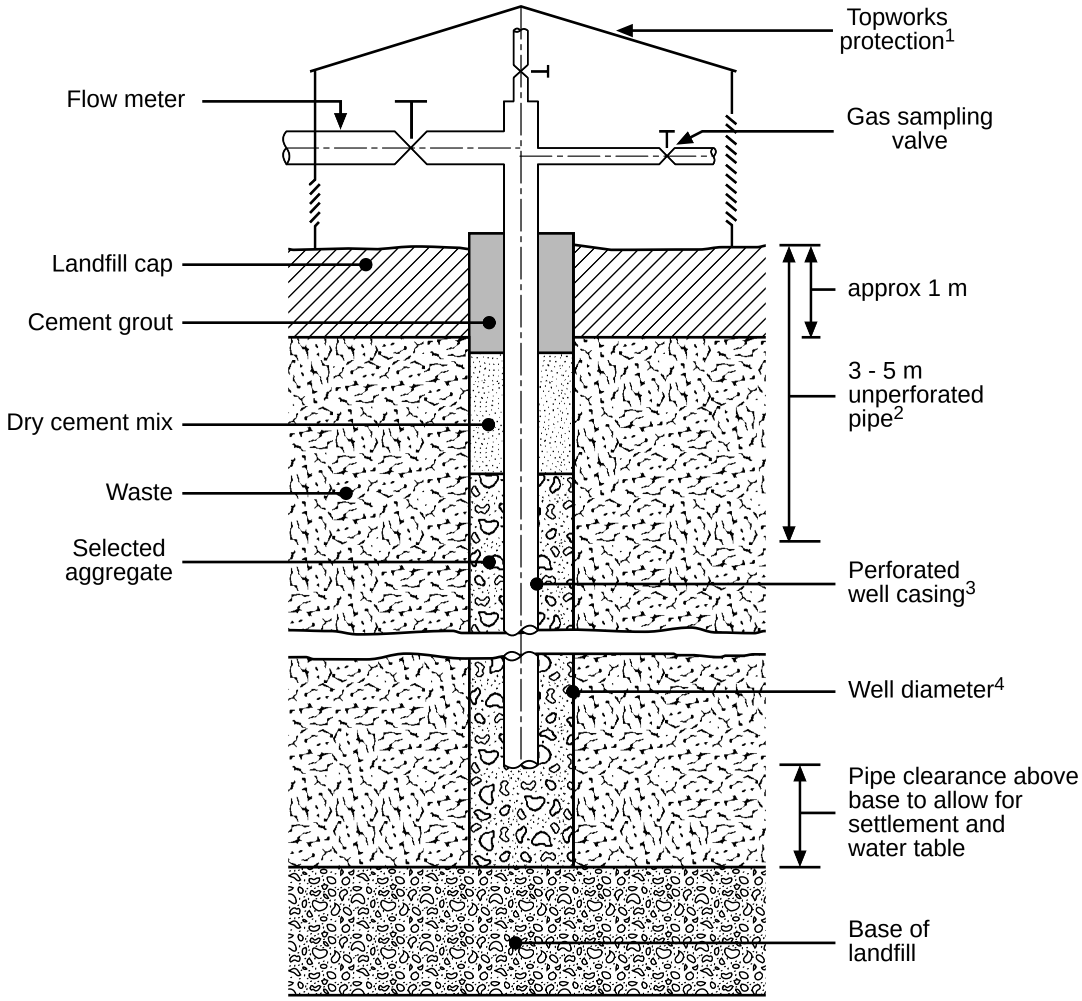
- daily cover to reduce:
  - — windblown litter;
  - — odour;
  - — vermin; and
  - — birds.
- intermediate cover to:
  - — minimise water ingress;
  - — complete cells; and
  - — provide fire protection.
- final cover to:
  - — control water ingress;
  - — reduce leachate generation;
  - — provide final contour;
  - — provide gas control;
  - — allow plant growth; and
  - — permit end use.

Landfill cover is addressed in more detail, with respect to landfill operations, in Section 5.10.

Daily Cover

Daily cover typically consists of a minimum of 150 mm thick earthen layer or an alternative material such as:

- geosynthetic blankets;
- shredded green waste;
- sawdust;
- spray on foam;
- contaminated soil (that complies with waste acceptance criteria);
- ash (that complies with waste acceptance criteria);
- stabilised sludge;
- paper pulp;
- composted material;



1 Topworks may be suitably protected above ground by a robust ventilated enclosure, or below ground in a manhole which does not compromise the integrity of the cap

2 Exact length of unperforated pipe depends on waste depth and presence of water/leachate table

3 Approximately 10% of pipe area should be perforated, at least 100 mm diameter, UPVC, MDPE, HDPE or polypropylene

4 Overall diameter determined by extraction rate required, established by static tests

Figure 4.6: Example of landfill gas extraction well

(Figure 8.3 from UK Department of the Environment Waste Management Paper No 27 (1991))

- small weave netting; and
- heavy duty reusable plastic sheets or tarpaulins.

Intermediate Cover

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

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

Final Cover

Final cover design is largely dictated by site design and management provisions with respect to enhanced degradation (i.e. leachate recirculation), landfill gas management and the proposed end use for the site. Nevertheless, the following is considered the minimum recommended specification for a final cover system:

- a compacted earth layer at least 600 mm thick, with a maximum hydraulic conductivity of 10^{-7} m/s; and

- topsoil at least 150 mm thick that is capable of sustaining plant growth.

Examples of final cover designs are shown in Figure 4.7.

Other issues that need to be considered in the design include the following:

- Surface gradients. These will be influenced by the proposed final use of the site, but should be generous enough to ensure effective shedding of precipitation. A minimum gradient of 1V:20H is recommended to promote drainage of the top of the landfill; a maximum gradient of 1V:3H is recommended to minimise erosion and post-closure care problems.
- Effects of settlement, which may cause cracking or ponding of water.
- Vegetation cover. For example, if the area is to be grassed then it is important to avoid creating a very low permeability hard pan under a shallow layer of topsoil. In such a case, the topsoil will tend to become soggy in winter and dry out in summer, inhibiting grass growth. A granular drainage layer immediately above the cap may be required. The advice of a professional soil scientist is recommended.

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

- Gas production will be accelerated, and the potential for adverse effects from odour, due to gas escape through the cover, increases.
- Settlement rates of the refuse are increased so that the bulk of settlement occurs much sooner.
- 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 and reduce the rate of degradation, a combination of a flexible membrane liner (1 mm to 1.5 mm thick), or geosynthetic clay liner and compacted soil layer, is typically used.

The following advantages and disadvantages need to be considered.

Advantages

- The quantity of leachate generated at any one time is much lower.
- 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 smaller.
- Potential for landfill gas to escape from the cover is very low, hence the potential for odour problems will be small.

Disadvantages

- The breakdown of materials in the landfill will be very slow.
- Leachate generation and gas production will continue for longer periods.

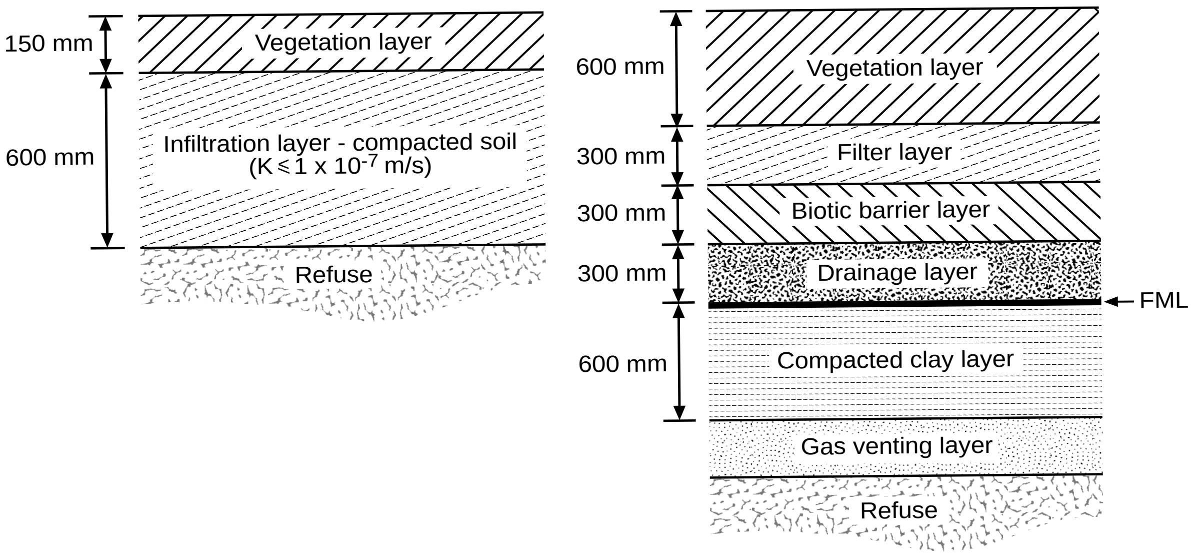


Figure 4.7: Examples of final cover designs

- Gas, leachate and settlement may become problems decades after refuse placement, resulting in a major after-care burden for the responsible authorities.

4.13 Construction Quality Assurance and Construction Quality Control

Construction quality assurance (CQA) and construction quality control (CQC) are critically important factors for overall performance of landfills. In order for the design to translate into a landfill that is protective of human health and the environment, it has to be properly constructed.

The manufacturing quality assurance (MQA) and manufacturing quality control (MQC) are also equally important for the geosynthetic materials used in landfill construction. The geosynthetic materials refer to factory fabricated polymeric materials like geomembranes or flexible membrane liners, geotextiles, geosynthetic clay liners, or geocomposites that include geonet and geotextiles.

This section presents the recommended tests and testing frequencies for the soil and geosynthetic components of landfills. The testing frequencies presented in this section should be used for guidance only. Actual testing frequencies should be decided based on site-specific and project-specific factors such as variability of material, experience and qualification of the contractor and the supervising technician or engineer. The recommended tests and testing frequencies for the soil and geosynthetic components of a landfill are presented in Tables 4.4 to 4.10. For details on the rationale for the tests and testing frequencies, the reader should refer to the CQA and CQC Guidance Document by the USEPA (1993).

The acceptance criteria, or the pass/fail decision for the constructed soil components and installed geosynthetic components, should be based on site-specific factors and the maximum allowable risk to human health and the surrounding environment from the landfill.

Soil Component	Test Name and Parameter(s) determined	Test Method (ASTM or Equivalent)	Minimum Testing Frequency
Compacted clay liner	Moisture Content	ASTM D2216	1 per 2,000 m^3 or each change in material type
	Sieve Analysis: Particle size distribution of fine and coarse aggregates.	ASTM C136	1 per 5,000 m^3 or each change in material type
	Hydrometer Analysis: Particle size distribution of fine fraction of soils.	ASTM D422	1 per 5,000 m^3 or each change in material type
	Atterberg Limits: Liquid limit and plastic limit	ASTM D4318	1 per 5,000 m^3 or each change in material type
	Soil Classification: Classification of soil	ASTM D2487	1 per 5,000 m^3 or each change in material type
	Standard or Modified Proctor: Moisture and density relationship	ASTM D698/1557	1 per 5,000 m^3 or each change in material type
	Hydraulic Conductivity: Permeability of aggregates (exclude for bedding gravel)	ASTM D2434	1 per 10,000 m^3 or each change in material type
Granular leachate drainage layer and bedding gravel	Sieve Analysis: Particle size distribution of fine and coarse aggregates	ASTM C136	per source
	Soil Classification: Classification of soil	ASTM D2487	1 per source
	Hydraulic Conductivity: Permeability of aggregates (exclude for bedding gravel)	ASTM D2434	1 per source
	Carbonate Content: Insoluble residue in carbonate aggregates	ASTM D3042	1 per source
Structural fill and final cover protective layer	Moisture Content	ASTM D2216	1 per source
	Sieve Analysis: Particle size distribution of fine and coarse aggregates	ASTM C136	1 per source
	Atterberg Limits: Liquid limit and plastic limit	ASTM D4318	1 per source
	Soil Classification: Classification of soil	ASTM D2487	1 per source
	Standard or Modified Proctor: Moisture and density relationship	ASTM D698/1557	

Note: Source: USEPA (September 1993), "Technical Guidance Document, Quality Assurance and Quality Control for Waste Containment Facilities", EPA/600/R-93/182

Table 4.4: Soils - recommended tests and testing frequencies for material qualification before construction

Soil Component	Test Name and Parameter(s) determined	Test Method (ASTM or Equivalent)	Minimum Testing Frequency
Subgrade for laying liner	Visual Observation: Monitor unsuitable soil zones, uneven ground surface.	N/A	As required
Compacted clay liner	Moisture Content	ASTM D2216	1 per 2,000 m^3 or each change in material type
	Sieve Analysis: Particle size distribution of fine and coarse aggregates.	ASTM C136	1 per 5,000 m^3 or each change in material type
	Hydrometer Analysis: Particle size distribution of fine fraction of soils.	ASTM D422	1 per 5,000 m^3 or each change in material type
	Atterberg Limits: Liquid limit and plastic limit	ASTM D4318	1 per 5,000 m^3 or each change in material type
	Soil Classification: Classification of soil	ASTM D2487	1 per 5,000 m^3 or each change in material type
	Standard or Modified Proctor: Moisture and density relationship	ASTM D698/1557	1 per 5,000 m^3 or each change in material type
	Hydraulic Conductivity: Permeability of aggregates (exclude for bedding gravel)	ASTM D2434	1 per 10,000 m^3 or each change in material type
Granular Leachate Drainage Layer and Bedding Gravel	Sieve Analysis: Particle size distribution of fine and coarse aggregates	ASTM C136	1 per 2,000 m^3
	Carbonate Content[2]: Insoluble residue in carbonate aggregates	ASTM D3042	1 per 2,000 m^3
	Hydraulic Conductivity: Permeability of aggregates (exclude for bedding gravel)	ASTM D2434	1 per 2,000 m^3
Structural Fill and Final Cover Protective Layer	Sieve Analysis: Particle size distribution of fine and coarse aggregates.	ASTM C136	1 per 2,500 m^3
	Atterberg Limits: Liquid limit and plastic limit	ASTM D4318	1 per 2,500 m^3
	Soil Classification: Classification of soil	ASTM D2487	1 per 2,500 m^3
	Standard or Modified Proctor: Moisture and density relationship	ASTM D698/1557	1 per 4,000 m^3

Note: Source: USEPA (September 1993), "Technical Guidance Document, Quality Assurance and Quality Control for Waste Containment Facilities", EPA/600/R-93/182.

