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

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Preface

The 1998/99 National Landfill Census was conducted by the Ministry for the Environment between November 1998 and January 1999. The census covered open and closed municipal landfills, dedicated landfills and cleanfills, and sought to establish the current state of landfill management practice in New Zealand.

In brief, the census results indicate:

- **number of consented landfills**: an improvement in the number of consented landfills, although there are still landfills operating without the necessary consents
- **compliance**: a significant level of non-compliance, with one-third of landfills having breached their resource consents since 1995
- **hazardous waste management:** a poor performance by landfill operators in the management of hazardous waste
- **open burning**: a decrease in open burning at landfills, although burning still occurred at 24% of landfill sites in 1998
- **landfill operator training**: a small improvement in landfill management training
- **consent conditions**: conditions still vary considerably throughout the country
- **closed landfills**: evidence of inadequate management of closed landfills.

Overall the 1998/99 National Landfill Census has shown that there has been some improvement since the 1995 Landfill Census, but that the standard of landfills and landfill management practice in this country is still not good enough.

The results of the latest census stimulated the development of the Ministry's Landfill Management Programme. The Ministry's aims for this programme are the adequate management of landfills and their environmental risk, by councils, through:

- controlling adverse and potential environmental effects from open and closed landfills
- managing landfills in an efficient and effective manner.

The objectives of the programme are for:

- all landfills to be consented and compliant with consent conditions
- landfill consent conditions to reflect nationally consistent standards of environmental management
- the practice of open burning to be banned
- all landfills to be managed by appropriately trained operators
- hazardous waste to be effectively managed and controlled
- closed landfill sites to be monitored and effectively managed
- the true cost of landfill management to be met through the correct pricing of waste disposal.

The Landfill Management Programme comprises:

- the development and implementation (with local government and other interested parties) of landfill management guidelines
- an exercise to audit and review landfills around the country
- selected intervention in the resource consent process, where appropriate.

Guidelines make explicit the Ministry's expectations. The following documents (box below) are currently being prepared through the programme. In addition, the Centre for Advanced Engineering *Landfill Guidelines* (funded by the Sustainable Management Fund) was published in May 2000. This guideline together with the Ministry guidelines provides a clear basis for the standards of landfill management that the Ministry expects to be achieved by 2010.

Landfill Management Programme – Guidelines

- *Guide for the Management of Closing and Closed Landfills in New Zealand*
- *Guide to Landfill Consent Conditions*
- *Guide to Managing Cleanfills*
- *Guide to Landfill Full Costing and Charging* – review and update
- *Waste Analysis Protocol* – review and modification

This *Guide for the Management of Closing and Closed Landfills* aims to increase awareness of the risks associated with closed landfills and to outline the best practical methods to manage closed landfill sites effectively, so that adverse environmental effects are minimised.

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1 Introduction

1.1 Closed landfills in New Zealand

1.1.1 Current management practice

Landfills are the conventional means of disposing of the majority of solid wastes in New Zealand. Until the 1980s most New Zealand landfills were no more than tip/dump sites, which were often poorly sited, designed and managed. There was little control on the acceptance of hazardous wastes, but, overall, hazardous waste generation rates were low by international standards.

Resource consents, issued under the Resource Management Act 1991 (RMA), are now the main means of controlling the environmental effects of landfills. Good consent conditions are an important method for the effective management of operational and closed landfills, and accordingly the Ministry for the Environment has produced a *Guide to Landfill Consent Conditions* (Ministry for the Environment, 2001). Broader controls may be provided through regional or district plans and the performance standards these contain. Since the introduction of the RMA, and with it more stringent environmental controls on landfills, management of landfills has improved and many of the older tip sites have been closed.

Although the exact number of closed landfills throughout the country is unknown, it is likely to be well in excess of 1000. Regional councils identified 914 closed landfills in their regions (1998/99 National Landfill Census), and responses to further questions to regional and territorial authorities indicate that in most regions not all closed landfills have been identified. Regional council responses (1998/99 National Landfill Census) indicated that 10 councils had a policy on closed landfills and eight maintained a register of these landfills. The most common types of information recorded in the closed landfill registers included location and current use, assessments of environmental effects, monitoring, resource consents, and any conditions of these consents. Most closed landfills in urban areas have been converted to public open space and are managed for recreation. Closed landfills in rural areas have generally reverted to the surrounding agricultural use (often this is grazing). Others have simply been abandoned.

The 1998/99 National Landfill Census has identified that management of closed landfills is being undertaken in an *ad hoc* manner throughout the country, particularly in relation to consents and consent conditions, appropriate record keeping and aftercare management and monitoring. A significant percentage (30–35%) of closed landfill sites do not have a closure or aftercare plan, but this probably reflects the fact that many of the older sites were closed some years ago when such plans were not identified as necessary for good practice. Although some closed landfills may be permitted activities, others are not and do not have the necessary or appropriate resource consents.

Management of closed landfills should address some or all of the following:

- leachate monitoring
- groundwater and surface water monitoring
- landfill gas monitoring
- stormwater control
- stability and slope analysis
- settlement monitoring and repairs to capping and collection systems (leachate/stormwater)
- revegetation (noting that in many instances grass is the only vegetation allowed)
- vermin control.

Typically, the number of matters on this list and the extent of monitoring are a function of the scale and nature of the landfill.

The Local Government Act requires territorial authorities to utilise Asset Management Plans to manage their assets effectively. For example, landfill assets such as containment structures, lining, leachate and gas collection systems should be depreciated to allow for replacement and maintenance costs. Auckland City Council uses its Closed Landfills Asset Management Plan to achieve this. Further developments in this area may follow the introduction of the Accounting Standard "Provisions, Contingent Liabilities, Contingent Assets".

Auckland City Council is also developing an Integrated Catchment Management approach, which includes the management of its closed landfills. Instead of treating each landfill in isolation as a discrete contaminated site with high priority for action, the entire catchment containing the landfill has all its contamination sources analysed and prioritised according to their impacts. This approach allows for the maximisation of environmental improvement in the catchment while rationalising expenditure.

1.1.2 Land uses on closed landfills

Many closed landfills in urban areas have been converted to reserves/parks (public open space or sports fields) and are managed for recreation. Closed landfills in rural areas have either reverted to the surrounding agricultural use (grazing), been used for forestry, or remain unused. Other recorded uses include car parking, a council yard, a tree nursery, restoration of native vegetation, residential dwellings, a marae, a museum and a school.

There are no apparent trends in land uses at closed landfills, although opinions obtained from interested parties indicate a preference for fewer sportsfields and more restoration of native vegetation. It should also be noted that there is a trend towards larger regional landfills, for which larger public open space activities such as golf courses and driving ranges may be more appropriate in the future.

A review of practices in a number of countries (see Appendix A) indicates that New Zealand land uses and management practices are similar to those in other countries.

1.1.3 Liability for closed landfills

Changes in land use on closed landfills may be associated with change in ownership of the land. Potential new owners need to be aware of the liability associated with the closed landfill (generally this will be a contaminated site). In October 1999 the Minister for the Environment announced the Government's policy on liability for historical contaminated sites. There have not yet been any legislative changes to implement this policy (a draft bill is expected to be introduced in 2001). Under the RMA the owner, occupier or polluter can be required to clean up a contaminated site where the contamination occurred after 1991.

The Government's proposal for historical contaminated sites (those sites where the contamination occurred prior to 1991) is to make the same three parties potentially liable for clean-up. This means that an owner or an occupier (or a polluter) of a site would be liable for the costs of clean-up, irrespective of when the site was contaminated (relative to their ownership or occupation).

The Government has also decided that an "innocent landowner" defence be introduced for those sites contaminated prior to 1991 that require clean-up. The "innocent landowner" defence removes from the group of potentially liable parties those who had no knowledge of the likely contamination or association with the site. It is unlikely that the "innocent landowner" defence will apply to most situations concerning closed landfills.

1.2 Basis for the preparation of the Guide

1.2.1 National Landfill Census

The *1998/1999 National Landfill Census Report* (Ministry for the Environment, 2000) has shown that there are a number of continuing problems with the consenting and management of landfills, both operating and closed. The census also showed that there is a lack of aftercare planning and rehabilitation of many closed landfill sites, and that some of these sites have the potential to cause significant environmental harm.

1.2.2 Potential environmental effects and general concerns

The potential environmental effects of closed landfills are in many respects the same or similar to those of operating landfills (see Figure 1.1), and include:

- discharge of leachate and subsequent contamination of groundwater or surface water (particularly for landfills sited in or close to sensitive watercourses/water bodies or sea/ estuary environments), and impairment of their life-supporting capacity or use
- discharge or migration of landfill gas (potentially explosive/flammable), which may have a noxious odour and/or may damage soil health and vegetation.

Other concerns regarding closed landfills relate to:

- emissions of greenhouse gases
- health and safety aspects relating to subsequent site use
- inadequacy of completion works relating to final capping, and grades for the expected long-term land use(s)
- subsidence and its effects on capping, causing increased leachate generation, or on leachate and landfill gas collection systems, or on the long-term land use and consequent health and safety risks
- stability, particularly with respect to erosion by land slip, sea or from changes in directions of a watercourse
- the unknown location or nature of some of the waste constituents, either by the owner/ operator or within the local community
- unwillingness of owners to monitor and, if required, to remediate
- no financial security for the community.

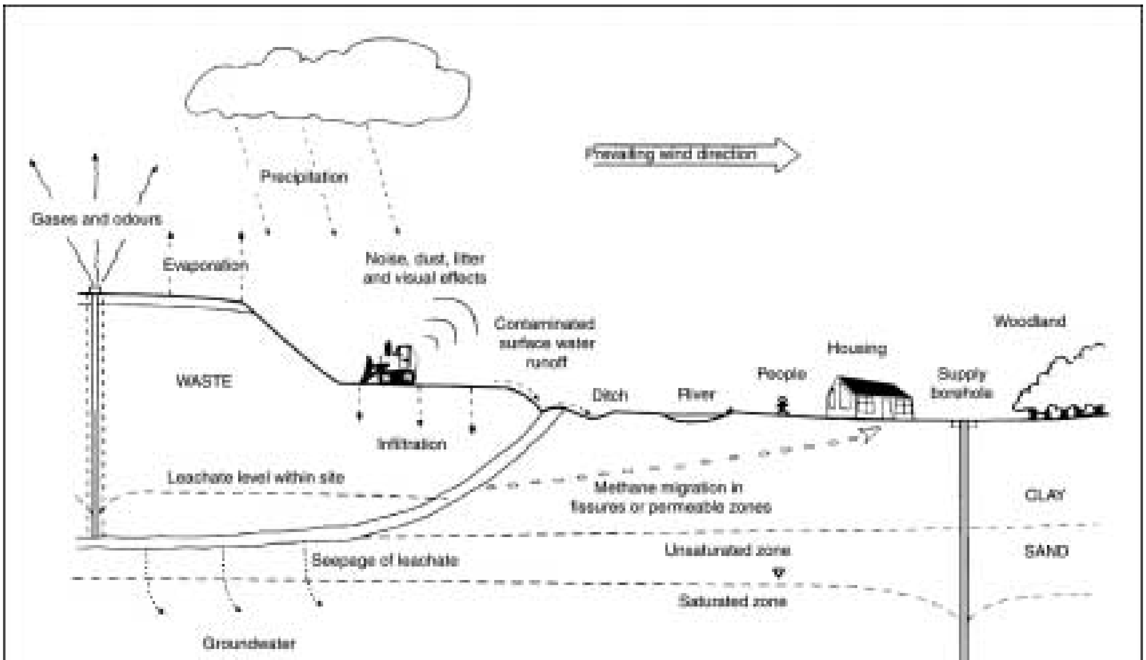

Figure 1.1: Environmental protection – illustration of source/receptor/pathway

Source: Modified Figure 3.4 from UK Department of the Environment, Waste Management Paper No. 26B, 1995.

1.2.3 Maori concerns

Closed landfills may also pose a significant cultural dilemma for Maori. The discharge of leachate without appropriate treatment to groundwater and surface water will result in local iwi downgrading the status of that water to wai piro or wai mate, making it effectively unusable.

Local iwi may also impose a rahui (prohibition on the collection of food from the adjacent waterway) where there is any doubt about the water quality of the adjacent stream or estuary. This is particularly important for closed landfills located in or close to the coastal marine area, as the collection of shellfish and other fish species is of key importance to Maori. Protection of kai moana may be the most important issue for Maori at these landfills.

Where parts of a landfill are thought to be unsafe to the public, the imposition of a tapu by local iwi may be warranted.

Consultation with iwi groups is crucial to the successful remediation of a closed landfill.

1.3 Objective, scope and applicability

1.3.1 Objective

The Ministry for the Environment considers that the lack of aftercare planning and rehabilitation and many of the ongoing problems of closed landfills stem from the absence of practical guidance for local government and other landfill managers, in addition to the historical lack of will to treat the issue as important. Accordingly, the Ministry has commissioned this *Guide for the Management of Closing and Closed Landfills in New Zealand* as a practical handbook outlining decision-making processes, engineering practices and alternative techniques for minimising environmental effects at closed landfill sites.

It should be noted that where reference is made in the *Guide* to particular approaches, programmes or models, these are only examples of good practice and alternatives exist. In many instances the management of a closed landfill will be a continuation – albeit at a reducing level – of the requirements for the operational phase of the landfill.

1.3.2 Scope

Throughout the text and in a number of appendices, the *Guide* provides background information on closed landfills and the applicable legislative framework in New Zealand. An indication of the various sections of the document where specific guidance can be found is given in Figure 1.2, and is also summarised below.

Chapter 1 describes the background to, and the basis for the preparation of the Guide and outlines its objective, scope and applicability.

Chapter 2 outlines the legislative framework applicable to landfills in New Zealand.

Chapter 3 provides information on landfill processes and the resultant potential discharges into the environment.

Chapter 4 gives guidance on the level of assessment likely to be required to determine an appropriate management regime for the landfill, and summaries of factors that should be taken into consideration at each level of assessment.

Chapter 5 details design measures and practices for closure and post-closure management.

Chapter 6 provides guidance on relevant monitoring programmes for leachate, local groundwater and surface water, and landfill gas.

Chapter 7 gives information on the range of costs for closure and post-closure management activities.

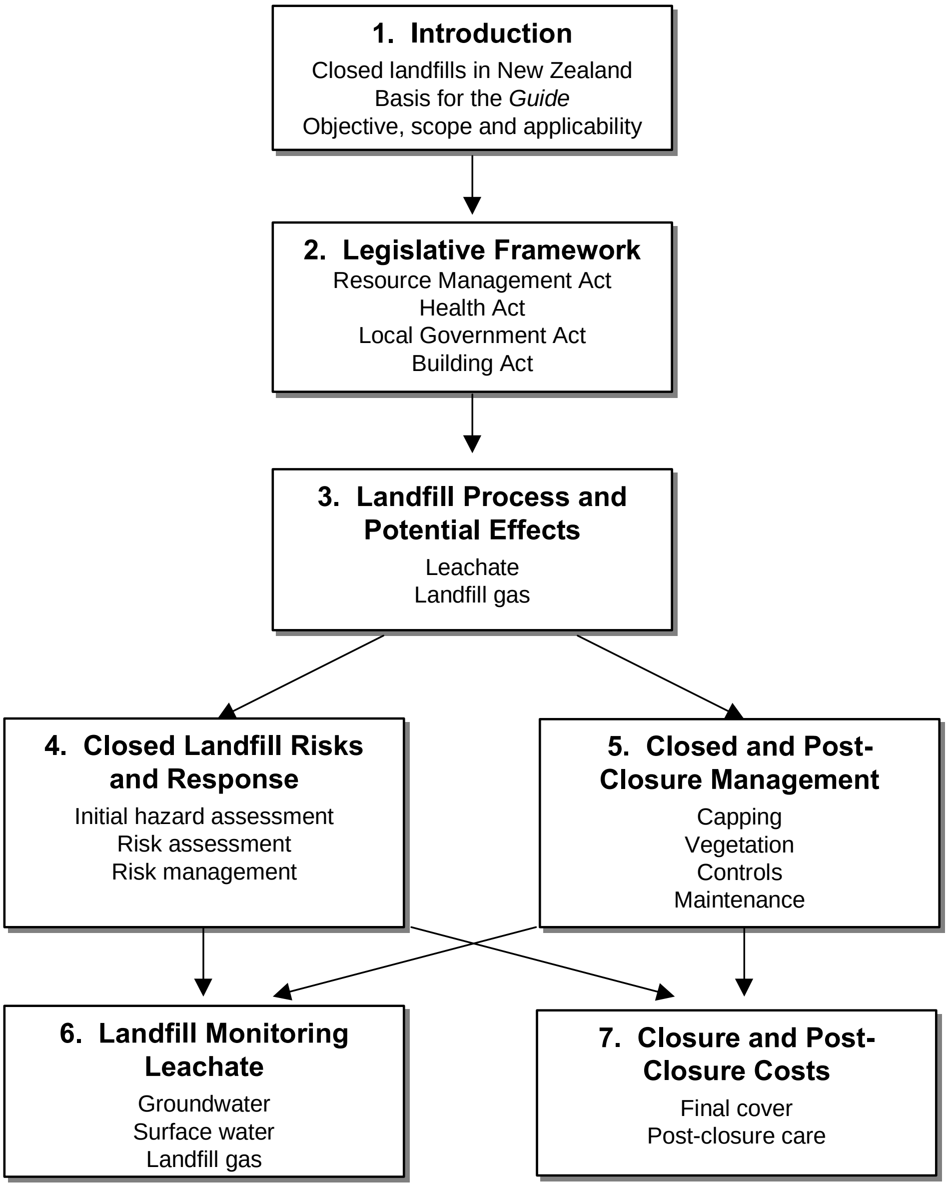

Figure 1.2: Sections of the document where specific guidance can be found

This *Guide* also provides comment on consent requirements for the ongoing management of such sites (further guidance can be found in the related *Guide to Landfill Consent Conditions* [Ministry for the Environment, 2001]). However, it does not address the consent process (nor does it replace it) or associated aspects such as public/affected party issues or consultation.

As there is a very wide range in size and age of closed landfills, the contents of the *Guide* can only be used as generalised guidance and must not be seen as a substitute for site-specific advice, which should be sought from well-qualified and experienced experts.

1.3.3 Applicability

The *Guide* is applicable to landfills that have already been closed, landfills that will be closed in the near future (within a maximum of two years), and landfills that have not yet had aftercare management plans prepared. However, in this context it is necessary to provide an interpretation of "landfill". The current definition of "cleanfill" used throughout the country would mean that many historical operations that may have been regarded at the time as cleanfills should, in fact, be classified as landfills. Old cleanfill sites that have had waste placed in them that may result in the generation of leachate or landfill gas (LFG), or in the site being classified as contaminated, are thus considered to be landfills as covered by this *Guide*. (A separate *Guide to Manage Cleanfills* is being prepared.) Similarly, fill/tip operations (typically on industrial land or in farm gullies) which contain fill materials that may result in the generation of leachate, LFG or a contaminated site are considered to be landfills covered by this *Guide*.

The *Guide* is applicable to all sizes of landfill and all environmental settings. It therefore provides sufficient detail for most situations. Some of the detail has been reproduced (with permission) from the *Landfill Guidelines* (Centre for Advanced Engineering, 2000), referred to throughout as the CAE *Landfill Guidelines*. Additional information on many of the aspects can be found in the CAE document, which should be used in conjunction with this *Guide*. Through the use of the tables included here a landfill manager, in consultation with the regional council, will be able to select the aspects and level of detail appropriate to a particular landfill. In many instances this will be a continuation of activities that have been components of the routine management of the landfill during its operational phase.

How to find out more

Ministry for the Environment. 2000. *1998/1999 National Landfill Census Report*. Ministry for the Environment, Wellington, New Zealand.

Centre for Advanced Engineering. 2000. *Landfill Guidelines*. Centre for Advanced Engineering. Christchurch, New Zealand (funded by Ministry for the Environment).

2 Legislative Framework

2.1 Resource Management Act 1991 (RMA)

The RMA is New Zealand's primary legislation dealing with the management of natural and physical resources. It provides a national framework to manage land, water, air and soil resources, the coast, subdivision and the control of pollution, contaminants and hazardous substances.

The RMA has a single overarching purpose:

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

For the purposes of the RMA, sustainable management means:

> *... managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural wellbeing and for their health and safety while –*
>
> *(a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and*
>
> *(b) Safeguarding the life-supporting capacity of air, water, soil and ecosystems; and*
>
> *(c) Avoiding, remedying or mitigating any adverse effects of activities on the environment.*

There are a number of parts to the RMA, but the three particularly relevant to this *Guide* are:

- Part II, the purpose and principles
- Part III, which sets out the duties and restrictions relating to different aspects of resource use
- Part V, which sets out the hierarchy of standards, policy statements and plans.

This section of the *Guide* sets out the key aspects of the RMA relevant to managing closed landfills. It is not a comprehensive overview of the RMA and readers are directed to the resource documents listed at the end of this section, and Appendix B for further information on the key aspects, including the respective roles of regional and district councils.

Consents

Consents for closed landfills will generally be a continuation of those already applying for the operating period (see the *Guide to Landfill Consent Conditions* [Ministry for the Environment, 2001] for further detail), and include the following:

Land

A land use consent is required for activities that contravene a rule in a district or regional plan (including proposed plans), unless the activity is an existing use allowed by Section 10 of the RMA. Section 10 relates only to rules in district plans (not regional plans), and provides for existing activities that were lawfully established, but now contravene a district plan, to continue if the effects are the same or similar in character, intensity and scale, and the use has not been discontinued for a continuous period of more than 12 months.

Land use consents are obtained from district, city or regional councils.

Water

Nobody may take, use, dam or divert water unless expressly allowed by a rule in a regional plan and in any relevant proposed regional plan, or by a resource consent. Some uses of water are allowed as of right provided there are no adverse effects on the environment (for example, reasonable domestic use and stock drinking water) and water may also be taken for fire-fighting purposes.

Water permits are obtained from regional councils.

Discharge of contaminants

Contaminants may not be discharged to air, water or land unless the discharge is expressly allowed by a rule in a regional plan, a resource consent, or regulations.

Discharge permits are obtained from regional councils.

2.2 Consents for closed landfills in New Zealand

Closed landfills are generally considered to be potentially contaminated sites with high priority for identification and evaluation for the following reasons.

- The nature of what was disposed of at the site is often not well characterised and has the potential to include hazardous substances.
- Contaminants in leachate or LFG can be discharged off the site.
- Many closed landfills are located inappropriately, particularly near waterways or sites with unsuitable underlying geology/hydrogeology.
- There is the potential for a wide range of contaminants to be released, including toxic, persistent and/or bioaccumulative compounds.

Many closed landfill sites do not have appropriate consents and controls in place to manage adverse environmental effects such as those that may result from leachate discharge or stormwater run-off.

The following sub-section provides a brief overview of consents that may be required for closed landfills. However, landfill operators/owners must always consult their regional and district council about the specific plan provisions concerning landfills and consent requirements. The need to obtain a consent may relate to the potential for adverse effects to arise rather than to whether they are currently occurring.

