F I N A L   R E P O R T

Basis for Landfill Classification System

Prepared for

Ministry for the Environment

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Introduction

This report has been prepared, by URS New Zealand, to provide the basis for the development of a nationally consistent landfill classification methodology. It is intended to provide technical background information and discuss implementation options for the Ministry for the Environment's (MfE) preferred option for the landfilling of wastes with hazardous properties.

The MfE preferred option involves a distinction between two classes of landfill (Class A and Class B) based on degree of environmental protection. Each class of landfill would have a different prescriptive list of waste acceptance criteria (WAC), with the Class B landfill WAC more stringent than that for Class A landfills. WAC may be a combination of concentration and mass thresholds, and leachability criteria.

Actual classification criteria for the different landfill classes (A and B) and specific waste acceptance criteria for the different classes of landfill are not determined at this stage, but a recommendation on a preferred classification methodology is made.

The classification methodology is not intended to be used to set standards for landfill siting, design or operations, but rather to define those landfills with the appropriate level of environmental protection, through siting, design and operational characteristics, for the different waste acceptance criteria.

Issues Associated With Landfill Classification

There are essentially three general types of landfill classification system:

- prescriptive;
- performance; and
- effects/risk based.

A prescriptive landfill classification system sets out requirements for siting, design and operations that must be met. These are generally set at a level to ensure that adverse environmental effects will be avoided in the majority of situations.

A performance based landfill classification system sets out criteria that must be met with respect to performance of the landfill at a specified compliance point or points.

An effects/risk based landfill classification system sets out criteria with respect to the receiving environment that must not be exceeded.

In practice classification systems are not exclusively prescriptive, performance or effects/risk based, but can use a combination of requirements and criteria.

The following technical issues, relevant to consideration of landfill classification systems, are discussed:

- contaminant transport in sub-surface materials;
- containment using engineered liner systems

- contaminant transport in surface water;
- contaminant transport via air discharges.

A number of different engineered liner systems and underlying geologies were modeled in order to compare differences between various site and engineered liner systems a number of landfill scenarios were modeled.

The results indicate the differences in contaminant concentrations at a downgradient compliance point for different leachate heads, liners and site geologies. They demonstrate the importance of a landfill site's underlying geology to the long term containment of contaminants. In addition, the design of the landfill liner and an effective leachate collection system can significantly reduce potential leakage, at least in the short term.

Siting, design and operational factors all need to be considered in developing a classification system. These factors were ascribed a ranking, which relates to the degree of certainty they afford in respect of long term environmental protection.

Of all the factors, geology and hydrogeology were given the highest ranking as they provide the basis for long term leachate containment and cannot be altered once a landfill is constructed. This indicates that siting is fundamental to any landfill classification system. Some designed components can be altered, retrofitted, or upgraded, at existing landfills and all can be altered or upgraded for lateral expansions of an existing landfill. Operational factors were given the lowest ranking as they can change, or be upgraded, at any landfill to improve environmental outcomes.

Review of Classification Systems and Methodologies

Existing international and New Zealand landfill classification systems were outlined.

There have recently been two classification systems published, by international environmental organisations, to provide general categories into which landfills can be classified in respect of the degree of environmental protection they offer. They are:

- UNEP General Landfill Categories; and
- ISWA International Guidelines for Landfill Evaluation.

Two different landfill classifications have been developed in New Zealand to assist in the setting of landfill waste acceptance criteria for specific waste types. These are:

- Health and Environmental Guidelines for Selected Timber Treatment Sites, which contains a landfill classification; and
- Effects Based Landfill Classification for Hydrocarbon Contaminated Waste Disposal.

Landfill classifications and criteria from the following countries were reviewed and summarised:

- South Africa;

- Australia (New South Wales);
- United States of America;
- Germany.

These classifications are associated with standards for landfill development. In general, all provide for a class of landfill accepting municipal solid waste (MSW) and another class with more stringent requirements for hazardous or industrial wastes.

Waste acceptance criteria for the different classes of landfill are either prescribed, or calculated by a set formula.

Assessment of Classification Systems

The different classification systems (prescriptive, performance and effects/risk based) were assessed and the advantages and disadvantages of each outlined.

A classification system using a combination of prescriptive, performance and effects/risk based criteria for different elements was discussed.

A classification methodology that would use prescriptive, performance based and effects/risk based classification systems progressively, in a tiered manner was also discussed.

Recommended Classification Methodology

A tiered methodology is recommended for classifying landfills in New Zealand.

This methodology would use prescriptive, performance based and effects/risk based classification systems progressively, in a tiered manner. Prescriptive requirements would be used to filter out those elements of siting, design and operations that require further analysis, using performance and effects/risk based criteria, to determine their classification.

The methodology would require the development of appropriate prescriptive, performance based and effects/risk based New Zealand criteria for siting, design and operations for Class A landfills.

There are a number of options for agencies, or bodies that could carry out landfill classifications. These include:

- regional councils;
- Ministry for the Environment, or central classification authority;
- accredited organisations or individuals.

1.1 Background

The Ministry for the Environment (MfE) is currently considering options for the implementation of nationally consistent landfill waste acceptance criteria (LWAC), to reduce the risk of releasing hazardous constituents into the environment via landfill discharges.

In its issues and options report "Landfill Acceptance Criteria for Wastes with Hazardous Properties", dated April 2001, the Ministry for the Environment identified a preferred option for developing waste acceptance criteria. The preferred option (Option B) proposes the following:

> "distinction between two classes of landfill (Class A and Class B) based on standards of environmental protection, with each class using a different prescriptive list to determine what wastes are suitable for disposal."

The MfE report refers to Class A landfills as being landfills that comply with site selection and design recommendations outlined in the CAE Landfill Guidelines (2000). Class B landfills are described as waste disposal facilities not meeting site selection and design recommendations outlined in the CAE Landfill Guidelines (2000).

The prescriptive lists that would comprise the waste acceptance criteria could be combinations of concentration and mass thresholds and leachability criteria.

1.2 Purpose of this Report

This report has been prepared, by URS New Zealand, to provide the basis for the development of a nationally consistent landfill classification methodology. It is intended to:

- to provide technical background information and discuss implementation options for the Ministry for the Environment's preferred option of a landfill classification system;
- outline the extent to which landfill design, siting criteria and operational management procedures should be considered during the development of a landfill classification system;
- recommend a classification methodology, or methodologies, that is robust, transparent, flexible (to allow for alternative designs and developments in technology) and able to be implemented for existing and proposed new landfills.

Actual classification criteria for the different landfill classes (A and B) and specific waste acceptance criteria for the different classes of landfill are not determined at this stage, but a recommendation is made as to a preferred classification methodology.

A copy of the project brief is attached as Appendix A

1.3 Assumptions

The following assumptions have been made with respect to this report:

- There will be two landfill classes, A and B. Class A landfills are those sited, designed and operated in accordance with the recommendations in the CAE Landfill Guidelines (2000). Class B landfills are those developed to a lesser standard;
- actual classification criteria for the different landfill classes (A and B) will not be determined at this stage, but a recommendation will be made as to a preferred classification methodology;
- waste acceptance criteria will be set for the different classes of landfill. However, specific waste acceptance limits for different contaminants will not be determined at this stage, but through a separate process;
- the classification methodology will relate to existing operating landfills and proposed new landfills, but not closed landfills;
- the classification methodology will relate only to landfills intended to accept municipal solid waste (MSW) and not cleanfills, construction and demolition (C & D) waste landfills or industrial waste landfills or monofills;
- the classification methodology is not intended to be used to set standards for landfill siting, design or operations, but rather to define those landfills with the appropriate siting, design and operational characteristics for different waste acceptance criteria;
- the classification methodology must use effects on the environment as the bottom line approach to classification, consistent with the Resource Management Act 1991.

It should be noted that because C & D waste landfills and most industrial waste landfills accept specific waste types (for example C & D waste, wood processing wastes, steel processing wastes) they need to be considered and evaluated on a waste and site specific basis. Therefore, it is not appropriate to include these types of landfills when considering issues associated with landfill classification.

1.4 Report Layout

This report is set out in the following sections:

- Issues Associated with Landfill Classification, which describes the types of landfill classification systems, technical considerations, modeling of landfill siting and design examples, the relative importance of landfill siting, design and operations and the CAE Landfill Guidelines (2000);
- Review of Classification Systems and Methodologies, which outlines international landfill classifications, previous New Zealand landfill classifications and landfill classifications in selected overseas countries;

- Assessment of Classification Systems, which discusses the various approaches to classification and models some hypothetical landfill examples;
- Recommended Classification Methodology, which discusses a recommended approach to classification.

2.1 Landfill Classification Systems

In its issues and options report "Landfill Acceptance Criteria for Wastes with Hazardous Properties", dated April 2001, the Ministry for the Environment describes a landfill classification system as follows:

> "A landfill classification system divides landfills into different groupings or classes. Landfills can be classified for a number of reasons (e.g. to prioritise environmental risk), therefore the basis for the division may be one or more of many factors e.g. prioritising environmental risk, size, location, age, extent of environmental protection systems etc."

2.2 Types of Classification System

Classification systems are generally used to either:

- evaluate and classify existing landfills; or
- stipulate siting, design and/or operational standards for new landfills in respect of the types of waste they can accept.

A classification system can provide a highly detailed set of requirements, or more generalised descriptions, depending on their intended use. A system used as the basis for standards or regulations for waste acceptance needs to be specific, detailed and robust. A system used in classifying existing landfills for information purposes may be less specific and detailed.

There are essentially three general types of landfill classification system:

- prescriptive;
- performance; and
- effects/risk based.

These systems are described in more detail below, and represented diagrammatically in Figure 2.1.

2.2.1 Prescriptive

A prescriptive landfill classification system sets out requirements for siting, design and operations that must be met. These are generally set at a level to ensure that adverse environmental effects will be avoided in the majority of situations.

Prescriptive requirements can be set for the following:

- landfill siting (for example, exclusions based on geology, hydrogeology, surface hydrology, stability);

- landfill design (for example base liner components, specifications, or leakage rate, leachate head restriction, cover requirements, landfill gas collection system requirements);
- landfill operations (waste acceptance and burial procedures, surface water management, monitoring)

An example of a prescriptive requirement for liner design is the USEPA CFR 40 part 258 criteria for liner performance for municipal solid waste landfills, which states:

"(a) New MSWLF units and lateral expansions shall be constructed:

(2) With a composite liner, as defined in paragraph (b) of this section,

(b) For the purposes of this section, composite liner means a system consisting of two components; the upper component must consist of a minimum 30-mil (1.5 millimetre) flexible membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 1.5 millimetres thick. The FML component must be installed in direct and uniform contact with the compacted soil component."