Table 4.5: Soils — recommended tests and testing frequencies prior to installation

Soil Component	Test Name and Parameter(s) determined	Test Method (ASTM or Equivalent)	Minimum Testing Frequency
Compacted clay liner	Moisture Content	ASTM D2216	1 per 2,000 m^3 or each change in material type
	Sieve Analysis: Particle size distribution of fine and coarse aggregates.	ASTM C136	1 per 5,000 m^3 or each change in material type
	Hydrometer Analysis: Particle size distribution of fine fraction of soils.	ASTM D422	1 per 5,000 m^3 or each change in material type
	Atterberg Limits: Liquid limit and plastic limit	ASTM D4318	1 per 5,000 m^3 or each change in material type
	Soil Classification: Classification of soil	ASTM D2487	1 per 5,000 m^3 or each change in material type
	Standard or Modified Proctor: Moisture and density relationship	ASTM D698/1557	1 per 5,000 m^3 or each change in material type
	Hydraulic Conductivity: Permeability of aggregates (exclude for bedding gravel)	ASTM D2434	1 per 10,000 m^3 or each change in material type
Granular leachate drainage layer and bedding gravel	Sieve Analysis: Particle size distribution of fine and coarse aggregates	ASTM C136	1 per source
	Soil Classification: Classification of soil	ASTM D2487	1 per source
	Hydraulic Conductivity: Permeability of aggregates (exclude for bedding gravel)	ASTM D2434	1 per source
	Carbonate Content: Insoluble residue in carbonate aggregates	ASTM D3042	1 per source
Structural fill and final cover protective layer	Moisture Content	ASTM D2216	1 per source
	Sieve Analysis: Particle size distribution of fine and coarse aggregates	ASTM C136	1 per source
	Atterberg Limits: Liquid limit and plastic limit	ASTM D4318	1 per source
	Soil Classification: Classification of soil	ASTM D2487	1 per source
	Standard or Modified Proctor: Moisture and density relationship	ASTM D698/1557	1 per source

Note: Source: USEPA (September 1993), "Technical Guidance Document, Quality Assurance and Quality Control for Waste Containment Facilities", EPA/600/R-93/182.

Table 4.6: Soils — recommended tests and testing frequencies during construction

Test Name	Test Method (ASTM or Equivalent)	Minimum Testing Frequency
Mass per unit area	ASTM D3776	1 test per 10,000 m^2
Grab strength	ASTM D4362	1 test per 10,000 m^2
Mullen burst	ASTM D3786	1 test per 10,000 m^2
Puncture resistance	ASTM D4833	1 test per 10,000 m^2
Permeability (for filter application only)	ASTM D4491	1 test per 10,000 m^2
Apparent opening size (for filter application only)	ASTM D4751	1 test per 10,000 m^2
Trapezoidal tear strength	ASTM D4533	1 test per 10,000 m^2
Thickness (for cushion application only)	ASTM D1777	1 test per 10,000 m^2

Notes:
1. Source: USEPA (September 1993), "Technical Guidance Document, Quality Assurance and Quality Control for Waste Containment Facilities", EPA/600/R-93/182.
2. Testing should be carried out at a frequency of one per lot or at the above listed frequency, whichever is less.

Table 4.7: Geotextile — recommended tests and testing frequencies

Test Name	Test Method (ASTM or Equivalent)	Minimum Testing Frequency
Specific gravity	ASTM D792 Method A	1 test per 10,000 m^2
Thickness	ASTM D751	1 test per 10,000 m^2
Tensile strength at yield	ASTM D638	1 test per 10,000 m^2
Tensile strength at break	ASTM D638	1 test per 10,000 m^2
Elongation at yield	ASTM D638	1 test per 10,000 m^2
Elongation at break	ASTM D638	1 test per 10,000 m^2
Tear resistance	ASTM D1004, Die C	1 test per 10,000 m^2
Carbon black content	ASTM D1603	1 test per 10,000 m^2
Carbon dispersion	ASTM D3015	1 test per 10,000 m^2
Peel adhesion[2]	ASTM D4437[3]	1 test every 150 m of seam length
Bonded seam strength[2]	ASTM D4437[4]	1 test every 150 m of seam length
Vacuum testing[2]	-	100% of extrusion welded seams
Air testing[2]	-	100% of dual hot wedge or dual track welded seams

Notes:
1. Source: USEPA (September 1993), "Technical Guidance Document, Quality Assurance and Quality Control for Waste Containment Facilities", EPA/600/R-93/182.
2. Applicable to geomembrane seams.
3. For peel adhesion, seam separation shall not extend more than 10 per cent into the seam interface. Testing shall be discontinued when the sample has visually yielded.
4. For shear tests, the sheet shall yield before failure of the seam.
5. Testing shall be carried out at a frequency of one per lot or at the above listed frequency, whichever is less.

Table 4.8: Geomembrane — recommended tests and testing frequencies

Test Name	Test Method (ASTM or Equivalent)	Minimum Testing Frequency
Density	ASTM D1505	1 test per 10,000 m^2
Thickness	ASTM D751	1 test per 10,000 m^2
Mass per Unit Area	ASTM D3776	1 test per 10,000 m^2
Hydraulic Conductivity	ASTM D5084	1 test per 10,000 m^2

Notes:

1. Source: USEPA (September 1993), "Technical Guidance Document, Quality Assurance and Quality Control for Waste Containment Facilities", EPA/600/R-93/182.
2. Testing shall be carried out at a frequency of one per lot or at the above listed frequency, whichever is less.

Table 4.9: Geosynthetic clay liner — recommended tests and testing frequencies

Test Name	Test Method (ASTM or Equivalent)	Minimum Testing Frequency
Geonet Component:		
Carbon Black Content	ASTM D1603	1 test per 10,000 m^2
Density	ASTM D1505	1 test per 10,000 m^2
Thickness	ASTM D1777	1 test per 10,000 m^2
Geotextile Components:		
Mullen burst strength	ASTM D3786	1 test per 10,000 m^2
Mass per unit area	ASTM D3776	1 test per 10,000 m^2
Apparent opening size (filter application only)	ASTM D4751	1 test per 10,000 m^2
Hydraulic conductivity (filter application only)	ASTM D4491	1 test per 10,000 m^2
Grab strength	ASTM D4632	1 test per 10,000 m^2
Trapezoid tear strength	ASTM D4533	1 test per 10,000 m^2
Puncture resistance	ASTM D4833	1 test per 10,000 m^2
Geocomposite:		
Hydraulic transmissivity	ASTM D4716	1 test per 10,000 m^2
Peel strength	ASTM F904	1 test per 10,000 m^2

Notes:

1. Source: USEPA (September 1993), "Technical Guidance Document, Quality Assurance and Quality Control for Waste Containment Facilities", EPA/600/R-93/182.
2. Testing shall be carried out at a frequency of one per lot or at the above listed frequency, whichever is less.

Table 4.10: Geocomposite — recommended tests and testing frequencies

Chapter 5
Landfill Operations

5.1 Introduction

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

This section addresses the following:

- landfill management plan;
- staffing and training;
- health and safety;
- site access;
- waste acceptance and monitoring;
- roading;
- visual impacts;
- waste compaction;
- cover;
- nuisance control;
- fire prevention;
- water control;
- landfill gas management; and
- closure and aftercare.

5.2 Landfill Management Plan

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

- site management structure and responsibilities;
- design parameters;
- site development and filling sequence;
- daily operating procedures;
- 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.

A recommended outline table of contents for a landfill management plan is provided in Appendix 3.

The following sections provide details of the aspects of landfill operations that should be addressed in the landfill management plan and options for operating procedures.

5.3 Staffing and Training

Staffing

The level of staffing should be adequate for environmentally-responsible and safe management of the landfill. Staffing requirements will vary as a function of size, types of wastes, and diversity and complexity of site operations. Landfill operators should provide adequate staffing to ensure that during operating hours all continuous tasks (including waste reception, and security, compaction and covering) are completed in accordance with the landfill management plan.

Training

Management and operating personnel must be familiar with the landfill facilities (including environmental protection systems), operational practices, the status of site activities, and resource consent conditions, and all operational staff should undertake training courses relevant to their particular duties. As a minimum, staff training should ensure that:

- staff who inspect or direct the placement of incoming wastes are capable of accurate data recording, and 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;
- staff who undertake sampling or testing are familiar with required testing and sampling protocols;

- all staff are familiar with site safety practices and procedures; and
- all staff are familiar with site emergency procedures.

All new employees should receive basic training as part of their orientation and refresher training should be performed on an annual basis. Documentation of training should be maintained in the site operating record.

5.4 Health and Safety

Landfill operations must be performed in accordance with the requirements of the Health and Safety in Employment Act 1992, and a Health and Safety Plan should be prepared for each site setting out the procedures to satisfy each of the requirements of the Act. These include the following:

- The identification of hazards present on the site. Examples include traffic (including landfill compaction equipment), landfill gas (LFG), sharp (injurious) refuse, steep and uneven terrain, and illegal disposal of hazardous waste.
- Hazard 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 engaged on the site.
- Appropriate training and supervision of employees at the site, including provision and use of safety equipment.
- Development of emergency procedures, also known as a contingency plan.
- Recording, reporting and investigation of accidents.

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 capital works contractors engaged on the site are fully conversant with the Health and Safety Plan. These contractors should be made fully aware of potential hazards associated with the landfill operations activities.

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

5.5 Site Access

Unauthorised entry to landfills can lead to illegal waste dumping, exposures to landfill hazards, fires, and vandalism of pollution control devices, as well as loss of amenity. In order to control site access, the perimeter of the landfill site should be securely fenced and the gates locked outside normal operating hours. Close control over the issue of keys to the landfill should be maintained to ensure public health is adequately safeguarded and the operational procedures are complied with at all times. All incoming vehicles should report to the weighbridge or reception office before proceeding further to waste reception or working areas. All landfill sites should be sign-posted at each entrance with the following information:

- landfill name;
- owner and operator;
- contact details for the owner and operator, including after-hours telephone contact for senior site staff;
- emergency telephone contacts;
- hours of operation;
- a general description of the types of wastes accepted at the site;
- a generalised list of prohibited wastes; and
- the requirement for a waste acceptance agreement to be in place before the site is used for waste disposal.

5.6 Waste Acceptance and Monitoring

Waste Acceptance Criteria

The purpose of establishing waste acceptance criteria (WAC) is to ensure that all wastes being disposed in the landfill are compatible with the operation of the landfill and do not lead to immediate or longer-term adverse environmental effects. Waste acceptance criteria should be determined during the resource consent process, based on landfill siting and design of retention, leachate collection and treatment/disposal systems.

Development of waste acceptance criteria should take into account the need to protect landfill processes, the potential for discharge of hazardous substances to the environment, and the need to minimise the risks associated with hazardous substances, such as effects on human health and safety.

The codisposal, or joint disposal, of untreated hazardous waste with municipal solid waste is no longer considered an appropriate management practice. Currently all but a few hazardous wastes are able to be pretreated to render them non-hazardous with respect to disposal in well-sited and well-designed municipal solid waste landfills.

It is recognised that the municipal solid waste stream contains a small proportion of hazardous waste from households and small commercial premises that standard waste screening procedures will not exclude from landfills.