The discharge of contaminants, or the taking, diversion or discharge of water from a closed landfill, requires a resource consent unless it is specifically provided for in a regional plan. In the absence of a regional plan, some discharges may be so minor that they can be ignored under the common law principle of *de minimis non curat lex* (sometimes restated as "the law does not concern itself with trifles"). However, care should be exercised when applying this principle, and the regional council needs to be consulted before proceeding on this basis, as considerable monitoring and assessment may be required to demonstrate adequately that the discharges are so insignificant that this is appropriate.

Resource consents may also be required for remediation works; for example, a land use consent for earthworks and sediment control, or a water permit for the diversion of groundwater where interception is proposed.

2.2.1 Leachate

The type of discharge consent related to the discharge of leachate from closed landfills is subject to differing interpretations by different regional councils. One view is that the discharge of leachate itself requires a consent to discharge to surface or groundwater. A second interpretation is that leachate arises from the discharge of refuse onto or into land in circumstances where it may result in a contaminant entering water, so a consent to discharge refuse onto or into land would be required prior to the landfill closing.

Either of these approaches allows conditions to be set that should achieve the same environmental outcome, so these regional differences in approach are not considered to be a significant issue.

2.2.2 Landfill gas

Discharges of LFG require a resource consent for discharge to air unless expressly permitted in a regional plan. The adverse effects of LFG are more likely to be related to health and safety issues in buildings or underground services in the vicinity of a closed landfill, rather than adverse local air quality effects *per se*. These health and safety effects should be addressed through the resource consent and may also be managed through controls on activities on or near the closed landfill site; for example, through the district plan or land use or building consents.

However, discharges of LFG are a significant contribution to the greenhouse gas problem and are likely to come under greater control as New Zealand meets its obligations under the Kyoto Protocol. Odour and dust may also be issues at some sites.

2.2.3 Diversion or damming of stormwater or groundwater

The water flow around or into and through a landfill is site-specific, and this is taken into account when consents for a landfill are determined by regional councils. Actual requirements for consents vary between the regional councils, and those for closed landfills are often just a continuation of, or similar to, those that applied during the operational period.

2.2.4 Land use

The district/city council's role in managing closed landfills under the RMA is to determine whether proposed or actual land uses are appropriate for a closed landfill site. Territorial authorities also have duties under other legislation, like the Building Act and Health Act, to ensure that buildings are constructed in such a way as to protect people's health and safety and protect the public from nuisance effects.

The regional council's role, in addition to consents for discharges and various aspects of management plans, will generally cover consents for bores and earthworks.

2.3 Rules for closed landfills

As indicated above, activities and discharges may be permitted (and a consent is not required) by a rule in a regional or district plan. These rules may be related to any of the aspects covered in 2.2.1 to 2.2.4 and may be in different plans for the different regions depending on the plans each council has decided to prepare for the good management of the resources of the region.

A review of relevant rules in operative and proposed regional council and unitary authority plans was undertaken in the latter part of 2000. There were found to be only a few instances of specific rules for closed landfills. A number of other rules are applicable to landfills (whether operational or closed), to discharges to air in general, or most commonly to contaminated sites, including closed landfills. It is, however, recognised that many of the plans are not yet completed and the content is likely to change at some stage. A good example of a specific rule for closed landfills is given in Appendix B.

A selection of district plans was also reviewed for relevant rules and none were found that specifically referred to closed landfills. A number had rules relating to contaminated sites. These were generally the same or similar to the corresponding rule in the relevant regional plan.

Greater use should be made of rules as an additional tool for the management of closed landfills and to provide clearer guidance on when they may be classified as permitted, controlled or discretionary activities.

2.4 Other legislation relevant to closed landfills

Health Act 1956

Territorial authorities (city, district and unitary councils) have a duty under Section 29 of the Health Act to control any nuisance or condition likely to affect the health of people in their district. In this context, a nuisance may include any accumulation or deposit or emission likely to be injurious or offensive to health. Closed landfills fall within the definition of a nuisance as they may harbour vermin, potentially pose a health risk and may also give rise to nuisance odours. Territorial authorities also have a duty to make regular inspections of the district, which could include identification of nuisances.

Territorial authorities are required under the Health Act to provide “sanitary works” for the collection and disposal of refuse, and therefore historically district/city councils have owned and operated municipal refuse landfills in New Zealand.

Local Government Act 1974

The Local Government Act deals with the organisation of districts and the effective and efficient administration of the wide-ranging functions of local authorities. Territorial authorities have a duty to encourage efficient waste management within their district and, as with the Health Act, ensure that the management of waste does not cause a nuisance, or become injurious to health. This duty covers the collection, transportation, storage, reduction, reuse, recycling, recovery, treatment and disposal of waste, and continues after a landfill has closed. The primary tool envisaged for ensuring efficient waste management is through a Waste Management Plan, which each territorial authority is obliged to prepare. However, as no date was set by which it must have been completed, some territorial authorities have not yet prepared a plan. Nor is the content specified, and as a result not all of those plans that have been prepared deal with waste management matters in a comprehensive and integrated way.

Local Government Official Information and Meetings Act 1987

The Local Government Official Information and Meetings Act provides for the establishment of a Land Information Memorandum (LIM).

A LIM is issued for a specific piece of land and must identify any special features or characteristics of the land including, among other things, the likely presence of hazardous contaminants. The LIM for a closed landfill must record its previous history and, among other matters, the likely presence of contaminants. Note that the LIM only has to contain such information as is known to the territorial authority and does not have to contain information that is in the district plan.

Not all closed landfills have been identified. Consequently, private properties on individual titles and built on closed landfills are particularly affected by the LIM requirements.

Section 44A of the Act enables people to apply to territorial authorities for a LIM.

In addition, the majority of regional councils and territorial authorities have developed a register of closed landfills in their area as a section of their register of selected land uses. As good practice, all regional councils should develop a register of their closed landfills in their district/ region.

Building Act 1991

The intent of the Building Act is to safeguard the health, safety and amenity of people, protect other property from damage, and facilitate efficient use of energy. Under the Building Act, territorial authorities have a duty to ensure that buildings are situated and constructed in such a manner that they are not likely to be injurious to health.

The Building Act authorises the making of regulations (known as the Building Code), which is contained in the First Schedule to the Building Regulations 1992. The following clauses are relevant to closed landfills.

- Clause B1 relates to the Stability of Properties, and the differential movement of land is of particular concern.
- Clause B2 relates to the Durability of Construction, such that it must remain serviceable throughout its life.
- Clause C refers to fire safety, and Clause F to Hazardous Agents on site. Both of these are relevant to LFG emissions.

Section 31 of the Building Act requires territorial authorities to provide, either on request or in conjunction with building consents, a Project Information Memorandum (PIM). A PIM provides information likely to be relevant to the design, construction or alteration of a building including, among other things, the likely presence of hazardous contaminants. The council is only required to provide information about the presence of contaminants that it knows about. The PIM also need not contain information that would be evident from the district plan.

How to find out more

Ministry for the Environment. 1998. *Resource Management Act Practice and Performance: A Guide to the Resource Management Act*. Ministry for the Environment, Wellington, New Zealand.

Ministry for the Environment. 1999. *Your Guide to the Resource Management Act: An essential reference for people affected by or interested in the Act*. Ministry for the Environment, Wellington, New Zealand.

Ministry of the Environment. 2001. *Guide to Landfill Consent Conditions*. Ministry for the Environment, Wellington, New Zealand.

3 Landfill Processes

3.1 Leachate generation

Leachate is generated when soluble components are dissolved (leached) out of the waste by percolating water (rainfall, surface water and groundwater within the deposited waste). Leachate may also carry water-insoluble liquids (such as oils) and suspended solids. Further contaminants may be added as the result of the biodegradation of the wastes. Leachate quality changes with time if the waste is changing in composition (for example, due to weathering or biodegradation), particularly in landfills containing domestic refuse. Any leachate not contained and managed within the site can partially escape through the base or sides of the landfill or overspill at the surface.

At the time of landfill closure, methanogenic conditions should have prevailed for some years and the leachate should be neutral or slightly alkaline, with a lower overall concentration of contaminants than in the early anaerobic stage (see Figure 3.1). However, it may still contain significant quantities of some pollutants (such as ammoniacal nitrogen and organic compounds). Leachate generation will continue after closure and, as biodegradation nears completion, aerobic conditions may return (after 30–50 years for a large landfill) and the leachate will eventually cease to be hazardous to the environment (after 60 years for a large landfill). The times given are only indicative and will vary considerably between sites.

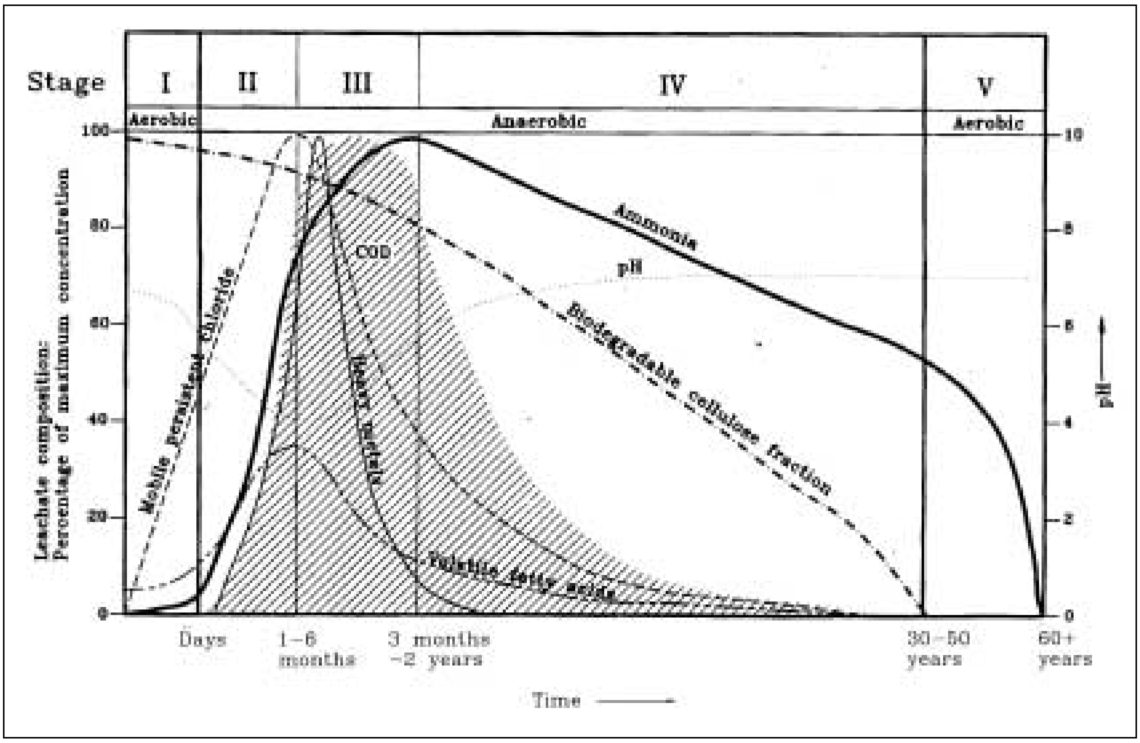

Figure 3.1: Changes in composition of leachate

Source: Modified Figure C.4 from UK Department of the Environment, Waste Management Paper No. 26B, 1996.

3.1.1 Factors affecting leachate generation

The rate of leachate generation is affected by a number of factors, including:

- waste type, composition (water content) and compacted density
- climate (including rainfall)
- topography
- landfill cover
- vegetation
- groundwater influences.

It should be noted that even at landfills in very dry conditions there is enough moisture from within the landfill to generate some leachate. The type of waste, water content of the waste and its form (bulk, shredded, etc) affect both the quantity and composition of the leachate. However, all other factors being equal, a site located in an area of high rainfall can be expected to generate more leachate than one in a drier location. As a rough rule of thumb, approximately 10% of the rainfall becomes leachate, illustrating the importance of stormwater diversion, contouring and good final cover material.

The topography affects the stormwater "run-on" and "run-off" from the site and thus the amount of water entering and leaving the site. The perimeter stormwater drains should be constructed to divert surface water run-on away from the site and the landfill cover constructed to promote run-off and reduce infiltration.

In addition to promoting run-off, an appropriately contoured landfill cover itself influences the degree of infiltration. Also, the less permeable the material used for the final cover, the lower the leachate production rate.

Vegetation plays an important part in controlling leachate generation. It limits infiltration by intercepting rainfall (with subsequent improved evaporation from the surface) and by taking up soil moisture and passing it back to the atmosphere by transpiration. However, care must be exercised that the roots of the vegetation do not penetrate the cap and provide a pathway for infiltration. Guidance on vegetation is provided in Section 5. Irrigation may be necessary to ensure the establishment and maintenance of vegetation. The timing and volume of irrigation water applied should be such that the evapotranspiration of water by the vegetation will generally be greater than the quantity of irrigation water.

3.2 Leachate migration

Leachate within the body of a landfill is rarely static. A portion of leachate generated will be stored by the waste. When the leachate stored in the waste exceeds the field moisture capacity of the waste, the leachate starts draining to the base of the landfill. Leachate may remain perched above low permeability layers at higher levels in the body of waste. Leachate collecting at the base of the landfill may be pumped out for treatment, recirculation and/or disposal. Figure 3.2 depicts this, as well as other factors affecting the water balance in and around closed landfills.

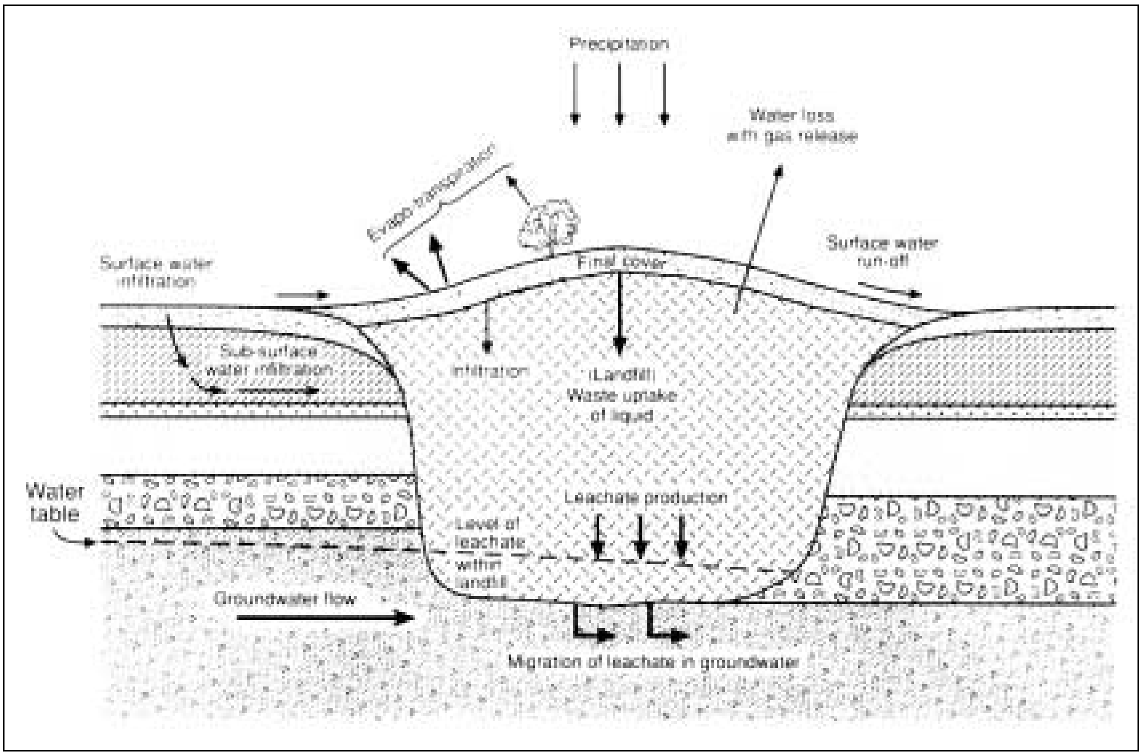

Figure 3.2: Landfill water balance

Source: Figure 3.3 from UK Department of the Environment, Waste Management Paper No. 26, 1996.

All landfills experience some degree of leachate loss to the surrounding environment. At more modern landfills, this occurs mainly as a result of slow seepage through the liner (often over many decades). At older sites, more general seepage through the base, sides and surface cover layers often occurs, together with a greater incidence of surface breakout of leachate from above-grade areas. The rate of leakage will be determined by:

- the type and permeability of material forming the base and sides (liner) and capping of the site (where old landfills have been constructed in marine areas, the geology may be that of marine sediment)
- the head of leachate on the base and sides of the site
- the presence of preferential flowpaths (for example, overspills to the surface, boreholes penetrating through the landfill base or other damage to the engineered containment, shell banks, or channels for old landfills in coastal areas).

The presence of potential preferential flowpaths could dominate leachate migration from a site and needs to be taken into consideration, as do other leakage mechanisms such as seepage through the base.

3.2.1 Groundwater flow

Once leachate seeps through the base or sides of a landfill, it begins to disperse in the surrounding media. The direction and rate of dispersal are determined by:

- the hydraulic properties of the surrounding soil or rock (geology)
- the prevailing groundwater flow conditions (hydrogeology).

An understanding of the geology and hydrogeology underlying the site is therefore essential to determining the contaminant flow paths and flow rates, which are then used to decide on monitoring locations and frequencies.

As water flows through soil and rock, there are continuous chemical interactions between substances dissolved in the water and the constituents of the soil or rock. These processes may lead to some attenuation (reduction) of contaminants in the leachate. As attenuation may not be significant nor persist over time, where it is relied on at any site it is essential that the monitoring programmes are specifically tailored to these mechanisms and their capacity to reduce the concentration of the contaminants. In such cases a risk assessment is strongly recommended.

3.2.2 Surface water flow

In comparison with groundwater flow, contaminated surface water flow may be:

- rapid, with contaminants transported to a receptor in minutes or hours, rather than days or years
- of high volume, with large dilution of contaminants (although there may be a need to contain/remediate large volumes)
- seasonally variable, and liable to rapid fluctuations over short time periods.

The risk assessment should therefore take into account the lowest flows in surface watercourses. Monitoring programmes need to be designed to take all these factors into account. Significant contamination of surface water flows is less likely for closed landfills, compared with operating landfills, unless there are leachate breakouts (overspills) from the landfill surface.

3.3 Characteristics and potential effects of leachate

3.3.1 Leachate composition

In general the composition of leachate will be a function of the type and age of the waste deposited, together with the physico-chemical and biological processes and water balance in the landfill. The main components of leachate from landfills can be grouped into four categories as follows:

- major cations and anions such as calcium, magnesium, sodium, potassium, iron, ammonia, carbonate or bicarbonate, sulphate and chloride

- trace metals such as zinc, manganese, chromium, nickel, lead and cadmium
- a wide variety of organic compounds, usually measured as total organic carbon (TOC), chemical oxygen demand (COD) or biological oxygen demand (BOD), volatile organic carbon (VOC) or semi-volatile organic carbon (SVOC)
- microbiological components (unlikely in landfills closed for several years).

Leachate composition can provide a guide to the age and trends in the degradation processes in the landfill (see Table 3.1). However, it is important to note that leachate monitored at a collection point may be a mixture of old and new, weak and strong leachate depending on the location of the collection point, landfill age and drainage configuration.

Table 3.1: Changes in leachate composition in different stages of a landfill

Parameters with differences between acetogenic 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)	13,000	4000–40,000	Na (mg/l)	1350	50–4000
COD (mg/l)	22,000	6000–60,000	K (mg/l)	1100	10–2500
BOD_5/COD	0.58	–	Alkalinity (mg $CaCO_3$/l)	6700	300–11,500
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
Methanogenic phase			AOX (µg/Cl/l)*	2000	320–3500
pH	8	7.5–9	As (µg/l)	160	5–1600
BOD_5 (mg/l)	180	20–550	Cd (µg/l)	6	0.5–140
COD (mg/l)	3000	500–4500	Co (µg/l)	55	4–950
BOD_5/COD	0.06	–	Ni (µg/l)	200	20–2050
SO_4 (mg/l)	80	10–420	Pb (µg/l)	90	8–1020
Ca (mg/l)	60	20–600	Cr (µg/l)	300	30–1600
Mg (mg/l)	180	40–350	Cu (µg/l)	80	4–1400
Fe (mg/l)	15	3–280	Hg (µg/l)	10	0.2–50
Mn (mg/l)	0.7	0.03–45			
Zn (mg/l)	0.6	0.03–4			

* AOX: adsorbable organic halogen.

Source: CAE *Landfill Guidelines*; original source: Ehrig, HJ, Water and element balances of landfills. In Lecture Notes in *Earth Sciences: The Landfill, 1989)*.

3.3.2 Potential environmental effects of leachate

Leachate contamination may affect receptors in a number of ways depending on the contaminant loading in the leachate and the nature and use of the receiving environment; for example:

- existing and potential water resources (groundwater or surface water) for public and private water takes for potable, agricultural, industrial or other permitted use
- surface water bodies (marine and freshwater, including wetlands of ecological value) and their biological communities
- surface water bodies used for leisure pursuits (such as fishing and boating).

A summary of some of the potential effects is given in Table 3.2. Leachate discharges may also result in discolouration, odour, surface scum and detritus. These may result in the water being unsuitable for recreational purposes, or classified as wai piro or wai mate by local iwi.

Table 3.2: Potential effects of leachate on water receptors

Leachate parameter	Short-term effect	Potential long-term effect
Dissolved toxic compounds	High concentration directly toxic to humans, stock or aquatic life	Bioaccumulation or biomagnification leading to toxic effects
High dissolved solids	Increased salinity altering ecology and reducing value of surface water for abstraction	Groundwater contamination
High suspended solids	Reduction of light inhibiting macrophyte growth; sedimentation causing smothering of aquatic life; organic particles increasing deoxygenation through microbial breakdown	Habitat alteration; adsorbed contaminants increase toxicity
Immiscible organic chemicals (e.g. oils and solvents)	Direct toxicity to humans, stock and aquatic life; reduction in reoxygenation rates through water surface; visible surface films	Possible carcinogenic and mutagenic effects on aquatic life; deoxygenation
High oxygen demand	Deoxygenation of surface water	Deoxygenation; ecosystem changes
Organic matter	Reduced oxygen levels	Deoxygenation; ecosystem changes
Nutrients (e.g. nitrate)	Plant/algal blooms	Eutrophication

3.4 Landfill gas generation

LFG is produced by the biological decomposition, volatilisation or chemical reaction of waste constituents in a landfill. Biological degradation of organic waste is the main mechanism for LFG production in landfills containing predominantly domestic refuse. LFG production proceeds through a series of chemically distinct stages. The major components of LFG and the various phases of gas generation are shown in Figure 3.3.