2.2.2 Performance Based

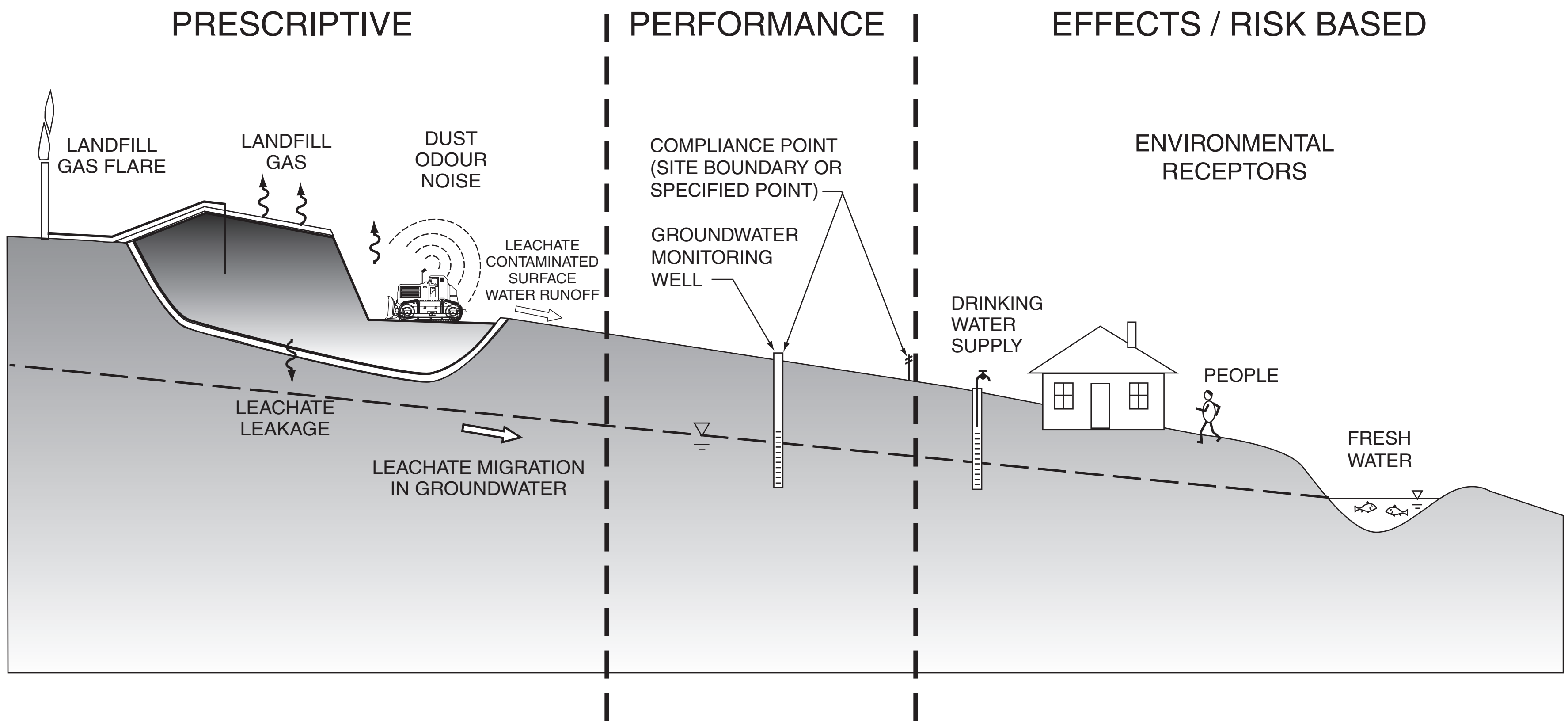
A performance based landfill classification system sets out criteria that must be met with respect to performance of the landfill at a specified compliance point or points.

With respect to leachate containment, a performance requirement can be a maximum rate of leachate leakage through an engineered liner. However, this does not take account of the containment and attenuation characteristics of underlying materials at a geologically favourable site, or lack of these characteristics at an unfavourable site.

Alternatively, a performance requirement can specify maximum concentrations of contaminants in groundwater at the site boundary, or a specified, arbitrary, distance from the edge of the landfill footprint within the boundary. Such maximum concentration limits are generally set at the detection limit of contaminants or a concentration at which no adverse environmental effects would be observed.

A performance based system enables classification requirements to be met through a combination of natural site characteristics and engineered base liner systems. Sites with less favourable natural characteristics can use a higher degree of engineered retention to meet performance requirements. Conversely, sites with highly favourable natural characteristics can use less robust or complex engineered liner systems and still meet the performance requirements.

A performance based system requires detailed characterisation of any engineered liner system and the underlying geology and hydrogeology of a site, as well as a comprehensive assessment of performance with respect to the prescribed criteria.



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LANDFILL CLASSIFICATION SYSTEMS
FIGURE 2-1

For consistent implementation standard assumptions, modeling methodologies and/or tools would need to be prescribed for use in assessing the performance of a landfill.

An example of a performance-based requirement for liner design is the USEPA CFR 40 part 258 criteria for liner performance for municipal solid waste landfills, which states:

"(a) New MSWLF units and lateral expansions shall be constructed:

(1) In accordance with a design approved by the Director of an approved State or as specified in Section 258.40(e) for unapproved States. The design must ensure that the concentration values listed in Table 1 [Table 2-1] will not be exceeded in the uppermost aquifer at the relevant point of compliance as specified by the Director of an approved State under paragraph (d) of this section

(c) When approving a design that complies with paragraph (a)(1) of this section, the Director of an approved State shall consider at least the following factors:

(1) The hydrogeologic characteristics of the facility and surrounding land;
(2) The climatic factors of the area; and
(3) The volume and physical and chemical characteristics of the leachate."

2.2.3 Effects/Risk Based

An effects/risk based landfill classification system sets out criteria with respect to the receiving environment that must not be exceeded.

The philosophy behind an effects, or risk, based approach to landfill classification is the use of the potential effects of contaminants on the surrounding receiving environment, to determine the appropriate level of engineered retention and/or other risk management procedures to complement a site's natural containment characteristics.

Environmental risk assessment and risk management involves determination of the following:

- environmental hazards and their properties;
- the ways receptors can be exposed to the hazards and probability and scale of exposure;
- the probability and scale of harm from the hazards;
- the significance of the risk and associated uncertainties;
- means to prevent, manage or minimise the risk.

Table 2-1 - USEPA Maximum Concentration Limits (MCLs)

TABLE 1	
(40 CFR 258.40; 56 FR 51022 October 9, 1991)	
Chemical	**MCL(mg/l)**
Arsenic	0.05
Barium	1.0
Benzene	0.005
Cadmium	0.01
Carbon tetrachloride	0.005
Chromium (hexavalent)	0.05
2,4-Dichlorophenoxy acetic acid	0.1
1,4-Dichlorobenzene	0.075
1,2-Dichloroethane	0.005
1,1-Dichloroethylene	0.007
Endrin	0.0002
Fluoride	4.0
Lindane	0.004
Lead	0.05
Mercury	0.002
Methoxychlor	0.1
Nitrate	10.0
Selenium	0.01
Silver	0.05
Toxaphene	0.005
1,1,1-Trichloroethane	0.2
Trichloroethylene	0.005
2,4,5-Trichlorophenoxy acetic acid	0.01
Vinyl Chloride	0.002

An effects/risk based landfill classification system therefore involves identification of:

- contaminant sources (leachate, landfill gas, dust);
- receptors (groundwater, surface water, air, ecosystems, people);and
- pathways (events or actions at the site which give rise to the release of contaminants into land, water and air).

In general the most sensitive environmental receptor(s) are used in determining risk.

As with a performance based system, an effect/risk based system requires detailed characterisation of any engineered liner system and the underlying geology, hydrogeology and surface hydrology of a site. It also requires a detailed assessment of the surrounding natural and physical environment and assessment of the likely effects and risks. Risks need to be assessed and quantified.

It is important that any assessment of effects on, or risk to, the environment be undertaken in a robust, systematic and transparent manner. For consistent implementation, modeling and assessment methodologies and/or tools would need to be prescribed for assessing effects/risks at a specific landfill site. The level of information and complexity of modeling required would, generally, be greater, and, therefore, more costly, than that for a performance based system.

2.2.4 Combinations of Different Systems

In practice classification systems are not exclusively prescriptive, performance or effects/risk based. Classification systems can use a combination of prescriptive, performance and effects/risk based requirements in the following ways:

- minimum prescriptive requirements can be specified in combination with performance or effects/risk based requirements to ensure an appropriate degree of redundancy. For example:
  - a minimum list of siting restrictions;
  - a minimum base liner requirement, like the use of an FML liner or minimum 300 millimetres minimum depth of compacted clay/soils;
- minimum performance or effects/risk based requirements can be specified with respect to landfill siting and liner design in combination with prescriptive requirements for other elements of design and site operations;
- requirements can be specified for all three systems and then used progressively, in a tiered manner.

2.3 Technical Considerations

The following technical issues are relevant to consideration of landfill classification systems:

- contaminant transport in sub-surface materials (determined through the landfill siting process);
- containment using engineered liner systems (determined during the landfill design process);
- contaminant transport in surface water (determined by design and landfill operations);
- contaminant transport via air discharges (determined by design and landfill operations).

2.3.1 Contaminant Transport in Sub-surface Materials

The type of sub-surface environment beneath a landfill is determined during the site selection process.

Leachate that escapes from a landfill may migrate through the underlying unsaturated zone and eventually reach the uppermost groundwater aquifer. However, in some cases the water table may be located above the base of the landfill, so that only saturated flow and transport from the landfill unit need to be considered. Once leachate reaches the water table, contaminants may be transported through the saturated zone to a point of discharge (for example a water supply well, a stream, or a lake).

The migration of contaminants in the subsurface depends on factors such as:

- the moisture content of the waste;
- the chemical and physical properties of the leachate constituents;
- the head of leachate on the base liner;
- climate;
- the chemical and physical properties of the subsurface (saturated and unsaturated zones).

A number of physical, chemical, and biological processes may also influence migration. Complex interactions between these processes may result in specific contaminants being transported through the subsurface at different rates. In addition, certain processes result in the attenuation and degradation of contaminants. The degree of attenuation is dependent on the following:

- the time that the contaminant is in contact with the subsurface material;
- the physical and chemical characteristics of the subsurface material;
- the distance that the contaminant has traveled;
- the volume and characteristics of the leachate.

Physical, chemical and biological processes that can control subsurface contaminant transport are outlined below, with physical and chemical processes described in more detail in Appendix B.

Physical Processes Controlling Subsurface Contaminant Transport

Physical processes that control the transport of contaminants in the subsurface include:

- advective flow (porous media and fracture flow);
- mixing and dilution as a result of dispersion and diffusion;
- mechanical filtration;
- physical sorption;
- multi-phase fluid flow.