Waste acceptance criteria should comprise prescribed lists that set out those wastes that are not acceptable and leachability criteria for wastes, which may include treated hazardous waste, that may be accepted.

Prohibited Wastes

Prohibited wastes are those, which due to their inherent characteristics, can impact on the safe operation of a landfill and pose a threat to people and the environment. A detailed list of characteristics of wastes that should be prohibited from municipal solid waste landfills, and types of waste that may exhibit these characteristics, is contained in Appendix 4 (Section A).

Some prohibited wastes may be acceptable in landfills that have engineered retention and high standard leachate collection and treatment systems, following treatment to remove their hazardous characteristic(s).

Acceptable Wastes

A detailed list of characteristics and types of wastes, which may be acceptable in a municipal solid waste landfill following treatment to render them non-hazardous with respect to landfill disposal, and types of waste that may exhibit these characteristics, is contained in Appendix 4 (Section B).

Waste acceptance criteria for these wastes should ensure that:

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

In the absence of any national requirements for landfill waste acceptance criteria, the following approach is recommended for well-sited landfills, which provide an equivalent level of environmental protection as those using designs recommended in Section 4.7.

Use of the USEPA Toxicity Characteristic Leaching Procedure (TCLP) and maximum leachability limits using the following are recommended in setting waste acceptance criteria:

- USEPA TCLP criteria, detailed in Appendix 5; and
- NSWEPA leachability criteria for "Solid Waste Landfills", detailed in Appendix 6.

The NSWEPA waste acceptance criteria for "Solid Waste Landfills" also include total concentration limits to be used together with leachability limits, in accordance with the NSWEPA assessment procedures.

The use of the above as acceptance criteria provides a reasonable assurance that wastes accepted at an appropriately sited and designed landfill will not result in adverse effects on the surrounding environment.

For contaminants where appropriate TCLP limits do not already exist, it is recommended that TCLP limits be set by a site-specific risk analysis based on the contaminant's characteristics and flowpaths to groundwater and surface water receptors, or setting limits at the "lesser of" following;

- NZS 9201 Model Trade Waste Bylaw limits;
- 100 times the New Zealand drinking water standard;
- 1000 times the guidelines for protection of aquatic species.

Landfills that do not have demonstrated retention and leachate collection systems, or where groundwater or surface water is already contaminated, should use more stringent acceptance criteria.

Notification of Customers

The next step in controlling the entry of wastes into landfills is to notify potential customers, landfill operators and regulators of the waste acceptance policy for the various sites. Specific policies and procedures for notification of customers are discussed below.

Waste Disposal Application

Commercial and industrial landfill users should complete a formal application to deposit waste prior to becoming a user of a site, or in the case of regular deliveries, before there is a change to the nature or volume of the waste being disposed of at a site. The application should identify the nature and volume of the waste to be disposed of at a site, and any additional relevant information. The applicant should be required to agree not to dispose of waste of a different nature or markedly different volume except with the prior consent of the landfill owner/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 owner/operator to evaluate the waste in a careful manner, requiring the generator to perform whatever tests are needed to characterise the waste. The disclosure also provides the basis for a record of the nature and volume of the waste disposed of to the landfill. (If a national manifest system for the storage, use and disposal of hazardous substances were to be implemented, the final copy of the manifest would form part of the disposal records of the site.)

Assessment of Application

The landfill owner/operator should evaluate the completed application against the specific requirements of the WAC. Wastes that meet the criteria could be admitted and disposed in the landfill. If additional tests to better characterise the waste are required, the generator should arrange for these tests to be performed.

Those wastes that do not meet the requirements may be able to be treated in such a way that they meet the criteria before being accepted at the landfill. Some wastes may not be able to be accepted regardless of treatment. Failing successful treatment, alternative disposal facilities will need to be identified and used. In some cases involving complex waste issues, assessment of the application by a regulatory authority may be necessary.

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 landfill operator should the applicant breach the terms of the agreement to accept waste. It should also set out the rights of the landfill operator to inspect, challenge, sample, test and, if necessary, reject any waste brought by the applicant to the site for disposal.

Notification of Alternatives

If the application for disposal of waste cannot be accepted, then the operator of the landfill should be required to advise the applicant of any known facilities that are able to accept the waste for storage or disposal. Alternatively, the landfill owner/operator should refer the waste generator or transporter to the regional council or other entity for further information on suitable disposal facilities.

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

Site Procedures

The final step in controlling the entry of waste into landfills is to implement policies and procedures to detect and deter illegal disposal of these wastes. Specific procedures that should be implemented are described below.

Random Load Inspections

The landfill owner/operator should implement a programme that involves performing random 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 received and the findings from previous inspections.

Random inspection of one load in every 50 commercial and industrial loads is suggested as an initial guide. However, if these inspections or other findings indicate that inappropriate waste is being received at a site, then the random programme should be modified to increase the frequency of inspections.

Notification of Authorities

The landfill owner/operator should notify appropriate authorities if hazardous waste is presented at the landfill for disposal without prior approval and appropriate documentation. These authorities may include the regional council or unitary authority, or other appropriate organisation.

If the landfill owner/operator identifies the hazardous waste while it is in the possession of the transporter, the load should be rejected and will remain the responsibility of the transporter.

If the hazardous waste is identified after deposition at the tipping face, then immediate steps must be taken to secure the waste. Contingency plans for identification of the waste must be urgently implemented. If the waste is identified as unacceptable then a plan for removal or neutralisation of the waste must be actioned as quickly as practicable. Landfill users and staff must be protected from any health and safety hazards that might be caused by the hazardous waste.

Record Keeping

Landfill owners/operators should maintain an operating record that includes information on waste acceptance, on-site recycling, load inspections, and operational activities. Information on waste acceptance and on-site recycling should include the quantity and, where possible, classification of wastes according to the Ministry for the Environment's Waste Analysis Protocol.

Information on load inspections should include:

- 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
- notification of authorities.

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

Supervision of the Tipping Face

Supervision of the disposal activity at the working face should be maintained when wastes are received at the landfill to ensure the accountability of those depositing unacceptable wastes at the site. Where a facility receives in excess of 500 tonnes per week (25,000 tonnes per annum), this supervision should be undertaken by someone other than the compactor driver.

Recording of Disposal Location

A landfill owner/operator at a site receiving wastes that require special handling procedures (for example, treated hazardous waste) should record the location of those wastes when placed into the landfill, including:

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

5.7 Roading

Roads at landfill sites provide access to the site generally, 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, 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 ideally be sealed. Access across the refuse should be constructed from a layer of heavy road metal.

5.8 Visual Impacts

Visual impacts associated with the operation of landfills can be minimised by following the recommended operating practices and conducting waste disposal activities behind purpose-built earth screening bunds. Landfills can also be screened by means of vegetation and/or placing shade-cloth screening at specific locations around the property. The benefit of these measures is to reduce visual impacts associated with landfill operations.

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.

5.9 Waste Compaction

Equipment Selection

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

- site characteristics;
- site preparation requirements;
- daily waste input quantity;
- type of waste;
- density of waste;
- cover requirements including the type of cover; 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

The width of the working face should be kept as narrow as possible in order to minimise the area of exposed refuse. There must, however, be sufficient room to permit vehicles to manoeuvre and unload quickly and safely. A balance must be achieved between the number of incoming vehicles and the need to minimise stormwater infiltration, cover requirements and odour and litter nuisances.

Waste Compaction

The amount of landfill space and land used to dispose of waste can be minimised by proper compaction. Compaction also improves the stability of landfills, and minimises the voids that would encourage vermin, fires or excess generation of leachate.

Refuse should be placed against a clay starter embankment or the previous day's refuse. As soon as it is unloaded, the refuse should be spread out in thin layers to form individual lifts. Pushing waste over a vertical face is not considered to be acceptable. The layers should be sloped away from the sides and final surfaces of the landfill, so as to minimise the chance of leachate tracking to the edge of the fill and breaking out on the surface.

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

Typically, lifts are between two and four metres thick, depending on the daily volume of refuse deposited at the site, however, heights of up to ten metres can be common in large operations.

Landfill operators are expected to ensure that maximum compaction is achieved for the capacity of the machines used. For landfills receiving over 50,000 tonnes of waste per annum, the waste compaction goal should be at least 800 kg/m^3, excluding cover material, as measured by a compaction test. For landfills receiving less than 50,000 tonnes of waste per annum, the waste compaction goal should be at least 600 kg/m^3, excluding cover material.

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

5.10 Cover

Use of soil cover material helps to provide the full range of environmental management objectives by limiting run-on and infiltration of water, controlling and minimising risk of fire, minimising emissions of landfill gas, suppressing site odour, reducing fly propagation and rodent attraction, and decreasing litter generation. Similarly, scavenging is reduced by removing the waste from view.

Daily Cover

Daily soil cover should be provided at all landfills, except where it can be shown that no significant adverse impact would occur without cover. Daily cover may be of any soil type and should only be applied after the refuse has been placed, compacted, and trimmed to the proper grade. A minimum of 150 mm of cover material should be placed over exposed refuse at the end of each operating day.

If low permeability soils are used it may be necessary to penetrate daily cover prior to refuse placement to avoid problems associated with perched water tables.

To ensure that there will always be sufficient cover material available to meet performance requirements, operators should maintain a stockpile or an area where cover can be won on-site in all weather conditions, which will be adequate to meet cover requirements of the landfill for two weeks.

Alternative Daily Cover

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

- geosynthetic blankets;
- shredded green waste;
- sawdust;
- spray on foam;

- contaminated soil (that complies with waste acceptance criteria);
- ash (that complies with waste acceptance criteria);
- stabilised sludge;
- paper pulp;
- composted material;
- small weave netting; and
- heavy-duty reusable plastic sheets or tarpaulins.

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;
- additional nuisance potential;
- potential contaminants within the material; and
- potential effect on site stability.

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

Intermediate Cover

Intermediate cover is used to close off a cell that will not receive additional lifts of refuse or final cover for some time. A minimum thickness of 300 mm of soil should be placed as soon as the refuse achieves the required cell profile. Intermediate cover surfaces that will remain exposed for a period exceeding three months should be temporarily grassed using conventional methods or by hyroseeding.

When refuse 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. If this is not done, the landfill may become stratified with impermeable layers, and perched leachate lenses could develop, with the possibility of surface breakouts. Gas could be horizontally dispersed with a tendency for lateral migration.

Final Cover

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

- intermediate soil cover;
- low permeability layer; and
- 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. Final cover material should be placed as soon as practicable over finished areas of the landfill above the previously placed intermediate cover, when weather conditions are suitable.

Details of final cover design are discussed in Section 4.12.

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 diligently 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.

5.11 Nuisance Control

Litter

Uncontrolled litter can contribute significantly to the loss of amenity experienced at a landfill site. As a basic rule, all litter outside the tipping area should be retrieved on a daily basis.

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.

Dust

The main activities responsible for dust generation on site 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 dust-type refuse.

In order to minimise dust emissions, permanent access roads between the site boundary and entrance facilities, including reception areas, weighbridge and washdown facility, should be sealed to a good standard. Unsealed roads should also be sprayed by water cart and sealed roads cleaned by mechanical road sweepers as required, especially during dry periods. If roads have speed humps and are properly maintained, dust problems will be kept to a minimum.

Modern landfill design and operation is based on careful control of liquids which may enter the landfill. Water, as a dust control measure, must be used very carefully. Water can enter the landfill and contribute to the formation of leachate. Indiscriminately applied water can also enter the groundwater and impact the groundwater monitoring wells.

In addition, dust-type waste should be considered a “special” or difficult disposal waste. The waste generator or transporter should be required to dampen down the load before delivery to the site.

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

Odour

The main sources of odour on a landfill site are:

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

The landfill operator needs to take appropriate good housekeeping steps 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 transmission of odours off-site.

Odour from incoming waste loads should also be minimised by requiring the generators of odorous waste to deliver the waste prior to putrefaction or, if appropriate, treat it to combat odours before delivery. Loads not complying with these requirements should be refused entry and returned for treatment. Odours originating from the generation of landfill gas can be controlled by the implementation of landfill gas control systems.

Application of deodorant chemicals by spray near the working face, or in areas of excavation in old refuse can be used to control odours. Excavations in old refuse should be kept to a minimum.

Odours can also be caused by emission of landfill gas and release of volatile organic compounds from leachate. Odours from landfill gas will be minimised by timely cover system construction and maintenance, and implementation of landfill gas controls. Leachate odours can be controlled by using pipes and covered storage facilities to limit escape of volatile organic compounds.

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

Birds

Birds, particularly gulls, can be attracted to landfill sites in large numbers for water, food, nesting or roosting. The birds may transfer pathogens to drinking water collection or storage areas 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 problems do not become established. In addition, sudden imposed control on access by birds to landfilled refuse 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 the landfill birds.

Landfills that do not operate continuously often provide a unique roosting habitat due to elevated ground temperatures and freedom from disturbance. Nesting 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 mowing and maintenance schedules.