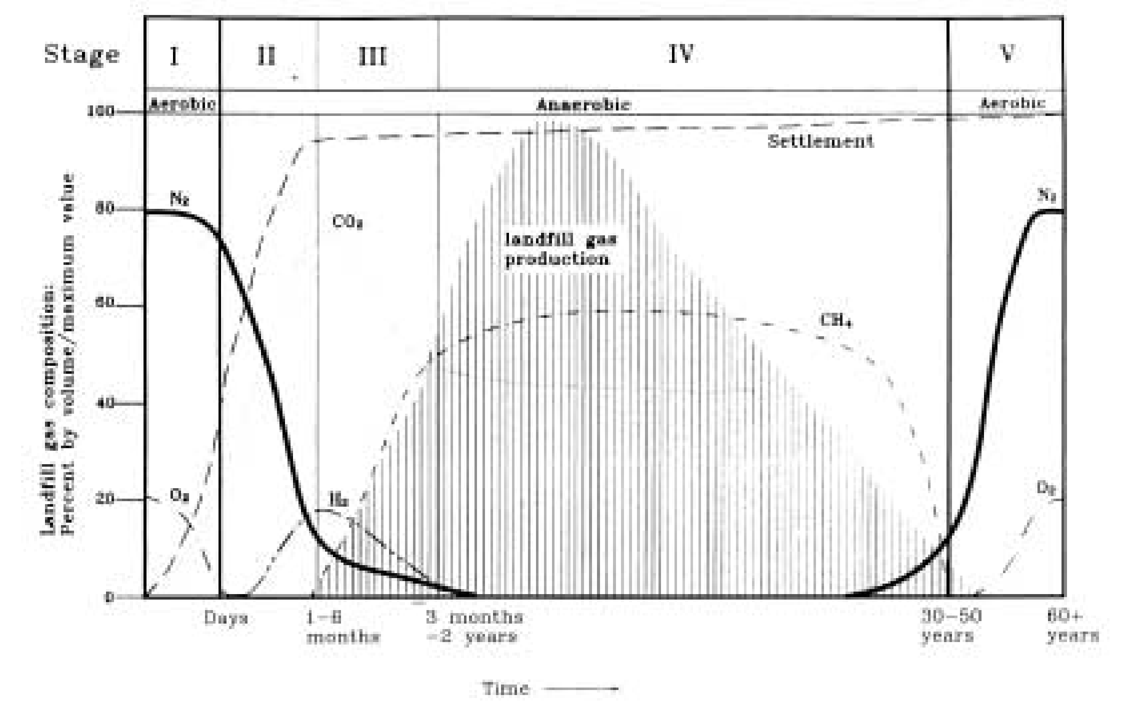

Figure 3.3: Changes in composition of landfill gas

Source: Modified Figure C.3 from UK Department of the Environment, Waste Management Paper 26B, 1995.

Waste decomposition is aerobic until the oxygen supply in the waste mass is exhausted. The main gaseous products of aerobic degradation are carbon dioxide and water vapour. The waste then proceeds through a series of anaerobic stages, the most significant being the steady methanogenic phase, which is typically reached around 2–4 years after waste placement. At this stage, LFG consists of approximately 50% methane and 50% carbon dioxide (by volume). "Steady state" methanogenic gas production can continue for several decades (and often much longer if waste has been baled before disposal or the landfill environment is relatively dry) before LFG production rates decline and LFG evolution at the landfill is no longer significant. There is no typical figure for the length of time that LFG will be produced, but it can be expected to continue for at least 20 years after the last depositing of waste. After several decades a semi-aerobic and ultimately aerobic environment is achieved in the remaining stabilised wastes.

In some cases, LFG production can recommence if changes occur at the site which reactivate microbial activity; for example, if development occurs on the site or if moisture levels within the waste increase.

3.4.1 Factors affecting LFG generation

The rate of LFG generation varies and is affected by a number of factors, including:

- waste type and composition, especially the amount of biodegradable materials
- waste density
- moisture content and pH
- temperature.

The composition of waste will affect the rate, composition and quantity of LFG produced per tonne of refuse. In general, the quantity of LFG generated per unit of waste is a function of the cellulose content of the waste. Different organic constituents in the waste will produce slight differences in methane/carbon dioxide ratios. The presence of hazardous or special wastes (for example, sewage sludges) in a landfill may affect the composition of LFG and, potentially, affect biological processes within the landfill.

Warm temperatures and increasing moisture content accelerate the waste decay process. Anaerobic decomposition produces heat, so that internal landfill temperatures are typically in the range of 30–35°C and in deeper landfills up to 45°C.

Domestic refuse typically has an average moisture content of about 25%, with food and garden waste having the highest moisture content. After waste placement, rainfall, surface water and groundwater infiltration, together with the products of waste breakdown, can contribute additional moisture. The rate of LFG production increases with moisture content, peaking at waste moisture contents of 60–78%.

The rate of LFG generation will also typically peak at approximately the time the landfill closes and will then decline over time (see Figure 3.3). The rate of LFG gas generation can be predicted using a theoretical model. The model now most commonly used in New Zealand is the United States Environmental Protection Agency (US EPA) Landfill Gas Emissions Model (LandGEM). A description of this model is contained in Appendix G. The model's predictions will become less accurate in the latter part of the anaerobic stage.

3.5 LFG movement and migration

The movement of LFG within a landfill and migration out of it is governed by a number of site-specific factors. The driving force for the movement of LFG is the gas pressure generated within the landfill cell and the pressure gradient within the surrounding strata.

Gas pressure within the landfill depends on the rate of LFG production, the permeability of the waste and the permeability of cover and liner layers. Gas pressures can also be affected by changes in:

- atmospheric pressure
- the leachate level in the waste
- the water table outside the landfill cell.

Any combination of these factors can alter the flow rates and pathways of the gas as it naturally moves from areas of higher to lower pressure. Methods for the management of LFG are described in Appendix G.

3.5.1 LFG movement within the site

Natural migration pathways usually develop in the waste as settlement occurs. Cracks in the landfill surface/capping material or dry weather conditions can give rise to localised areas of increased emissions. In uncapped or poorly capped landfills, LFG will diffuse through the surface of the landfill. The placement of capping inevitably results in gas pressure building up, leading to uncontrolled migration of gas from the site, unless this is catered for. Therefore any remediation works involving the placement of capping must usually be accompanied by provision of gas vents.

3.5.2 Migration outside the site

The potential for the migration of gas beyond the site boundary will depend on the geological characteristics of the adjoining strata, coupled with any man-made pathways such as service ducts, drains and building foundations. It should be noted that LFG can be found several hundred metres from the boundary of the landfill footprint.

3.6 Characteristics and potential effects of LFG

3.6.1 Composition of LFG

In the later stages of anaerobic decomposition of waste (methanogenic phase), LFG comprises approximately 50% methane and 50% carbon dioxide (by volume), plus traces of other compounds. These other constituents can include ammonia, hydrogen sulphide, nitrogen, hydrogen chloride, carbon monoxide and a variety of organic compounds, including volatile organic compounds (VOCs). Normally, less than 1% (by volume) of LFG are non-methane organic compounds (NMOCs). Carbon monoxide is not a typical LFG constituent and is generally only found where there has been combustion of the waste underground.

Typical constituents found in LFG are shown in Table 3.3.

Table 3.3: Typical constituents in landfill gas

Compound	Percent (dry volume basis)		
	Min.		Max.
Methane	45	–	60
Carbon dioxide	40	–	60
Nitrogen	2	–	5
Oxygen	0.1	–	1.0
Sulphides, disulphides, mercaptans, etc	0	–	1.0
Hydrogen	0	–	0.2
Carbon monoxide	0	–	0.2
Trace constituents	0.01	–	0.6

Source: CAE *Landfill Guidelines*

LFG composition can change as it reacts along a migration pathway. For example, carbon dioxide can be taken up by adsorption, absorption or dissolution, thereby increasing the methane concentration of the gas. Alternatively, methane can be oxidised by bacteria along the migration pathway, increasing the concentration of carbon dioxide.

Most of the NMOC emissions from landfills result from the volatilisation of organic compounds contained in the waste. Therefore if a landfill contains only very small amounts of organic commercial/industrial wastes, the NMOC emissions are expected to be low. “Dumps” containing chemical waste are a potential exception, although monitoring data is not available to support this hypothesis.

3.6.2 Potential adverse effects of LFG

Methane and carbon dioxide are colourless, odourless gases, but the presence of trace compounds, such as hydrogen sulphide, can result in LFG having an odour. LFG will usually be corrosive and saturated with water vapour. It will also often be warmer than the ambient air temperature. The potential effects of LFG are set out below.

Flammability

Methane is a colourless, odourless gas that is only slightly soluble in water and burns readily in air. It is generally very stable; however, when mixed with air at concentrations of around 5–15% by volume it is highly explosive. There is a risk of explosion or fire occurring 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.

Asphyxiation

LFG can act as an asphyxiant by displacing or diluting air, so that the oxygen concentration is reduced in confined spaces such as trenches, manholes or buildings in or near a landfill site. The NZ Workplace exposure standards state that the concentration of oxygen in air should be maintained at or above 19.5% v/v under normal atmospheric pressure.

The density of LFG will vary with its composition, the density increasing with increasing carbon dioxide concentrations. At typical concentrations produced during later stages of waste decomposition, LFG can be slightly lighter than air or slightly heavier, as shown in the following table. Under still conditions, LFG may form a layer of dense gas, leading to a hazardous situation in confined spaces such as services trenches or manholes, or even in depressions or against barriers such as buildings, walls or impermeable fences.

Table 3.4: Density of landfill gas, its constituents and air

Compound/mixture	Density (kg/m^3)
Methane	0.72
Carbon dioxide	1.98
Air	1.29
LFG (50% methane)	1.35
LFG (60% methane)	1.22

Toxicity

Methane is a simple asphyxiant and is generally not of concern from the point of view of toxicity. The New Zealand workplace exposure standards for other constituents of LFG are shown in the Table 3.5.

Table 3.5: New Zealand workplace exposure standards for constituents of landfill gas

	Short-term exposure limit (15-minute average)	8-hour time-weighted average
Carbon dioxide	3% v/v	0.5% v/v
Hydrogen sulphide	15 ppm	10 ppm

Some of the trace constituents in LFG could have toxic effects if present in high enough concentrations, and there has been increasing interest in the potential toxicity of LFG. One study found elevated levels of VOCs, including benzene, vinyl chloride and dichlorofluoromethane (CFC 21) in LFG from a municipal solid waste landfill that operated between 1983 and 1988, about six years after landfill closure (ENDS, 1994, p14). However, trace gases do not normally represent a hazard following atmospheric dilution.

LFG can also have detrimental effects on soils and vegetation within the completed landfill and adjacent sites.

Odour

Carbon dioxide and methane are essentially non-odorous. The odorous compounds associated with LFG include ketones, esters, volatile fatty acids, hydrogen sulphide and mercaptans. These compounds are primarily generated during the early stages of anaerobic waste decomposition. The offensiveness of the odour of LFG is reduced as the waste enters the methanogenic biodegradation stage (2–4 years after waste placement). As a result, odours are not generally a significant issue with LFG from closed landfills. However, odour release can be reactivated if oxygen is introduced into the waste; for example, due to exposure of the waste to air, or aerated water intrusion into the waste mass.

Greenhouse gas effects

The major constituent of LFG is methane, which has been estimated as having approximately 15 times the effect of a similar amount of carbon dioxide in reducing the rate of loss of heat from the Earth's surface. While most of the international policy development and practical measures are directed at reducing the amount of carbon dioxide discharged to the atmosphere, considerable attention also focuses on reducing discharges of methane, including LFG. Where practicable, LFG should be collected and used for energy generation or, where the amount of gas is insufficient for economic use, burned without energy recovery to convert it to the less damaging carbon dioxide.

How to find out more

UK Department of the Environment. 1986. *Landfilling Wastes*. Waste Management Paper No 26. HMSO. London.

UK Department of the Environment. 1991. *Control of Landfill Gas*. Waste Management Paper No 27 (revised). HMSO. London.

Centre for Advanced Engineering. 2000. *Landfill Guidelines*. Centre for Advanced Engineering. Christchurch, New Zealand (funded by Ministry for the Environment).

Environmental Data Services Ltd (ENDS). 1994. *Landfill Gas Migration Study Highlights Vinyl Chloride Risk*. Ends Report 228. Environmental Data Services Ltd, London, UK.

4 Closed Landfill Assessment

4.1 Introduction

This *Guide* is intended to assist managers and regulators of a wide variety of landfill sites – from small, long-closed sites to larger landfills approaching closure. The amount and quality of information on which to base management decisions will vary considerably. Therefore, a staged approach to assessing environmental and human health risks is outlined, suitable for assessing very different sites. Guidance is also given for estimating the potential for risk at sites where little or no monitoring information is available. An indication of the level of assessment that may be required for a range of landfill sizes and ages is given in Tables 4.1a and 4.1b. However, if it is known that there are water quality or LFG problems associated with a particular landfill, a more detailed assessment than that given in these tables will be required.

Table 4.1a: Level of assessment recommended for sensitive locations

Years since closure	> 85% MSW	< 85% MSW
Landfill size: < 15,000 m^3		
< 15	Detailed assessment	Detailed assessment
15–40	Initial assessment	Detailed assessment
> 40	Initial assessment	Detailed assessment
Landfill size: 15,000–100,000 m^3		
< 15	Detailed assessment	Detailed assessment
15–40	Detailed assessment	Detailed assessment
> 40	Initial assessment	Detailed assessment
Landfill size: > 100,000 m^3		
< 15	Detailed assessment	Detailed assessment
15–40	Detailed assessment	Detailed assessment
> 40	Detailed assessment	Detailed assessment

Table 4.1b: Level of assessment recommended for less sensitive locations

Years since closure	> 85% MSW	< 85% MSW
Landfill size: < 15,000 m^3		
< 15	Initial assessment	Detailed assessment
15–40	No further assessment	Initial assessment
> 40	No further assessment	Initial assessment
Landfill Size: 15,000–100,000 m^3		
< 15	Detailed assessment	Detailed assessment
15–40	Initial assessment	Detailed assessment
> 40	No further assessment	Initial assessment
Landfill size: >100,000 m^3		
< 15	Detailed assessment	Detailed assessment
15–40	Detailed assessment	Detailed assessment
> 40	Initial assessment	Detailed assessment

Notes:

1 'No further assessment' means no more than having determined age, size and likely nature of wastes. The more detailed assessment for < 85% MSW is for situations where the proportion of waste that is not MSW is more hazardous than MSW.

2 'Initial assessment' means based on existing information.

3 'Detailed assessment' means that, based on baseline and/or additional monitoring information, specific studies may be necessary to obtain the monitoring information.

4 If there is uncertainty with respect to sensitivity of location, size or nature of waste, the more conservative assessment should be undertaken.

The recommended approach for evaluating environmental and human health risk related to closed or closing landfills, and for subsequent management decision-making, is as follows.

1) Review available data (setting, construction, contents, monitoring).
2) Make a preliminary assessment of potential risks.
3) If the preliminary assessment indicates that low potential for risk exists, undertake no further investigation and consult the relevant regulatory agency.
4) If moderate or high risk is indicated, or if there is a high level of uncertainty, initiate appropriate investigations to collect further information.
5) Carry out more structured risk assessment(s) as further information becomes available.
6) Initiate management or remediation action in consultation with the relevant regulatory authority.

Additional guidance, or formal requirements may be imposed by regional or district plan rules. Early liaison with council staff is recommended.

4.2 Initial hazard assessment

4.2.1 Review available data

Initial assessment of a landfill should involve collecting and evaluating data on landfill details, exposure routes and receptors. When combined, this information will allow evaluation of the potential for effects and allow informed decisions on future management. Types of information, and typical sources, are summarised in Table 4.2.

Table 4.2: Sources of information for initial assessment

Information Type		Source
Landfill details	Size; construction	Regional council consent files (note landfills closed prior to 1991 may not be consented) and contaminated site databases; operator (e.g. district council) files/staff; old district plans and schemes; historical air photographs (LINZ, NZ Aerial Mapping, DOC, district council); site visit
	Contents	Interviews – residents; DC/operator staff; age (see notes below); air photographs
	Landfill monitoring data	Regional council files; owner files
Exposure routes	Services trenches; old culverts; surface sealing; geology; topography	District council files; utility providers files (e.g. Telecom); air photographs; topographic maps (slope, distance to streams); geological maps and publications; GIS; site visit
Receptor information	Surface water, aquifers, freshwater and marine ecology; residents	Geological maps and publications; air photographs; regional Council consent and hydrology databases/files; GIS; site visit

A minimum of one (and preferably more) site visit must be made as part of the assessment. If only one visit is possible, this should preferably be in winter (or the high rainfall season) when leachate production is greatest. A sample checklist for site inspection visits is presented in Table 4.3.

Table 4.3: Sample site inspection checklist

Site stability/cover condition	• Smooth contours or hummocks indicating settlement • Holes; desiccation cracks • Exposed refuse; sharps • Slopes on site • Deep-rooting trees or fallen trees (indicating cap holes)
Receptors	• Surrounding land uses • Distance(s) to nearest sensitive receptors (e.g. residences) • Distance to nearest watercourse • Areas of vegetation die-off (gas or refuse toxicity) • Depth to groundwater; distance to nearest well
Exposure routes	• Slopes surrounding site • Buried services (e.g. stormwater lines) beside or across landfill • Evidence of leachate discharges (iron staining, hydrocarbon sheen) • Evidence of LFG discharges (vegetation die-off, odour, gas analyser)

4.2.2 Potential effects

A preliminary assessment of the potential for a landfill to have adverse human health and environmental effects can be made on the basis of existing documentary information and a thorough walkover inspection. Landfill-related effects occur in four main ways:

- discharge of leachate to sensitive receiving environments (toxicity, visual effects)
- discharge of LFG to sensitive receiving environments (explosion or fire, asphyxiation, toxicity, odour)

- physical contact with landfill contents (such as glass, metal, pathogens)
- settlement impacts on structures.

The potential for effects to arise from any particular landfill depends on:

- the likelihood that a hazard source exists:
  - generation of significant flows and/or concentrations of LFG (primarily methane and carbon dioxide, with traces of hydrogen sulphide)
  - generation of significant volumes and/or concentration of contaminants in leachate
  - a significant number of sharps or pathogens in landfill or cover material
- existence of an effective exposure route:
  - potential for accumulation and migration of LFG (for example, via services trenches or foundations to poorly ventilated buildings) and presence of ignition source
  - flow pathways for leachate (for example, to an aquifer or stream)
  - exposure, or potential for exposure (for example, by cap erosion or failure)
- presence of sensitive receptor(s):
  - people or biota susceptible to asphyxiation or fire/explosion
  - estuarine, aquatic or marine environments; highly visible ground areas
  - pedestrian traffic, particularly where ground contact is likely (for example, children, contact sports).

The three most common effects are:

- waste protruding through cover
- leachate impact on the watercourse in the vicinity
- LFG/anaerobic conditions effecting vegetation in the vicinity.

If a substantial source, effective pathway and sensitive receptor coincide, a high potential for effects will exist. If one of these elements is missing, it is far less likely that there will be effects. For example, an actively gassing landfill presents little potential for local effects in an isolated rural setting with no buildings nearby, but has high potential if gas-trapping buildings were constructed on or beside the landfill. However, the contribution to the greenhouse gas load also needs to be taken into consideration.

4.2.3 Landfill as a hazard source

Monitoring, as set out in Section 6, can readily assess the quantity and quality of leachate or LFG. For an initial assessment, monitoring data may not be available. Visual inspection may provide some evidence of leachate discharges (iron staining) or LFG migration (vegetation die-off can occur where substantial gas discharges occur from younger landfills).

Where no monitoring data exists, desk study data can be used for comparison. Table 4.4 summarises observations on LFG and leachate from landfills studied in New Zealand.

Table 4.4: Summary of discharge observations at New Zealand landfills

Age/contents	Discharges	Notes
Pre-1940 – all sites	Negligible gas; typically low concentrations of metals only in leachate.	A high level of recycling and composting was common pre-1940, as were tended fires, which kept putrescible levels very low. These older landfills contained predominantly street sweepings and construction/demolition debris. The main exception was primary industry: specific landfills such as paunch-waste landfills at freezing works, and gasworks waste sites.
1940s to early 1960s municipal waste	LFG generation low to negligible; CO_2 dominated. Typical BOD values in the range of tens of mg/l and COD levels in the range of hundreds of mg/l; low metals; NH_4 levels generally low, tens of mg/l.	Domestic and municipal refuse increased; fires became less common, resulting in increasing putrescible content. Industrial wastes still limited, typically site-specific. Exception: armed forces wastes, around major military bases, particularly US bases fully closed in late 1940s.
"Cleanfill"	Localised gas and leachate generation possible in places – site-specific checks required.	Typically contained > 90% inert wastes, but local accumulations of putrescible or hazardous waste in some sites.
Post 1960s to present, municipal waste	1960s–1970s low to moderate gas generation in larger landfills. CH_4 variable (2%–50%); CO_2 also variable (2%–30%); leachate; BOD typically tens of mg/l; COD typically hundreds of mg/l; NH_4 up to 100 mg/l. Metals moderate; trace levels of pesticides; phthalate esters possible. 1980s–1990s: moderate to high gas generation in larger landfills, CH_4 more consistent (20 to 60%); CO_2 also more consistent (10% to 40%). BOD in the range of hundreds of mg/l; thousands in an operating landfill; COD in the range of thousands of mg/l; up to 30,000 to 40,000 mg/l in an operating landfill. NH_4 100 mg/l plus; up to 1500 mg/l in an operating landfill. Metals moderate trace levels of pesticides, phthalate esters and hydrocarbons (TPH) likely.	Steadily increasing domestic and municipal refuse raised putrescible contents. Industrial production increased substantially so metals, solvents, etc. were more frequently disposed of to landfills; close to industrial areas; organochlorines appeared in the 1960s; other pesticides still occur.

Information on sharps exposure can typically only be obtained by visual observation or interviews with site visitors. Anecdotal evidence of frequent skin infections is common where closed landfills are used as sports fields. Discussions with council staff or park users are the only way such issues can be highlighted.

4.2.4 Exposure routes

For an initial assessment, unless there is good evidence to the contrary (design drawings and construction records), it is prudent to assume no base or perimeter containment other than that naturally existing at the site, and limited non-engineered cover material. Conservative assumptions should be made regarding the potential for discharges from any landfill without engineered and documented containment.

If a landfill overlies an aquifer, free discharge of leachate to the aquifer should be assumed. Any buried services/trenches crossing a landfill should be assumed to provide LFG or leachate migration conduits. Unless clear records exist of the limits of the landfill, where buildings or services lie close (within metres), it would be prudent to assume the landfill extends beneath them, potentially creating a gas migration pathway.

Some potential for surface cover failure and exposure of sharps may exist where slopes exceed 1V:3H, or where unprotected side slopes could be eroded by stream or wave action.