These processes, in turn, are affected by hydrogeologic characteristics, such as hydraulic conductivity and porosity, and by chemical processes.

Chemical Processes Controlling Subsurface Contaminant Transport

Chemical processes that are important in controlling subsurface transport include:

- precipitation/dissolution;
- chemical sorption;

- redox reactions;
- hydrolysis;
- ion exchange;
- complexation.

In general, the above processes, except for hydrolysis, are reversible. The reversible processes tend to retard transport, but do not permanently remove contaminants from the system.

Biological Processes Controlling Contaminant Transport in the Subsurface

Biodegradation of contaminants may result from the enzyme-catalyzed transformation of organic compounds by microbes. Contaminants can be degraded to harmless byproducts or to more mobile and/or toxic products through one or more of several biological processes.

Biodegradation of a compound depends on environmental factors such as:

- redox potential;
- dissolved oxygen concentration;
- pH;
- temperature;
- presence of other compounds and nutrients;
- salinity;
- depth below land surface;
- competition among different types of organisms;
- concentrations of compounds and organisms.

The transformations that occur in a subsurface system are difficult to predict because of the complexity of the chemical and biological reactions that may occur. Quantitative predictions of the fate of biologically reactive substances are subject to a high degree of uncertainty, in part, because limited information is available on biodegradation rates in soil systems or ground water. First-order decay constants are often used instead.

Landfill operations can introduce bacteria and viruses into the subsurface. The fate and transport of bacteria and viruses in the subsurface is an important consideration in the evaluation of the effects of landfills on human health and the environment. A large number of biological, chemical, and physical processes are known to influence virus and bacterial survival and transport in the subsurface. Unfortunately, knowledge of the processes and the available data are insufficient to develop models that can simulate a wide variety of site-specific conditions.

2.3.2 Containment Using Engineered Liners

The degree of containment afforded by a landfill, in addition to that provided by underlying materials at a landfill site, is determined through the design of an engineered liner system.

At some sites, significant containment and attenuation is provided by the underlying geology. At others, reworking of the underlying materials and/or use of manufactured lining materials is necessary to provide an appropriate degree of environmental protection.

Leachate Leakage through Engineered Liners

The purpose of a liner system is to reduce leachate discharge from a landfill to the minimum practicable amount and enable the collection of leachate. It is universally accepted that any engineered landfill base liner system will not provide total containment, but will allow some leachate leakage. This is due to the permeable nature of any natural compacted clay/soil liner and manufacturing and construction defects in geomembrane liner systems.

An assessment of leakage (the volumetric release of leachate through the base of a liner) should be based on analytical approaches supported by empirical data from existing operating landfills of similar design, if available. In the absence of such data, conservative analytical assumptions should be used to estimate anticipated leakage rates.

An assessment of liner leakage must consider all components of the liner system, which can comprise:

- a geomembrane, or flexible membrane liner (usually HDPE but may also be manufactured from PVC or polypropylene); and/or
- a compacted clay liner; and/or
- a geosynthetic clay liner (GCL).

Geomembrane Liners

The transport of fluids and waste constituents through geomembrane liners differs, in principle, from transport through soil liner materials. Flow through holes and penetrations is the dominant mode of leachate transport through geomembrane liner components. Darcian flow is the dominant mode of leachate transport through soil components.

For geomembrane liners, the most significant factor influencing liner performance is penetration of the liner, including tears, improperly bonded seams or pinholes caused by construction defects in the geomembrane.

Transport through geomembranes where tears, punctures, imperfections, or seam failures are not involved is dominated by molecular diffusion. Diffusion occurs in response to a concentration gradient and is governed by Fick's first law. Diffusion rates in geomembranes are several orders of magnitude lower than comparable hydraulic flow rates in low-permeability soil liners, including compacted clays.

However, construction of a completely impermeable geomembrane is difficult. A small rate of leakage over a large surface area still results in measureable volumes of leachate.

In the absence of an underlying low-permeability soil liner, flow through a defect in a geomembrane is essentially unrestrained. The presence of a low-permeability soil liner beneath a defect in the geomembrane, and intimate contact between the geomenbrane and underlying liner, reduces leakage by limiting the flow rate through the defect.

It is considered that a geomembrane installed with excellent control over defects may yield the equivalent of a one-centimetre diameter hole per 0.4 hectares of liner installed. If the geomembrane were to be placed over sand, this size imperfection under 300 millimetres of constant hydraulic head could be expected to account for as much as 31,000 litres per hectare per day of leakage. Based upon measurements of actual leakage through liners at facilities that have been built under rigorous control an actual leakage rate, under 300 millimetres of constant head, of 200 litres per hectare per day has been estimated by the USEPA, as reported in its Solid Waste Disposal Facility Criteria Technical Manual.

Compacted Clay/Soil Liners

Fluid flow through compacted clay/soil liners can be conservatively estimated by Darcy's Law, where discharge (Q) is proportional to the head loss through the soil (dh/dl) for a given cross-sectional flow area (A) and hydraulic conductivity (K) where $Q = -KA(dh/dl)$.

The thickness of compacted clay/soil liners is important to:

- improve the chemical containment of the liner by reducing the concentration gradient and hence the mass flux of contaminants passing through the liner as a result of diffusion;
- reduce the potential for leakage from holes or penetrations of the liner surface by sharp, or, long, items in refuse;
- provide some attenuation of contaminants during migration through the liner.

Recent monitoring of compacted clay/soil liners at existing landfill sites indicates that, in some cases, they have lower leakage rates, than would be expected, based on Darcy’s law. It has been postulated that lower than expected hydraulic conductivity of some liners is due to clogging of the upper portions of the liner through the build-up of biological media, or “biofilm”. It is thought that the most desirable conditions for the development of biofilms at the liner surface are:

- low liner surface gradient;
- continuous leachate saturation of the liner surface; and
- an unsaturated zone between the between the liner surface and the groundwater table.

However, the development of biological clogging cannot be relied upon, or taken account of when modeling liner performance, for the following reasons:

- biological clogging may not necessarily occur in all cases and cannot be designed for;

- clogging may not be uniform across the base of the landfill;
- the development of biological media cannot be monitored;
- as yet there is insufficient data on which to base quantitative assumptions on its potential contribution to the liner containment system.

Composite Liners

Flow through the soil component of a composite geomembrane/soil liner is controlled by the following:

- the size of the defect in the geomembrane;
- the available air space between the two liners into which leachate can flow;
- the hydraulic conductivity of the soil component;
- the hydraulic head of leachate.

The uniformity of the contact between the geomembrane and the soil liner is extremely important in controlling the effective flow area of leachate through the soil liner. Porous material, such as drainage sand, filter fabric, or other geofabric, should not be placed between the geomembrane and the low permeability soil liner. Porous materials will create a layer of higher hydraulic conductivity, which will increase the amount of leakage below an imperfection in the geomembrane. Construction practices during the installation of the soil and the geomembrane affect the uniformity of the geomembrane/soil interface, and strongly influence the performance of the composite liner system.

A composite liner system is an effective hydraulic barrier because it combines the complementary properties of two different materials into one system.

Geosynthetic Clay Liners

A relatively new product, now being used in liner systems, is the geosynthetic clay liner (GCL). GCLs consist of a layer of pure bentonite clay (between five and ten millimetres thick) backed by one or two geotextiles. GCLs exhibit properties of both soil liners and geomembranes and can be used as a substitute for some of the compacted clay/soil component of a composite liner system. GCLs are believed to transport fluids primarily through diffusion, according to their low hydraulic conductivities (that is, in the order of 1×10^{-11} metres per second reported by manufacturers).

Due to the plastic nature of bentonite when hydrated, GCLs are considered to have significant self-healing properties when torn or punctured. That is, they can provide a seal around a protrusion through the liner and/or provide some sealing of defects or holes in an overlying geomembrane under certain conditions.

Performance of Geomembranes and Geosynthetic Clay Liners

In determining liner performance it is difficult to account for the variations in quality of installations for geomembranes and geosynthetic clay liners. HELP modeling, assuming poor installation quality and lack of intimate contact for geosynthetic liners, indicates minimal reduction in leachate flow relative to a soil liner.

It is also difficult to model contaminant transport through geomembranes or geosynthetic clay liners as:

- they may sustain puncture damage;
- geomembranes do not uniformly limit travel time if damaged;
- resistance to organic solvents is different for different geomembrane materials.
- flow time through a geosynthetic clay liner is controlled by diffusion rather than advection;
- the long term performance of both geomembranes and geosynthetic clay liners with respect to high strength organic solvents has not been fully demonstrated.

Therefore, there is some question as to the long-term reliability and performance of geomembranes and geosynthetic liner components compared to compacted soil/clay liners.

Groundwater Control

In areas where the groundwater table is at the base of the landfill the potential for leachate to migrate to the underlying aquifer can be reduced by the installation of a groundwater under-drainage system. This can serve to:

- relieve upward groundwater pressure, that could otherwise damage liner components; and
- collect leachate migrating through the liner and enable treatment and/or disposal.

Alternative Liner Designs

In some cases it may be appropriate for a classification system to allow for alternative designs in meeting prescriptive or performance based criteria.

Because different liner components and materials have different physical characteristics and dominant modes of contaminant transport, it is important to specify the performance parameters by which equivalence will be judged. Therefore, in addition to hydraulic conductivity, other parameters should also be specified, such as:

- chemical attenuation capacity;
- diffusion rate;
- leachate dispersion characteristics;
- resistance to puncturing.

2.3.3 Contaminant Transport in Surface Water

Leachate can reach surface water bodies in the following ways:

- discharge of leachate or gas contaminated groundwater;
- direct discharge of surface leachate outbreaks;
- discharge of leachate contaminated stormwater.

Discharge of Leachate Contaminated Groundwater

Groundwater, contaminated by constituents of leachate or landfill gas, may migrate from the landfill and discharge to surface water bodies. The time taken for contaminated groundwater to reach surface water and the concentration of contaminants in surface water will depend on a number of factors including:

- distance from the landfill to surface water;
- aquifer characteristics;
- physical, chemical and biological factors controlling subsurface transport of contaminants, as discussed in Section 2.3.1 above.

Where groundwater beneath a landfill is contaminated there are a number of management options available, including:

- natural attenuation (requires modeling and continued monitoring to demonstrate);
- retrofitting of a leachate collection system beneath the base of the landfill;
- groundwater cut-off and collection using a trench or wells;
- groundwater abstraction using vertical or horizontal wells;
- containment (for example, vertical cut-off barriers);
- in-situ leachate treatment technologies (for example, air sparging, injection of chemical reagents and reactive barriers).