Measures can be adopted to minimise the attraction of birds to the landfill. These include:

- good litter control;

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

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

- increasing cover thickness;
- changing cover type, density or frequency of application;
- use of mobile high wires;
- special kites, including realistic models of the bird's natural predators;
- bird scare audio recordings;
- shooting of species not protected by law;
- composting or processing of organic wastes before disposal; and
- shredding, milling or baling of waste containing food sources.

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

Flies

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

Prompt, 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

Rats can spread disease, cause property destruction and contaminate food. They are difficult to eliminate once a colony is established. Rat populations occur because they are brought to the site in loads or migrate to the site. Appliance storage areas, voids in bulky or demolition wastes, or poorly compacted cover soils can create shelter.

The most satisfactory way to counter rat infestation is by effective site management. Prompt, good compaction and application of cover are essential to the control of rats. It is also desirable 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.

If alternative cover materials or systems are used, the landfill operator should identify the method by which it can quantitatively monitor changes in vermin population as a result of the new cover. A plan to manage vermin should be developed.

Noise

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

- noise from any single source does not intrude generally above the prevailing background noise level; 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.

Acceptable noise attenuation measures could include buffer zones, acoustical barriers, and acoustical treatment of equipment. Good bunding design will ensure limitation of 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 coincide with adjacent land uses.

5.12 Fire Prevention

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

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

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

The adoption of good site management practices should minimise the risk of fire from any of these factors. Landfill fires can generally be classified either as surface fires or deep-seated fires. Surface fires are fires in recently deposited refuse 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.The best way to control and extinguish a surface fire is to smother it with large volumes of wet or damp soil. To accomplish this fire fighters may have to wet the fire to extinguish any flames and cool the area. The fire should then be covered as rapidly as possible.

Deep-seated Fires

Deep-seated fires are started by spontaneous combustion through aerobic decomposition. Ensuring that refuse 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 fill 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 refuse and the establishment of aerobic conditions. The resulting temperature rise can lead to combustion within the fill. Increased temperatures at gas extraction points may indicate that aerobic conditions are developing.

The area of the 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 reduce 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 escape of combustion gases and entry of oxygen. If practical, the area of the fire can be isolated by deep trenches backfilled with clay.

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 and operations staff should be trained in the use of such equipment and 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;
- 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.

Further information on landfill fires is contained in the document *Hazards of Burning at Landfills* (MfE, 1997).

5.13 Water Control

Leachate

Leachate Generation

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

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

Leachate Control

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

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

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

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

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

Leachate Monitoring

Because of the complex processes operating within the landfill, and their potential environmental effects, monitoring is required to confirm that the landfill is behaving as predicted and to provide management information. It can indicate the effectiveness of attenuation processes or any treatment processes (such as recirculation) used. Changes in composition can act as a warning and assist in identifying problems such as overloading with a particular waste. Environmental monitoring will generally also be necessary to confirm that effluent quality is within the discharge consent conditions.

The monitoring programme will be site-specific, but ambient measurements should be obtained prior to commencement of operations to determine the environmental effect that can be directly attributed to landfilling operations.

Stormwater

Stormwater Control

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

Surface water from outside the area of exposed earthworks should be diverted around the perimeter of the works. Surface water from within the area of exposed landfill earthworks should be treated in silt retention systems prior to discharge in accordance with resource consent requirements. The access road to the working face should be aligned to prevent it from channelling surface water to the face. Side channels on access roads should be intercepted short of the face and diverted away from the filling area. 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. Typical items that should be addressed include:

- regular 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 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 that a month should be stabilised to minimise soil erosion.

Landfill washouts can occur during periods of high intensity rainfall. Remedial work must be undertaken as soon as practicable to minimise any adverse environmental effect. If not repaired, relatively minor washouts can result in a release of refuse, leachate and gas, and promote landfill instability. Depending on the severity of the washout, proper repair and reinstatement may involve substantial effort.

Stormwater Monitoring

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

5.14 Landfill Gas Management

Landfill Gas Generation

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

Landfill Gas Control

A landfill gas control system can have a number of objectives, including:

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

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

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

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

A regular 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 routine 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. Monitoring should commence approximately six months after establishment of the landfill and continue until landfill gas production has fallen below the level where it constitutes a risk. For most sites this will be in excess of 30 years after closure.

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

Migration monitoring should be concentrated at locations considered to be most at risk and should provide a clear indication of the changes in gas quantity, composition and movement with respect to time. Pressure and temperature can also be relevant.

Surface emission monitoring should demonstrate that the cover material and extraction system is controlling the emission of landfill gas. The landfill operator should arrange testing of the atmosphere with appropriate equipment a short distance above the ground surface in areas of intermediate or final cover where wastes have been placed.

The safety of personnel involved in monitoring must be carefully considered. Written safe working procedures should be adopted and practised prior to undertaking gas monitoring.

5.15 Closure and After-care

Closure

Upon completion of waste disposal operations in part of a landfill, closure works should be undertaken as soon as practical. The closure works will include:

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

Construction of ground water control systems may also be necessary for old landfills that are subject to groundwater ingress.

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

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

After-care

The natural processes within landfills continue to produce leachate and gas that require environmental management for many years after landfilling. Operations to support environmental management should be undertaken in the post-closure period. Post-closure operations should follow the direction of a closure plan prepared to reassess the provisions made during the development of the landfill. The plan should take into account the status of the landfill and the degree of control over the release or migration of contaminants from the landfill. The plan should specify:

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

These operations would typically include:

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

Monitoring for environmental effects and site integrity should be continued until the landfill no longer has the potential for adverse environmental effects. Remedial actions should be completed as required.

Chapter 6
Landfill Monitoring

6.1 Introduction

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

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

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

This section addresses:

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

6.2 Objectives of Monitoring

The physical, chemical and biological breakdown of refuse within a landfill produces leachate and landfill gas.

Leachate discharging through the base of a landfill can contaminate groundwater, leading to contamination of surface water. Leachate can also contaminate surface water via discharges from the landfill surface and stormwater management systems.

Landfill gas can give rise to asphyxiation and explosion hazards, and odour nuisance.

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

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

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

6.3 Leachate Monitoring

Purpose of Leachate Monitoring

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

Leachate monitoring should be undertaken at any landfill where it is collected 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 strength and composition; and

- monitoring changes in leachate strength 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 refuse accepted at the site.

Analysis of the leachate chemistry can be used to modify the parameters to be monitored in groundwater and surface water, in cases where monitoring uses a small number of leachate indicator parameters.

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

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

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

Table 6.1 gives is a list of chemical parameters that would typically be included in a leachate monitoring programme for a regional landfill.

Detection Limits

A detection limit relates to the lowest level that a particular analysis method can detect a parameter 99% of the time. Detection limits should be set within a sampling plan and be based on the likely concentration range of the parameter in leachate. Because of the concentrated nature of leachate, use of detection limits significantly higher than those required for groundwater and surface water monitoring may be possible for some parameters.

6.4 Groundwater Monitoring

Purpose of Groundwater Monitoring

As prime receptors of wastes located within natural settings, landfills inherently pose issues for retention of contaminants. Groundwater can be at risk from escape of leachates through the base of the fill materials and/or from ancillary activities such as composting. In some situations, groundwater can be directly disturbed by site construction activities. Groundwater monitoring seeks to identify actual or potential effects on the resource as part of the overall environmental management of the site. In particular, groundwater monitoring seeks to achieve the following purposes:

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

Objectives of Groundwater Monitoring

Monitoring objectives usually seek to achieve reliable, long-term information about the behaviour of groundwater at a site and the effects from the landfill. However, obtaining reliable and pertinent information on groundwater behaviour and characteristics requires a sufficient understanding of hydrogeological conditions in the site vicinity. The basic details of a monitoring programme cannot be developed without knowledge of fundamental information on groundwater flow directions, aquifer configuration and characteristics. Due to the high cost of typical groundwater investigation programmes, monitoring and investigation objectives are often integrated so that boreholes serve both purposes as much as possible.

Specific objectives for investigation/monitoring include:

- characterisation of the groundwater regime including pressures, flows and quality;
- identification and tracking of baseline conditions over time;
- characterisation and tracking of effects of the landfill on groundwater;
- characterisation of the interactions of groundwater with surface waters; and
- characterisation of the interactions of leachate components with groundwater, migration pathways and attenuating effects likely in the groundwater system.

PARAMETERS	UNITS	MONITORING FREQUENCY
Physico-chemical parameters		Bi-annual/Annual
Alkalinity	g/m^3	✔
Aluminium	g/m^3	✔
Ammoniacal Nitrogen	g/m^3	✔
Arsenic	g/m^3	✔
Biological Oxygen Demand	g/m^3	✔
Boron	g/m^3	✔
Cadmium	g/m^3	✔
Calcium	g/m^3	✔
Chloride	g/m^3	✔
Chromium	g/m^3	✔
Chemical Oxygen Demand	g/m^3	✔
Conductivity	mSm^{-1}	✔
Dissolved Reactive Phosphorous	g/m^3	✔
Total Hardness	g/m^3	✔
Iron	g/m^3	✔
Lead	g/m^3	✔
Magnesium	g/m^3	✔
Manganese	g/m^3	✔
Nickel	g/m^3	✔
Nitrate Nitrogen	g/m^3	✔
pH		✔
Potassium	g/m^3	✔
Sodium	g/m^3	✔
Sulphate	g/m^3	✔
Suspended Solids**	g/m^3	✔
Silica	g/m^3	✔
Total Kjeldahl Nitrogen	g/m^3	✔
Total Organic Carbon	g/m^3	✔
Zinc	g/m^3	✔
Total Phenols	g/m^3	✔
Volatile Acids	g/m^3	✔
Volatile Organic Compounds	g/m^3	✔
Semi-volatile Organic Compounds	g/m^3	✔

Table 6.1: Example leachate monitoring programme for a regional landfill

Groundwater Drainage Discharge Monitoring

At sites where a groundwater drainage system is installed beneath the liner, groundwater discharge flowrate and quality need to be regularly monitored to detect any leachate contamination. This should form part of the overall landfill monitoring programme.

In the first instance, monitoring could be for an indicator prevalent in leachate. If contamination is indicated then more detailed analysis is required to determine the characteristics of the contaminant.

Chemical parameters and characteristics that would generally be measured include:

- pH;

- conductivity;
- chloride; and
- ammoniacal nitrogen.

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

Design of a Groundwater Monitoring Programme

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

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

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 for migration of contaminants and travel rates. Degree of certainty in understanding the ground conditions affects the number of wells. Complex hydrogeology normally requires a larger number of wells than simple, uniform conditions. Various analytical or computer analysis methods can be applied to estimate the possible positions of contaminant plumes from landfills to assist in the selection of well locations (Haduk, 1998).

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

Key factors for selecting well sites include:

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

Pathways for the movement of contaminants can be affected by:

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

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

- Hydraulic conductivity, K
  - — very slow $K < 10^{-8}$m/s
  - — slow $10^{-6} > K > 10^{-8}$ m/s
  - — medium $10^{-4} > K > 10^{-6}$ m/s
  - — rapid $K > 10^{-4}$ m/s;
- Effective porosity;
- Hydraulic gradient; and
- Soil/rock/leachate species interaction as given by the Distribution Coefficient, K_d
  - — very mobile $K_d < 1$ ml/g
  - — mobile 100 ml/g $> K_d >$ 1 ml/g
  - — immobile $K_d > 100$ 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 loose detection sensitivity to vertically variable water quality and provide only a gross measure of contamination. Screens should be positioned on main flow pathways and intersect the water table, where immiscible floating contaminants such as petrol, and some solvents are likely to be found, if present.

- *Casing and Screen Materials*. Common practice is to use PVC materials due to their chemical and corrosion resistance. Stainless steel is also suitable. Joints should use mechanical connections without the use of glues that can affect the sample integrity.

- *Casing Diameter*. 50 mm diameter casing meets common sampling and construction objectives. Special sampling tools are available for smaller diameters.

- *Drilling and Construction Limitations.* Drilling methods need to be appropriate for the target zone(s) and soil/rock type, along with secure emplacement and sealing of screen sections. Wells should be developed following construction to remove drilling fluid contaminants, clean the well and remove fines from around screens.

- *Filter Pack and Annular Seals for Screened Zones.* Filter materials selected for packing screens should be 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.

- *Quality Assurance/Quality Control Procedures.* Specifications for monitoring well construction need to cover quality requirements for materials, methods and testing to ensure satisfactory performance of the completed well.

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; 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 such as sometimes occur in fractured rock or dissolved cavity aquifers (for example, karst limestone aquifers), entrained solids in fluid contaminants are filtered in the first layers of soil. However, some contaminants may be in pure liquid form (such as petroleum products) beneath or floating on the water table. Others, such as some metals, may move by intermittently changing between solid and dissolved phases. In cavity flow systems, contaminants can move by attachment to colloids or very fine sediment.

The main focus is normally on parameters that are soluble in the ambient groundwater at the site.