4.2.5 Receptors

Receiving environment sensitivity can be broadly characterised from site-setting information and available documents. Site-specific information is needed to define sensitive receptors at any given landfill, but sensitive receiving environments include:

- aquifers, particularly unconfined aquifers
- marine environments, particularly enclosed and estuarine areas with limited flushing
- freshwater streams and other water bodies
- active users of former landfill areas (for example, children or contact sport participants)
- users of buildings on or near landfills, particularly those with potential gas accumulation areas (such as concrete basements) and/or ignition sources (electric switches).

4.3 Hazard assessment

Once data has been collated, it is reviewed to determine if sensitive receptors could be exposed to significant sources of LFG, leachate or other hazards, which could result in a significant adverse environmental or human health effect.

Based on the result of this hazard assessment process, a decision can then be made regarding appropriate site management.

If the initial evaluation identifies significant uncertainty about the potential for effects, or identifies a need for management action, then further investigations may be required.

The nature and objectives of these investigations will vary but are likely to cover one or more of the issues outlined in Table 4.5. Further investigations or monitoring should only be undertaken when a clear objective has been identified, and should be designed to match that objective. Unfocused investigations or monitoring can produce data which is of little or no value.

Table 4.5: Further investigations

Objective	Issue	Method
Characterise potential effects	LFG concentrations or discharge rates	Install and monitor standpipe wells
	Leachate quality	Install and monitor standpipes; sample leachate collection systems or discharges or receiving waters in the vicinity
	LFG/leachate generation potential	Trial pit inspection of refuse and cover; computer modelling
	Cover material condition (e.g. sharps)	Trial pits; inspection; interviews
Exposure routes	Landfill extent/boundaries and proximity to receptors	Aerial photographs; site inspection; hand augers/trial pits
	Services, trenches	Electronic detectors; drainage files; Telecom/gas/power company files; inspections
	LFG entry to buildings	Building inspections; confined space gas monitoring
	Aquifer vulnerability	Drilling investigations – permeability testing
Receptor sensitivity	Aquatic/marine ecology	Ecological assessments; macroinvertebrate diversity indices
	Surface/ground water quality, use	Install wells; analyse water; survey use
	Visual issues	Interviews/survey; landscape architect review
Remediation options	Basal geology	Drilling/trial pit inspection
	Cap/perimeter bund composition and construction	Trial pit inspection

4.4 Risk assessment

Risk assessment is a staged process, the key steps being (refer NZS 4360 1999 Risk Management):

1) establish the context and identify the risks
2) analyse risks
3) evaluate risks
4) treat (manage) risks.

Analysis is the process of quantifying or otherwise characterising risk, while evaluation involves determining whether a known risk is acceptable or must be managed. Analysis involves tools such as fate and transport models; evaluation involves comparison with broad risk acceptance practice or guidelines.

Initial assessment procedures are outlined above. Monitoring procedures, outlined in Chapter 6, provide data on which risk assessment and management decisions can be based. The results from these monitoring procedures will provide information on whether substantial risk sources exist and whether sensitive receptors are likely to be exposed to hazards.

The following sections outline guidance for analysis and evaluation of risk and for structured decision-making on management options.

4.5 Risk analysis

Analysis of environmental and human health risk typically follows a tiered approach, ranging from simple, low-cost, conservative guideline comparison to more complex and expensive, but precise, modelling options.

Typically, the process involves:

- Tier 1: comparison with generic guidelines
- Tier 2: site-specific evaluation with analytical models
- Tier 3: site-specific evaluation using more complex numerical models.

A large number of Tier 1 guidelines have been developed for environmental and human health risk evaluation. Most of the existing Tier 2 and Tier 3 evaluation tools have been developed for human health risk evaluation. Development of ecological risk evaluation tools is in its early stages at the time of writing. A New Zealand-specific model is being developed for a limited range of contaminants on contaminated sites. The current model and progressive updates are available on the web site http://contamsites.landcare.cri.nz, which also contains a number of useful databases and links.

4.5.1 Landfill gas

The key areas of LFG-related risk are explosion (flammable gas, essentially methane) and asphyxia (carbon dioxide). Minor toxic components (such as hydrogen sulphide, particularly where plaster-board or pulp and paper wastes are present) can also be an issue on some sites, and odour – a non-risk issue – can also cause effects. No specific analysis guidelines have been developed for odour as yet, although a number of subjective investigation and evaluation tools have been or are being developed, for example *Odour Management under the RMA* (Ministry for the Environment, 1995).

Some debate exists over the basis for interpreting LFG monitoring data and assessing risk. Most guidance is given in terms of LFG concentrations, but logically migration potential should be considered also. This potential can be expressed in terms of pressure gradients and flow rates, both of which can vary with barometric conditions (relevant guidance documents are given at the end of the section).

Currently, the only Tier 1 New Zealand guidance is the Department of Labour OHS Workplace Exposure Standards for carbon dioxide and hydrogen sulphide. The UK guidance *Control of Landfill Gas* (UK Department of Environment, 1991) is commonly referenced in New Zealand, but it is not formally recognised..

A summary of applicable and useful comparable Tier 1 guidance is presented in Table 4.6.

Table 4.6: Landfill gas Tier 1 guidelines

Source	Gas	Guideline	Application point
NZ OHS Workplace Exposure Standards (1994)	CO_2	15 minute 30,000 ppm	Point of exposure
		8 hr 5000 ppm	Point of exposure
	H_2S	15 minute 15 ppm	Point of exposure
		8 hr 10 ppm	Point of exposure
UK DOE Waste Management Paper No 27 (1991)	CO_2	0.5% by volume	Landfill boundary
	CH_4	1% by volume	Landfill boundary
USEPA 1991*			
Indiana, Maine, Kentucky, New Hampshire*	CH_4	1.25% by volume	In landfill buildings
Indiana, Maine, Kentucky*	CH_4	5% by volume	At landfill boundary
New Hampshire*	CH_4	2.5% by volume	At landfill boundary
New Jersey, New York	CH_4	1.25% by volume	At landfill boundary

* US EPA. 1995. *Air Emissions from Municipal Solid Waste Landfills – Background Information for Final Standards and Guidelines*. EPA-453/R-94-021. Office of Air and Radiation. North Carolina.

It should be noted that whether or not a particular site exceeds any of the guidelines values, the issue of whether or not a consent is required needs to be confirmed with the regional council.

No Tier 2 or 3 analysis tools currently exist for LFG-related risk.

4.5.2 Leachate

Leachate related risk primarily arises via toxicity to aquatic organisms, or as health effects via drinking water following migration of leachate to groundwater or surface water. Relevant Tier 1 guidance is provided in:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality 1992 (revised version due March 2001)
- New Zealand Drinking Water Standards 2000.

The ANZECC document also provides guidelines for other exposure routes, such as dermal contact and stock watering.

Overseas publications also provide useful guidance, but are not officially recognised in New Zealand. These include:

- United States Environmental Protection Agency, Quality Criteria for Water (USEPA 1999, Ref. 822-2-99-001)
- Canadian Council of Ministers of the Environment, A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life (CCME 1991).

These guidelines all apply to receiving environment water quality. Suitable allowance must be made for dilution if leachate is to be considered in relation to these guidelines. This should also be assessed formally by the regional council as part of a resource consent.

Tier 2 and 3 analysis can be carried out using published "fate and transport" models. The most commonly used examples are RBCA (Groundwater Services Inc, Houston, Texas), BPRisk (BP Europe-Brussels 32-2774-3280) and CalTox (Department of Toxic Substances Control, California Environmental Protection Agency). These models take concentrations of contaminants at source and physical environment information and allow estimation of resulting concentrations at points of exposure and consequent quantitative human health risk. Currently, the commonly accepted procedure for analysing ecological risk is to calculate point of exposure concentrations using fate and transport models and compare these values with Tier 1 guidelines.

4.5.3 Direct contact with waste

There are currently no models for analysing risk related to exposure of sharps, micro-organisms or other potentially hazardous materials in landfill refuse or caps. A common approach is to quantify the level of exposure (for example, sharps per square metre) and the potential for contact (high, low), and then attempt to quantify risks in terms appropriate for comparison with broadly equivalent risks.

4.5.4 Non-risk issues

Non-risk issues – such as odour, visual appearance and cultural perspectives – also need to be analysed in some way to allow full and balanced evaluation and decision-making on landfill management.

4.6 Risk evaluation

Many management options for closed landfills are very costly. It is important to put landfill-related risks in context, to ensure risk acceptance and spending are compatible with those in comparable infrastructure areas, such as roading and wastewater management. As outlined above, tools exist to quantify human health risk and thus allow ready transparent evaluation of risk.

Ecological risk is less readily quantifiable, and other management issues (such as cultural perspectives) generally cannot be quantified. Risk evaluation involves comparing risk levels against predetermined criteria to determine management priorities. If relevant quantitative criteria have not been established, it is important at least to establish a general level of acceptable risk, to allow transparent management decision-making.

Because of the range of issues involved in landfill management, risk evaluation should where possible be carried out in a way that allows comparison of risks with different levels of quantification and non-risk issues.

Multi-criteria evaluation matrices are a useful tool for combining such differing information. *The New Rational Manager* (Kepner and Tregoe, 1981) gives useful guidance on the use of this tool.

Depending on the amount of data available, this can be done very simply; for example, Yes/No for each element if data is limited or dealing with a single landfill, or by using a number of comparative rating systems for a larger number of sites. Two illustrative examples of comparative rating approaches are included in Appendix C. A simple preliminary evaluation of 45 sites was based on desk study information. This was then updated to include more detailed evaluations and a more complex rating approach after walkover inspections and the collection of further information.

Because landfill settings and risks vary in nature and scale, it is not appropriate for this guide to define generic criteria for this type of evaluation process. It is important to consider all significant areas of risk and to consider them in a transparent and reasonable way: the examples in Appendix C are intended to illustrate this process rather than provide a definitive guide.

4.7 Risk treatment and management decisions

Once risks have been assessed and compared with criteria, decisions can be made regarding management action. Most often an application for a resource consent provides the best path to formalise the appropriate action and/or remediation/management plans. Broadly, the options for management are:

Investigate further	Insufficient information is available to make a transparent and reasonable management decision.
No action	All risks are considered acceptable.
Remediate	Control the source and/or exposure route to reduce unacceptable risk.
Management Plan	Monitor and, if required, implement Contingency Plan (measures to reduce exposure).

Remediation options will depend on the particular risk scenarios that need to be addressed and include:

- leachate interception, with subsequent treatment and/or disposal to sewer
- gas barriers or gas venting
- installing or upgrading the cover and/or cap.

Management measures will need to be defined for specific risk issues at each site. It is important to consider all risks together and consider the potential side effects of remedial action. For example, capping a landfill with imported clay will reduce leachate generation (and hence discharges) and should eliminate surface exposure of sharps. However, such a cap will also contain LFG and may lead to changed gas migration patterns, possibly increasing the potential for gas to accumulate in neighbouring buildings.

How to find out more

Canadian Council of Ministers of the Environment. 1991. *A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life*. Water Quality Branch. Environment Canada, Ottawa, Canada.

Crowhurst, D, Manchester, SJ. 1993. *The Measurement of Methane and Other Gases from the Ground*. Report 131. Construction Industry Research and Information Association. London.

Harries, CR, Witherington PJ, McEntee, JM. 1995. *Interpreting Measurements of Gas in the Ground*. Report 151. Construction Industry Research and Information Association. London.

Ministry of Health. 2000. *Drinking Water Standards for New Zealand*. Ministry of Health, Wellington.

O'Riordan, NJ, Milloy, CJ. 1995. *Risk Assessment for Methane and Other Gases from the Ground*. Report 152. Construction Industry Research and Information Association. London.

Raybould, JG, Rowan, SP, Barry DL. 1995. *Methane Investigation Strategies*. Report 150. Construction Industry Research and Information Association. London.

US EPA. 1987. *Quality Criteria for Water*. Criteria and Standards Division, Office of Water, Washington, DC.

US EPA. 1995. *Air Emissions from Municipal Solid Waste Landfills – Background Information for Final Standards and Guidelines*. EPA-453/R-94-021. Office of Air and Radiation. North Carolina.

Wilson, SA, Card, GB. 1999. Reliability and risk in gas protection design. *Ground Engineering* 32(2): 33-36.

5 Closure and Post-Closure Management

5.1 Introduction

Once a landfill or a landfill cell reaches its capacity, it should be progressively closed by constructing a final cover (or cap), which is the key component to minimising:

- infiltration of rainfall to control quantity of leachate produced, thus minimising groundwater impacts
- the potential for refuse to come in contact with humans and other ecological receptors
- vermin access and impact
- discharge of LFG and fire/explosion potential
- odours
- erosion, while providing a surface to sustain landscaping and improve visual aesthetics.

At this time a summary should be prepared of the operational history of the site, any remedial measures that have been undertaken, the location of any bores and monitoring points, and the final cap details. Copies of these records should be retained and archived by the landfill manager and provided to the consent authorities. Such records provide a means to ensure that buildings and structures are not constructed on the landfill, nor the immediate surrounds, if it is not appropriate to do so.

It is possible, particularly for smaller landfills with ready public access, that in the period immediately following closure a certain amount of "fly tipping" will occur. The site should be fenced and locked to prevent access, and signs established advising of the alternative disposal location(s). The site should be regularly monitored and any waste removed to minimise similar behaviour. If the problem persists, the assistance of neighbours to the site should be sought, to identify those responsible.

It is also possible that there will be a problem with vermin, notably rats, especially if these have become established during the operation of the landfill. A continuing problem with rats (or birds or flies) suggests that the final cover is insufficient. However, before undertaking an upgrade of the final cover, a comprehensive programme of poisoning (with appropriate precautions to protect other species) should be undertaken.

5.2 Final cap design features

The design of the final cap of a landfill is primarily influenced by:

- design of the landfill liner and the leachate collection system
- landfill leachate and gas quality
- proximity to potential receptors
- landfill operations history, including type of waste accepted
- hydrogeological and meteorological factors
- end use of the landfill.

These factors are discussed in detail below.

5.2.1 Design considerations

Influence of the Design of the Landfill Liner and Leachate Collection System: Concepts of dry and wet landfills

If the bottom liner of the landfill is capable of significantly restricting the seepage of leachate and the landfill has an active leachate collection system in place, a final cap consisting of natural soils can be used. In the absence of a leachate collection system, the landfill will potentially fill up with infiltrated water, which will become leachate. Conversely, if the existing landfill is unlined and the risk of impacting on the receiving environment is high, a final cap having a relatively low infiltration rate is necessary to reduce the quantity of leachate generated to minimise potential impacts. In such situations, a final cap consisting of a compacted clay layer and/or a geomembrane or a geosynthetic clay liner should be used.

Climate

Local climate significantly influences the water balance and long-term performance of the final cap. At locations where rainfall is relatively high and potential evapotranspiration is low, compacted clay caps or geosynthetic caps will be more effective in reducing infiltration and hence limiting leachate quantities. However, where rainfall is relatively low and potential evapotranspiration is high, compacted clay caps may not be necessary. In fact, if compacted clay caps are used in such dry climates, the cap should be designed to resist desiccation cracking. In such climates, capillary barriers or geosynthetic caps (discussed in Section 5.2.3) may be more effective.

Slope stability

Slope stability of the final cap is primarily influenced by the slope and materials used to construct the cap. If possible, the final cap slope should be limited to 1V:4H, to reduce the potential for erosion. Slope stability issues are especially critical when the cap consists of compacted clay and/or geomembrane. Typically, weaker shear planes exist along the geomembrane or compacted clay interfaces. In such situations, to increase the factor of safety, a lateral drainage layer consisting of coarse-grained soils (such as sand or gravel) or geocomposite may be necessary.

Slope stability will also be influenced by the proposed/possible end uses. If grazing by sheep or cattle is a possible end use, then slopes need to be designed accordingly, particularly for cattle.

Desiccation and freeze thaw

It is critical that the physical integrity of the landfill cap is maintained against the formation of cracks due to desiccation and freeze/thaw cycles. These cracks can potentially provide preferential flow paths for migration of infiltrated water into refuse, resulting in higher leachate production. Such cracks can also provide pathways for LFG to escape into the surrounding environment. Such an escape of LFG may pose fire, explosion, health and ecological hazards.

The desiccation and freeze/thaw cracking potential of cover soils is mainly influenced by the site climate, soil type and compaction criteria. By compacting the cover soils at water contents less than the optimum, the desiccation potential of the soils can be minimised. In addition, less-plastic (less clay, more silt) soils can be used to reduce desiccation cracking. The capping layer can also be protected from desiccation and freeze/thaw cracking by burying the capping layers under an adequately thick layer of soil, or by placing a geomembrane layer above the soil layer.

Settlement

Decomposition of refuse is the primary cause of landfill surface settlement. Differential settlement of landfill cap may:

- jeopardise overall landfill stability
- damage LFG management and leachate recirculation systems
- damage stormwater management systems and landscaping.

Hence, the final cap design should take into account the settlement of waste, intermediate and daily cover layers, and underlying foundation soils. If significant differential settlement or subsidence is expected within 2–4 years after a landfill cell reaches its final grades, an interim cover should be placed. The intermediate cover should consist of a minimum of 300 mm of compacted soil, seeded to grow vegetation. Once the estimated settlement or subsidence is nearly complete, the intermediate cover should be replaced or incorporated into a final cap. This approach will reduce maintenance costs.

Data shows that for an existing MSW landfill, where it is more than 10 years since waste disposal operations ceased, most of the ultimate settlement or subsidence has already occurred. In these circumstances interim capping would not be necessary.

Erosion

Erosion of the final cap is primarily caused by wind and stormwater. The final cap should be designed so that erosion-related soil loss does not exceed 4 tonnes per hectare per year. This will minimise long-term maintenance of the cap. Typically, the use of final slopes less than 1V:4H and stormwater cut-off drains placed at approximately 6 m vertical increments can meet the erosion requirement. Vegetation should also be used to control erosion (see section 5.4).

5.2.2 Recommended final cap design

A recommended final cap design for all MSW landfills is presented in Figure 5.1. This design can be altered to suit the site-specific requirements provided that the adequacy of the alternative design is demonstrated. For some old sites with negligible or minor effects and associated risks, there may be no need to place a cap.

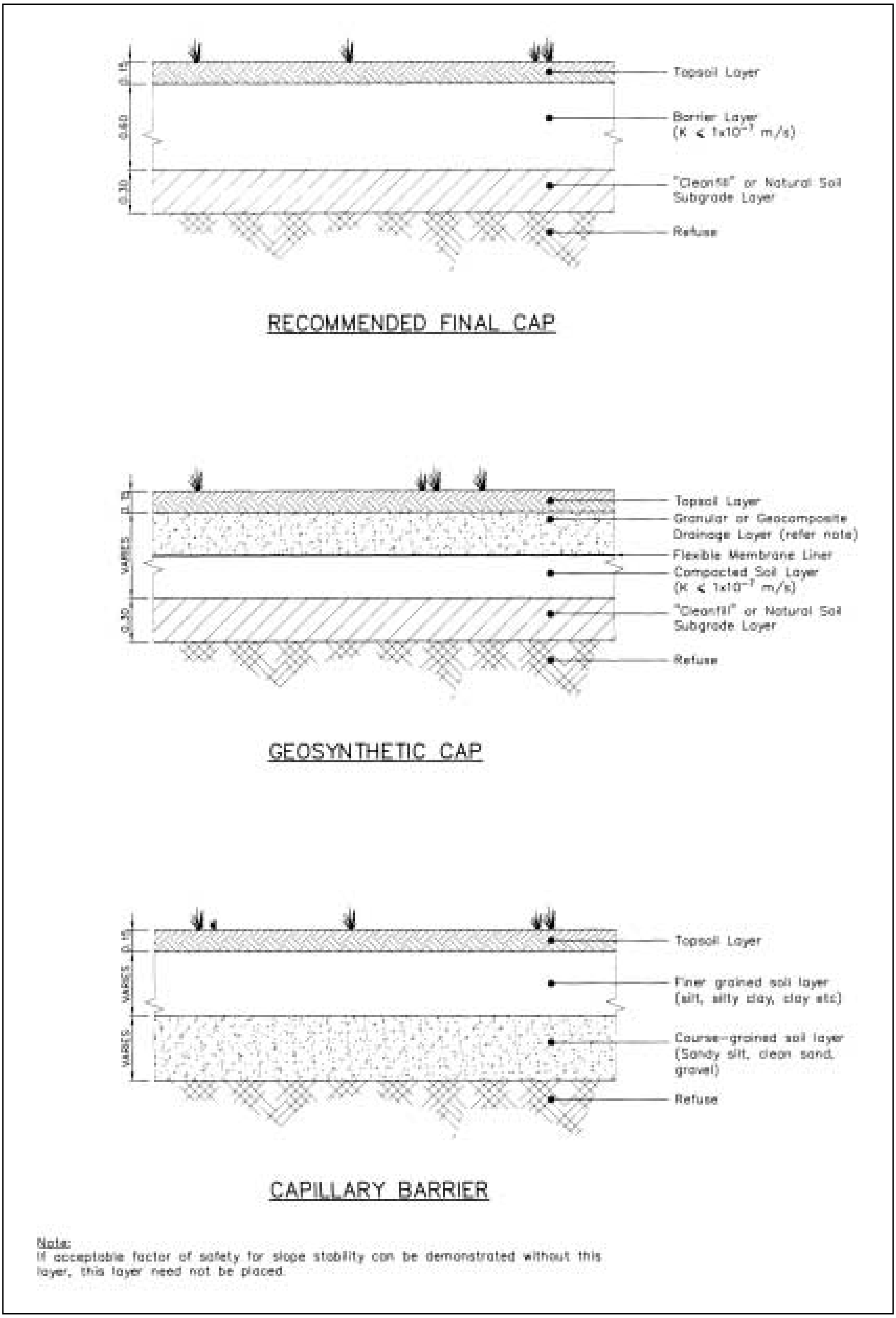

Figure 5.1: Alternative final cap designs for MSW landfill

Source: Tonkin & Taylor Ltd, March 2001.

The recommended final cap from top to bottom should consist of:

- 150 mm topsoil layer for vegetation
- 600 mm compacted barrier layer (silt, silty clay, clay k ≤ 1 x 10^{-7} m/s)
- 300 mm compacted subgrade or foundation layer.

The 300 mm subgrade layer can be an intermediate cover placed immediately after the landfill cell reaches its final grades. It can be a cleanfill layer consisting of appropriately graded (less than 50 mm) demolition concrete chunks, bricks, or inert natural material. The function of the subgrade layer is to cover the waste and provide a uniform surface for placing the barrier layer, followed by the topsoil layer.

The barrier layer restricts the amount of infiltration into the underlying waste. After rainfall, infiltrated water is partially stored in this layer. A fraction of this stored soil water is released to the atmosphere via evapotranspiration.

The topsoil layer is used to support vegetation growth. In regions where vegetation cannot be maintained or sustained, particularly in semi-arid or arid regions, other materials can be selected to minimise erosion and allow for surface drainage (for example, cobbles, gravel or stones).

In some situations, thicker layers may be required and/or a subsoil layer provided between the barrier and topsoil layers.