Surface Leachate Outbreaks

Leachate outbreaks can occur from the landfills working face, or as a result of perched leachate or improperly installed or maintained areas of intermediate or final cover. These can result in contamination of surface water bodies via:

- overland flow, where no surface/stormwater controls exist;
- contamination of the site stormwater system and subsequent discharge to surface water.

The potential for surface outbreaks to contaminate surface water can be reduced by:

- reducing the potential for perched leachate (preventing barriers to downward leachate flow);
- effective separation of site leachate and stormwater flows;
- appropriate design, construction, maintenance and monitoring of site capping;

Discharge of Leachate Contaminated Stormwater

Contamination of the site stormwater system can result in discharge of contaminants to surface water where the contamination is not detected prior to discharge. This can be avoided through:

- retention of stormwater and monitoring prior to discharge;
- continuous monitoring of discharge(s) and alarm/shut off if contamination is detected;
- regular site walkover inspections.

2.3.4 Contaminant Transport Via Air Discharges

Contaminants can be transported beyond the boundaries of a landfill site via the following discharges to air:

- landfill gas;
- particulate matter.

In addition odour from landfills can be a nuisance and adversely affect people.

Air discharges can affect people and the natural environment and restrict land uses in areas immediately surrounding landfills.

Landfill Gas

Landfill gas is produced when solid wastes decompose. The quantity and the composition depend on the types of solid waste that are decomposing. Methane (CH_4) and carbon dioxide (CO_2) are the major constituents of landfill gas. Other gases are also present in very small quantities, but are responsible for the characteristic landfill gas odour. Hydrogen sulphide may be generated at a landfill if it contains a large amount of sulphate such as gypsum board. Non-methane organic compounds (NMOCs), which include volatile organic compounds (VOCs), are also present and may impact on air quality when emitted through the cover or vent systems.

The typical composition of landfill gas is shown in Table 2-2.

The two most significant potential hazards associated with landfill gas are:

- the flammability of methane; and

- the asphyxiating aspects of high concentrations of both methane and carbon dioxide in confined spaces.

The measured emission concentrations of some minor compounds, such as hydrogen sulphide, can also be in excess of the recommended short (and long) term exposure standards at some landfill sites.

Table 2-2 - Typical Constituents Found in Landfill Gas

Component	Percentage (dry gas basis)
Methane	55
Carbon dioxide	40
Nitrogen	4
Oxygen	0.1-1.0
Sulphides, disulphides, mercaptans, etc	0-1.0
Hydrogen	0-0.2
Carbon monoxide	0-0.2
Trace constituents (NMOCs)	0.01-0.6

Other toxic or potentially hazardous compounds in landfill gas are the VOCs. These can include:

- vinyl chloride;
- benzene;
- ethylene dichloride;
- vinyl chloride;
- perchloroethylene;
- carbon tetrachloride;
- trichloroethylene;
- chloroform;
- vinylidene chloride.

These compounds are implicated with a number of health effects including:

- leukaemia;
- damage to liver, lung, kidney, and central nervous system;
- possible embryotoxicity;
- possible human carcinogenicity;
- asthma and other respiratory effects.

VOCs have two basic sources:

- incoming waste, or
- chemical reactions occurring within landfilled waste.

The volume of VOCs in landfill gases are usually relatively low, typically less than 0.5 percent, by volume, of all landfill gas. Several health risk assessments have been undertaken in respect of air discharges at New Zealand Landfills, for example, Health Risk Assessment for Proposed Hampton Downs Landfill (1999). The general conclusion of these assessments is that the concentrations of VOCs present in landfill gas do not pose a health risk to the surrounding community.

The rate of generation of landfill gas is dependent on many parameters, such as:

- the composition and moisture content of the refuse;
- the age of the landfill;
- the pH of the landfill;
- the quantity and quality of the nutrients in the waste.

The quantity of gas generated can be approximated by the use of models. However, the quantity of gas emitted to the atmosphere can be significantly less than that generated within the landfill.

Landfill gas can be captured and flared, or used as an energy source. Landfill gas collection systems can typically recover in excess of 50 to 75 percent of the generated gas. Landfill gas, not captured by a collection system, generally does not remain in the landfill.

A portion of the gas passes directly to the atmosphere via cracks or flaws in the capping. However, most of the landfill gas will pass through the capping, which acts as a biofilter and removes most of the VOCs.

Landfill gas can also migrate laterally from a landfill through porous or fractured sub-surface materials.

The risks to people and the environment from landfill gas can be reduced through appropriate siting, liner and cover design, use of engineered systems to collect and either flare or use landfill gas discharges and use of buffer zones between the landfill and site neighbours.

Particulate Matter

Particulate emissions from landfills result from fires or activities that create dust. Particulate matter (PM) is the general term used for a mixture of solid particles and liquid droplets found in the air. Some particles are large or dark enough to be seen as dust, soot or smoke. Others are so small they can be detected only with an electron microscope. These particles come in a wide range of sizes. Fine particles are less than 2.5 micrometers in diameter and coarser-size particles are larger than 2.5 micrometers.

Fine particles (PM_{10}) can result from the accidental or deliberate burning of refuse at landfills.

Localised effects resulting from landfill fires (or even deliberate burning of refuse) include visible air pollution, eye irritation, soiling, and local vegetation damage caused by phytotoxic chemicals in the smoke plume. More serious effects can result from burns and exposure to carbon monoxide as well other toxic chemicals that are volatilised in the fire and others which become airborne as a result of the fire. Such compounds may include agrochemicals (pesticides and herbicides), lead from paints, asbestos (from old linoleum), and formaldehyde (from reconstituted wood products) among others.

Effects at larger distances include odour, increased levels of potentially harmful particulate matter, sulphur dioxide and other acid gases, as well as increased exposure to carcinogens such as polychlorinated dioxins, furans and polycyclic aromatic hydrocarbons (PAH's).

The potential for fires at landfills can be reduced through control of potential ignition sources, waste acceptance monitoring and appropriate operational practices.

Coarse particles (larger than PM_{10}) are generally emitted from sources such as road construction, vehicles traveling on unpaved roads, or materials handling operations, as well as windblown dust.

The greatest dust emissions occur as a result of vehicle movements, followed by that generated by depositing waste. The potential effects from dust emissions can be reduced by good landfill management procedures, placing controls on these activities and use of buffer zones between the landfill and site neighbours.

Odour

Landfill odour is due to trace compounds in landfill gas and uncovered material at the landfill face. Odour has the potential to be a considerable nuisance. People vary in their sensitivity to particular odours, with an odour that cannot be detected by some people causing nausea in others.

Odour can be reduced by good landfill management procedures, landfill gas management systems and use of buffer zones between the landfill and site neighbours.

2.4 Modeling of Landfill Examples

In order to compare the differences between various site geologies and engineered liner systems a number of landfill scenarios were modeled.

A one hectare lined cell (100 metres by 100 metres square or a circle of radius 56.4 metres) was used as the basis for a model to compare different:

- contaminant movement;
- leachate heads;
- liner systems;
- underlying geologies;

- compliance points.

The model landfill is shown in Figure 2-2.

An unlined landfill, with no leachate collection system was also modeled to provide a comparison to landfills with engineered liners.

It should be noted that the examples of liner and underlying geologies modeled do not represent any real landfill site, but were set up to compare a number of assumptions.

2.4.1 Contaminants

Two contaminants were used to model the performance of the liners and subsurface characteristics, one inorganic (nickel) and one organic (vinyl chloride, or methylene chloride). These contaminants were chosen for the following reasons:

- they are common constituents of leachate;
- both nickel and vinyl chloride are USEPA "priority pollutants";
- both are relatively mobile;
- vinyl chloride is persistent.

Leachate concentrations of the contaminants were set at the USEPA TCLP criteria for each contaminant:

- nickel – 2.0 grams per cubic metre;
- vinyl chloride – 0.2 grams per cubic metre.

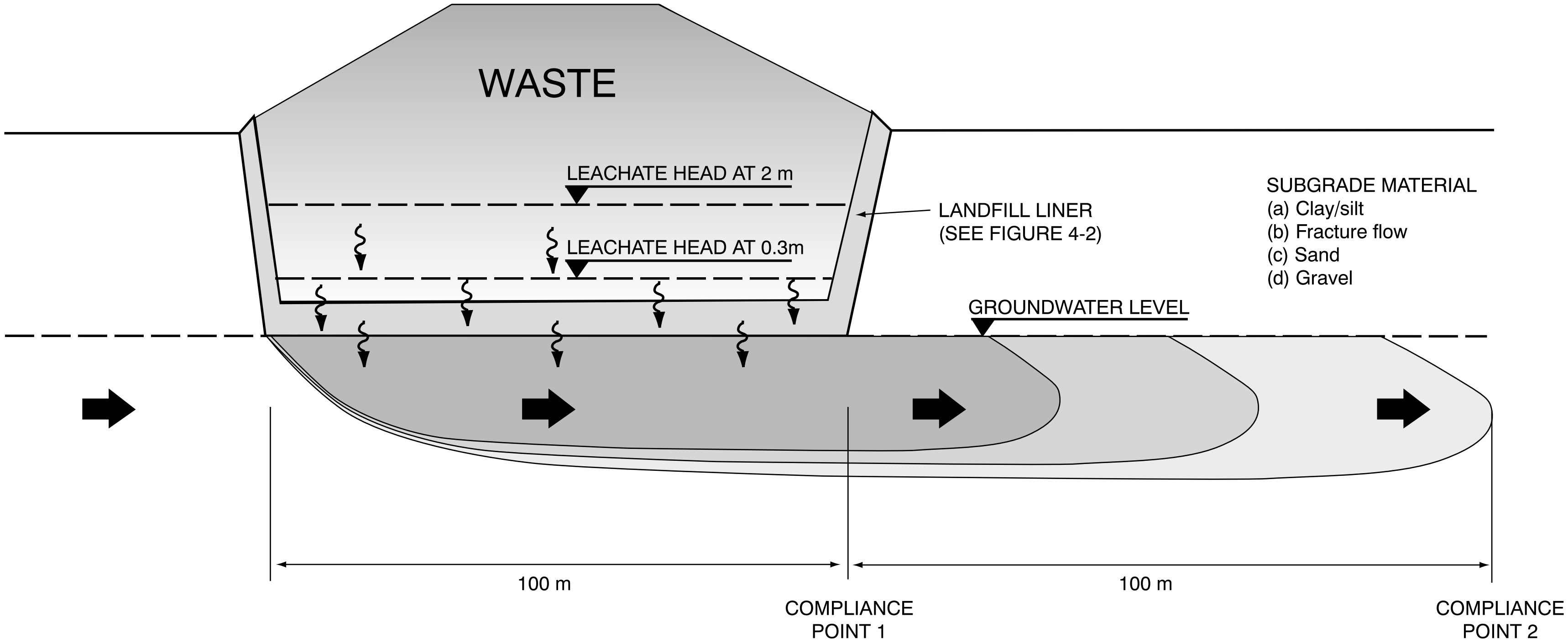
Vinyl chloride has a half life of 720 days in anaerobic conditions in groundwater.