Table 6.2 contains a list of parameters that could be measured for a regional scale municipal solid waste landfill. The list is by way of example and may need to be amended for specific situations according to the characteristics of the wastes in the landfill.

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

- water level;
- pH;
- conductivity;
- alkalinity;
- chloride;
- ammoniacal nitrogen;
- nitrate nitrogen, or total nitrogen;
- total organic carbon; and
- soluble zinc.

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

Monitoring Frequency and Timing

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

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

These objectives are normally achieved by a monitoring programme that has a tiered structure to provide information on the behaviour of the groundwater system and any contaminants within it, in a reliable and efficient manner. Each tier defines a parameter, timing and frequency suite that achieves a specific purpose according to the particular site conditions and requirements. 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 that allows more costly measurements 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 is investigated and remedied.

The tiered system in Table 6.2 shows measurements being taken on a fortnightly/monthly, quarterly/bi-annual and yearly basis. 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 consider seasonal groundwater behaviour to incorporate extremes in the variability of parameter values. 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 landfill sites, it is recommended that groundwater monitoring be undertaken at least twice a year, to coincide with high and low groundwater levels.

Sampling and Analytical Requirements

The capture of representative groundwater samples, and the achievement of a subsequent unbiased analysis

PARAMETERS	UNITS	MONITORING TIER			
		Baseline	**Indicator**	**Comprehensive***	
			Fortnightly/ Quarterly	Quarterly/ Bi-annual	Yearly
Physico-chemical parameters					
Water Level	m	✔	✔	✔	
Alkalinity	g/m^3	✔		✔	
Aluminium	g/m^3	✔		✔	
Ammoniacal Nitrogen	g/m^3	✔	✔	✔	
Arsenic	g/m^3	✔		✔	
Boron	g/m^3	✔		✔	
Cadmium	g/m^3	✔		✔	
Calcium	g/m^3	✔		✔	
Chloride	g/m^3	✔		✔	
Chromium	g/m^3	✔		✔	
Chemical Oxygen Demand	g/m^3	✔		✔	
Conductivity	mSm^{-1}	✔	✔	✔	
Dissolved Reactive Phosphorous	g/m^3	✔		✔	
Total Hardness	g/m^3	✔		✔	
Iron	g/m^3	✔		✔	
Lead	g/m^3	✔		✔	
Magnesium	g/m^3	✔		✔	
Manganese	g/m^3	✔		✔	
Nickel	g/m^3	✔		✔	
Nitrate Nitrogen	g/m^3	✔			
pH		✔	✔	✔	
Potassium	g/m^3	✔		✔	
Sodium	g/m^3	✔		✔	
Sulphate	g/m^3	✔		✔	
Suspended Solids**	g/m^3	✔	✔	✔	
Silica	g/m^3	✔		✔	
Total Kjeldahl Nitrogen	g/m^3	✔			
Total Organic Carbon	g/m^3	✔		✔	
Zinc	g/m^3	✔		✔	
Organic Screen					
Total Phenols	g/m^3	✔		✔	
Volatile Acids	g/m^3	✔		✔	
Volatile Organic Compounds	g/m^3	✔			✔
Semi-volatile Organic Compounds	g/m^3	✔			✔

Notes:

***** this parameter list also applies for contingency monitoring

** only where samples are not pre-filtered

Table 6.2: Example groundwater monitoring programme for a regional landfill

of results, can present considerable challenges for groundwater monitoring programmes. A groundwater 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.

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

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

Factors that need to be taken into account in these steps include:

- *Sampling Methods and Equipment.* Methods for sampling groundwater range widely and are continually being improved. In general, the less disturbance that a sample receives before capture in a sample bottle, the more likely it is to retain its integrity. Some types of pumps, for example, may release volatile components such as benzene from the sample, while others may draw in sediment by pumping too hard.
- *Sample Collection Protocols.* The well should be purged of stagnant water before taking a sample. Normal practice is to purge three to five well volumes. Samples for trace metals analysis should normally be field-filtered prior to placement in the sample bottle. In some cases, laboratory pre-filtering may be more practical if samples are highly turbid and transit time to the laboratory is short. Micro-purging (Stone, 1997) is an alternative method, usually undertaken at pumping rates of less that 1 L/min, that can avoid highly turbid samples (and the need for pre-filtering) and large purge volumes.
- *Sample Storage and Transport.* The use of laboratory supplied bottles and transport containers is usually the most secure and quality-assured sample holding method.
- *Sample Analysis Protocols.* Selection of analysis methods needs to consider factors including likely parameter concentrations, detection limits, regulatory requirements, and cost. More details of analytical methods can be found in APHA (1998) .
- *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. Approximately 10% to 15% of the sampling effort should be devoted to QA/QC (ANZECC, 1992). 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; and
  - — checking of analysis results by comparison with previous measurements.

Detection Limits

A detection limit relates to the lowest level that a particular method of analysis can detect a parameter 99% of the time. Detection limits should be set within a sampling plan and be based on:

- the likely concentration range of the parameter in the groundwater;
- applicable regulatory or performance standards, including trigger levels for the groundwater at the site; and
- practical limitations of the sampling and analysis process.

Detection limits should be set in prior consultation with the laboratory to ensure that the objectives of the sampling can be met. Normally they should be set 10 times or more below the applicable site standard to provide clear indication of any adverse trends.

6.5 Surface Water Monitoring

Purpose of Surface Water Monitoring

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

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

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

- sub-surface migration of leachate as a result of normal seepage or an accidental breach/failure of the landfill liner;
- discharge of sediments from the landfill as a result of earthworks or structural failure;
- above-surface leachate break-outs or spills;
- other 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:

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

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

Controls for Surface Water Monitoring

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

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

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

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

Design of a Surface Water Monitoring Programme

The design of a surface monitoring programme for landfill operations should take into account a number of key considerations, including:

- the objectives of the monitoring programme;
- nature and location of hazards with the potential to contaminate surface waters;

- selection of suitable monitoring points;
- selection of suitable monitoring parameters;
- monitoring frequency;
- sampling requirements;
- analytical detection limits;
- analysis and review of monitoring data; and
- trigger levels.

Determining Locations for Stormwater and Surface Water Monitoring

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

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

Parameters for Surface Water Quality Monitoring

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

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

Physico-chemical Water Quality

Table 6.3 provides a list of water quality parameters that are typically included in a surface water monitoring programme for a regional landfill, including parameters for baseline, comprehensive and indicator monitoring.

While the list is representative, it needs to be reviewed for different landfill operations and locations. For smaller landfills, some parameters may be omitted. Conversely, for a regional landfill that receives large quantities of treated hazardous waste, specific parameters may need to be added.

Sediment Quality

Monitoring of sediment quality may be necessary for those landfills located in the vicinity of depositing surface water environments such as slow-flowing rivers, lakes or estuaries. In these environments, certain contaminants with an affinity to particulate matter may accumulate in sediments, particularly trace metals and organic constituents. Table 6.3 lists the parameters that are appropriate for inclusion into a sediment monitoring programme.

Biological Quality

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

Mostly, biological parameters are used for baseline or comprehensive monitoring to describe the general status of surface water resources. They are less suitable for indicator monitoring because of their high inherent level of variability and associated high sampling and analytical costs. Further, destructive sampling methods may contribute to the degradation of biological indicators that are monitored.

Overall, the need for biological monitoring needs to be evaluated carefully for each landfill operation and location, based on the above considerations. In most cases, specialist technical expertise is needed to ensure that biological sampling and data analysis is carried out in a competent and reliable manner.

Whole Effluent Toxicity Testing

Whole Effluent Toxicity (WET) tests are commonly used in the US to test the toxicity of effluents to selected aquatic organisms. WET tests enable the assessment of complex mixtures of chemicals on the environment.

The application of WET tests in landfill surface water monitoring programmes in New Zealand has been

PARAMETERS	UNITS	MONITORING TIER					
		Water Quality					Sediment Quality
		Baseline	Indicator		Comprehensive		
			Continuous	Fortnightly Monthly	Quarterly Bi-annual	Yearly	Yearly
Physico-chemical parameters							
Flow	l/s	✓	✓		✓		
alkalinity	g/m^3	✓			✓		
Aluminium (TOT/AS)	g/m^3	✓			✓	✓	✓
Ammoniacal Nitrogen	g/m^3	✓		✓	✓		
Arsenic (AS)	g/m^3	✓			✓	✓	✓
Boron	g/m^3	✓			✓		
Cadmium (AS)	g/m^3	✓			✓	✓	✓
Calcium	g/m^3	✓			✓		
Chloride	g/m^3	✓		✓	✓		
Chromium (AS)	g/m^3	✓			✓	✓	✓
Chemical Oxygen Demand	g/m^3	✓		✓	✓		
Conductivity	mSm^{-1}	✓	✓	✓	✓		
Copper (AS)		✓			✓	✓	✓
Dissolved Reactive Phosphorous	g/m^3	✓			✓		
Total Hardness	g/m^3	✓			✓		
Iron (TOT/AS)	g/m^3	✓		✓	✓	✓	✓
Lead (AS)	g/m^3	✓			✓	✓	✓
Magnesium	g/m^3	✓			✓		
Manganese (TOT/AS)	g/m^3	✓			✓	✓	✓
Nickel (AS)	g/m^3	✓			✓	✓	✓
Nitrate Nitrogen	g/m^3	✓			✓		
pH	g/m^3	✓		✓	✓		
Potassium	g/m^3	✓			✓		
Sodium	g/m^3	✓			✓		
Sulphate	g/m^3	✓			✓		
Suspended Solids	g/m^3	✓		✓	✓		
Temperature	g/m^3	✓			✓		
Total Kjeldahl Nitrogen	g/m^3	✓				✓	✓
Total Organic Carbon	g/m^3	✓				✓	✓
Turbidity	NTU	✓	✓		✓		
Zinc (AS)	g/m^3	✓		✓	✓	✓	✓
Organic Screens							
Total Phenols	g/m^3	✓			✓		
Volatile Acids	g/m^3	✓			✓		
Volatile Organic Compounds	g/m^3	✓				✓	✓
Semi-volatile Organic Compounds	g/m^3	✓				✓	✓
Biological Parameters							
Aquatic Biota		✓				✓	✓
WET						✓	

Table 6.3: Example surface water monitoring programme for a regional landfill

limited to date, as leachate is rarely discharged directly to the environment. Although WET protocols have been used to test receiving water toxicity in surface waters below landfills with leachate irrigation systems, the effectiveness of such testing is limited due to the high variability of receiving waters and the current high costs of WET tests.

Monitoring Frequency and Timing

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

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

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

Monitoring frequency and timing must also take into account the variability of the receiving environment through time and space, such as high and low tides in estuarine/marine environments, seasonal low and high flows in rivers, or daily water quality changes in lakes. Therefore, monitoring needs to reflect the spectrum of environmental change and, as a minimum, worst case conditions. Worst case conditions are represented by extreme conditions where the risk of adverse environmental effects is high, such as during low flow or high temperatures.

To optimise monitoring efforts and costs, surface water monitoring strategies are often based on a tiered approach where monitoring frequency and timing vary. Table 6.4 outlines an example of a tiered monitoring strategy for surface waters.

Sampling and Analytical Requirements

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

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

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

Sampling and analytical protocols should specify the methods used for visual observations, field measurements, sample collection and analytical testing. There are a number of references that may be used for this purpose, including APHA (1991), Hellawell (1978), Metcalfe-Smith (1992) and Standards Association of Australia (1987). A full range of references is provided in ANZECC (1992). Protocols must be passed on to external contractors involved in the monitoring programme.

Sampling protocols also need to address sample handling, preservation, processing, transport and storage. It is beyond the scope of this document to go into details, but a range of references may be used for this purpose (see Bibliography).

Processing of water samples for trace metal analyses is an issue that has received specific attention over recent years. As metals have an affinity to adsorb to particulate matter, they tend to be only partially available to aquatic organisms and therefore exhibit only limited toxicity. Historically, the trend has been to measure metals using total extraction techniques. Recent recommendations by the USEPA indicate that only soluble metals need to measured. However, the practice in New Zealand over recent years has been to adopt acid-soluble processing techniques, where trace metals adsorbed to sediments are partially extracted by a weak acid prior to analysis.

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

- maintenance and calibration of field instrumentation;
- use of field and bottle blanks to verify sampling and bottle cleanliness;
- use of reagent blanks, duplicates, known additions and references material by laboratories involved in analytical testing;

Monitoring Tier	Frequency/Description of Parameters	Purpose
Baseline	Monthly to quarterly monitoring of general water and sediment quality (refer Table 6.3) and biological parameters	Establish the status of existing surface water resources at selected monitoring stations before commencement or a change in landfill operations
Indicator	Continuous record of flow	Automatic flow meter installed at one or more stations to record catchment and landfill 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
	Fortnightly water quality sampling (refer Table 6.3)	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 exceedence
Comprehensive	Quarterly sampling (refer Table 6.3)	Long list of parameters checking general water quality and a wide range of possible contaminants (some parameters used as for baseline monitoring)
	Yearly sampling	Selected parameters including organic screening tests, sediment and biological sampling, WET tests (optional)

Table 6.4: Example surface water monitoring strategy

- use of independently certified contractors (for example, Telarc registered laboratories); and
- checks by independent third parties.