5.2.3 Alternative final cap designs

The recommended final cap design presented in Figure 5.1 may not be the most appropriate design for all landfills. Availability of suitable soils for the construction of the final cap, climate, maintenance, proximity to sensitive receptors and long-term performance of the cap may entail the use of an alternative final cap design such as one of those presented below.

Capillary barrier

In semi-arid and arid climates, capillary barriers can be more effective in restricting infiltration than traditional clay caps (the latter are also referred to as resistive barriers). In its basic form, a capillary barrier from top to bottom should consist of:

- 150 mm topsoil layer
- ~ 500 mm finer-grained soil layer (for example, clayey silt or silt)
- ~ 500 mm coarser-grained soil layer (for example, clean sand or gravel).

A typical cross-section of a capillary barrier is also presented in Figure 5.1.

The capillary barrier offers the following advantages over the clay cap.

- Neither moisture conditioning of clay nor comprehensive compaction criteria are necessary for construction.
- There is far less potential for desiccation or freeze/thaw cracking.
- Animal burrows are less likely as coarse-grained soils collapse.

- Less maintenance is necessary (if the capillary barrier is properly vegetated).
- It is less expensive to construct if clay is not available.
- If designed properly, it allows less infiltration into the waste, thus reducing the quantity of leachate produced.

The capillary barrier has the following disadvantages compared with the clay cap.

- It is appropriate only for semi-arid or arid climates where annual precipitation is below 600–700 mm.
- It is prone to significant infiltration into waste if stressed by extreme hydrologic events (such as a large snow melt, or a large amount of rainfall in a short duration).
- Rigorous water balance models such as UNSAT-H (Fayer *et al*., 1992) or analytical techniques are necessary to design capillary caps (the HELP model cannot be used).
- LFG leakage through capillary barriers is potentially larger.

Capillary barriers are not recommended for landfills where a shallow and sensitive groundwater aquifer exists at the site. The cost savings achieved by using a capillary barrier should be weighed against the potential risks, and the risks should be factored into the design of the cap. Design guidelines for capillary barriers are presented in detail in Khire *et al*., (2000).

Geosynthetic barrier

Geosynthetic barriers typically consist of either a geosynthetic clay liner or a geomembrane (for example, HDPE, PVC, PP, etc.), or a combination of both. A typical cross-section of a geosynthetic cap is presented in Figure 5.1. Geosynthetic caps are used where it is necessary to limit infiltration and hence leachate production to a bare minimum. Use of a geosynthetic cap should be considered where:

- a shallow and sensitive aquifer is located beneath an unlined landfill
- hazardous waste is present
- the landfill does not have a leachate collection system.

Geosynthetic caps are also used to increase LFG collection efficiency and reduce leakage of LFG through the final cap. If a landfill is located in a densely populated area, leakage of LFG through the final cap can be a critical criterion. Similarly, if a landfill historically accepted significant volumes of hazardous waste, restricting infiltration to limit leachate production is vital. In the above situations, a final cap consisting of geosynthetics should be considered.

Selection of appropriate geosynthetic layer(s) should be based on site-specific factors such as:

- waste composition
- liner and leachate control system designs
- LFG production rates
- potential receptors and associated risks
- desired long-term performance.

5.3 Assessment of cap of existing closed landfill

For a closed landfill, the existing cap should be assessed by the landfill owner or responsible party.

The assessment should include one or more of the following:

- reviewing available reports to find topographical maps, aerial photographs, landfill operations history, properties, composition, and a cross-sectional profile of the existing cap
- interviewing personnel who work(ed) at the landfill for information on existing cap and operational history, including the types of waste accepted
- mapping the visual aspects of the landfill cap from observations during a site walkover, such as stressed vegetation, exposed waste, ground colour, and leachate seeps
- drilling bores penetrating through the existing cap to log the composition and properties of the cap and refuse immediately below the cap
- cutting a narrow trench in the cover material with a spade
- conducting a topographical survey of the landfill
- reviewing the monitoring data.

The assessment will provide information on the thickness and composition of the existing cap. Geotechnical and hydrologic properties of the cap may need to be measured in the field or laboratory. Geotechnical properties may include shear strength, soil classification and hydraulic conductivity. Hydrologic properties may include the erosion index, state of vegetation, and rooting depth. Once this information is collected, an assessment of the existing cap can be performed. US EPA's Hydrologic Evaluation of Landfill Performance (HELP) model can be used for water balance assessment of the cap. The Universal Soil Loss Equation can be used to assess the erosion potential of the existing cap.

If the existing cap does not meet the final cap criteria it may need to be upgraded. However, for older landfills generating weak leachate, the existing cap may be sufficient.

5.4 Vegetation establishment

The importance of soils in achieving successful establishment of vegetation and restoration of the landfill site has often been overlooked. The depth and quality of soil overlying the cap is an important factor in determining the available water capacity, and shallow soils may restrict the growth of roots and nutrient supply. Inappropriate soil handling techniques, such as poor timing of operations and unsuitable machinery use, can cause a reduction in pore space, aeration, water holding capacity, gaseous exchange and root penetration. Waterlogging in the winter and the growth of rushes, buttercups, etc. are conditions that often occur on closed landfill sites as a result of poor soil handling practices.

For a number of years following landfill closure, grass is considered the most suitable vegetation for the aftercare period as it tolerates poor soil conditions, provides all-year-round soil cover, promotes the development of soil structure and can accommodate the environmental pollution control systems. It also facilitates the regular walkover inspections required.

The choice of grass varieties is site-specific and dependent on the intended after use. Advice should be sought from local pastoral experts.

Soil analysis will identify the nutrient status of the soils, indicating the fertiliser requirement for the growing crop. The fertiliser can be applied during cultivation, at sowing, or applied as top dressing for the growing crop. Adequate rainfall or irrigation is required to establish a good sward. Establishment of grass cover is often affected by the level of discharge of LFG through the cap. If this continues to be an ongoing problem, the cap may need to be upgraded or a gas collection system installed.

A significant number of years (generally more than 20) after closure, the decomposition processes within the landfill may have proceeded sufficiently for other vegetation to be established, ultimately including vegetation types whose roots will penetrate the cap when this is no longer considered to be a significant issue. In general, a top soil layer thicker than 150 mm would be required for vegetation other than grass. While this other vegetation may include exotic species, the following guidance is provided for native species based on the principles of "natural succession":

> *Under natural conditions vegetation develops on a bare site through a series of stages. This can be seen in areas that have been burnt or subject to landslides. The textbook model of succession is as follows: the first plants to grow on or colonise the area are lichens, then mosses and small herbs. With time, soil fertility builds up and hardy shrubs and trees become established. They create a sheltered, shaded environment, attract birds carrying other seeds and eventually taller tree species become established. These taller trees overtop and shade out the smaller trees and shrubs, and in time, replace them. Eventually taller, slower growing canopy trees become established. Each group of plants in the succession makes the site suitable for the next group of plants and unsuitable for themselves, so they are eventually replaced. Eventually there is a period of relative stability where the vegetation does not change much over a long time.*
>
> (Porteous, T, 1993)

Native colonising and nurse plants suitable for the initial stages of revegetation are given in Appendix D. The plants should be of the genetic variant found in the locality.

5.5 Post-closure care

Post-closure care includes the maintenance and monitoring of the landfill. Maintenance ensures that the various landfill components function appropriately, and monitoring keeps any potential impacts to the land and water under check. A minimum 30-year post-closure care period is recommended for an MSW landfill. The owner or operator of the landfill should submit a post-closure care and management plan to the regional council for approval. The management plan should have provision to reduce the monitoring requirements or extend the post-closure care period subject to the results of the periodic monitoring.

The post-closure care and management plan should include:

- start and estimated end dates of the post-closure care period
- detailed description and basis of the monitoring parameters and frequencies for monitoring
- periodic and incidental maintenance
- a health and safety plan
- corrective action measures if adverse impacts (for example, surface water or groundwater contamination, odour, fire) are observed
- a contingency plan (for fire, earthquake, flood event, etc)
- an end-use plan for the landfill.

The maintenance activities should be undertaken at least annually, and at the minimum include:

- maintaining stormwater cut-off drains
- removing sediments from stormwater cut-off drains and any treatment devices
- cleaning the leachate collection pipes by hydro-flushing
- maintaining the gas-venting or gas-flaring system
- controlling the erosion of the final cap by performing routine vegetation management (for example, irrigating, mowing and planting) and repair of the subsided cap
- inspecting and maintaining the final cap following a flood or severe drought
- grazing for vegetation management.

The monitoring should include periodic evaluation of the:

- groundwater quality downgradient of the landfill
- leachate and LFG
- surface water quality in the adjacent wetlands or natural surface water bodies (as necessary)
- state of capping (cracking, subsidence, erosion, stock damage, leachate breakout)
- state of vegetation cover

An outline Table of Contents for an Aftercare Management Plan is given in Appendix E.

How to find out more

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US EPA. 1991. *Design and Construction of RCRA/CERCLA Final Covers*. EPA report no. 625/4-91/025. Office of Research and Development. Washington, DC.

US EPA. 1994. *Design, Operation, and Closure of Municipal Solid Waste Landfills*. EPA report no. 625/R-94/008. Washington, DC.

US EPA. 1994. HELP Model. URL: http://www.wes.army.mil/el/elmodels/

6 Landfill Discharges Monitoring

6.1 Purposes of leachate and water monitoring

The design of a monitoring programme requires an assessment of the potential risks to each water receptor in the vicinity of the site. These depend on both the leachate composition and age, and engineering/site management controls.

Specific purposes of monitoring leachate, groundwater and surface water are to demonstrate and provide:

- compliance with consent conditions
- confirmation that the landfill engineering measures (where these have been implemented) are operating as designed
- information on the processes occurring within the landfill site
- information on the state and rate of stabilisation of the waste
- an early warning of potential adverse environmental effects
- information to enable decisions on the management of the site to be taken
- a determination of the nature, extent and rate of migration of contaminants from the site
- data to support predictions of the future impact of leachate on receptors
- data to justify reliance on natural attenuation measures
- data to justify and follow remediation measures
- data to support or justify regulatory action.

Monitoring should be regarded as part of the overall management system for the landfill and should be undertaken in a variety of situations; for example, low flow and high flow.

6.2 Leachate monitoring

The CAE *Landfill Guidelines* provide guidance on procedures for regular monitoring of leachate quantities generated within a landfill and the strength and composition of the leachate. They also provide a list of parameters that would be typically included in a leachate-monitoring programme for an operating regional solid waste landfill (see Table F.1, Appendix F). Generally, during the operational phase leachate should be monitored at least 6-monthly. However, for a closed landfill the frequency and parameters monitored should be modified based on site-specific factors such as:

- whether the landfill has an engineered liner and leachate collection system
- hydrogeology of the site, which will affect the rate of leachate migration
- proximity to sensitive receptors (potential impact on human or stock health or ecology)

- time since closure
- a statistical trend (up or down) observed in the concentration of contaminant(s) in down-gradient wells.

The number and location of leachate monitoring wells is primarily based on the history of disposal of waste and the types of waste in the landfill. If the composition of waste in the landfill varies, at least one leachate monitoring well is needed in each type of refuse to monitor overall leachate quality. If the composition of waste is unknown, the number and locations of leachate monitoring wells should be based on the vertical and lateral extent of the landfill, topography, and hydrogeology of the site. It is important that the monitoring wells do not penetrate the base of the landfill.

If the landfill is located on a permeable site, it is possible that there will not be sufficient leachate to collect samples. If initial investigations prove this to be the case, no leachate monitoring is required – only groundwater or surface water monitoring.

6.3 Surface water monitoring

The required number of surface water monitoring points and the distance between them will be site-specific and for a closed landfill will depend on the assessed likelihood of contamination and the sensitivity of the receiving environment. As a general guide, there should be:

- for flowing waters, at least two monitoring points – one upstream and one downstream of, and both in close proximity to, the site (taking into account any reasonable mixing zone)
- for surface waters sensitive to small changes in water quality (such as wetlands), at least two monitoring points upstream and two downstream
- at least one additional monitoring point within the down-gradient catchment area if sensitive receptors are potentially at risk.

Further monitoring points may be required in specific circumstances. However, if the volume of leachate discharge is small relative to the surface water flow/volume, monitoring may not be necessary at all.

Parameters chosen for surface water-quality monitoring programmes should be able to:

- describe adequately the overall status of the waters
- detect reliably contaminants discharged from the landfill or other relevant sources
- be measured consistently, quickly and cost-effectively.

Guidance on suitable parameters and monitoring frequencies for operating regional landfills is given in the CAE *Landfill Guidelines* (see Table F.2, Appendix F).

A reduction in the number of parameters and frequency should be possible for closed landfills if, or when, several rounds of monitoring data are available.

In some situations biota surveys may also be necessary.

6.4 Groundwater monitoring

6.4.1 Selection of groundwater monitoring well locations

The location and number of monitoring wells should be selected such that migration of leachate constituents can be detected in enough time to take appropriate measures to mitigate any adverse effects. The following site-specific factors influence the location and number of monitoring wells:

- hydrogeology of the site
- orientation of the landfill footprint with respect to the groundwater flow direction(s)
- proximity to sensitive aquifers or surface water bodies
- distance between the landfill footprint (edge of refuse) and any compliance points.

The total number and configuration of monitoring wells is site-specific, with fewer required for sites where low-permeability soils are present. A minimum of three monitoring wells is necessary to establish the groundwater flow direction. A minimum of one up-gradient well for each aquifer unit is necessary to establish the background groundwater quality. At least one of the sites should be within the contaminant plume, if its presence has been established.

If a single well is used for monitoring, this should be at the most down-gradient site, adjacent to the toe of the landfill.

Well clusters consisting of more than one well at a location may be necessary if multiple aquifers exist at the site. If groundwater is deep, monitoring wells may be necessary in the vadose zone. Typically more monitoring wells are necessary if:

- the hydrogeology is complex
- the landfill does not have an engineered liner or a leachate collection system
- sensitive receptors exist within a relatively short distance down-gradient of the landfill.

Where the site lies in low-permeability soils, or has been closed for some time, fewer wells may be necessary. A groundwater monitoring well layout for an example site is presented in Figure 6.1.

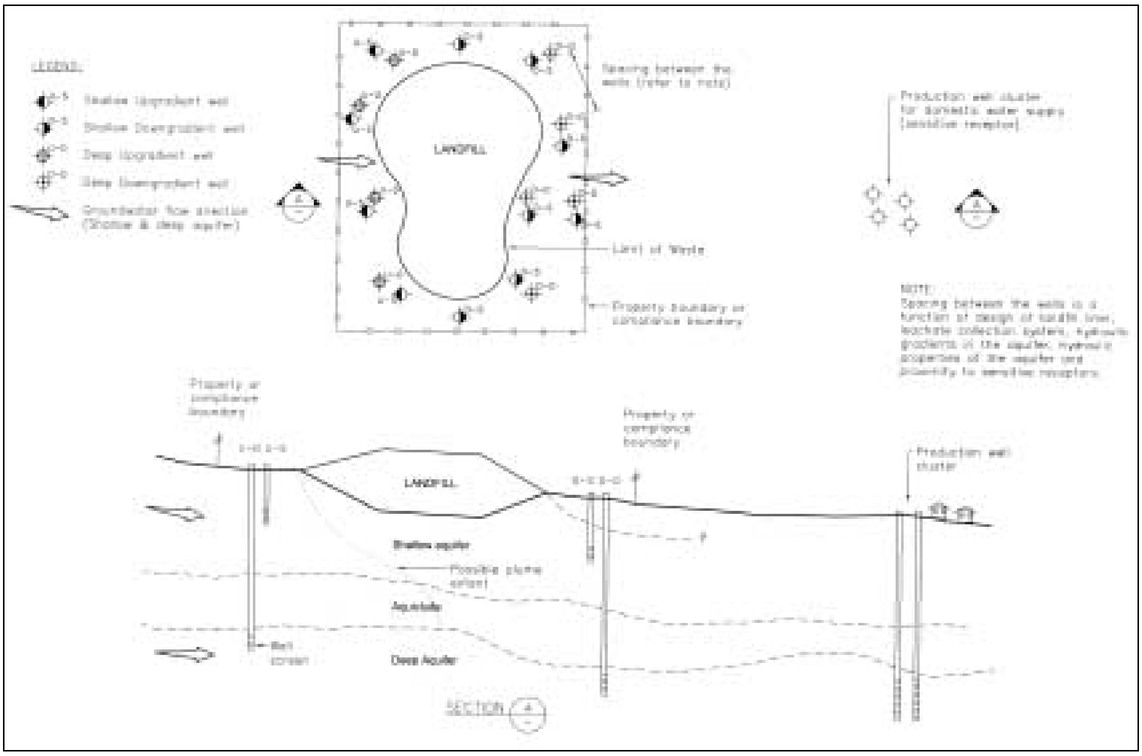

Figure 6.1: Groundwater monitoring well layout for sample landfill site
Source: Tonkin & Taylor Ltd, March 2001

6.4.2 Installation and sampling of monitoring wells

Before installing any wells, the regional council should be consulted to determine whether a permit is required (for example, the Auckland Regional Council and Environment Canterbury generally require a permit where groundwater is to be taken or monitored).

In order for the monitoring well to provide representative and consistent samples of groundwater, appropriate installation techniques and sampling procedures need to be followed. The purpose of the monitoring well and the contaminants likely to be present in the groundwater or leachate affect the materials used for well screens and casings. The geology of the site affects the installation detail, including the screen size, location, and material used for the filter pack. Although PVC is the most common material used for casings and screens, stainless steel and polytetrafluoroethylene (Teflon) casings and screens can also be used. (It should be noted that materials used for casings and screens, and for securing them, may contribute contaminants to the water samples.) A casing diameter of 50 mm and a filter pack consisting of clean, graded sand or pea-gravel are commonly used. The filter pack size is based on the grain size of the naturally occurring formation surrounding the well screen. The aperture size of the slots or perforations in the screen is based on the size of the filter pack grains. Screen aperture sizes typically range from 0.25 mm to 1.5 mm. The monitoring well must be installed to ensure that there is adequate sealing at the ground surface and between aquifers.

Shallow monitoring wells should be screened in such a way that there is approximately 0.5 m clearance between the top of the average annual groundwater level and the top of the screen. This allows sampling of light non-aqueous phase liquids (LINAPLs), which typically float on the groundwater surface. Further information on installation and sampling of monitoring wells can be obtained from US EPA, 1994.

Following installation, the wells should be clearly marked or fenced off to avoid damage by mowers, machinery, etc.

6.4.3 Monitoring frequency and monitoring parameters

Deciding on an appropriate frequency for monitoring is important. Monitoring too often results in unnecessary expense, whereas monitoring too infrequently may result in groundwater impacts not being detected in time. Monitoring frequency should be decided by taking into consideration the following factors on a site-specific basis:

- hydraulic conductivity and hydraulic gradients (seepage velocity) in the aquifer, where there is a defined aquifer
- distance to the down-gradient compliance or monitoring location
- distance to sensitive receptors
- quality of leachate and liner, and the leachate collection system design
- possible need to cover both high- and low-rainfall seasons.

The CAE *Landfill Guidelines* recommend a tiered approach for groundwater monitoring for an operational landfill (see Table F.3, Appendix F). Each tier defines a list of parameters that corresponds to a specific frequency. Indicator parameters such as water level, ammoniacal nitrogen, conductivity, pH and total suspended solids are sampled most often, typically at least on a quarterly basis. A more comprehensive list of parameters is sampled on a bi-annual basis. A reduction in the number of parameters and frequency should be possible for closed landfills if, or when, several rounds of monitoring data are available.

6.5 Monitoring closed landfills for water quality

The actual monitoring frequency and list of parameters should be based on the site-specific factors and contaminants detected in the leachate. Laboratory analysis methods need to have appropriate detection levels for the likely concentrations (guidance is provided in Table 3.1) of the analytes being monitored. The frequency should be sufficient to ensure that contaminants can be detected before reaching compliance points or receptors. *In-situ* data loggers are an extremely useful tool for monitoring by giving actual recordings rather than sampling on schedule, which can give records after the event. Guidance on monitoring leachate, groundwater and surface water for closed landfills is given in Table 6.1. However, for a particular landfill, the exact programme must be determined by the regional council.

Initial monitoring of a landfill site closed for more than 10 years to determine whether groundwater (or surface water) is being adversely affected may only focus on a limited range of parameters: alkalinity, ammoniacal nitrogen, boron, conductivity and zinc.

Table 6.1: Recommended water monitoring for closed landfills

Years since closure	Size of landfill		
	<15,000 m^3	15,000–100,000 m^3	>100,000 m^3
0–5	***Comprehensive*** Leachate – once only Groundwater – once only Surface water – once only ***Indicator*** Groundwater – yearly Surface water – yearly	***Comprehensive*** Leachate – yearly Groundwater – yearly Surface water – yearly ***Indicator*** Groundwater – bi-annually Surface water – bi-annually	***Comprehensive*** Leachate – yearly Groundwater – bi-annually Surface water – bi-annually ***Indicator*** Groundwater – quarterly Surface water – quarterly
5–15	NR	***Indicator*** Groundwater – bi-annually Surface water –bi-annually	***Comprehensive*** Groundwater – yearly Surface water – yearly ***Indicator*** Groundwater – bi-annually Surface water – bi-annually
15–40	NR	NR	***Indicator*** Groundwater – yearly Surface water – yearly
> 40	NR	NR	NR

Notes:

The recommended monitoring assumes that there has been at least one screening investigation to establish whether there is a possible problem, and if so, that there has been monitoring to establish a baseline (see Appendix F).

Landfills in sensitive locations or with waste composition likely to have been less than 85% MSW should be monitored at the level recommended for the next larger size of landfill.

In consultation with the regional council, it may be possible to reduce the frequency of monitoring if the monitoring results (groundwater or surface water) remain essentially unchanged for at least three consecutive monitoring periods. In consultation with the regional council, monitoring may be discontinued if the results (groundwater or surface water) are essentially at background levels for three monitoring periods.

6.6 Trigger levels

Trigger levels can be used by:

- landfill operators for operational purposes
- 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 non-compliance issues.

In New Zealand a common approach is to adopt a two-tier trigger level system for surface water monitoring regimes. The first tier (TL1) is designed to alert management to the fact that the landfill is about to deviate from normal operating conditions and may be leading to regulatory non-compliance. TL1s are normally set at a specified level or percentage (for example 70%) of the regulatory binding TL2 trigger level that is considered suitable for management purposes. Exceedance of the TL1 trigger level generally requires a specified response to investigate the cause of the exceedance and to remedy/mitigate the cause as necessary.

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.

(Further guidance can be found in the CAE *Landfill Guidelines*, from which this section was adapted).

6.7 Statistical data interpretation

Statistical methods are needed to make a judgement on whether the groundwater quality is showing impacts from a landfill, or if the data is consistent with the background levels. Statistical methods for assessing monitoring data range from simple methods such as plotting pollutant concentrations over time to assess changes visually, to more rigorous methods of parametric or non-parametric analysis of variance followed by multiple comparisons procedures. The complexity of the monitoring data and the analysis objectives influence the selection of the appropriate statistical method.