2.4.2 Leachate Head

Two different leachate heads were modeled:

- 300 millimetres;
- 2 metres.

The unlined landfill was modeled to achieve no leachate head. That is leachate discharge through the base of the landfill was at the rate of liquid percolation through the landfill cover and refuse.



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MODEL LANDFILL
FIGURE 2-2

2.4.3 Landfill Liners

The following engineered landfill liners were used as representative of designs recommended in the CAE Landfill Guidelines, 2000 and/or consented or constructed in New Zealand in the past.

Landfill liners are shown diagrammatically in Figure 2-3.

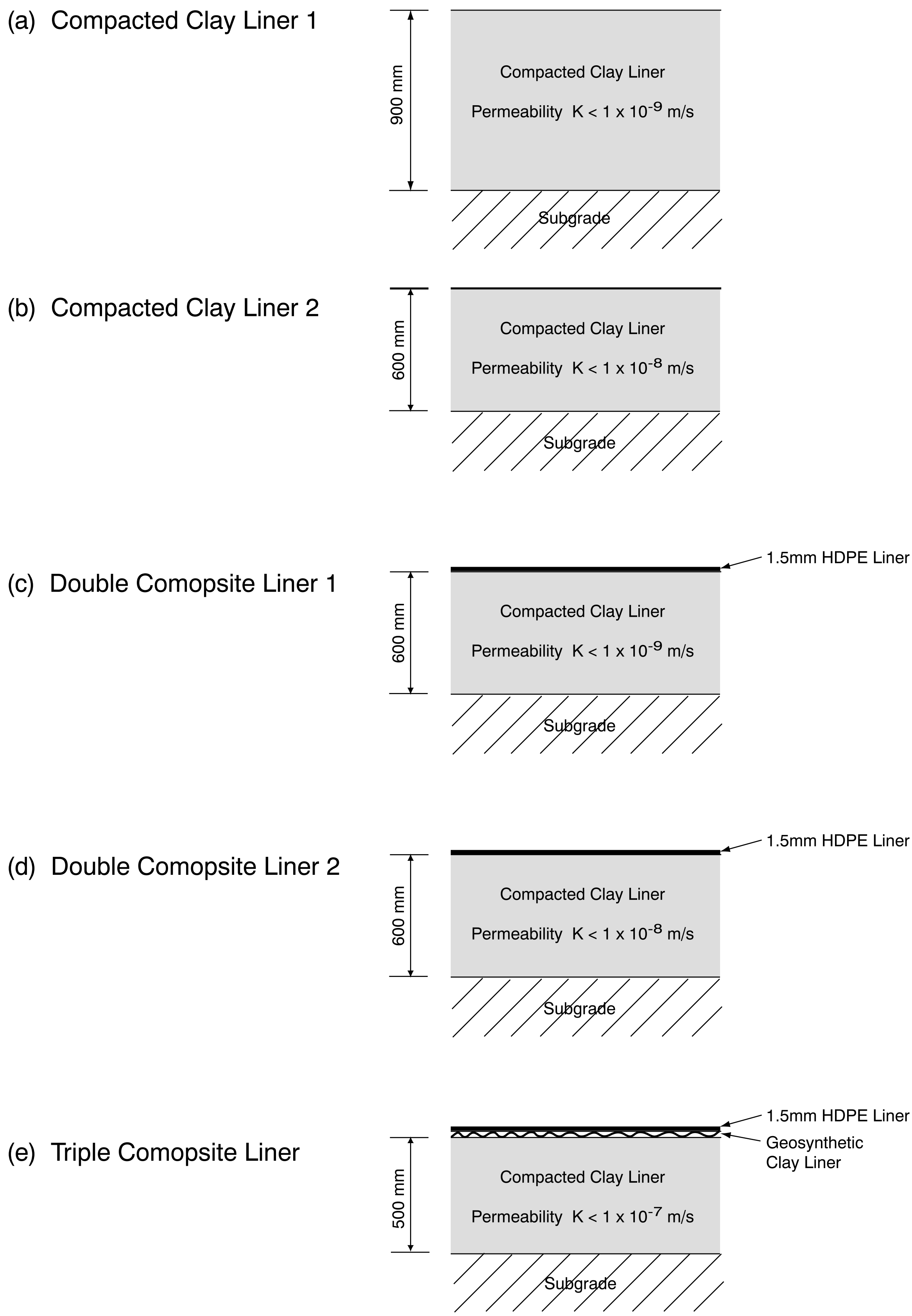
a) Compacted Clay Liner 1
   - 900 millimetres of clay compacted to a permeability (K) of less than or equal to 1 x 10^{-9} metres per second.

b) Compacted Clay Liner 2
   - 600 millimetres of clay compacted to a permeability (K) of less than or equal to 1 x 10^{-8} metres per second;

c) Double Composite Liner 1, from top to bottom:
   - 1.5 millimetre thick HDPE flexible membrane liner with a permeability (K) of less than or equal to 2 x 10^{-15} metres per second;
   - 600 millimetres of clay compacted to a permeability (K) of less than or equal to 1 x 10^{-9} metres per second;

d) Double Composite Liner 2, from top to bottom;
   - 1.5 millimetre thick HDPE flexible membrane liner with a permeability (K) of less than or equal to 2 x 10^{-15} metres per second;
   - 600 millimetres of clay compacted to a permeability (K) of less than or equal to 1 x 10^{-8} metres per second;

e) Triple Composite Liner, from top to bottom
   - 1.5 millimetre thick HDPE flexible membrane liner with a permeability (K) of less than or equal to 2 x 10^{-15} metres per second;
   - Geosynthetic clay liner, 6 millimetres thick with a permeability (K) of less than or equal to 3 x 10^{-11} metres per second;
   - 500 millimetres of clay compacted to a permeability (K) of less than or equal to 1 x 10^{-7} metres per second.



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MODEL LANDFILL LINERS
FIGURE 2-3

2.4.4 Underlying Geology

Four different types of underlying geology were modeled:

a) clay/silt;

b) fracture flow;

c) sand;

d) gravel.

The hydrogeological properties are listed in Table 2-3. In general the most conservative parameters were used.

It was assumed that the groundwater table is at the base of the lowest liner component.

The groundwater table for the unlined example was assumed to be at the base of the refuse.

Table 2-3 - Hydrogeological Properties of Underlying Geology

	Clay/silt	Fracture Flow	Sand	Gravel
Permeability (K) (m/s) **(Typical Range)**	10^{-5} (10^{-5} - 10^{-9})	10^{-5} (10^{-5} - 10^{-8})	10^{-3} (10^{-3} - 10^{-6})	10^{-2} (10^{-2} - 10^{-3})
Gradient (I) **(Typical Range)**	0.1 ($2 \times 10^{-1} – 1 \times 10^{-3}$)	0.01 ($1 \times 10^{-2} – 1 \times 10^{-3}$)	0.01 ($1 \times 10^{-2} – 1 \times 10^{-4}$)	0.001 ($1 \times 10^{-3} – 1 \times 10^{-5}$)
Effective Porosity (n_e) **(Typical Range)**	0.4 (0.01 – 0.4)	0.05 (0.01 – 0.1)	0.35 (0.1 – 0.35)	0.35 (0.1 – 0.35)
Bulk Density (kg/m^3) **(Typical Range)**	1.4 (1.4 - 2.3)	1.3 (1.3 – 2.3)	1.7 (1.3 - 2.3)	1.3 (1.3 - 1.9)
Longitudinal Dispersivity (m) **(Typical Range)**	20 (0.10 – 20)	20 (0.10 – 20)	20 (0.10 – 20)	20 (0.10 – 20)
Transverse Dispersivity (m) **(Typical Range)**	1 (0.1-2)	1 (0.1-2)	1 (0.1-2)	1 (0.1-2)
Retardation Coefficient [1] [1+K_d.(b/n)]	1.7	2.0	1.0	1.9

[1] For vinyl chloride, K_d = 2, ($K_d = f_{oc} \times K_{oc}$ Organic carbon content (f_{oc})= 5, K_{oc} =0.39)

2.4.5 Compliance Point

Contaminant concentrations have been determined at two compliance points:

- the downgradient edge of the landfill;
- 100 metres downgradient of the landfill edge.

2.4.6 Leachate Leakage Through Liners

Leachate leakage rates were estimated using the USEPA "Hydrological Evaluation of Landfill Performance" (HELP) model.

This computer model is used to evaluate alternative landfill designs and gives an indication of likely landfill leachate production and leakage through the base of the liner system.

The HELP Model requires rainfall; solar radiation; wind; humidity and mean daily temperatures as climatic inputs. Published data from South Auckland was used to generate twenty years of climatic data for input into the model. The mean annual rainfall used for the data set was 1349 millimetres, which is considered to represent typical New Zealand temperate climatic zone.

Landfill design parameters (drainage slope length and drainage layer permeability) were amended with each HELP model run to achieve the required hydraulic head of 300 millimetre and 2000 millimetre head of leachate above the liner.

Liners were modeled with a two percent slope.

Difficulties were encountered in achieving a 2000 millimetre leachate head for the Compacted Clay Liner 2 (compacted clay with a permeability of 1×10^{-8} metres per second). Provisional leakage values were high and a leachate head of 1000millimetres above the liner was achieved by creating a high permeability landfill cap and reducing the permeability of the refuse and drainage layer.

For the HDPE liner components it was assumed that there were 2 pinhole (one millimetre diameter) manufacturing defects per hectare and 4 installation defects (one centimetre in area) per hectare. Installation quality was assumed to be good (in the range excellent; good; fair; and poor).

The results of HELP modeling are detailed in Table 2-4.

These results indicate that maintenance of a low leachate head, through a combination of leachate collection system design and control of rainwater infiltration, significantly reduces leakage through a landfill liner.

Leakage rates do not take account of retardation of contaminants within the compacted clay component of liners.

Table 2-4 - Leachate Leakage from Liners

Liner	Liner Details	Leachate Head (mm)	LeachateVolume[1] (m^3/year)
Unlined	NA	NA	7549
a	Compacted Clay 1	300	413
	Compacted Clay 1	2000	1006
b	Compacted Clay 2	300	4537
	Compacted Clay 2	1000[2]	8570
c	Double Composite 1	300	1.08
	Double Composite 1	2000	8.09
d	Double Composite 2	300	33
	Double Composite 2	2000	224
e	Triple Composite	300	0.8
	Triple Composite	2000	6.7

[1] Based on 1Ha landfill cell.
[2] Leachate head only achievable with high K cap and low K refuse.