Approximately 10% to 15% of the total effort of a surface water monitoring programme should be devoted to QA/QC (USEPA, 1992). All QA/QC protocols and results should be documented in a manner that enables them to pass regulatory authority scrutiny.

Detection Limits

Detection limits refer to the level that a measurement or an analysis of a monitoring parameter must achieve. The setting of detection limits is usually based on the following criteria:

- the ability to provide useful information for management purposes;
- applicable environmental performance standards or trigger levels (as a rule, detection limits should be set an order of magnitude lower than applicable trigger levels); and
- practical limitations, such as the reliability of an observer, or the sensitivity of an instrument or an analytical analysis.

Detection limits for surface water monitoring programmes must be determined at the outset, and any external parties, such as analytical laboratories, must be advised. This enables data to be collected and evaluated in a consistent and standard manner.

6.6 Analysis and Review of Monitoring Data

General

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

- establish baseline conditions;
- track changes to baseline conditions in relation to site activities, climatic and external factors;
- provide a basis for interpretation of overall groundwater and surface water behaviour and effects over time;
- check compliance against site performance standards and resource consent requirements;
- provide information for reporting to regulatory authorities;
- reviewing QA/QC information;
- process and storage of data (preferably using computer software); and
- prepare monitoring reports.

Analytical methods applied to the data should take account of:

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

Leachate

Leachate monitoring data from landfill sites needs to be analysed to:

- establish leachate volume produced;
- track changes in leachate strength; and
- determine if additional parameters should be added to, or removed from, groundwater and surface water monitoring programmes.

Groundwater

Data from groundwater monitoring usually has both spatial and temporal components. Interpretation of spatial data involves assessment of conditions throughout the zone of interest based on the available measurement points. In the first instance, interpolation needs to be limited within zones of hydrogeological similarity, taking account of features such as faults, strata boundaries and hydraulic conductivity conditions. Common methods of interpolation include contouring and kriging. Numerical groundwater flow and transport models can be used for complex situations.

Temporal analysis can involve simple time-series plots or more detailed statistical analysis. There are a number of methods and tools that can be used, depending on the analysis objectives and complexity of the data. Most computer spreadsheet programs will perform regression and variance-type analyses.

For contaminant detection, assessment tests of statistical significance are used. These assist in determining whether a data set shows evidence of contamination or natural variability. Packages such as GRITS/STAT (USEPA, 1992) or general statistics type packages (eg SYSTAT®) can be used. A discussion of methods is given in Neilson (1991) and Lachance and Stoline (1995).

Surface Water

Statistical methods should be applied to surface water monitoring data to:

- examine data variability;
- evaluate the significance of adverse environmental effects; and
- determine compliance with trigger levels.

A detailed description of statistical methods available to evaluate surface water monitoring data exceeds the scope of this document. However, a range of statistical terms are used to describe the variability of monitoring data, including means, medians, standard deviations and percentiles. Similarly, there is a range of statistical methods to test the significance of the difference between groups of data (for example, the difference in water quality between an upstream and a downstream monitoring location).

In applying statistical tests, care must be taken to check whether monitoring data is normally distributed or not. This will determine whether parametric or non-parametric tests need to be applied. Suitable computer software to undertake such tests includes EXCEL® and SYSTAT®. Useful references include McBride (1998), Ward et al. (1990), Keith (1988) and Sanders et al. (1983).

Trigger Levels

Trigger levels consist of specified numerical values or narrative descriptors for the protection of groundwater and surface water resources that must be met by the landfill.

Trigger levels can be used:

- by landfill operators for operational purposes; and
- by consent authorities to set regulatory limits.

Landfill operators will normally set triggers on parameters that have been set by the consent authority, but at lower levels to provide early warning of possible compliance issues. Other parameters relevant to their operational requirements are often measured also.

In New Zealand, a common approach is to adopt a two-tier trigger level system for surface water monitoring regimes. The first tier (TL1) has a mainly landfill-management related function. It is designed to alert management to the fact that the landfill is about to deviate from normal operating conditions and is leading to regulatory non-compliance. Therefore, TL1 levels serve as an indicator of landfill operations for management purposes only.

Exceedance of the TL1 trigger level requires a specified response to investigate the cause of the exceedance and to remedy/mitigate the cause as necessary. TL1 trigger levels are normally set at a specified level or percentage of the regulatory binding TL2 trigger level that is suitable for management purposes — for example at 70% of the TL2 level.

The second tier of trigger levels (TL2) consists of regulatory binding environmental performance standards. Exceedance of a TL2 trigger level indicates non-compliance with the resource consent conditions imposed on the landfill.

Groundwater

Trigger levels provide warning that something is happening in the groundwater system that is abnormal and should be investigated. Where data from monitoring rounds are normally fully collated and analysed six monthly or yearly, trigger levels provide a ready comparator to test for any problems from each round of monitoring.

Trigger levels set for the detection of effects from the landfill activities are usually compiled from an assessment of the natural baseline conditions. Where the baseline conditions vary uniformly and can be described statistically by a normal distribution, the baseline for any parameter can be set as an envelope within some number of standard deviations from the mean value. Three standard deviations from the mean are used by some regulatory authorities which relates approximately to the 95% confidence level.

Trigger levels may also reflect drinking water or aquatic life standards (e.g. Ministry of Health (1995) or ANZECC (1992)) as appropriate for the likely down-gradient use of the groundwater.

Surface Water

Performance standards form the basis to determine compliance of landfill operations with operational and resource consent requirements for surface waters.

For surface monitoring programmes, TL2 trigger levels are usually based on:

- national/international criteria for the protection of aquatic life (for example, USEPA (1991) or ANZECC (1992));
- average background levels established for control sites (usually based on the mean plus three times the standard deviation [$\bar{x}$ + 3 x STD]); and
- visual controls, such as photographs and maps.

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. Examples are listed below.

- 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.
- For quarterly and annual monthly monitoring data, compliance with trigger levels can be assessed using individual data points.

6.7 Landfill Gas Monitoring

Purpose of Landfill Gas Monitoring

Monitoring of landfill gas is important 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 for the effective operation of the extraction system. Monitoring results provide the ability to:

- determine the effectiveness of landfill gas control measures and identify any requirements for modification;
- permit a gas field to be "tuned" effectively to provide optimum gas control;
- determine the extent of landfill gas migration offsite;
- identify migration pathways;

- assess risks to neighbouring properties; and
- assess the fire risk potential of the landfill gas both within and outside the refuse.

Characteristics Affecting Monitoring Requirements

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

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

Subsurface Gas Monitoring

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

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

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

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

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

The probe should remain sealed between monitoring periods. Opening of the probe cap (to obtain water table levels, etc.) should only be done at the completion of a monitoring procedure.

The number and locations of monitoring probes depends on a number of site parameters as listed earlier. Probe spacing and depths will be site specific and should be determined only after a detailed review of site conditions by specialists in the field of landfill gas monitoring.

Monitoring Frequency

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

As a minimum, monitoring of each probe should be carried out six monthly until probe gas concentrations have stabilised below 1% by volume methane and 1.5% by volume carbon dioxide.

In the absence of buildings within 250 metres of the landfill boundary, the USEPA guidance value, above which gas control is required, is 5% methane in a boundary probe.

More frequent monitoring will be required where gas is found 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, evidence of capping cracking and discernible landfill gas odours. Findings from a visual inspection should be confirmed using instantaneous surface monitoring.

- Instantaneous surface monitoring (ISM) — an ISM is conducted over a prescribed or random walk pattern across a site using a flame ionisation detector (FID). Methane is sampled via a wand with a funnelled inlet held 50 mm to 100 mm above the ground surface. Site conditions should be dry and wind velocities less than 15 km/hr on average. During the monitoring process the technician makes recordings at regular intervals and includes any areas of elevated emission levels.

- Integrated surface sampling (ISS) — an ISS is 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.

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% LEL 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.

Landfill Gas Control System Monitoring

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

- air is not sucked into the landfill, creating the potential for an underground fire;
- gas quality is appropriate for the flaring system or end use;
- gas is flared at an adequate destruction efficiency (where a flare is used);
- there is adequate control to permit areas of the site to be isolated or gas extraction rates adjusted; 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 frequency should be as frequent as possible and ideally weekly. However monthly monitoring is commonly adopted once a gas field has been "tuned" (adjusted to a stable condition).

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

Flares

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

- a flame arrestor;
- an automatic slam-shut isolation valve; 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 shutdown the extraction system.

Candle flares are typically monitored for methane flow rate and oxygen on the incoming gas contents. There are usually no specific combustion controls other than flame outage monitoring equipment.

Ground flares usually have facilities to measure methane flow rate and oxygen on the incoming gas, combustion temperature monitoring and also facilities for high temperature gas sampling.

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

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Glossary

Aquifer

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

Background Level

Ambient level of a contaminant in the local area of the site under consideration.

Bio-accumulation

Accumulation within the tissues of living organisms.

Cleanfill

A cleanfill is any landfill that accepts only cleanfill material and inert wastes, including clean excavated natural materials.

Cleanfill Material

Material that when discharged to the environment will not pose a risk to people or the environment, and includes natural materials such as clay, soil, rock and such other materials as concrete, brick or demolition products that are free of:

- combustible, putrescible or degradable components;
- hazardous substances or materials (such as municipal solid waste) likely to create leachate by means of biological breakdown;
- any products or materials derived from hazardous waste treatment, stabilisation or disposal practices;
- materials such as medical and veterinary waste, asbestos or radioactive substances that may present a risk to human health if excavated; and
- contaminated soil and other contaminated materials.

Closed Landfill

Any landfill that no longer accepts waste for disposal.

Co-disposal

The disposal of hazardous waste by mixing in an informed and predetermined manner, with municipal refuse, so as to use the attenuation and biochemical processes operating within the landfill to reduce the environmental impact from the mixed waste to an insignificant level.

Contaminant

Any substance (including gases, liquids, solids, and microorganisms) or energy (excluding noise) or heat, that either by itself or in combination with the same, similar, or other substances, energy or heat:

a) when discharged into water, changes or is likely to change, the physical, chemical or biological condition of water; or

b) when discharged onto or into land or into air, changes or is likely to change, the physical, chemical or biological condition of the land or air onto or into which it is discharged.

Corrosivity

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

Discharge

Includes emit, deposit and allow to escape.

Discharge Permit

A consent to do something that otherwise would contravene section 15 of the RMA.

Ecosystem

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

Ecotoxicity

Adverse toxic effects on ecosystems or ecological communities.

Environment

Includes:

- ecosystems, including people and communities: and
- all natural and physical resources; and

- those qualities and characteristics of an area that contribute to the community's reasonable enjoyment; and
- the cultural, economic, aesthetic, and social conditions that affect the above.

Flammability

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

Geomembrane

A polymeric sheet material that is impervious to liquid as long as it maintains its integrity.

Geosynthetic Clay Liner (GCL)

A relatively thin layer of processed clay (typically bentonite) either bonded to a geomembrane or fixed between two sheets of geotextile.

Geotextile

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

Hazardous Waste

Hazardous waste is waste that poses a present or future threat to people or the environment as a result of one or more of the following characteristics:

- explosiveness;
- flammability;
- capacity to oxidise;
- corrosiveness;
- toxicity; and
- eco-toxicity.

Hazardous Waste Landfill

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

Industrial or Trade Premises

- Any premises used for industrial or trade purposes; or
- 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
- Any other premises from which a contaminant is discharged in connection with any industrial or trade process and includes any factory farm, but does not include production land.

Industrial Waste

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

Industrial Waste Landfill

An industrial waste landfill is a landfill that is designed to accept predominantly industrial waste.

Land Use Consent

A consent to do something that otherwise would contravene section 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 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

The liquid effluent produced by the action of water percolating through waste, and that contains dissolved and/or suspended liquids and/or solids and/or gases.

Municipal Solid Waste

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

Municipal Solid Waste Landfill

A municipal solid waste landfill is any landfill that accepts municipal solid waste.

Oxidise

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

Resource Consent

A coastal permit, discharge permit, land use consent or water permit.

Biosolids

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

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

Transfer Station

A facility where wastes are transferred from smaller vehicles (cars, trailers, trucks) into larger vehicles for transport to a disposal site.

Treatment

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

Waste

Any contaminant, whether liquid, solid, gaseous, or radioactive, which is discharged, emitted or deposited in the environment in such volume, constituency or manner as to cause an adverse effect on the environment and which includes all unwanted and economically unusable by-products at any given time, and any other matter which may be discharged, accidentally or otherwise, into the environment.

Water Permit

A consent to do something that otherwise would contravene section 14 of the RMA.