If the data under consideration is distributed normally or log-normally, parametric test procedures such as a t-test can be used (a minimum confidence interval of 95% is recommended). However, often the data is not normally or log-normally distributed, and non-parametric test procedures such as Kruskal-Wallis have to be used. Detailed information on such statistical methods used for evaluating monitoring data can be obtained from US EPA, 1992b. Software packages such as GRITS/STAT (US EPA, 1992a) can be used to evaluate groundwater monitoring data.

6.8 Methodology for contingency monitoring

When a down-gradient monitoring well, or a set of wells, or a surface water monitoring location, indicates a statistically significant increase in the concentrations of one or more contaminants over background levels, contingency monitoring is required. However, it should first be established that the contamination is not from another source, or that there has not been an error in sampling or analysis. Variation in the background groundwater quality should also be considered before reaching a conclusion on groundwater or surface water contamination.

The objective of contingency monitoring is to confirm the increase and assess whether the landfill is causing (or likely to cause) adverse effects and to gather sufficient data to determine the reason for the effects such that appropriate remediation measures can be taken. If leachate is escaping and the leachate plume extent (or “hot spots”) has been identified, sampling of a selective subset of wells is appropriate. The suite of parameters for contingency monitoring is based on the parameter(s) showing a statistically significant increase and leachate quality data. If, for example, a semi-volatile organic compound (SVOC) is showing a statistically significant increase in concentration in a down-gradient well, groundwater as well as leachate should be sampled for the entire SVOC suite to clarify the potential for adverse effects. Once the source contaminant(s) is identified, the appropriate actions can be determined.

If, during subsequent contingency monitoring, the contaminant(s) detected with a statistically significant increase remains above background levels, the regional council should be notified and corrective measures taken in accordance with the consent conditions. If the contaminant(s) previously detected with a statistically significant increase is no longer present above background levels for at least two consecutive samples, contingency monitoring can be discontinued and regular monitoring resumed.

6.9 Purposes of landfill gas monitoring

Monitoring of LFG is an important tool to identify and manage onsite and offsite risks. Monitoring at and around a closed landfill site will help to:

- determine the extent of any LFG migration offsite
- identify migration pathways
- assess risks onsite and at neighbouring properties
- identify any requirement for LFG control measures.

6.9.1 Nature and frequency of monitoring

The nature and frequency of LFG monitoring is governed by a number of parameters, including:

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

Some broad guidance on when monitoring may be required is given in Table 6.2.

Table 6.2: Recommended LFG monitoring for closed landfills

Years since closure	Size of landfill		
	< 15,000 m^3	15,000–100,000 m^3	> 100,000 m^3
0–5	Annual: • visual inspection • building monitoring	Six-monthly: • visual inspection • building monitoring • subsurface monitoring	Three-monthly: • visual inspection • surface monitoring • subsurface monitoring • building monitoring
5–15	NR	Annual: • visual inspection • building monitoring	Six-monthly: • visual inspection • building monitoring • subsurface monitoring
15–40	NR	NR	Six-monthly: • visual inspection • building monitoring
> 40	NR	NR	NR

Notes:

NR = No monitoring required unless high-risk site (population density high or sensitive uses in close vicinity) or adverse effects.

Building monitoring (includes services trenches) is required for all within 250m of the site.

Additional monitoring is required at any site where there is an active gas collection system.

6.9.2 Monitoring techniques

The following guidance is based on the CAE landfill gas monitoring guidelines.

Visual monitoring

There are a number of key indicators of elevated LFG emissions that can be observed during a visual inspection of a landfill site. These include:

- areas of distressed vegetation
- evidence of capping cracking
- discernible odours.

Surface gas monitoring

Several techniques exist for monitoring surface emissions from a landfill. These methods are set out in detail in the CAE document. The most useful techniques for closed landfills are visual inspections and instantaneous surface monitoring.

The most convenient and commonly used monitoring technique is instantaneous surface monitoring. This is carried out by walking over the landfill site in a prescribed pattern, continuously monitoring methane concentrations using a hand-held flame ionisation detector.

The methane is sampled via a wand with a funnelled inlet held 50 to 100 mm from the landfill surface. Site conditions should be dry and wind velocities less than 15 km/hour. The measured methane concentration should be recorded at regular intervals and any areas of elevated emissions noted.

Monitoring also needs to be undertaken at pipe and culvert entrances/exits, at the base of drains, and in manholes, having proper regard at all times for personal safety.

Subsurface gas monitoring

Subsurface LFG monitoring is particularly useful for identifying offsite migration of LFG. Monitoring should comprise measurement of methane, carbon dioxide and oxygen, and recording the barometric pressure and ground pressure.

Gas spiking surveys can be carried out to provide an initial assessment of subsurface gas levels. Spiking surveys involve making holes in the ground and measuring gas concentrations via a tube inserted into the hole. The top of the hole must be sealed around the tube during sampling. Spiking surveys are of limited use if gas migration is occurring at depth.

Permanent monitoring probes generally take the form of a length of pipe made from an inert material (such as PVC) with a perforated section over the required sampling length. The probe depth should generally be at least 3 m, although site factors such as depth of refuse and groundwater should be taken into account.

Subsurface gas monitoring at closed landfills will usually be targeted at key areas around the perimeter to identify subsurface migration of gas offsite. Monitoring of the probes should be carried out during low and falling barometric pressures to obtain worst-case results.

Monitoring in buildings

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. If possible, measurements should be made in each location before allowing ventilation (for example, measure under a door before opening).

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.

If the methane concentration is greater than 10% LEL (lower explosive limit), that is, 0.5% by volume, gas control measures and further monitoring will be required.

Landfill gas control system monitoring

In this context, LFG control refers to the active collection and flaring or removal of the gas from site for utilisation. LFG control has only occasionally been installed at closed landfill sites, although this is likely to become more common as currently operating landfills close.

Monitoring is required to ensure that the system is operating effectively.

Surface and subsurface monitoring (as described above) should be undertaken to ensure that there is efficient collection. It is also important to monitor and control the pumping so that overpumping does not occur, allowing excess air into the waste. The composition of the gas being pumped should be monitored for flammable gas/methane and/or oxygen concentrations, or other steps taken to prevent danger from an explosion.

The purpose of flaring gas and/or energy recovery is to dispose of the flammable constituents safely and remove odour to prevent nuisance. Consideration needs to be given to the health risks associated with the products of combustion. Monitoring is required of the combustion efficiency and the emissions from the combustion process.

How to find out more

Centre for Advanced Engineering. 2000. *Landfill Guidelines*. Centre for Advanced Engineering. Christchurch, New Zealand (funded by Ministry for the Environment).

UK Department of the Environment. 1999. *Guidance of the Monitoring of Landfill Leachate, Groundwater and Surface Water*. Version 8. HMSO. London.

US EPA. 1992b. *Statistical Training Course for Groundwater Monitoring Data Analysis*. EPA report no. 530-R-93-003. Office of Solid Waste, Washington DC.

US EPA. 1994. *Design, Operation and Closure of Municipal Solid Waste Landfills*. EPA report no. 625/R-94/008. Washington DC.

7 Closure and Post-Closure Costs and Financial Assurance

7.1 Introduction

Under a user-pays system, the landfill disposal cost of refuse is calculated such that all incurred and anticipated future costs are built into the tipping fee or gate fee. Incurred costs typically include:

- costs to obtain consents
- cell development costs
- operation costs
- air, leachate, groundwater, stormwater, or LFG monitoring
- closure costs.

Anticipated future costs typically include:

- post-closure maintenance
- post-closure monitoring
- corrective action.

A number of closed landfills, upgrades of existing landfills and new landfills have all recently been consented under the RMA. In these cases, resource consent conditions have generally required the preparation of a written closure and post-closure plan for approval by the appropriate authorities. In general, the objectives of such plans should be to identify the steps necessary to:

- close the facility
- care for the facility during post-closure
- estimate the costs of post-closure activities
- provide financial assurance documentation as a guarantee that the necessary funds will be available for closure and post-closure activities.

Financial assurance is a means of ensuring that the owners/operators of landfill facilities adequately plan for early closure, closure, post-closure care, and corrective actions, by providing a specific mechanism or combination of mechanisms to accumulate the required funds during the life of the landfill. Mechanisms for providing financial assurance are given in Appendix H. This financial assurance is required until discharges and/or the need for consents cease. It may not be necessary for territorial authorities to provide such financial assurance.

For existing or new landfill facilities, the opportunity exists to levy each tonne of solid waste disposed at the facility via the tipping fee, as a disposal cost levy (section 542 of the Local Government Act) to provide the funds for these costs. Another method is to pay the costs of closure and post-closure using rates or taxes collected from the relevant community, or a combination of rates, taxes and disposal cost levy. If financial assurance for meeting future costs has not been implemented during the operational life of the now-closed facility, the costs of closure and post-closure will probably have to be met by the community in the form of rates and taxes.

7.2 Closure and post-closure costs

While there are some closure activities that are common to all landfill sites, others are site-specific and/or resource consent-specific. Nevertheless, typical closure activities include:

- construction of the final cover
- gas management system
- leachate management system
- surface water management system.

Closure and post-closure activities can be conducted on parts of the landfill that are at final elevation, even if other parts of the same site are still accepting solid waste. Table 7.1 presents indicative costs for these closure components. It is important to reiterate that actual costs will be site-specific and may vary significantly from those presented in the table.

Table 7.1: Typical average final cover system costs

Activity/system	Cost range	Reason for cost variability
Intermediate cover	$4–$11/m^3	Material availability – onsite or offsite; thickness of layer
Low-permeability (barrier) layer placement		
Clay layer	$8–$25/m^3	Clay availability – onsite or offsite; thickness of layer
Geosynthetic layer	$70,000–$120,000/ha	Synthetic material type; material properties
Drainage layer	$60,000–$120,000/ha for sand $75,000–$150,000/ha for gravel	Type of material; availability of required material; thickness of drainage layer
Erosion control (vegetative layer)	$5–$15/m^3	Material availability; material required (topsoil, general soil, etc); thickness of layer
Vegetation	$5000–$15,000/ha	Seed/mulch requirements; end use
Landfill gas management system		
Venting layer	$20–$40/m^3 for sand	Type of material; availability of material
Extraction wells	$15,000–$100,000/ha	Well spacing and depth; waste characteristics
Passive well head	$2500–$5000/well	Design of well head
Active well head	$12,000–$18,000/well	Design of well head
Laterals/headers	$15,000–$55,000/ha	Design of final cover system; well spacing
Active candle flare set up	$40,000–$250,000/flare	Expected gas volumes; design of flare set up
Active enclosed flare set up	$250,000–$1,000,000/flare set up	Expected gas volumes; design of flare set up
Leachate management system		
Wells	$6000–$25,000/well	Well design and depth; waste characteristics
Recirculation trenches	$200–$500/m	Trench design
Pumps/controllers	$5000–$15,000/pump	Pump size required
Compressors	$5000–$50,000/compressor	Number of pumps; pump sizes
Laterals/headers	$15,000–$60,000/ha	Landfill size; well layout
Force main	$150–$350/m	Geology of area; system design
Tanks	$200–$700/m^3	Tank design; secondary containment requirements
Pre-treatment/treatment plant (on site)	$250,000–$1,000,000/facility set up	Treatment requirements; volume of leachate
On-site surface water control system		
Stormwater drains, channels	$70–$350/m	Standards; overall design of system
Sedimentation ponds	$25,000–$250,000/pond	Standards; consent conditions; pond size and number of ponds; earthworks
Engineering		
Design consultants/third party engineering	$10,000–$30,000/ha for final cover system $5000–$15,000/ha for each gas system and leachate system	Variability in consent conditions; number of components required to be constructed during closure

Post-closure costs include all of those costs associated with the maintenance and monitoring of a landfill after it has stopped accepting solid waste. Table 7.2 presents some of the typical individual costs that an owner/operator may incur during post-closure.

Table 7.2: Typical average post-closure care costs

Activity/system	Cost range	Reason for cost variability
Inspection	\$150–\$600/ha/yr or \$50–100/hr/inspector	Overall size of facility; requirements of post-closure plan
Final cover	\$2500–\$10,000 /ha/yr	Size of repairs; personnel; equipment and materials required
Vegetation	\$2500–\$7500/ha for revegetation \$1000/ha/yr for mowing	Seed/mulch requirements; extent of repairs; local contractor costs
Leachate management system		
Leachate disposal	\$500–\$55,000/ha/yr (\$5–\$100/m^3)	Cover type; leachate generation; complexity of leachate system; size of landfill; utility costs
System maintenance	\$500–\$1000/ha/yr	Cover type; leachate generation; complexity of leachate system; size of landfill; utility costs
Electricity	\$2000–\$5000/ha/yr	Size of landfill; utility costs
Gas management system		
Maintenance	\$500–\$3000/ha/yr	Size of repairs; complexity of system; landfill size; utility costs
Replacement	\$8000/ha/yr	Size of repairs; complexity of system; landfill size; utility costs
Electricity	\$2000–\$5000/ha/yr	Landfill size; utility costs
Environmental monitoring system		
Groundwater	\$1500–\$5000/ha/yr (\$1000–\$3000/station)	Monitoring programme requirements; frequency of well/event sampling; number of sampling points; size and layout of site
LFG	\$300–2000/ha/yr (\$100–200/well/event)	Monitoring programme requirements; frequency of sampling; number of sampling points; size and layout of site
Leachate	\$600–1000ha/yr (\$1000–\$3000/point/event)	Monitoring programme requirements; frequency of sampling; number of sampling points; size and layout of site
Stormwater	\$600–\$1000ha/yr (\$600–\$1200/point/event)	Monitoring programme requirements; frequency of sampling; number of sampling points; size and layout of site
Corrective action	To be determined at the time of impact event, cap failure, liner failure, instability, flood, etc	Each case has a unique solution; extent of required remediation; time period for remediation.
End of post-closure sign-off/certification	\$30,000–\$200,000	Reporting requirements; detail of monitoring/ inspection reports; environmental status of facility

Closure and post-closure cost estimates are best developed using actual costs from current landfill operations, as well as historical costs from closure and post-closure activities. Changes are likely to occur in the estimates over time due to increasing regulatory requirements and/or new technologies. In general, the following major components of post-closure may decrease over time.

- **Leachate management**: the management of leachate has the potential to be the most expensive aspect of post-closure care. The decreases in volume of leachate produced at the site following final cover installation may reduce cost over time.
- **Compliance monitoring**: monitoring requirements of a landfill facility have increased since landfills have been consented under the RMA. However, if a facility is in environmental compliance, the frequency and extent of monitoring may be reduced by the regional council. Most landfill consent conditions include review provisions. Section 127 of the RMA allows consent holders to apply for a change or cancellation of consent condition.
- **Gas management**: as the landfill ages and decomposition of refuse slows down, the production of LFG decreases, resulting in lower gas management costs.

7.3 Remediation/corrective action costs

If corrective action measures are required at a landfill facility, a detailed scope of work, appropriate cost estimates, and financial assurance documentation should be submitted to the appropriate regulatory authority. Corrective action (CA) plans will be site-specific and will vary widely.

7.4 Key financial considerations

Key financial considerations for closure and post-closure are as follows.

- In order to determine the cost of closure and post-closure care, the landfill owner/operator must determine the steps necessary, as required by the resource consent conditions, to close a facility, as well as care for the facility during post-closure.
- Closure and post-closure costs are scale-dependent and can be a significant part of the facility's tipping fee.
- Design, construction, operating practices, and maintenance are all factors that influence potential closure and post-closure costs, as well as remediation / corrective actions.
- It is important to apply site-specific cost models when developing closure and post-closure cost estimates.
- Actual historical costs from site operations and construction activities should be used whenever possible. Cost guidelines and estimates from published sources should only be used as supplementary reference materials.
- Applying any "typical" per hectare costs to sites should be avoided, as these could grossly underestimate or overestimate closure and post-closure costs.

How to find out more

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Appendix A: Overseas Landfill Practices

A1 Land uses at closed landfills overseas

In most overseas countries closed landfills have been mainly used for recreational purposes. However, in some countries there has been pressure for alternative land uses. The following is a very brief overview of land uses for closed landfills in the listed countries.

Australia

The majority of closed landfill sites have been approved, after a fallow period, for public use (for example, parklands, gardens). There have been instances of subsequent residential use but several of these were later closed down due to children becoming ill after contact with the soil, or excessive settlement making the houses uninhabitable.

Canada

The majority of post-closure uses have been recreational (for example, parks and golf courses). There have been some public housing developments with reports of LFG problems. However, more recently, there has been development of wetlands and natural ecosystems.

Ireland

Traditionally post-closure uses have been a mix of unused "brownfield" sites and industrial or recreation uses. There has been an increase in "green" uses, and to this end *Landfill Restoration and Aftercare* is one of a series of Landfill Management Manuals that have been developed. Specific guidance is provided on restoration and aftercare for amenity (sports fields, golf and pitch and putt courses, and nature conservation), agricultural use or woodland establishment.

Germany

Historically most closed landfill sites have become unused "fenced brownfield" sites. However, where the site location is good, a future use such as industrial is included in the remediation plan and a greater investment is made in remediation to allow an increased range of uses.

Netherlands

Post-closure land uses have predominantly been recreational (for example, parks, sportsfields, golf courses). However, because of limited building area in the Netherlands there has been significant investigation into the environmental effects of closed landfills. This has shown less contamination and dispersal of contamination than expected, and other types of land use (such as industry) are being considered.

France

Traditionally sites have been "fenced and monitored brownfields" for a period of time (not defined) and then converted to a relatively heavy industrial use (for example, chemicals or pharmaceuticals manufacture, or waste treatment), as light industry/commercial have the same standards as residential. More recently there has been pressure for greater remediation and management to allow multifunctional use of these sites.

A2 Closed landfill management overseas

In many overseas countries high population density creates a great pressure to use and re-use land, and this has led to a greater focus on the remediation and management of closed landfills. The following is a very brief overview of some of the management aspects of closed landfills in the listed countries.

Australia

Landfills, operational and closed, are covered by state legislation, and although the exact requirements differ in each state, they are comprehensive. The responsibility for closed landfills lies with both the state and the local authority. At closure the state EPA sets the criteria for post-closure monitoring on a site-specific basis, and the landowner is responsible for carrying it out. The monitoring is directed at leachate, groundwater and LFG. The sites may be sold but any subsequent development is subject to approval by the local authority, and if sufficiently large in size, the state government may also become involved.

Canada

A mixture of state and provincial legislation applies to the management of landfills, operating and closed. For its operation and post-closure period, a landfill requires a consent (Certificate of Approval). Prior to issuing a Certificate, the provincial regulatory agency requires a closure and post-closure plan for the landfill. Monitoring programmes throughout the landfill life and for the post-closure period are directed at LFG, leachate composition and groundwater. When it is demonstrated that there is very little or no environmental impact, the regulatory agency permits monitoring to be reduced to lower frequencies.

Germany

In Germany the federal (national) legislation provides the framework, and the corresponding state legislation gives more detailed regulations. Although there are some minor differences in state legislation, there are no differences in the important aspects of the laws. During the operation of a landfill, the Emission Protection Act and the Waste Act are the dominant environmental laws. During the closure procedure, the Water Act and the Soil Protection Act become more relevant. There is a federal guideline on the design and construction of landfills, and all state authorities use this in their approvals.

The management of closed landfills is carried out under state legislation and is the responsibility of both the "upper waste authority" (state) and the "lower waste authority" (bigger cities or regions). Each permit is site-specific and the lower authority is responsible for the permit procedure. However, for more complex sites/issues, they have to involve the upper authority and the state Environmental Authority (advisory, not decision-making).

Under the Soil Protection Act, authorities must register all contaminated sites, including closed landfills, and the owner / responsible party must provide a remediation plan. The remediation plan may range from no action, to just monitoring, to complete excavation and disposal elsewhere. The permit is given on written acceptance of the remediation plan and the authorities have to make their decision taking into account ecological and economic aspects and the future land use. However, the owner does not have to remediate to a standard higher than that of the land use prior to the landfill operation.

In almost all circumstances, monitoring is focused on groundwater due to the very stringent requirements of the Water Act. Theoretically, no contamination at all is acceptable, but in practice it occurs. If significant, there is a legal expectation of some action and in other situations the monitoring continues for several decades.

Netherlands

The management of closed landfills is based on national legislation, with variations written into regional policy documents. The differences in the regional documents relate to local geology/ hydrogeology and geographical circumstances. There are site-specific consents for closed landfills where there is the potential for significant environmental impact. The major emphasis of monitoring is of groundwater quality beneath and downstream of the landfill site. There is also a requirement for five-yearly monitoring of the thickness and integrity of the capping layer, but typically this aspect is overlooked.

France

There is no national or local authority legislation that deals specifically with landfills (active or closed). However, active landfills are covered by the state legislation concerning wastes, which deals with specifications of categories of wastes authorised to be disposed, following classification of the landfill, and design and construction criteria for the landfill. The main legislation in France regarding environmental matters is that covering "classified installations". A landfill during all its phases is a classified installation and so the general provisions of the legislation apply to landfills and, in particular, those applying to classified installations closure apply to the closure of landfills.

The basic principles governing the prevention of soil pollution are covered in national guidelines, which also give guidance on simplified risk assessment to establish whether remediation works are required and to set priorities for such works. Detailed risk assessment is required if the simplified approach cannot give a definite answer.

A recent amendment to the classified installation legislation now obliges the former landfill operator, at closure, to submit a "memoire" to the authorities covering risk assessment, proposals for remediation works (if any), future use and future monitoring. This memoire, sometimes modified after discussion with the authorities, forms the basis of a new permit for the post-closure period. Groundwater monitoring is mandatory in all cases, and is extensive if a potable supply is taken in the area. Other monitoring is dictated by the findings of the risk assessment.

Appendix B: Regulatory Controls under the Resource Management Act for Closed Landfills

B1 Role of regulatory agencies

Regional councils

There are 12 regional councils in New Zealand. Section 30(1) of the RMA sets out the functions of regional councils. The key provisions relevant to closed landfills are:

> *(1) Every regional council shall have the following functions for the purpose of giving effect to this Act in its region:*
>
> *(a) The establishment, implementation, and review of objectives, policies and methods to achieve integrated management of the natural and physical resources of the region ...*
>
> *(c) The control of the use of land for the purpose of ...*
>
> *(v) The prevention or mitigation of any adverse effects of the storage, use, disposal or transportation of hazardous substances ...*
>
> *(f) The control of discharges of contaminants into or onto land, air or water and discharges of water into water.*

The regional council also has responsibilities under Section 35 to gather information and to carry out research so that it can effectively carry out its functions under the RMA:

> *(1) Every local authority shall gather such information, and undertake or commission such research, as is necessary to effectively carry out its functions under this Act.*
>
> *(2) Every local authority shall monitor –*
>
> *(a) The state of the whole or any part of the environment of its region to the extent that is appropriate to enable the local authority to effectively carry out its functions under this Act.*

Territorial authorities

There are 69 territorial authorities (district and city councils) in New Zealand. Section 31(b) of the RMA sets out the functions of territorial authorities relating to the control of the use of land in the management of hazardous substances:

> *Every territorial authority shall have the following functions for the purpose of giving effect to this Act:*
>
> *(b) The control of any actual or potential effects of the use, development, or protection of land, including for the purpose of ... the prevention or mitigation of any adverse effects of the storage, use, disposal, or transportation of hazardous substances.*

Section 35 of the RMA (the duty to gather information and carry out research) also applies to territorial authorities.