2.4.7 Contaminant Concentrations at Compliance Points

Contaminant transport in the various underlying subgrade geologies was modeled using WinTran. WinTran is a simple combined steady-state groundwater flow model and contaminant transport model. It considers groundwater flow and contaminant transport in two dimensions in a horizontal plane. It assumes that groundwater flow is horizontal and that contaminant concentrations are the same throughout the entire aquifer thickness. It also assumes that hydraulic conductivity is isotropic and homogeneous.

The only chemical attenuation considered during this modeling process was the first order decay of vinyl chloride in anaerobic conditions in groundwater (half life of 720 days). Travel time through the liner was not considered in attenuation calculations.

It was conservatively assumed that there would be no attenuation of nickel.

The results of modeling are shown in Table 2-5 (Nickel) and Table 2-6 (vinyl chloride).

Only results exceeding the practical quantitation limit are reported (0.0005 grams per cubic metre for nickel and 0.0004 grams per cubic metre for vinyl chloride).

Table 2-5 - Contaminant Concentrations for Nickel in Groundwater when 2.0 g/m³ in Leachate (g/m³)

Liner	Geology	Clay/silt		Fracture Flow		Sand		Gravel	
	Compliance Point Travel time (days) Steady State (days)	Landfill edge	100 m 463 3970	Landfill edge	100 m 578.7 33100	Landfill edge	100 m 40.5 523	Landfill edge	100 m 40.5 492
	Leachate Head (mm)								
No Liner	NA	0.011	0.01	0.84 [1]	0.68 [1]	0.015	0.014	0.014	0.014
a	300	0.0006	0.0006	0.045 [1]	0.012	0.0009	0.0008	0.0009	0.0008
	2000	0.0016	0.0014	0.14 [1]	0.11 [1]	0.0021	0.0019	0.0021	0.0019
b	300	0.0071	0.0063	0.58 [1]	0.45 [1]	0.0095	0.0085	0.0095	0.0085
	1000	0.013	0.012	0.96 [1]	0.76 [1]	0.018	0.016	0.0018	0.0016
c	300	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	2000	<0.0005	<0.0005	0.0012	0.0009	<0.0005	<0.0005	<0.0005	<0.0005
d	300	<0.0005	<0.0005	0.0064	0.0052	<0.0005	<0.0005	<0.0005	<0.0005
	2000	0.0005	<0.0005	0.042 [1]	0.035 [1]	0.0007	0.0006	0.0007	0.0006
e	300	<0.0005	<0.0005	0.0019	0.0014	<0.0005	<0.0005	<0.0005	<0.0005
	2000	<0.0005	<0.0005	0.016	0.012	<0.0005	<0.0005	<0.0005	<0.0005

[1] Exceeds New Zealand Drinking Water Standard (0.02 g/m³)

Table 2-6 - Contaminant Concentrations for Vinyl Chloride in Groundwater when 0.2 g/m^3 in Leachate (g/m^3)

Liner	Geology	Clay/silt		Fracture Flow		Sand		Gravel	
	Compliance Point Travel time (days) Steady State (days)	Landfill edge	100 m 463 3970	Landfill edge	100 m 578.7 33100	Landfill edge	100 m 40.5 523	Landfill edge	100 m 40.5 492
	Leachate Head (mm)								
No Liner	NA	0.0007	<0.0004	0.017 [1]	0.0004	0.0015	0.0012	0.0015	0.0012
a	300	<0.0004	<0.0004	0.001	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
	2000	<0.0004	<0.0004	0.0025	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
b	300	0.0004	<0.0004	0.011 [1]	<0.0004	0.0009	0.0008	0.0009	0.0008
	1000	0.0008	<0.0004	0.019 [1]	0.0005	0.0017	0.0014	0.0017	0.0014
c	300	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
	2000	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
d	300	<0.0004	<0.0004	0.0017	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
	2000	<0.0004	<0.0004	0.011 [1]	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
e	300	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
	2000	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004

[1] Exceeds New Zealand Drinking Water Standard (0.005 g/m^3)

Travel time for the contaminant plume to reach the compliance point, 100 metres downgradient of the landfill edge, varies from 40 days, in sand and gravel, to in the order of 500 days in fracture flow and clay/silt. The time for the contaminant plume to reach a steady state concentration at that point varies from sixteen months, in gravel, to ninety years in fracture flow in fracture flow. The time taken to reach steady state concentrations in fracture flow could be significantly less depending on geological setting, which is heterogeneous, rather than that the homogeneous geology assumed by the model.

Nickel concentrations are generally in the same order of magnitude for clay/silt, sand and gravel geologies, and one to two orders of magnitude higher in fracture flow. Vinyl chloride concentrations are generally an order of magnitude lower for clay/silt, compared to those where the underlying geology is sand or gravel. In fracture flow, vinyl chloride concentrations are two orders of magnitude higher than in clay/silt.

The permeability used for clay/silt in the modeling examples is at the higher end of the expected range and the results do not take into account the effect adsorption of contaminants would have on further reducing downgradient concentrations for clay/silt. The adsorption will be less significant for sand, gravel and fracture flow geologies, particularly for less mobile leachate constituents.

Modeling results also indicate the effectiveness of an engineered liner (as opposed to no liner) in reducing leachate leakage from landfills and, as a consequence, downgradient contaminant concentrations.

The example using 600 millimetres of clay compacted to a permeability (K) of less than or equal to 1×10^{-8} metres per second and 1000 millimetres leachate head was used to represent a landfill with a low specification clay liner and poor leachate drainage. While the leachate leakage is high it does not take into account some attenuation of less mobile leachate constituents.

The results for different liner examples indicate the potential effectiveness of geomembrane and geosynthetic clay liners in reducing leachate leakage. However, as stated in Section 2.3.2, their effectiveness is dependent on manufacture and construction quality and preventing liner punctures. In addition there is some question as to the long-term reliability and performance of geomembranes and geosynthetic liner components compared to compacted soil/clay liners.

Maintenance of a low leachate head on the liner reduces leachate significantly, when compared to poor drainage and a high leachate head, particularly in the case of composite liners.

Overall the results of the modeling exercise demonstrate the importance of a landfill site's underlying geology to the long-term containment of contaminants. In addition, the design of the landfill liner and an effective leachate collection system can significantly reduce potential leakage, at least in the short term.

The results also indicate some of the potential shortcomings of simplified modeling approaches when used to assist in determining the performance of leachate containment systems.

2.5 Relative Importance to Classification of Landfill Siting, Design and Operations

A landfill classification system needs to consider the siting, design and operational aspects of landfill sites. Landfill owners/operators can influence actual and potential effects of a landfill during the site selection process, the design process and then by management of site operations.

2.5.1 Siting

In siting a new landfill, or considering the expansion of an existing landfill, the following issues need to be considered:

- geology, including the nature and permeability of underlying materials;
- hydrogeology, including:
  - location of aquifer recharge areas, seeps or springs;
  - depth to groundwater table;
  - dispersion characteristics of aquifers;
  - rate and direction of groundwater flow;
  - existence of groundwater divides;
  - distance to and sensitivity of water users;
  - baseline water quality;
- surface hydrology, including:
  - proximity of water bodies or wetlands;
  - return period for flooding;
  - sensitive water users or aquatic ecosystems;
- stability, including;
  - shallow instability
  - active geological faults;
  - areas of geothermal activity;
  - consolidation and liquefaction potential;
  - karst terrain;
- climate;
- compatibility with surrounding lands use.

Locating a landfill in an area with favourable geology, hydrogeology and surface hydrology is fundamental for the long term containment of leachate. While there is no such thing as a perfect landfill site, characteristics such as low permeability underlying materials, good separation between the base of the landfill and groundwater, well defined groundwater flows and large distance to surface water contribute to:

- natural leachate containment; and
- time and distance over which for attenuation of contaminants can occur prior to environmental receptors.

In addition, the surrounding land uses will have a significant bearing on the number of people likely to be affected by activities associated with the landfill.

Favourable siting can provide a high degree of redundancy and make it easier to implement contingency measures to address leachate contamination, should failure of engineered containment systems occur.

During the site selection process these issues must be weighed up against each other and the possibility of improving the natural characteristics of a site through engineered measures should be considered. However, there will be some site characteristics which could be considered fatal flaws, for example areas with:

- active faults;
- karst geology
- within a 100 year flood plain.

Once a site is chosen and a landfill constructed, the site characteristics effectively cannot be changed. Therefore, when considering the continued use or expansion of an existing landfill, siting issues should be reconsidered, in conjunction with potential design measures to improve containment, if required.

Because engineered liner systems rely on high quality construction and have a finite lifetime the ability of the underlying materials to minimise the potential for liquids to migrate out of the landfill into the environment should the liner either degrade, tear, or crack needs careful consideration.

2.5.2 Design

The term design includes all engineered systems for landfills, namely:

- groundwater control systems;
- liners and leachate collection systems;
- leachate treatment and/or disposal systems;
- final covers;
- surface water and stormwater diversion and retention;

- landfill gas extraction, treatment and/or disposal systems;
- site roads.

With the exception of liners, the designed systems listed above can be installed at any existing landfill to improve environmental performance. However, retrofitted groundwater control and/or leachate collection systems are not as effective as those developed during initial landfill design and construction.

In the case of liners, engineered systems are used to augment natural site characteristics and to provide the primary leachate barrier.

In some cases, engineered systems may be used as a substitute for natural site containment characteristics. However, the integrity of any engineered system depends on its design, type of materials used and the effectiveness of quality control/quality assurance processes used during construction.

With any engineered system there is the possibility of failure, potentially leading to discharge of contaminants into the environment. Therefore, design is considered to be of secondary importance, relative to siting, with respect to a classification system.

2.5.3 Operations

A high standard of operating procedures can be achieved at any landfill site. This is important to reduce the level of nuisance suffered by site neighbours due to dust, odour, vermin and vectors.

A classification system can simply prescribe minimum operational, performance or effects based requirements for specific classes of landfill, or a minimum set of requirements for all landfills.

Operations include all day to day activities associated with the following:

- waste acceptance and monitoring;
- traffic control;
- waste compaction;
- cover, including:
  - daily cover;
  - intermediate cover;
- nuisance control, including:
  - litter;
  - dust;
  - odour;
  - birds;

  - flies;
  - vermin;
  - noise;
- surface/stormwater separation;
- leachate treatment/disposal system operation;
- landfill gas collection and treatment/disposal system operation;
- monitoring, including:
  - leachate;
  - groundwater;
  - stormwater/surface water;
  - landfill gas;
  - settlement.