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Appendix 1
Relevant Case Law

1.1. Introduction

Set out below is a summary of the recent case law relating to the establishment and operation of landfills under the Resource Management Act. It is important to seek specific legal advice for particular issues.

1.2 Discharge of Contaminants

The discharge of a contaminant into a stormwater drain that in turn discharges into water is not a discharge of a contaminant into water (section 15(1)(a)) but a discharge in terms of section 15(1)(b); see *Southland RC v Southern Delight Ice Cream Co* (1995) 2 ELRNZ, 34.

The definition of discharge in section 2 allows for something broader than merely the direct action of a person. Instead the consequences of a person's activity are included by the words "emit" or "allow to escape". Consistent with the policy of preventing contamination in waterways and with *Union Steam Ship Co of NZ Ltd v Northland Harbour Board* [1980] 1 NZLR 273 (CA), a person can be indirectly liable for a discharge of contaminant through a failure to act on their behalf or an action of an employee. The causal link between the person charged and the discharge will be a question of fact in each case.

In *AFFCO NZ Ltd v Far North DC* (No 2) [1994] NZRMA 224 (PT), the Tribunal accepted that some discharges to air are so insignificant that they could be ignored under the principle of *de minimis non curat lex*. However, it rejected the proposition that because the discharges were not discernible beyond the boundaries of the site the principle applied. In particular, unlike discharges to water, the RMA does not provide for mixing zones for discharges to air (section 107(1)).

1.3 Existing Use Rights

A private individual cannot rely on section 10(1)(b) to establish existing use rights. In *Wilson v Dunedin City Council* (decision no. C50/94), the Tribunal doubted section 10(1)(b) was ever intended to provide privately owned and operated activities with the benefits of existing use rights acquired by virtue of the lawful establishment of a public work. Designation procedures apply only to the activities of Ministers of the Crown, local authorities and duly appointed network utilities operators.

In assessing an application for the expansion of existing activities, councils may take into account the past record of operators. See *Philp v Taranaki Regional Council* (decision no. W186/96).

1.4 Application for Resource Consent

Sufficient particulars need to be given with an application to enable those who might wish to make submissions on it to be able to assess the effects of the proposed activity on the environment and on their own interests. See *Affco v Far North DC* (No. 2), [1994] NZLR 224.

When such an assessment is deficient, the Council and Environment Court may have no jurisdiction to hear the case, see *Scott v New Plymouth DC* [1993] 2 NZPTD 116. See also *Affco NZ Ltd v Far North District Council* [1994] NZRMA 224.

Where several resource consent applications are required for the same project, their assessment should take into account the relevant cumulative effects of the development as a whole: *see Burton v Auckland CC* [1994] NZRMA 544.

1.5 Plan Change

Note that the provision for a private-initiated plan change request to a district plan applies only to an operative district plan, not to a proposed district plan. See *Hall v Rodney DC* [1995] NZRMA 537. Because a request for a plan change cannot be rejected on the ground that the district plan is proposed but not yet operative (Clause 25 of the First Schedule), a proposed district plan cannot be changed until it becomes operative. However, notification of a requested change can proceed.

Appendix 2
Relevant Regulatory and Best Practice Background

2.1 USA

Legislation and Regulations

New waste containment facilities (both hazardous and non-hazardous) are regulated at the federal level under the Resource Conservation and Recovery Act (RCRA).

Abandoned dumps and other contaminated sites that require corrective action are regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund.

Under the RCRA, hazardous and non-hazardous solid waste landfills are regulated differently. Hazardous waste landfills are regulated under "subtitle C" and non-hazardous waste landfills are regulated under "Subtitle D". Regulated non-hazardous solid waste landfills can be of two types: industrial waste and municipal solid waste (MSW). Municipal solid wastes are regulated under Subtitle D of the RCRA, hence, MSW landfills are known as RCRA Subtitle D or USEPA Subtitle D landfills.

General

In the USA, regulation is also implemented at the state level. In most states, the state regulatory agency has the actual authority for implementing RCRA solid waste landfill permitting and compliance monitoring. Many states have their own set of regulations, which cannot be less stringent than federal regulations. Thus, federal regulations set what is known as "minimum technology guidance" or MTG.

USA Municipal Solid Waste Landfills (MSWL), i.e. Subtitle D Landfills

Regulations covering all aspects of municipal solid waste landfills in the United States are found in Title 40, Part 258 of the Code of Federal Regulations. The citation for the applicable regulation is thus 40CFR258.

Landfill liner for MSWLs (i.e. Subtitle D Landfills)

The landfill liner shall consist of a composite liner and a leachate collection system that is designed and constructed to maintain less than a 30 cm depth of leachate over the liner.

Composite liner means a system consisting of two components. The upper component must consist of a minimum 30 mil (0.75 mm) flexible membrane liner (FML) and the lower component must consist of at least a two foot (600 mm) layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-9} m/s. FML components consisting of high density polyethylene (HDPE) shall be at least 60 mil (1.5 mm) thick. The FML component must be installed in direct and uniform contact with the compacted soil component.

An alternative liner system may be approved. The alternative design must ensure that the concentration values of chemicals listed in Table 1 of Section 258.40 (Design Criteria) will not be exceeded in the uppermost aquifer at the relevant point of compliance, as specified by the Director of an approved state.

Landfill Covers for MSWLs (i.e. Subtitle D landfills)

The final cover must be designed to minimise infiltration and erosion. The final cover must be designed and constructed to:

- have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1×10^{-7} m/s, whichever is less; and
- minimise infiltration through the closed MSWL by use of an infiltration layer that contains a minimum 450 mm of earthen material; and
- minimise erosion of the final cover by use of an erosion layer that contains a minimum 150 mm of earthen material that is capable of sustaining native plant growth.

An alternative final cover design that includes an equivalent infiltration and erosion layer may be approved.

Post closure care and maintenance is required for at least 30 years, unless a different period is approved.

2.2 Germany

Legislation

In Germany it is mandatory to handle waste in such a way that any contamination of the ground, as well as ground and surface water is prevented. Cognisant of this, the Federal Government enacted the Waste Act (Abfallgesetz (AbfG)) and the Water Act (Wasserhaushaltsgesetz (WHG)). In addition, specific technical instructions have been promulgated under federal law with the objective being the establishment of a technical framework to reach the same degree of safety in containment, disposal, and management of waste materials in all German states.

For the protection of the groundwater, there is the "1st General Administrative Instruction on the Protection of Groundwater for Storage and Deposition of Waste". For hazardous and for municipal waste landfills, the federal government has issued "Technical Instructions on the Storage, Chemical, Physical and Biological Treatment, Incineration and Landfilling of Waste" (TA Abfall 10.04.1990 GMB1.2.170; or TA-A) and "Technical Instructions on Recycling, Treatment and other Management of Municipal Waste" (TA Siedlungsabfall, 01.06.1993, Bundesanzeiger or TA-SI).

As in the USA, German states have supplemented these federal regulations with their own state regulations.

Furthermore, there are government-appointed task groups and professional groups, which establish technical guidance. For example, during the past 15 years, the geotechnical aspects of solid waste landfills have been compiled by a task group of the German Geotechnical Society and edited as technical recommendations under the German title *"Empfehlungen des Arbeitskreises Geotechnik der Deponien und Altalsten"* or GDA. The topics covered by the GDA recommendations were adapted to both international and European conditions and published as "Geotechnics of Landfill Design and Remedial Works: Technical Recommendations".

General

The German regulations specify minimum requirements for the geological features of landfill sites. Special attention is paid to the properties and the placement of the waste material. The waste body is considered a barrier by itself.

Three categories of solid waste landfills are distinguished with respect to the deposited waste material. The technical requirements of the three landfill categories are documented in the Federal Technical Instructions (TA-A and TA-SI). The chemical composition of the constituents of the waste is the governing criterion for the assignment of the landfill category.

Municipal Solid Waste Landfills (MSWL) i.e. Category II Landfills

The landfill Category II comprises the majority of solid waste landfills, since typical municipal solid waste and similar materials with respect to their contents of dangerous substances are assigned to them. Following the philosophy that the waste body itself is an important barrier against the contamination of the environment, very strict criteria have to be met for solid waste assigned to Category II landfills. The most stringent requirement is that the content of organic carbon of the waste material is not allowed to exceed 5% by weight. This means that essentially all domestic waste must be treated in an incinerator, i.e. waste received at Category II landfills by the year 2005 will be mainly incinerator ash.

Landfill Liner for MSWLs (Category II Landfills)

The liner must be a composite liner of 750 mm of compacted clay, placed in three lifts and a geomembrane of 2.5 mm minimum thickness. The hydraulic conductivity of the compacted clay must be less than 5×10^{-10} m/s in all cases. In order to achieve the same quality in all German states, geomembranes used in landfill construction must be approved by the Federal Institution for Material Research and Testing.

Leachate Collection and Removal

The lining system includes a drainage blanket above the geomembrane liner. The drainage blanket is specified to consist of gravel or coarse rock of no less than 16 mm to 32 mm grain diameter.

Landfills must be designed in such a way that the leachate collection and removal system works by gravitational flow. Perforated HDPE collection pipes are installed at spacings of 30 metres or less. Present practice in Germany uses HDPE pipes of at least 200 mm internal diameter and wall thickness of about 15 to 40 mm, depending on the waste overburden.

Landfill Covers for MSWLs (Category II Landfills)

German cover regulations are focussed on surface/protection layers, drainage layers, barrier layers and gas venting/foundation layers. The surface/protection layer must be adequate for long-term maintenance and reliability. The drainage layer placed above the hydraulic barrier layer, according to German regulations (TA-A and TA-SI), is a layer of granular soil at least 300 mm thick with a minimum hydraulic conductivity of 0.1 cm/s (1 x 10^{-3} m/s). At many sites, the same 16/32 mm rounded stone required in the leachate collection system is used in the cover system as well.

The German regulations (TA-SI) do not give detailed requirements for the hydraulic barrier layer of old Category II landfill covers. Most barriers are similar to Category I, i.e. a 500 mm thick compacted clay layer placed in two 250 mm thick lifts, with a hydraulic conductivity of 5 x 10^{-9} m/s or less.

The hydraulic barrier system for Category II landfills will eventually consist of a geomembrane over compacted clay. The compacted clay is described above. The geomembrane, by German TA-SI regulations, must be high density polyethylene (HDPE) with a minimum thickness of 2.5 mm. The regulations permit the use of recycled polymers, however none have been approved to date.

A gas venting layer must be provided in current Category II landfills accepting degradable municipal solid waste. For future Category II landfills where no gas is generated, a gas venting layer will not be necessary.

The soil foundation layer placed directly over the waste is critical in setting the grade (minimum gradient is 5% and the maximum slope is not steeper than 3H:1V) for all the overlying cover layers.

2.3 Australia (New South Wales)

Legislation and Regulations

The Waste Minimisation and Management Act (1995) introduced a state-wide scheme for licensing waste activities and the Waste Minimisation and Management Regulation (1996) detailed the state-wide licensing and reporting scheme.

In NSW, landfills are subject to environmental protection regulation in two stages: planning and operation.

Regulation at the planning stage is via the Environmental Planning and Assessment Act and at operational stage through the new waste licensing scheme via the Waste Minimisation and Management Regulation.

The State Environmental Planning Policy (SEPP) establishes the Minister of Urban Affairs and Planning as the consent authority for regional putrescible landfill proposals from local councils, waste planning and management boards or from the waste service. Local councils are still responsible for determining applications for individual local council landfills.

Assessment and classification of waste for landfill disposal is addressed in the *Environmental Guidelines: Assessment, Classification and Management of Non-Liquid Wastes 1997* (Waste Guidelines).

In short, NSW classifies waste in the following order, ranging from the least harmful to the most harmful to the environment:

- inert waste;
- solid waste;
- industrial waste; and
- hazardous waste.

The 1996 EPA Landfill Guidelines ("Environmental Guidelines: Solid Waste Landfills") outlined the environmental performance requirements and provided benchmark techniques for the operation of solid waste landfills. The 1998 EPA draft addendum to the Landfill Guidelines (*Draft Environmental Guidelines for Industrial Waste Landfilling*, April 1998) set out the additional management requirements for industrial waste landfilling.

Leachate Barrier System (Landfill Liner) for Solid Waste Landfills

Characteristics of a suitable liner include:

- recompacted clay or modified soil liner at least 900 mm thick with an in-situ permeability less than 1 x 10^{-9} m/s;
- liner or barrier surface should be formed so that once settling is finished, the upper surface of the liner or barrier must have a longitudinal gradient of greater than 1% and transverse gradient of greater than 3%; and
- if the landfill is located in an area of poor hydrological conditions or otherwise poses a significant threat to groundwater or surface water, the compacted clay or modified soil liner should be overlain with a flexible membrane liner (FML) at least 1.5 mm thick and with a minimum permeability of 1 x 10^{-14} m/s.