Unitary authorities

Unitary authorities have the functions of both regional councils and territorial authorities. Usually these are separately organised within the unitary authority structure for accountability. The unitary authorities are Gisborne, Marlborough, and Tasman District Councils, and Nelson City Council.

B2 Standards, policy statements and plans

The RMA contains a hierarchy of policy statements and plans. To date, the New Zealand Coastal Policy Statement is the only national policy statement and no national environmental standards have been prepared.

Regional policy statements

Each regional council is required to prepare a regional policy statement that provides the basis for integrated resource management for its region. The regional policy statements establish a directional framework for regional and district plans.

Regional plans

The RMA allows regional councils to prepare regional plans to address any issue relating to their functions under the RMA. Regional plans (except regional coastal plans) are optional, and may be produced as and when the need arises. All regional councils have prepared regional coastal plans. For other aspects of the environment, most regional councils have chosen to prepare a suite of documents, and many are still in the development phase.

Regional plans must not be inconsistent with any national or regional policy statements or other regional plans (of the region concerned), and must also have regard to planning documents prepared by iwi authorities (for example, iwi/hapu management plans). Regional plans must be reviewed every 10 years.

Most regional councils have assumed responsibility for regional planning documents prepared under previous legislation, such as water classifications, general authorisations and certain types of bylaws. These are known as transitional regional plans, and have legal force until they are replaced by operative regional plans prepared under the RMA. However, these transitional plans may not address all issues relevant to landfills (such as air discharges).

District plans

District plans are mandatory and are designed to assist territorial authorities in carrying out their functions under the RMA. Each plan describes the district's significant resource management issues, and sets out the objectives, policies and methods to address these issues. A district plan must not be inconsistent with national or regional policy statements, or regional plans. As with regional plans, district plans must be reviewed every 10 years. However, changes can be made within that period.

Under previous legislation, district and city councils were required to produce what were known as "district schemes", which needed to be replaced under the RMA to reflect the focus of the new legislation. This has been a gradual process and, in the interim, district schemes have been given the status of transitional district plans, and continue to carry weight until the district plans become operative.

B3 Closed landfills: example regional plan rule

Rules relating to closed landfills and contaminated sites (at 30 September 2000) were reviewed. The following is a methodical and unambiguous example for closed landfills.

Proposed Waikato Regional Plan

Discretionary Activity Rule 5.2.7.2 – Closed Landfills

The discharge of contaminants into or onto land, and any subsequent discharge of contaminants into water or air (excluding discharges to air permitted by Section 6.1.13.1 of this Plan) from a closed landfill that does not have a current resource consent with conditions relating to the management of those discharges that continue to occur after closure, is a discretionary activity (requiring resource consent).

Advisory notes:

The information Environment Waikato will require to assess any application under this Rule is set out in Section 8.3.4.6 of this Plan.

Small scale discharges of biogas to air (<10 cubic metres per day) are permitted by Section 6.1.13.1 of this Plan.

District plans may also contain rules relating to these sites.

The rule allows for small discharges of biogas (LFG) which are unlikely to cause adverse effects to be permitted activities. In all other situations it is clear that a consent is required and that the consent must contain conditions relating to management of discharges after closure of a landfill.

It also makes reference to where additional information can be found within the plan and to possible requirements in district plans.

B4 Information requirements for resource consent applications (proposed Waikato Regional Plan)

Environment Waikato has provided guidance on the types of information that will be required relating to specific types of consent applications, and an indication of the key decision-making criteria relevant to determining consent applications as follows:

a) A description of any actual or potential adverse effects on land, water and air arising from any discharges emanating from the site.

b) The action that is to be taken to avoid, remedy or mitigate any adverse effects of these discharges.

c) An assessment of the extent to which the discharges can comply with the water classification for affected water bodies as identified in the Water Management Class Maps of this Plan.

d) The extent to which any discharge to air will comply with Policy 1 in Chapter 6.1 of this Plan, with regard to objectionable effects from odour and particulate matter effects.

e) The presence, in any discharge to air of any hazardous air contaminants as listed in Chapter 6.7 of this Plan.

f) The extent to which any discharge to air creates actual or potential effects on the global atmosphere (within the scope of government policy).

g) An Aftercare and Monitoring Plan for the site detailing items such as:

- *i) basis for the aftercare and monitoring strategy (including factors such as stormwater management, leachate management, revegetation, landfill gas management and other discharges to air)*
- *ii) design plan for any works to be undertaken*
- *iii) restoration works*
- *iv) landfill site aftercare*
- *v) monitoring and record keeping*
- *vi) quality assurance and control measures.*

h) The location of the site relative to any water body, high risk erosion area, cave or cave entrance, significant geothermal feature, or any areas prone to natural hazard events such as deep seated land instability, earthquakes or floods.

i) The effect of the activity on areas of significant indigenous vegetation, significant habitats of indigenous fauna, and significant natural features such as cave and karst systems.

Appendix C: Examples of Comparative Rating Systems for Landfill Sites

C1 Desk study ranking methodology

In 1993–94 Tonkin and Taylor Ltd undertook an assessment of closed landfills for Auckland City Council. A preliminary ranking exercise was carried out following an initial desk study, to provide a basis for prioritising site inspections. At that stage, the only information available for every site covered geological and hydrologic setting, age, size and current land use. This information was used to produce a rough index of potential risk to the environment and public health. Simple values were assigned for each of these information categories, as set out in Table C.1, and these were summed to provide an overall risk index.

Table C.1: Desk study ranking criteria

Rank	Groundwater factors	Surface water factors	Years since site closure	Size	Site development
3	Basalt, with down-gradient abstraction	Coastal/streambank setting	< 20	Large	Recent housing or other buildings
2	Basalt near coast, Waitemata Group' with down-gradient abstraction of groundwater	Close to coast or stream(s) with steep topography	20–40	Medium	Recent roading
1	Waitemata Group near coast	Moderate distance from coast/stream(s); flat topography	40–70	Small	Old roading or houses
0	Intertidal/terrace muds	Distant from coast/stream(s)	> 70	Very small	Playing fields; motorway development

C2 Risk index development

Based on the information above, a set of criteria was developed to assign an index figure, ranking the level of potential environmental and public health risk at each site. These criteria are set out in three separate groups, as outlined below and detailed in Tables C.2, C.3 and C.4.

(i) A subjective weighting was given to different areas of evaluation. For example, food gathering and groundwater resources issues are perceived to be of greater inherent value and so are given a higher weighting than visual and terrestrial ecology aspects (Table C.2, Issue Weighting).

(ii) The characteristics of the landfill and its immediate environment were evaluated to determine a site value. For example, where shellfish are available immediately beside the site, a high value was given, with a medium value given where fish could be caught near the site and a low weighting where no food gathering is carried out around the site (Table C.3, Site Characteristics).

(iii) The potential for a landfill to affect a given value was assessed. For example, a young site with high leachate-generating potential was assessed as having a higher potential to affect food gathering than an old site in the same position (Table C.4, Potential for Effects).

The landfill assessment data was utilised to produce rankings for site characteristic and effects potential for each site. An overall risk index for each site was then obtained by multiplying the weighting, attribute and effects values together for each evaluation category, and then summing the category results for each site. The aim of this system is to combine relatively simple and easily determined rankings (weighting, site characteristic and effects potential rankings) to produce a qualitative index, which clearly differentiates between low- and high-risk sites.

Table C.2: Index development procedure – issue weighting

Issue	Weighting
Resources	
Groundwater resources	5
Surface water resources	1
Buildings	1
Ecology	
Terrestrial	1
Freshwater	3
Marine	5
Social	
Maori	3
Visual	1
Public health	
Food gathering	5
Physical contact	3
Gas exposure	5

Table C.3: Index development procedure – site characteristics

Issue	High (3)	Medium (2)	Low (1)	None (0)
Resources				
Groundwater resources	Basalt aquifer with down-gradient abstraction	Basalt near coast, Waitemata Group with down-gradient abstraction of groundwater	Waitemata Group near the coast	Intertidal/terrace alluvium
Surface water resources	Large stream; stream near coast or culverted stream	Small stream	Ephemeral stream or stormwater culverts	No stream
Buildings	Rigid new buildings	Flexible new buildings	Old buildings	No buildings/piled
Ecology				
Terrestrial	Native vegetation	Exotic vegetation	Grassed	No planting
Freshwater	Open stream by site	Culverted stream	Close to stream	Distant from streams
Marine	Coastal setting	Riparian on coast	Riparian close to coast; aquifer near coast	Distant from coast
Social				
Maori	Marine/riparian site	–	Stormwater culverted through site	Distant from stream/coast
Visual	High visibility site landscaped (e.g. coastal, large park)	Moderate visibility site (e.g. park)	Moderate–low visibility site (e.g. suburban road infill)	Low visibility site (e.g. near section)
Public health				
Food gathering	Shellfish gathering near site	–	Fishing near landfill	No food gathering
Physical contact	Swimming from site	Swimming near site; contact sport on site	Passive recreation on site	No site use or road cover
Gas exposure	Concrete buildings on site	–	Other buildings on site, or airtight buildings near site	No gas risk buildings

Table C.4: Index development procedure – potential for effects

Issue	High (3)	Medium (2)	Low (1)	None (0)
Resources				
Groundwater resources	< 40 yr; > 5 ha	< 40 yr; > 5 ha	40–70 yr	> 70 yr
Surface water resources	< 40 yr; > 5 ha	< 40 yr; > 5 ha	40–70 yr	> 70 yr
Buildings	< 20 yr	20–40 yr	40–70 yr	> 70 yr
Ecology				
Terrestrial	< 40 yr; > 5 ha or very steep sides slopes	< 40 yr; > 5 ha or steep sideslopes	40–70 yr	> 70 yr
Freshwater	< 40 yr; > 5 ha	< 40 yr; > 5 ha	40–70 yr	> 70 yr
Marine	< 40 yr; > 5 ha	< 40 yr; > 5 ha	40–70 yr	> 70 yr
Social				
Maori	Leachate discharges to surface water	Leachate discharges to surface water via ground	Leachate discharges occur, but don't reach surface water	No leachate discharges
Visual	Landfill conditions significantly affect local visual values	Landfill visually intrusive	Landfill visible but not intrusive	Landfill not visible
Public health				
Food gathering	< 40 yr; > 5 ha	< 40 yr; > 5 ha	40–70 yr	> 70 yr
Physical contact (a) water sports or (b) playing fields	< 40 yr, > 5 ha or poor cover; refuse exposed	< 40 yr; > 5 ha, or refuse incorporated in cover material	40-70 yr or steep side slopes	>70 yr good cover
Gas exposure	< 40 yr	–	40–70 yr	> 70 yr

Appendix D: Native Colonising and Nurse Plants (Native Forest Restoration/QEII National Trust)

These are plants that are quick growing, and capable of being planted in full sun and moderately exposed conditions. Once established, less hardy species can be planted among them, taking advantage of the microclimate created.

Scientific name	Common name	Growing conditions
Aristotelia serrata	Wineberry	Most sites, some shelter
Cassinia fulvida	Coastal cottonwood	Coastal, dunes, dry, exposed
Cassinia leptophylla	Tauhinu	Any dry site
Coprosma parviflora	Mingimingi	Anywhere, especially swampy
Coprosma propinqua	Mingimingi	Similar to above
Coprosma repens	Taupata	Exposed seasides; frost tender
Coprosma robusta	Karamu	Most sites, especially moist
Cordyline australis	Cabbage tree	Most sites; hardy
Coriaria spp.	Tutu	Nitrogen fixing; stony, mineral soils
Cortaderia fulvida	Toetoe	Dry, poor, disturbed, compacted sites
Cortederia toetoe	Toetoe	Wet to swampy
Dodonea viscosa	Akeake	Exposed, dry sites
Hebe salicifolia (S. Is)	Koromiko	Some shelter; streamside
Hebe stricta (N. Is)	Koromiko	Moist, exposed site
Kunzea ericoides	Kanuka	Most well-drained, exposed sites
Leptospermum scoparium	Manuka	Anywhere, according to seed source
Macropiper excelsum	Kawaka	Partial shelter, most sites
Malicytus ramiflorus	Mahoe	Anywhere, according to seed source
Metrosideros excelsa	Pohutukawa	Exposed seasides; frost tender
Myoporum laetum	Ngaio	Exposed sites, including coastal; very hardy
Olearia avicenniaefolia	Tree daisy	Dry to moist; poor ground; shelter
Olearia paniculata	Akiraho	Exposed dry sites, including coastal
Olearia solandri		Dry, partial shelter
Phormium cookianum	Mountain flax	Coastal, rocks, mountains, exposed
Phormium tenax	Lowland flax	Exposed, swamps and streamsides
Pittosporum crassifolium	Karo	Exposed
Pittosporum eugenioides	Lemonwood	Some shelter
Pittosporum tenuifolium	Kohuhu	Some shelter
Pseudopanax arboreus	Five finger	Some shelter
Pomaderris kumeraho	Kumerahou	Poor, dry clay soils; frost tender
Solanum aviculare	Poroporo	Some shelter; frost tender
Solanum laciniatum	Poroporo	Best in partial shade; hardier

Appendix E: Closed Landfill Aftercare Management Plan – Outline Table of Contents

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Remedial works

Monitoring

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Final cover
Vegetation
Complaints
Records and reporting

Emergency procedures

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Leachate breakout
First aid

Appendix F: Example Monitoring Programmes for Leachate, Surface Water and Groundwater

Table F.1: Example leachate monitoring programme for an operating regional landfill

Parameters	Units	Monitoring frequency
Physico-chemical parameters		Bi-annual/annual
Alkalinity	g/m^3	Y
Aluminium	g/m^3	Y
Ammoniacal nitrogen	g/m^3	Y
Arsenic	g/m^3	Y
Biological oxygen demand	g/m^3	Y
Boron	g/m^3	Y
Cadmium	g/m^3	Y
Calcium	g/m^3	Y
Chloride	g/m^3	Y
Chromium	g/m^3	Y
Chemical oxygen demand	g/m^3	Y
Conductivity	mSm^{-1}	Y
Dissolved reactive phosphorous	g/m^3	Y
Total hardness	g/m^3	Y
Iron	g/m^3	Y
Lead	g/m^3	Y
Magnesium	g/m^3	Y
Nickel	g/m^3	Y
Nitrate nitrogen	g/m^3	Y
pH		Y
Potassium	g/m^3	Y
Sodium	g/m^3	Y
Sulphate	g/m^3	Y
Suspended solids**	g/m^3	Y
Silica	g/m^3	Y
Total Kjeldahl nitrogen	g/m^3	Y
Total organic carbon	g/m^3	Y
Zinc	g/m^3	Y
Total phenols	g/m^3	Y
Volatile acids	g/m^3	Y
Volatile organic compounds	g/m^3	Y
Semi-volatile organic compounds	g/m^3	Y

** Only where samples not pre-filtered.
Source: CAE *Landfill Guidelines*

Table F.2: Example surface water monitoring programme for an operating regional landfill

Parameters	Units	Water quality					Sediment quality
		Baseline	Indicator		Comprehensive*		
			Continuous	Fortnightly/ monthly	Quarterly/ bi-annual	Yearly	Yearly
Physico-chemical parameters							
Flow	l/s	Y	Y		Y		
Alkalinity	g/m^3	Y			Y		
Aluminium (TOT/AS)	g/m^3	Y		Y	Y		
Ammoniacal nitrogen	g/m^3	Y		Y	Y		
Arsenic (AS)	g/m^3	Y			Y	Y	Y
Boron	g/m^3	Y			Y		
Cadmium (AS)	g/m^3	Y			Y	Y	Y
Calcium	g/m^3	Y			Y		
Chloride	g/m^3	Y		Y	Y		
Chromium (AS)	g/m^3	Y			Y	Y	Y
Chemical oxygen demand	g/m^3	Y		Y	Y		
Conductivity	mSm^{-1}	Y	Y	Y	Y		
Copper (AS)	g/m^3	Y			Y	Y	Y
Dissolved reactive phosphorous	g/m^3	Y			Y		
Total hardness	g/m^3	Y			Y		
Iron (TOT/AS)	g/m^3	Y		Y	Y	Y	Y
Lead (AS)	g/m^3	Y			Y	Y	Y
Magnesium	g/m^3	Y			Y		
Manganese (TOT/AS)	g/m^3	Y			Y	Y	Y
Nickel (AS)	g/m^3	Y			Y	Y	Y
Nitrate nitrogen	g/m^3	Y			Y		
pH	g/m^3	Y		Y	Y		
Potassium	g/m^3	Y			Y		
Sodium	g/m^3	Y			Y		
Sulphate	g/m^3	Y			Y		
Suspended solids	g/m^3	Y		Y	Y		
Temperature	g/m^3	Y			Y		
Total Kjeldahl nitrogen	g/m^3	Y				Y	Y
Total organic carbon	g/m^3	Y				Y	Y
Turbidity	g/m^3	Y	Y		Y		
Zinc (AS)	g/m^3	Y		Y	Y	Y	Y

Parameters	Units	Water quality					Sediment quality
		Baseline	Indicator		Comprehensive*		
			Continuous	Fortnightly/ monthly	Quarterly/ bi-annual	Yearly	Yearly
Organic screens							
Total phenols	g/m^3	Y			Y		
Volatile acids	g/m^3	Y			Y		
Volatile organic compounds	g/m^3	Y				Y	Y
Semi-volatile organic compounds	g/m^3	Y				Y	Y
Biological parameters							
Aquatic biota	g/m^3	Y				Y	Y
WET (whole effluent toxicity)	g/m^3					Y	

Source: CAE *Landfill Guidelines*

Table F.3: Example groundwater monitoring programme for an operating regional landfill

Parameters	Units	Monitoring tier			
		Baseline	Indicator	Comprehensive*	
			Fortnightly/ quarterly	Quarterly/ bi-annual	Yearly
Physico-chemical parameters					
Water level	M	Y	Y	Y	
Alkalinity***	g/m^3	Y		Y	
Aluminium	g/m^3	Y		Y	
Ammoniacal nitrogen***	g/m^3	Y	Y	Y	
Arsenic	g/m^3	Y		Y	
Boron***	g/m^3	Y		Y	
Cadmium	g/m^3	Y		Y	
Calcium	g/m^3	Y		Y	
Chloride	g/m^3	Y		Y	
Chromium	g/m^3	Y		Y	
Chemical oxygen demand	g/m^3	Y		Y	
Conductivity***	mSm^{-1}	Y	Y	Y	
Dissolved reactive phosphorous	g/m^3	Y		Y	
Total hardness	g/m^3	Y		Y	
Iron	g/m^3	Y		Y	
Lead	g/m^3	Y		Y	
Magnesium	g/m^3	Y		Y	
Manganese	g/m^3	Y		Y	
Nickel	g/m^3	Y		Y	
Nitrate nitrogen	g/m^3	Y			
pH	g/m^3	Y	Y	Y	

Parameters	Units	Monitoring tier			
		Baseline	Indicator	Comprehensive*	
			Fortnightly/ quarterly	Quarterly/ bi-annual	Yearly
Potassium	g/m^3	Y		Y	
Sodium	g/m^3	Y		Y	
Sulphate	g/m^3	Y		Y	
Suspended solids**	g/m^3	Y	Y	Y	
Silica	g/m^3	Y		Y	
Total Kjeldahl nitrogen	g/m^3	Y			
Total organic carbon	g/m^3	Y		Y	
Zinc***	g/m^3	Y		Y	
Organic screen					
Total phenols	g/m^3	Y		Y	
Volatile acids	g/m^3	Y		Y	
Volatile organic compounds	g/m^3	Y			Y
Semi-volatile organic compounds	g/m^3	Y			Y

* This parameter list also applies for contingency monitoring.
** Only where samples are not pre-filtered.
*** Screen for significance.

Source: CAE *Landfill Guidelines*

Appendix G: Landfill Gas Controls and Emission Model

Gas should not be allowed to escape from a closed landfill in an uncontrolled manner, unless the volume of LFG being generated in the landfill is so small or there is an adequate buffer distance (taking into account topography and possible conduits) and there is no potential for any health, safety or environmental effects. At all but the largest closed landfills, passive venting of LFG is sufficient to manage LFG so that it does not migrate offsite in an uncontrolled manner. There are a number of control methods available to intercept or collect and vent LFG, and the selection of an appropriate method from those discussed below will depend on site-specific factors.

Gas barriers

Gas barriers are used to prevent the offsite migration of LFG through the sides of the landfill. However, they do not specifically provide for the venting of gas and are generally not recommended as the sole means of control for closed sites.

Gas barriers generally comprise a trench dug just outside the waste, which is then filled with a low permeability slurry or a synthetic liner. Trenches are generally only suitable for shallow sites (maximum waste depths of 5 m or less). Grout curtains have also been used as gas barriers. These are generally constructed by drilling boreholes close together along a line (typically 1 m centres) and backfilling them with a cement slurry under pressure to form a curtain.

The use of gas barriers is limited by the depth of trench that can be dug and the fact that barriers cannot be constructed beneath the waste.

Permeable trenches

Permeable trench-venting systems are constructed around the perimeter of a closed landfill and combine an impermeable barrier with passive venting of the intercepted gas.

Trenches are dug about 1 m wide at the edge of the waste. The outside edge of the trench (furthest from the waste) is lined with a low permeability clay or synthetic material. Perforated or slotted collection pipes made from a suitable material (HDPE, MDPE, polypropylene or uPVC) are installed in the trench and connected to surface vent pipes of similar construction. The vent pipe spacing should generally be not more than 50 m. The trench is backfilled with uniformly sized crushed aggregate (containing no fines) and capped to prevent surface water ingress.

Difficulties in using permeable trenches include:

- wind-blown waste or fines can block or partially block trenches, reducing gas flow
- the trench can form a drain for surface water or leachate into the base of the site.

These trenches are only suitable for shallow sites where waste depths are no more than 8 m.

Gas wells

Gas wells are constructed by drilling into the refuse and installing slotted or perforated pipe made of suitable material (HDPE, MDPE, polypropylene or uPVC) surrounded by uniform-sized crushed aggregate (containing no fines). The collection pipes are connected to a vent, which is sealed at the surface with bentonite clay or similar material.

The wells should generally be constructed about 10 to 15 m in from the edge of the waste and not more than 20 m apart.

The main advantages of gas wells are that:

- gas is collected from waste at all levels
- they retain their integrity better than trenches
- they are more readily sealed from rainwater ingress than trenches
- they can be installed at closed landfill sites where the waste is relatively deep.