2.5.4 Assessment of Landfill Siting, Design and Operational Factors

Table 2-7 summarises siting, design and operational factors with respect to their use in a classification system. Factors are listed and it is noted whether, or not, they can be changed, or upgraded, at an existing landfill site, and through a lateral expansion of an existing site. For example, a liner at an existing landfill cannot be altered, but the design for a lateral expansion at the same site can be changed to take account of new technology or to achieved improved levels of environmental protection.

All listed factors are then ascribed a comparative ranking of 1, 2 or 3, based on the ease with which they can be altered (1 - not possible, 2 - possible but difficult, 3 - possible). This relates to the degree of certainty they afford in respect of long term environmental protection.

Of the listed factors for siting, geology and hydrogeology provide the basis for long term leachate containment and cannot be altered once a landfill is constructed. This, and the results of modeling discussed in Section 2.4, indicate that siting is fundamental to any landfill classification system. That is, these siting components of a landfill cannot be degraded through poor design, construction or operational practices. In addition, the local climate of a site can affect leachate production and landfill operations and cannot be altered. Therefore, these factors have been given a ranking of 1.

Some designed components can be altered, or upgraded, at existing landfills and all can be altered or upgraded for lateral expansions of an existing landfill.

At some sites, surface hydrology and stability may technically be altered or improved by engineering measures, and these factors have been given a ranking of 2 (possible but difficult). However, these measures are likely to be costly and their effectiveness may still be limited.

Table 2-7 - Assessment of Landfill Siting, Design and Operational Factors

ISSUE		EASE OF ALTERATION 1 - not possible 2 - possible but difficult 3 - possible	
		Existing Landfill	**Lateral Expansion**
Siting	Geology	1	1
	Hydrogeology	1	1
	Surface Hydrology	2 [1]	2 [1]
	Stability	2 [1]	2 [1]
	Climate	1	1
	Compatibility with Surrounding Lands Use	2 [2]	2[2]
Design	Groundwater Control System	2 [3]	3
	Liner	1	3
	Leachate Collection System	2 [3]	3
	Leachate Disposal System	3	3
	Final Cover	3	3
	Surface/Stormwater Systems	2 [2]	3
	Landfill Gas System	3	3
Operations	Site Roads	3	3
	Waste Acceptance	3	3
	Waste Compaction	3	3
	Cover	3	3
	Nuisance Control	3	3
	Traffic Control	3	3
	Surface/Stormwater Management	3	3
	Leachate Treatment/Disposal	3	3
	Landfill Gas System Management	3	3
Monitoring	Leachate, Groundwater, Surface Water, Landfill Gas	3	3

[1] Dependent on site characteristics and level of engineering possible.

[2] Dependent on ability to alter surrounding landuse, purchase properties or create buffer zones.

[3] Some retrofitting possible.

Compatibility with surrounding land use has also been given a ranking of 2 as it may be altered. However, this may require re-zoning of surrounding areas, or buying surrounding land and instituting buffer zones.

In respect of design, retrofitting of groundwater control and leachate collection systems is possible to a degree at some existing landfills. These measures are likely to be costly and their effectiveness may still be limited. Liners cannot be altered at existing landfills but can for a lateral expansion. These factors have, therefore, been given a ranking of 2.

All other design factors and all operational factors can be altered, or upgraded, at any landfill site.

It should be noted that if a design or operational factor can be upgraded it can also be downgraded or susceptible to lower environmental performance, due to a change in design, poor management or operating practice.

Groundwater control and leachate collection systems are also given a ranking of 2, as some retrofitting is possible. A liner cannot be retrofitted to an existing landfill, but can be installed for a lateral expansion.

Landfill gas system design is given a ranking of 3 (possible) as gas extraction systems can be retrofitted to almost any landfill, by installation of collection wells or collection pipes beneath a final cover system (or a combination of the two).

Operational factors are given a ranking of 3 as they can change, or be upgraded, at any landfill to improve environmental outcomes.

2.6 CAE Landfill Guidelines 2000

In its issues and options report "Landfill Acceptance Criteria for Wastes with Hazardous Properties", dated April 2001, the Ministry for the Environment refers to Class A landfills as being those landfills that meet site selection and design standards outlined in the CAE Landfill Guidelines, 2000.

The CAE Landfill Guidelines 2000 were prepared by the University of Canterbury's Centre for Advanced Engineering. They are endorsed by the Ministry for the Environment as New Zealand's national landfill guidelines for the siting, design and operation of MSW landfills.

However, it should be noted that the Landfill Guidelines are not standards and do not represent binding requirements. The effects based nature of the Resource Management Act (1991) (RMA) means that final requirements with respect to landfill siting, design, operations and monitoring are determined by the appropriate regional council, or Environment Court, on a site-specific basis through the resource consent process.

The Guidelines:

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

  - experience in the use and implementation of the existing Guidelines by landfill operators and regulatory authorities; and
  - experience in the implementation of the Resource Management Act (1991).
- outline the key considerations in the siting, design, operation and monitoring of landfills on a site specific basis;
- provide a consistent approach to landfill design and management to reduce the actual and potential effects of landfills on the environment.

Siting, designing and operating of landfills in accordance with the Guidelines is likely to provide a reasonable assurance that the landfill will not have significant adverse effects on the environment. However, at some sites lower standards of engineered design and operation may be justified, or higher standards of design and operation may be required, based on landfill size and site conditions.

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

The key Guideline criteria and recommendations with respect to landfill siting, design and operations of landfill sites are given in Appendix C.

3.1 International Landfill Classifications

There have recently been two classification systems published by international environmental organisations. They are:

- UNEP General Landfill Categories; and
- ISWA International Guidelines for Landfill Evaluation.

These are intended to provide general categories into which landfills can be classified in respect of the degree of environmental protection they offer. These landfill classifications are intended to be used to assess landfills and do not have any associated waste acceptance criteria.

3.1.1 UNEP General Landfill Categories

The United Nation Environment Programme (UNEP), in its International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management, groups landfills into three general categories:

- open dumps;
- controlled dumps;
- sanitary landfills.

It recognises that the three types of landfill are points on a continuum, with landfills in developing countries most often falling somewhere between open dumps and controlled dumps. Each category has a number of general, prescriptive requirements for each category. The main distinguishing features of each of the categories are outlined in Table 3-1.

Table 3-1 - Features of UNEP Landfill Categories

Open Dump	Controlled Dump	Sanitary Landfill
• poorly sited • unknown capacity • no cell planning • little or no site preparation • no leachate management • no gas management • only occasional cover • no compaction of waste • no fence • no record keeping • waste picking and trading	• sited with respect to hydrogeology • planned capacity • no cell planning • grading and drainage in site preparation • partial leachate management • partial or no gas management • regular (not usually daily) cover • compaction in some cases • fence • basic record keeping • controlled waste picking and trading	• site based on an environmental risk assessment • planned capacity • designed cell development • extensive site preparation • full leachate management • full gas management • daily and final cover • compaction • fence and gate • records of waste volumes, type and source • no waste picking

3.1.2 ISWA International Guidelines for Landfill Evaluation

The International Solid Waste Association (ISWA), through its Working Group on Sanitary landfill has prepared a set of international guidelines for determining the degree of environmental protection offered by landfills (Ham, R.K., "International Guidelines for Landfill Evaluation", 1999, ISWA Times, Issue 1, p. 22-3). The guidelines contain what are described as essential parameters for evaluation of landfill standards world-wide, both in developed and in developing countries. Landfills are evaluated in respect of the following:

- aesthetics/regard for health safety and quality of life of neighbours and passers-by;
- groundwater protection;
- surface water protection;
- landfill gas;
- on-site health and safety.

Under each heading there are a number of prescriptive requirements that lead to a landfill being evaluated as one of the following:

- no protection;
- some protection;
- good protection;
- extensive protection.

The requirements for each classification are detailed in Table 3-2.

Table 3-2 - ISWA International Guidelines for Landfill Evaluation

Evaluation	Aesthetics/Regard for Health, Safety, & Quality of Life of Neighbours & Passersby	Groundwater Protection
No Protection	• No curve, steep slopes, uncompacted waste burning, birds, vectors, ponding, muddy conditions visible for property boundary • Accepts uncovered vehicles hauling waste • Extensive wind-blown debris, dusty off site • Major erosion problems, visible from off & or site	• Rock, gravel, sand, or undefined soils • No liner, no leachate collection pipes • < 50 m to groundwater or unknown • Not arid or semi-arid • No groundwater monitoring, no control of groundwater use
Some Protection	• Waste compacted, but not covered & visible from boundary • Minimal vegetation • Steep slopes (> 4/1) • Birds & minimal vector control • Some muddy roads • Periodic wind-blown debris & dusty off site • Erosion channels, some ponding & muddy conditions visible from off site • No burning • Accepts uncovered vehicles	• Silt or clay soils ≥ 5 m thick under waste • ≥ 5 m to groundwater under waste • No liner or leachate collection pipes • No groundwater monitoring but no groundwater use within 1 km
Good Protection	• Exterior slopes covered and vegetated, no steeper than 3/1 • Road cleaned & debris removed weekly or more frequently if needed • No erosion, no vectors, minimal birds • No burning • Waste compacted & covered, small working face and only one work face	• Plastic or clay liner, or natural clay soils > 5 m thick under waste • Leachate collection pipe system and treatment • > 10 m to groundwater under waste • Groundwater monitoring & no groundwater use within 500 m
Extensive Protection	• Exterior slopes covered & vegetated, < 3/1 • Roads free of mud, dust, & debris • No wind blown dust & debris except in rare conditions • No erosion, no vectors, minimal birds • No burning, minimal odours • Waste confined to one working face, compacted immediately, covered daily • Surface water controlled, no ponding	• Plastic and/or ≥ 1-m-thick clay liner • Full leachate collection system, treatment • No groundwater use within 500 m of waste • Full groundwater monitoring