Leachate Collection System for Solid Waste Landfills

Acceptable designs include the following:

- A drainage layer with permeability greater than 1 x 10^{-3} m/s and at least 300 mm thick should be installed over the liner.
- Gravel or a combination of gravel and a geonet may be used. The gravel should ideally be rounded, smooth surfaced, of grain size greater than 20 mm, relatively uniform in grain size, non-reactive in mildly acidic conditions, and free of carbonates.
- Perforated collector pipes placed within the drainage layer should not be at intervals of more than 50 metres. Pipes should generally be a minimum of 150 mm in diameter and have a minimum longitudinal gradient of 1%.

Landfill Covers for Solid Waste Landfills

The landfill final capping should consist of:

- the seal bearing surface — designed and engineered layer;
- the gas drainage layer — minimum thickness 300 mm;
- the sealing layer — compacted clay (permeability less than 1 x 10^{-8} m/s) of 500 mm minimum thickness;
- the infiltration drainage layer — minimum thickness 300 mm, permeability greater than 1 x 10^{-5} m/s; and
- the revegetation layer — minimum thickness 1000 mm.

The final settlement of the seal bearing surface should leave a gradient of greater than 5% to defined drainage points.

2.4 United Kingdom

Legislation and Regulations

All landfill sites in the UK are subject to legislative controls and landfill development cannot proceed without necessary consents.

There are three main areas of legislative control relating to landfill developments:

- the planning system, which controls the development and use of land in the public interest, and affects the choice of site location;
- pollution control legislation, incorporating waste management licensing and measures for environmental protection; and
- regulations and statutory controls to protect health and safety and ensure minimum standards for engineering construction.

Legislation and guidance on its application are found in a range of documents including:

- The Environmental Protection Act, 1990;
- The Water Resources Act, 1991;
- The Controlled Waste Regulations, 1992;
- The Waste Management Licensing Regulations,1994;
- The Environmental Protection (Duty of Care) Regulations, 1991;
- The Special Waste Regulations, 1995;
- The Town and Country Planning Act, 1990;
- The Government and Industry Codes of Practice; and
- The Department of Environment (DoE) circulars, guidance notes and waste management papers.

Planning control is exercised through the local authorities, whilst waste management licensing is the responsibility of the waste regulatory body, at present the Waste Regulation Authority (WRA). Water pollution control is a function of the National Rivers Authority (NRA) in England and Wales and the River Purification Authorities (RPA) in Scotland.

General

The DoE's *Waste Management Paper* No 26B provides guidance on the overall development of landfill sites, encompassing landfill design, construction and operational practice.

WMP26B's guidance to Waste Regulation Authorities (WRAs) is non-statutory: a WRA is thus not obliged to have regard to it. In substituting its own view, however, the WRA should ensure that it informs licensees, applicants and intending applicants what its intentions and requirements are. To do otherwise might be to disregard the statutory guidance in Waste Management Paper No 4 (WMP4:*Licensing of Waste Management Facilities*).

The guidance embodied in WMP26B is based on:

- a holistic approach to landfill design and operation, utilising scientific and engineering skills as an integrated process from initial conception through to final capping, restoration and aftercare; and

- use of a site-specific risk assessment, rather than a prescriptive approach to environmental protection, for each element and at each stage in the project, in order to determine the overall design and operational practices appropriate to the environmental settling of each individual landfill site.

Design standards fall into the categories of:

- absolute standards;
- performance standards; and
- guidelines.

Landfill Liners

The selection of a liner system is a complex process which should be determined on a site-specific basis.

Liner systems include single-liner, composite-liner, double-liner, or multiple-liner systems

For clay liners, a typical specification is that “the material should be placed and compacted in layers to form a homogeneous layer with a total thickness no less than 1000 mm with a hydraulic conductivity of no greater than 1×10^{-9} m/s

For composite-, double- or multiple-liner systems, the thickness of the clay liner should never be less than 600 mm.

Leachate Collection and Removal

The NRA (1995) Internal Guidance Note No 8 *Leachate Management* suggests the following standards for construction of leachate collection systems:

- base slope 2%;
- drainage blanket 300 mm Type B filter drainage media;
- 200 mm diameter perforated smooth bore pipes; and
- possible geotextile or geonet at waste/drainage blanket interface.

Landfill Cover

The five possible components are the:

- surface layer;
- protection layer;
- drainage layer, pipework zone;
- barrier layer; and
- gas collection layer.

Detailed guidance on the design and construction of the capping system is given in Waste Management Paper No 26E, *Landfill Restoration and Post Closure Management* (1995).

Appendix 3
Landfill Management Plan Outline Table of Contents

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Appendix 4
Waste Classification for Landfill Disposal

NOTES: 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.

A Waste Prohibited from Landfills

1 Characteristics

- H1 Explosives
- H2 Gases
- H3 Flammable liquids
- H4.1 Flammable solids
- H4.2 Substances or wastes liable to spontaneous combustion
- H4.3 Substances or wastes, which in contact with water emit flammable gases
- H5.1 Oxidising substances
- H5.2 Organic peroxides
- H6.2 Infectious substances
- H7 Radioactive materials[1]
- H8 Corrosives
- H10 Liberation of toxic gases in contact with air or water
- H13 Capable, by any means after disposal, of yielding another material, e.g. leachate, which possess any of the above characteristics

2 Waste types which may exhibit the above characteristics

Cyanides, surface treatment and heat treatment wastes

- A100 Cyanide containing waste from treatment of metals
- A110 Cyanide containing waste from heat treatment and tempering
- A120 Complexed cyanides
- A130 Other cyanides

Acids

- B100 Sulphuric acid
- B110 Hydrochloric acid
- B120 Nitric acid
- B130 Phosphoric acid
- B140 Chromic acid
- B150 Hydrofluoric acid
- B160 Sulphuric/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>61ºC), n.o.s.

G120 Non-halogenated (FP<61ºC), n.o.s.

G130 Halogenated (FP>61ºC), n.o.s.

G140 Halogenated (FP<61ºC), n.o.s.

G150 Halogenated n.o.s.

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

H120 Nitrogen-containing pesticides

H130 Halogen-containing pesticides

H140 Sulphur-containing pesticides

H150 Mixed pesticide residues

H160 Copper-chrome-arsenic (CCA)

H170 Other inorganic wood preserving compounds

H180 Organic 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 PCBs)

J150 Other (cutting, soluble oils)

J160 Tars and tarry residues (including tarry residues arising from refining and any pyrolytic treatment)

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

L140 Textile effluent

L150 Other industrial plant washdown water

Organic chemicals

M100 Polychlorinated biphenyls (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

Clinical 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

B Wastes possibly suitable for municipal landfill disposal — solids and sludges

1 Characteristics

H6.1 Poisonous substances

H11 Toxic substances (chronic or delayed effects)

H12 Eco-toxic

2 Waste types which may exhibit the above characteristics

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

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)

M250 Surfactants and detergents

M260 Highly odorous (eg. mercaptans, acrylate)

M270 Methacrylate compounds

M280 Other (hazardous substances must be specified)

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

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[2]

N230 Synthetic mineral fibres

Clinical and pharmaceutical wastes[3]

R120 Pharmaceuticals and residues

R140 Wastes from the production and preparation of pharmaceutical products

Miscellaneous

T120 Scrubber sludge

T130 Photographic chemicals which do not contain silver

T140 Inert sludges/slurries (eg. clay, ceramic suspensions)

T150 Used tyres/tyre wastes

T190 Other (hazardous substances must be specified)

1 Some radioactive wastes may be able to be landfilled-refer Guidelines for Disposal of Radioactive Substances – National Radiation Laboratory

2 Refer to Asbestos Regulations 1983

3 Some clinical wastes such as non-sharp, non-infectious and non-pathological wastes may be able to be landfilled —Department of Health

Appendix 5
USEPA Toxicity Characteristic Leaching Procedure Limits

In the case of a Category A or B waste (as detailed in Appendix D) that has received treatment, 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 unrestricted landfill disposal.

Contaminant Examples	Maximum Concentration (mg per litre)
Arsenic	5.0
Barium	100.0
Benzene	0.5
Cadmium	1.0
Carbon Tetrachloride	0.5
Chlordane	0.03
Chlorobenzene	100.0
Chloroform	6.0
Chromium	5.0
Endrin	0.02
m-Cresol	200.0*
o-Cresol	200.0*
p-Cresol	200.0*
1,4-Dichlorobenzene	7.5
1,2-Dichloroethane	0.5
1,1-Dichloroethylene	0.7
2,4-Dinitrotoluene	0.13
2,4-Dichlorophenoxyacetic acid	10.0
Heptachlor	0.008
Hexachloro – 1,3-butadiene	0.5
Hexachlorobenzene	0.13
Hexachloroethane	3.0
Lead	5.0
Lindane	0.4
Mercury	0.2
Methoxychlor	10.0
Methyl ethyl ketone	200.0
Nitrobenzene	2.0
Pentachlorophenol	100.0
Pyridine	5.0
Selenium	1.0
Silver	5.0
Tetrachloroethylene	0.7
Toxaphene	0.5
Trichloroethylene	0.7
2,4,5-Trichlorophenol	400.0
2,4,5-Trichlorophenoxypropionic acid	1.0
2,4,6-Trichlorophenol	2.0
Vinyl chloride	0.2
Sulphides	50 ppm
Cyanides	50 ppm
Asbestos	Any amount if unbound in matrix (so as to prevent fibres being airborne)
Total Halogenated Compounds	**1,000 ppm**
Total Synthetic Non-halogenated Compounds	**10,000 ppm**
Polychlorinated Biphenyls	**50 ppm**

* Total of all cresols not to exceed 200

Appendix 6
NSWEPA Leachable Concentration and Total Concentration Values for Solid Waste Landfills

Contaminant threshold (CT) is the maximum allowable concentration if a TCLP test is not carried out. Leachable concentration limits and total concentration limits are used together in accordance with NSWEPA (1999) *Environmental Guidelines: Assessment and Management of Liquid and Non-liquid Wastes.*

Contaminant	Contaminant Threshold (mg per litre)	Leachable Concentration (mg per litre)	Total Concentration (mg per litre)
Arsenic	100	5.0	500
Benzene	10	0.5	18
Benzo(a)pyrene	0.8	0.04	10
Beryllium	20	1.0	100
Cadmium	20	1.0	100
Carbon Tetrachloride	10	0.5	18
Chlorobenzene	2000	100	3600
Chloroform	120	6	216
Chromium (VI)	100	5	1900
m-Cresol	4000	200	7200
o-Cresol	4000	200	7200
p-Cresol	4000	200	7200
Cresol (total)	4000	200	7200
Cyanide (amenable)	70	3.5	300
Cyanide (total)	320	16	5900
2,4-D	200	10	360
1,2-Dichlorobenzene	86	4.3	155
1,4-Dichlorobenzene	150	7.5	270
1,2-Dichloroethane	10	0.5	18
1,1-Dichloroethylene	14	0.7	25
Dichloromethane	172	8.6	310
2,4-Dinitrotoluene	2.6	0.13	4.68
Ethylbenzene	600	30	1080
Fluoride	3000	150	10000
Lead	100	5	1500
Mercury	4	0.2	50
Methyl ethyl ketone	4000	200	7200
Molybdenum	100	5	1000
Nickel	40	2	1050
Nitrobenzene	40	2	72
C6-C9 petroleum hydrocarbons	N/A	N/A	650
C10-C36 petroleum hydrocarbons	N/A	N/A	10000
Phenol (non-halogenated)	288	14.4	518
Polychlorinated biphenyls	N/A	N/A	<50
Polycyclic aromatic hydrocarbons (total)	N/A	N/A	200

Contaminant	Contaminant Threshold (mg per litre)	Leachable Concentration (mg per litre)	Total Concentration (mg per litre)
Scheduled chemicals *	N/A	N/A	<50
Selenium	20	1	50
Silver	100	5.0	180
Styrene (vinyl benzene)	60	3	108
1,1,1,2 - Tetrachloroethane	200	10	360
1,1,2,2 - Tetrachloroethane	26	1.3	46.8
Tetrachloroehylene	14	0.7	25.2
Toluene	288	14.4	518
1,1,1 – Trichloroethane	600	30	1080
1,1,2 – Trichloroethane	24	1.2	43.2
Trichloroethylene	10	0.5	18
2,4,5-Trichlorophenol	8000	400	14400
2,4,6-Trichlorophenol	40	2	72
Vinyl chloride	4	0.2	7.2
Xylenes	1000	50	1800

*Scheduled Chemicals
Aldrin
Benzene, hexachloro
Benzene, pentachloronitro
Alpha-BHC
Beta-BHC
Gamma-BHC Lindane
Delta-BHC
Chlordane
DDD
DDE
DDT
Dieldrin
Endrin
Endrin aldehyde
Heptachlor
Heptachlor epoxide
Hexachlorophene
Isodrin
Pentachlorobenzene
Pentachlorophenol
1,2,4,5-tetrachlorobenzene
2,3,4,6- trichlorobenzene
2,4,5-trichlorophenoxyacetic acid, salts and esters

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