Landfill gas emission model

The rate of LFG generation can be estimated for a landfill using a theoretical model. There are a number of different models available, and the predictions from different models will vary widely. The model most commonly used in New Zealand is the United States Environmental Protection Agency (US EPA) Landfill Gas Emissions Model (LandGEM). This model calculates average methane generation rates using a first-order decay rate equation, and these are converted to total LFG using the average methane concentration (typically 50%).

LandGEM assumes that the gas generation rate:

- is at its highest per unit of waste on initial placement of the waste
- is at its peak for the total quantity of waste at the time of landfill closure (assuming constant annual refuse acceptance)
- decreases exponentially over time following closure of the landfill.

The first-order decay equation that is the basis of LandGEM is as follows:

$$Q_{Methane} = L_0R(e^{-kc} - e^{-kt})$$

where:

$Q_{Methane}$	=	methane generation rate at time t (cubic metres per year)
L_0	=	the potential methane capacity of the refuse (cubic metres per tonne of refuse)
R	=	average annual refuse acceptance rate during the active life (tonnes per year)
k	=	the methane generation rate constant (1/year)
c	=	time since closure (c = 0 when the landfill is active) (years)
t	=	time since initial refuse placement (years).

In the case of a closed landfill, it will be necessary to make reasonable estimates for some of these values. A sensitivity analysis is recommended so that the model predictions are presented as an expected range, rather than as absolute values.

The selection of appropriate values for the first-order decay equation variables L_o and k are discussed in more detail below.

Potential methane capacity (L_0)

The potential methane generation capacity of the refuse(L_o) depends only on the nature of the refuse. It can be calculated stoichiometrically from the organic carbon content of the refuse (the higher the cellulose content, the higher the methane generation capacity). The values for theoretical and measured L_o range from 6.2 to 270 m^3/tonne. The default values of L_o used in the LandGEM model are 170 m^3/tonne for the Clean Air Act (CAA) default option and 100 m^3/tonne for the AP42 default option.

Typical values of L_o used in New Zealand range from 100 to 230 m^3/tonne. A value at the higher end of the range (170–230 m^3/tonne) would generally be recommended to provide a conservative estimate for a landfill containing a relatively large proportion of green waste and paper (as would be expected for an old landfill in New Zealand).

Methane generation rate constant (k)

The methane generation rate constant (k) describes how quickly the waste decomposes in the landfill. The higher the value of k, the faster the methane generation rate increases and then decays over time. The value of k is a function of (see Section 3.4.1):

- refuse moisture content
- availability of nutrients for methanogens
- pH
- temperature.

The US EPA has reported theoretical and measured k values ranging from 0.003 to 0.21/year. The default values recommended in the LandGEM model are 0.05/year (the CAA default), or 0.04/year (the AP42 default for areas receiving 25 inches (635 mm) or more of rain per year).

Typical values for k used in New Zealand range from 0.036 to 0.15/year. Values towards the higher end of the range would be recommended for very wet landfills (high rainfall areas and poor landfill cover). However, this will have the effect of predicting a very rapid decrease in LFG generation, and a value of k = 0.05/year would provide a more conservative estimate.

Example

A LandGEM simulation has been conducted for a landfill that operated between 1970 and 1985, accepting approximately 1000 tonnes per year of domestic refuse. The model has been run using a range of reasonable values for L_0 and k, to represent different refuse methane potential and site conditions. The methane content of the landfill gas is assumed to be 50%.

Scenario 1: Average refuse methane potential, average decomposition rate

Scenario 2: High refuse methane potential, average decomposition rate

Scenario 3: Average refuse methane potential, fast decomposition rate

Year	Landfill gas generation rate (m3/day)		
	Scenario 1	**Scenario 2**	**Scenario 3**
Landfill closure (1985)	500	680	900
1990	390	530	425
2000	235	320	95
2010	145	195	21
2020	88	118	5

Appendix H: Financial Assurance

Owners or operators of all landfill facilities must demonstrate at the consenting stage that they have sufficient funds to cover the costs associated with closure, post-closure, and corrective action/remediation measures. Financial mechanisms to pay for potential corrective action, should it be determined that a facility poses a threat to the environment or human health, must also be presented at the consenting stage. The cost estimates associated with these requirements must be prepared based on the assumption that a third party will implement the activities.

The following financial assurance mechanisms may be appropriate sources for the required funding.

- **Funds**: held by a reputable third party or trustee until the funds are needed. Payments are made annually into the trust fund. The initial payment must be made before waste acceptance or before the effective dates for closure and post-closure as specified in the facility's resource consent conditions.
- **Surety bonds**: issued by private firms, which typically require full collateral for the bond, excluding the landfill. A payment or performance surety bond is acceptable for closure and post-closure financial assurance. However, only performance bonds should be acceptable for corrective action. If the surety bond is the main source of financial assurance, then a standby trust fund must also be set up. The bond must be made effective before waste acceptance or before the effective dates for closure and post-closure as specified in the facility's resource consent conditions.
- **Letter of credit**: which must be good for at least one year and irrevocable. The letter of credit must be re-issued at the end of each term. It must also be made effective before waste acceptance or before the effective dates for closure and post-closure as specified in the facility's resource consent conditions.
- **Insurance**: an insurance policy must be issued for face value in the amount of at least the current cost estimate of closure and post-closure. The policy must include a provision to provide the assured funds to a third party, if necessary. The policy must be made effective before waste acceptance or before the effective dates for closure and post-closure as specified in the facility's resource consent conditions.
- **Corporate or Local Government financial tests and guarantees**: criteria for financial assurance for corporate and government tests and guarantees will be set by central government and/or appropriate regulatory or statutory authorities.
- **Combination of the previously mentioned sources**: any combination of the above-mentioned mechanisms or any other mechanism may be used, as long as they are determined to be independent of each other and acceptable to the appropriate regulatory/ statutory authority.

The financial requirements for landfills in the United States and Australia are given below for comparison.

United States

In the United States, municipal solid waste landfills (MSWL) are regulated under Subtitle D of the Resource Conservation and Recovery Act (RCRA). The municipal solid waste landfill facility criteria are described in Part 258 of Chapter 40 of the Code of Federal Regulations (40 CFR Part 258). Financial Assurance criteria for MSWLs are described in Sub-part G of Part 258.

The following is a brief summary of Subpart G: Financial Assurance Criteria. It has been extracted from Subpart G of Part 258.

> *The Part 258, Subpart G, financial assurance criteria require demonstration of responsibility of the costs of closure, post-closure care, and known corrective action. EPA (United States Environmental Protection Agency) believes that compliance with these requirements will help ensure responsible planning for future costs. Adequate funds must be available to hire a third party to carry out all necessary closure, post-closure care, and known corrective action activities in the event that the owner and operator declare bankruptcy or lacks the technical expertise to complete the required activities.*
>
> *COST ESTIMATES*
>
> *The amount of financial assurance, using acceptable financial mechanisms, must equal the cost of a third party conducting these activities. To determine these costs each MSWLF owner and operator must prepare a written, site-specific estimate of the costs of conducting closure/post-closure care and known corrective action.*
>
> *Closure*
>
> *The owner and operator must calculate a detailed cost estimate for closure based on the largest area of a MSWLF unit that may ever require a final cover during its active life. The cost estimate must equal the expense of closing the area when the extent and manner of operation would make closure most expensive.*
>
> *... the owner and operator must increase both the closure cost estimate and the amount of financial assurance maintained if the closure plan is adjusted or if changing unit conditions (e.g. increases in design capacity) raise the maximum cost of closure. The closure cost estimate and the amount of financial assurance maintained may also be reduced if, as a result of changes in facility conditions (e.g. partial closure of a landfill), the existing cost estimate exceeds the maximum cost of closure during the remaining life of the MSWLF unit. The owner and operator must document evidence supporting such a reduction.*
>
> *Post-Closure Care*
>
> *The financial assurance requirements for post-closure are similar to the requirements for closure of MSWLF units. The owner and operator must have a detailed, site-specific written estimate of the cost of hiring a third party to conduct post-closure care for the MSWLF unit. This cost estimate must account for the total costs of conducting post-closure care, including annual and periodic costs described in the post-closure plan. Post-closure care cost estimates must be based on the most expensive costs during the post-closure care period. As with closure cost estimates, changes in facility conditions or the post-closure plan may require the owner and operator to modify the post-closure care cost estimate and the amount of financial assurance.*

Corrective Action

... the owner and operator of a MSWLF unit required to undertake corrective action must have a detailed, site-specific written estimate of the cost of hiring a third party to perform corrective action for known releases. The corrective action cost estimate must account for the total expense of activities described in the corrective action plan. Again, the corrective action cost estimate and amount of financial assurance must increase or decrease in response to changes in either the corrective action program or MSWLF unit conditions.

Adjustments for Inflation

Due to changes in inflation and interest rates, cost estimates must be annually adjusted for inflation. Updated cost estimates must account for added inflationary costs to ensure that adequate funds will be available if needed ...

Allowable Mechanisms

The mechanisms used to demonstrate financial assurance must ensure that the funds necessary to meet the costs of closure, post-closure care, and known corrective action will be available when needed. Owners and operators may use any of the following financial mechanisms:

- *Trust fund*
- *Surety bonds guaranteeing payment or performance*
- *Letter of credit*
- *Insurance*
- *Corporate financial test*
- *Local government financial test*
- *Corporate guarantee*
- *Local government guarantee*
- *State-approved mechanism*
- *State assumption of financial responsibility.*

In addition, the Agency expects to add financial tests and guarantees as allowable mechanisms for corporations to demonstrate financial assurance. The performance standard requires that any approved financial assurance mechanism satisfy the following criteria:

- *The amount of funds assured is sufficient to cover the costs of closure, post-closure care, and corrective action for known releases when needed*
- *The funds will be available in a timely fashion when needed*
- *The mechanisms for closure and post-closure care must be established by the owner and operator by the effective date of these requirements or prior to the initial receipt of solid waste, whichever is later. The mechanisms for corrective action must be secured no later than 120 days after the corrective action remedy has been selected, and maintained until the owner and operator are released from financial assurance responsibilities*
- *The mechanisms must be legally valid, binding, and enforceable under state and federal law.*

Two further financial assurance mechanisms, in addition to those listed above, are available (effective 9 April 1997) for local government owners and operators of MSWL facilities. These additional mechanisms – a financial test for use by local government owners and operators, and a provision for local governments that wish to guarantee the costs for an owner or operator – are designed to be self-implementing.

Effective 10 April 1998, two mechanisms were added to those currently available to corporate owners and operators of MSWL facilities. The two mechanisms are a financial test for use by private owners and operators, and a corporate guarantee that allows companies to guarantee the costs for another owner or operator.

Australia

The following has been extracted from the New South Wales Environmental Protection Authority *Environmental Guidelines: Solid Waste Landfills* (NSW EPA, 1996):

> *Financial assurance is a means of ensuring that landfill occupiers adequately plan for emergency closure, site remediation and post-closure care, by providing a specific mechanism to accumulate requisite funding during the life of the landfill. This mechanism encourages development of the necessary long-term financial planning to protect all environmental objectives.*
>
> - *The Landfill Environmental Management Plan (LEMP) should include a well-documented assessment of the potential cost, prepared by an independent consultant, for a third party contractor to undertake each of the following:*
>   - *close down the current operation at anytime and remediate the site to a standard acceptable for its planned future use*
>   - *continue post-closure care and monitoring (bearing in mind that the period of after-care is significantly influenced by the design philosophy)*
>   - *complete the required remediation of environmental impacts that may be identified.*
> - *The financial assurance required by the Environment Protection Authority (EPA) will be negotiated in one or more of the following forms:*
>   - *an insurance policy*
>   - *a bank guarantee of funds or letter of credit*
>   - *a bond*
>   - *a third party guarantee*
>   - *a fund established and maintained by a public authority*
>   - *any other form of security that the EPA considers appropriate and specifies in the licence as a condition.*
>
>   *The preferred approach must be nominated in the LEMP.*
> - *The annual report for a landfill ... may nominate any variations for the level at which the financial guarantee is set for the forthcoming years' activity for a particular site based on the current operations and the extent of site activity planned. The nominated variations must be approved by the EPA.*

- *A financial assurance (or any part of it) may be called on by the EPA if the EPA:*
  - *is satisfied that the last licensee has failed to comply with the requirements of the closure plan approved by the EPA, or*
  - *is satisfied that a licensee has contravened any condition of the licence relating to site remediation work, or*
  - *incurs or proposes to incur costs or expenses in taking action that is covered by financial assurance.*
- *The requirement to provide a financial assurance lapses and no longer binds the person who was required to provide it if the EPA is satisfied:*
  - *that the site remediation work has been completed in accordance with a post-closure plan approved by the EPA (as detailed in 29. Closure of Landfill), and*
  - *that further environmental management of the premises is not required.*

  The person may provide the EPA with a certified statement of completion to the effect that site remediation work has been completed and the further environmental management of the premises is not required. If the EPA approves the statement, the requirement for provision of the financial assurance lapses.

Glossary

Acceptable leakage rate	A designed leakage rate for leachate migration through an engineered landfill lining system based on quantitative assessment of environmental risk.
Acetogenic phase	The initial period during the decomposition of refuse in a landfill when the conversion of organic polymers, such as cellulose, to simple compounds, such as acetic and other short-chain fatty acids, dominates and little or no methanogenic activity takes place.
Aftercare Management Plan	A plan outlining the aspects to be managed and describing the methods for that management, which is applicable to a landfill after it has been closed. It may be part of a Landfill Management Plan.
Analyte	A specific compound or element of interest undergoing chemical analysis.
Aquifer	A geological formation or layer of rock or soil that is able to hold or transmit water. A confined aquifer is where an upper layer of low permeability confines groundwater in the aquifer under greater than atmospheric pressure. An unconfined aquifer is where the upper surface of a saturated zone forms a water table within the water-bearing stratum.
Aquitard	A geologic stratum or formation of low permeability that impedes the flow of water between two aquifers.
Attenuation	A decrease in contaminant concentration through biological, chemical and physical processes, individually or in combination (e.g. dilution, absorption, adsorption, precipitation, ion-exchange, biodegradation, oxidation, reduction).
Baseline	Measurements that characterise physical, chemical or other distinctive properties of groundwater and surface water unaffected by leachate contamination.
BOD	Biological oxygen demand.
Borehole	A hole sunk into the ground by drilling for abstraction of water or for observation purposes. A borehole may be lined with suitable casing and screened at appropriate depths.
Borehole development	The process of cleaning out a borehole following its construction in order to remove fine material within and immediately around the screened section of the borehole.
Catchment	The area from which water drains to a specified point (e.g. to a reservoir, river, lake, borehole).
Cleanfill	A cleanfill is any landfill that accepts only cleanfill material and inert wastes.

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 and 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 • contaminated soil and other contaminated materials.
Closed landfill	Any landfill that no longer accepts waste for disposal.
COD	Chemical oxygen demand.
Contaminant	Any substance (including gases, liquids, solids, and micro-organisms) or energy (excluding noise) or heat, that either by itself or in combination with the same, similar, or other substance, energy or heat: • when discharged into water, changes or is likely to change, the physical, chemical or biological condition of water; or • when discharged onto or into land or into air, changes or is likely to change, the physical, chemical or biological condition of the land or air onto or into which it is discharged.
Contaminated site	A site at which (not naturally occurring) hazardous substances are present in concentrations above background levels and in a state such that they may pose or may be likely to pose an immediate or long-term hazard to human health or the environment.
Diffusion	Migration of dissolved substances within a fluid due to random movement of particles. This can be significant when flows are low.
Down-gradient	In the direction of decreasing water level (in groundwater this is following the *hydraulic gradient*).
Ecotoxic	Capable of causing ill health, injury, or death to any living organism.
Effluent	A liquid waste.
Geologic formation	An assemblage of rocks which have some characteristics in common, whether origin, age or composition. Normally used to refer to an identifiable rock unit within a particular area.
Groundwater	All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.
Groundwater system	A saturated groundwater-bearing formation, or group of formations, which form a hydraulically continuous unit.

Head (hydraulic head)	The sum of the elevation head, the pressure head and the velocity head at a given point in a water system. In practical terms, the height of the surface of a column of water above a specified datum elevation.
Hydraulic conductivity	A coefficient of proportionality describing the rate at which a fluid can move through a medium. The density and kinematic viscosity of the fluid affect the hydraulic conductivity, so that this parameter is dependent on the fluid as well as the medium. Hydraulic conductivity is an expression of the rate of flow of a given fluid through unit area and thickness of the medium, under unit differential pressure at a given temperature. (See also *permeability*.)
Hydraulic gradient	The change in total head (of water) with distance in a given direction. The direction is that which yields a maximum rate of decrease in head.
Hydrogeology	The study of water in rocks (including subsurface-earth).
Hydrology	The study of water at ground surface.
Hydrolysis	The chemical reaction of a compound with water to produce other compounds.
Inert waste	Wastes that when deposited at a landfill under normal conditions do not undergo any significant physical, chemical or biological reactions or cause environmental pollution.
Infiltration	The entry of water, usually as rain or melted snow, into soil or a landfill.
Landfill	A waste-disposal site used for the controlled deposit of solid wastes onto or into land.
Landfill catchment	An area encompassing the up-gradient groundwater and surface water catchment areas containing the landfill site, and the area down-gradient of the site, which could potentially be influenced by leachate discharges from the landfill site.
Landfill footprint area	The area of land in a landfill facility over which the waste is deposited.
Landfill gas	Gas generated as a result of decomposition processes or biodegradable materials deposited in a landfill. It consists principally of methane and carbon dioxide, but includes minor amounts of other components.
LCS	Leachate collection system.
Leachate	Liquid that has percolated through or emerged from solid waste, and that contains dissolved and/or suspended liquids and/or solids and/or gases.
LFG	Landfill gas.
Methanogenic phase	A later stage of anaerobic decomposition of refuse, when methane is produced in significant quantities.
Mixing depth	The depth of groundwater into which leachate escaping from a landfill site is mixed. Used for dilution calculations.

Monitoring	A continuous or regular periodic check to determine the ongoing nature of the potential hazard, conditions along environmental pathways and the environmental impacts of landfill operations to ensure that the landfill is performing according to design. The general definition of monitoring includes measurements undertaken for compliance purposes and those undertaken to assess landfill performance.
Monitoring well	A borehole, suitably lined and screened, used for monitoring leachate within a landfill, or groundwater around a landfill.
MSW	Municipal solid waste.
Natural attenuation	Natural processes that reduce the concentration of contaminants in groundwater.
NMOC	Non-methane organic compound.
Organochlorine	An organic compound with one or more chlorine atoms in its molecules.
Pathway	The route by which contaminants are transported between their source and a receptor.
Permeability	A measure of the rate at which a fluid will move through a medium. The permeability of a medium is independent of the properties of the fluid.
Phreatic zone	See *Saturated zone*.
Piezometer	An instrument for measuring hydraulic pressure. The term is commonly applied to a lined borehole of any diameter in which a short screened or porous section, or pressure-measuring device, is isolated by annular seals in order to allow water level measurement and sampling from a specific vertical interval.
Plume	An ellipsoidal volume of water containing elevated levels of contaminants, emanating from a point or line source of those contaminants.
Purging	The process of removing water that is unrepresentative of the surrounding strata or waste from a borehole, prior to sampling.
Receptor	A resource (including humans) that may be affected by a contaminant, via a pathway.
Remediation	The process of improving the quality of a polluted body of water or an area of land, by managing the contaminant source and/or by treatment of the affected water or land.
Risk	A quantitative or qualitative combination of the probability of a defined hazard causing an adverse consequence at a receptor, and the magnitude of that consequence.
Risk assessment	The process of identifying and quantifying a risk and assessing the significance of that risk in relation to other risks.

Risk-based monitoring review	A review document using the results of site investigation and risk assessment to rationalise monitoring priorities for a landfill.
Run-off	Rain or melted snow that drains from the land surface.
Saturated zone (phreatic zone)	The zone in which the voids of the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined groundwater system. In general, flow is horizontal and typically faster than for unsaturated zone flow. Flow rates between different types of strata vary over several orders of magnitude.
Sensitive location	Recognised wildlife habitat, significant wetland or area of native bush, inter-tidal area, close proximity to groundwater or surface water, close proximity to residences, national/regional and local park or reserve (historic or scenic or recreational), site of historical or cultural significance.
Site monitoring plan	A reference document detailing the design, management and implementation of a monitoring programme for a landfill.
Surface water	Any accumulation of water on the ground surface, including puddles, ponds, lakes, wetlands, drains, ditches, springs, seepages, streams and rivers.
SVOC	Semi-volatile organic compound
TOC	Total organic carbon.
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; chronic toxicity means the effects that occur either after prolonged exposure or an extended period after initial exposure.
TPH	Total petroleum hydrocarbons.
Tradewaste effluent	Liquid waste discharged to a reticulated sewer/waste system under the control of a trade waste consent.
Transpiration	The transfer of water from soil to atmosphere by plants.
Upgradient	In the direction of increasing hydraulic head (in groundwater this is moving up the hydraulic gradient).
Unsaturated zone (vadose zone)	The zone between the land surface and the water table. The pore space contains water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched groundwater may exist in the unsaturated zone. Also called the vadose zone. Overall flow is downward (gravity driven); moisture content is low and water normally flows slowly in close contact with the rock matrix.
Vadose zone	See *Unsaturated zone*.
VOC	Volatile organic compound.

Waste	Any material, whether it is liquid, solid or a contained gas, that is unwanted and unvalued and discarded or discharged by its holder.
Waste Management Plan	A plan making provision for the collection and reduction, reuse, recycling, recovery, treatment or disposal of waste in the district. The plan must also provide for its effective implementation, or for activities considered appropriate for that purpose to be undertaken by, or under contract to, the territorial authority.
Water balance	An evaluation of all the sources of supply, storage and corresponding discharges of water, e.g. within a landfill site or an entire surface water catchment area.
Water body	A continuous mass of water with similar characteristics, which can be represented on a map or plan. For example, groundwater within a specific stratum, water in a lake, water in a stream course, leachate in a landfill cell.

About the Ministry for the Environment Manatū Mō Te Taiao

Making a difference through environmental leadership.

The Ministry for the Environment Manatū Mō Te Taiao advises the Government on policies, laws, regulations, and other means of improving environmental management in New Zealand. The significant areas of policy for which the Ministry is responsible are: management of natural resources; sustainable land management; air and water quality; management of hazardous substances, waste and contaminated sites; protection of the ozone layer; and responding to the threat of climate change. Advice is also provided on the environmental implications of other Government policies.

The Ministry monitors the state of the New Zealand environment and the operation of environmental legislation so that it can advise the Government on action necessary to protect the environment or improve environmental management.

The Ministry carries out many of the statutory functions of the Minister for the Environment under the Resource Management Act 1991. It also monitors the work of the Environmental Risk Management Authority on behalf of the Minister.

Besides the Environment Act 1986 under which it was set up, the Ministry is responsible for administering the Soil Conservation and Rivers Control Act 1941, the Resource Management Act 1991, the Ozone Layer Protection Act 1996 and the Hazardous Substances and New Organisms Act 1996.

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