Surface Water Protection	Landfill Gas	On-Site Health and Safety
• Waste indirect contact with lake, ocean, stream, pond, or wetland • Waste in flood plain • Runoff from waste uncontrolled and direct to surface water body	• Rock, gravel, sand, or undefined soils • No liner • < 500 m to buildings or occupied areas • < 20 m to groundwater	• Large areas of exposed waste, minimal or no compaction • Burning • No checking for and rejection of hazardous waste • No safety procedures, education, or control of workers • Water ponding, muddy areas • Dusty • Steep interior slopes (steeper than 4/1) • No animal or vector control
• Waste does not contact any surface water other than rare flooding (< 1 time/5 years) • Waste may contact isolated wetland • Runoff from waste channeled, but direct to surface water body	• Silt or clay soils, no liner • Groundwater > 20 m deep • No building > 500 m from waste, or if so, monitor gas between landfill and buildings	• Large areas of exposed waste, but incoming waste confined to specific working areas; other areas covered • Minimal checking and rejection of unwanted or hazardous wastes • Minimal education or control of workers, few safety procedures • Some muddy areas and ponding, but not where workers are • Interior slopes not steep (> 4/1)
• Totally isolated (> 100 m) from surface water body, wetland, or flood plain • Positive surface water drainage (minimal ponding) with control of waste contact runoff by berms for treatment • Runoff controlled & released after sedimentation ponds	• Plastic or clay liner (≥ 1 m) or natural silt or clay (≥ 5 m) • > 20 m to groundwater • Gas pumped or vented • > 300 m to buildings with gas monitoring in buildings and in soils between buildings and landfill	• Waste confined to working areas; all other waste covered • Waste compacted immediately • Incoming waste checked and hazardous or unwanted waste rejected • No burning, no steep slopes • Worker safety, education, and control procedures in place • Interior slopes no steep (< 4/1)
• Totally isolated from surface water, wetland, or flood plain • Area of landfill not in low area with historical wetland or flood plain • All waste contact runoff collected & treated, waste area surrounded by berms • Other runoff to sedimentation pond for discharge • No on-site ponding	• Fully lined landfill and/or ≥ 5 m clay soils • Active gas extraction for flare or use • > 300 m to buildings, full gas monitoring system in buildings and soils • Land use control within 1 km of landfill	• Waste covered except at working face, which is covered daily • Incoming waste confined to one working area and compacted immediately • Careful checking and routine rejection of hazardous or unwanted waste • No burning, all interior slopes < 4/1 • Worker safety training and procedures operational • Dust and vector controls operational

3.2 New Zealand Landfill Classifications

Two different landfill classifications have been developed in New Zealand to assist in the setting of landfill waste acceptance criteria for specific waste types. These are:

- Health and Environmental Guidelines for Selected Timber Treatment Sites, which contains a landfill classification; and
- Effects Based Landfill Classification for Hydrocarbon Contaminated Waste Disposal.

3.2.1 Health and Environmental Guidelines for Selected Timber Treatment Sites

The 1997 Health and Environmental Guidelines for Selected Timber Treatment Sites, published by the Ministry for the Environment and Ministry of Health, contains a landfill classification with three broad classes in respect of disposal of timber treatment wastes (copper, chromium, arsenic, pentachlorophenol (PCP)):

- Class 1, which represents the formation of a small specially developed and lined cell within a Class 2 site;
- Class 2, which is a site that is suitable for co-disposal of wastes containing relatively low concentrations and quantities of potentially hazardous constituents within the framework of operating procedures common to such landfills in New Zealand;
- Class 3, which is the standard that an appropriately sited, engineered and operated landfill of older design, receiving municipal refuse only, should currently be able to meet.

Each class has a set of loosely prescriptive criteria in respect of siting design and operations. Determination as to whether a specific site meets a number of the criteria requires a subjective assessment. A list of some of the criteria given for distinguishing the landfill classes is detailed in Table 3-3. This list is intended to be only indicative of desirable site characteristics, rather than rigidly specific.

Each landfill class also has the following factors to prescribed, for use in conjunction with environmental and agricultural criteria to calculate landfill acceptance limits for timber treatment chemicals at specific sites:

- Assumed Solid Waste Mix Factor, the ratio of other wastes to timber treatment waste;
- Assumed Capping Control Factor, the protection afforded by the landfill's capping;
- Leachate Mix Factor, which accounts for leachate mixing and dilution;
- Receiving Water Dilution Factor, which assumes a level of dilution in the receiving water.

Table 3-3 - Landfill Classification Criteria for Disposal of Selected Timber Treatment Chemicals

Class	Landfill Design and Operation Criteria
1.	• meets class 2 criteria; and • accepted hazardous waste to be mixed with mature refuse if appropriate, and disposed in discrete cells with low permeability capping and lining material; • has leachate capture and either recirculation, treatment, or disposal to sewage treatment facility.
2.	• meets Class 3 criteria; and has appropriately designed and operated leachate and groundwater quality; • has an appropriately designed and operated leachate and groundwater quality surveillance programme which indicates insignificant levels of groundwater contamination and will be regularly monitored for potentially hazardous constituents following acceptance; • site applies cover on a daily basis and low-permeability intermediate and final cover; • site has adequate low-permeability/attenuating liner materials and appropriate subsoil conditions as evaluated by a detailed hydrogeological investigation; • site is further than 3 km from any significant point of water abstraction and use within the same hydrogeological catchment.
3.	• site is securely fenced and has personnel in attendance during all times of operation capable of assessing whether documentation with wastes is adequate. Additionally, personnel must be available who can decide how to evaluate specific wastes and determine the required disposal option, and who are fully instructed in the requirements for safe handling of the particular waste both for themselves and other landfill users. Where wastes are proposed to be accepted, appropriate testing (concentration and leachability of constituents) should be carried out; • site has at least 4 m depth of well-compacted refuse available above the site base; • site has acceptable control of stormwater, and applies cover at least on a weekly basis; • site is further than 1 km from any significant point of water abstraction and use; • closure to include a low-permeability protective cap; • site to be further than 500 m from residential areas; • site to be located and engineered such that extreme meteorological events will not cause significant mobilisation of wastes by such processes as erosion, wave action, and stormwater runoff; • site to have in place appropriate operational, quality assurance, emergency response, and post-closure management plans.

The Guidelines state that the landfill classifications and method for developing waste acceptance limits may also be applied to other wastes.

The 1997 Guidelines for Assessing and Managing Contaminated Gasworks Sites in New Zealand, published by the Ministry for the Environment, also uses the landfill classification in the Health and Environmental Guidelines for Selected Timber Treatment Sites when discussing landfill disposal of gasworks site wastes. Contaminants of concern include poly alkylated hydrocarbons (PAHs), BTEX (benzene, toluene, xylene and ethyl benzene), phenolics and cyanides.

Low level contaminated materials which meet the landfill acceptance criteria may be disposed of to Class 1 and 2 landfills. High level contaminated materials, which exceed the landfill acceptance criteria, either require pre-treatment before landfilling or disposal in a purpose-built repository.

3.2.2 Effects Based Landfill Classification for Hydrocarbon Contaminated Waste Disposal

In 1999 the Oil Industry and Environmental Working Group (OIEWG) undertook a project directed at the development of waste acceptance criteria for the disposal of hydrocarbon contaminated soils in landfills. As part of this project an effects based landfill classification system was developed as a pilot study to assist in setting acceptance criteria. There are four classes of landfill A, B C and D, divided on the basis of size, level of containment, operational procedures and monitoring requirements, using a mixture of prescriptive and performance criteria.

The system then uses a tiered approach in setting landfill WAC, using the landfill classification. Three different tiers, ranging from Tier 1 (generic approach) through to Tier 3 (site specific risk assessments) are used, as described below.

Tier 1

A specific landfill is classified in accordance with the landfill classification prescriptive and performance characteristics outlined in Table 3-4. Acceptance criteria for that landfill are set in accordance with the classification. If a landfill does not meet each and every requirement, it drops to the next classification.

Tier 2 (addition of site specific info required)

The model spreadsheet (used to determine acceptance limits using criteria in Table 3-3) is modified to better reflect site specific performance characteristics of a landfill. The performance parameters which could be varied, based on site specific data and investigations are:

- environmental receptor (aquatic organisms, potable water, other);
- groundwater flowpath length;
- underlying geology (clay/silt, fracture flow, sand, gravel).

Tier 3 (addition of further site specific information)

In addition to the Tier 2 modifications the following are also included in preparing a site specific risk assessment:

- landfill design;
- detailed site hydrogeology;
- distance to environmental receptors; and,
- sensitivity of receiving environment.

Table 3-4 - Landfill Classification Criteria for Disposal of Hydrocarbon Contaminated Waste

Class	A	B	C	D
Hydrocarbon Contaminated Waste (Maximum) (weight%)	2	1	1	0
Consented Volume (Minimum) (m^3)	2,000,000	350,000	35,000	NA*
Water Infiltration (Maximum) (m^3/d)	Not Limited	1.6×10^{-3}	2.4×10^{-3}	NA*
Minimum Liner Thickness (mm)	600	600	No liner	No liner
Leachate Flow to Groundwater[1] (Maximum) (m^3/ m^2/d)	2.3×10^{-4}	8.06×10^{-3}	NA*	NA*
Surface Water Management	Separation and continuous monitoring or retention of discharges	Separation and daily monitoring or retention of discharges	Separation and periodic monitoring of discharges	Limited separation
Landfill Management Plan	Comprehensive and documented	Comprehensive and documented	Key procedures documented	Little or no documentation
Staffing	Trained staff on site at all times	Trained staff on site at all times	Trained staff on site at all times	Staff on site at all times
Waste Acceptance	Prior approval and waste manifest documentation required	Prior approval and waste manifest documentation required	Prior approval required	Prior approval required
Waste Screening	Random load inspections	Random load inspections	Random load inspections	No random load inspections
Leachate Monitoring	Annual monitoring of BTEX and naphthalene	Annual monitoring of BTEX and naphthalene	Not analysed	Not analysed
Groundwater Monitoring	Annual monitoring of BTEX and naphthalene	Annual monitoring of BTEX and naphthalene	Annual monitoring of BTEX and naphthalene	Not analysed
Groundwater Monitoring Results	BTEX and naphthalene not above PQL	BTEX and naphthalene not above PQL	BTEX and naphthalene not above PQL	NA

Note: [1] Calculated using Darcy's Law. To meet this requirement it is therefore necessary to measure leachate head within the landfill.
BTEX – benzene, toluene, xylene and ethyl benzene.
PQL – practical quantitation limit.
* NA – Not Applicable

3.3 Landfill Classifications in Selected Countries

Landfill classifications from the following countries were reviewed and summarised:

- South Africa;
- Australia (New South Wales);
- United States of America;
- Germany.

Table 3-5 summarises the classifications and additional details are provided in Appendix D.

The classifications are associated with standards for landfill development. In general, all provide for a minimum set of requirements for a class of landfill accepting MSW. An additional, more stringent, set of requirements, is provided for another class of landfill for hazardous or industrial wastes.

Waste acceptance criteria for the different classes of landfill are either prescribed or calculated by a set formula.

A comparison of the selected overseas classifications with the CAE Landfill Guidelines, for MSW landfills and the proposed New Zealand landfill classes is given below.

3.3.1 Landfill Classifications

Landfill Classes

All four countries classify MSW landfills separately from landfills accepting waste with more hazardous properties.

In South Africa, New South Wales and Germany, MSW landfills are further divided into different sub-classes.

South Africa has eight sub-classes based on landfill size and leachate production, while New South Wales and Germany each have two, based on waste acceptance.

The CAE Guidelines contain guidance and recommendations on MSW landfills only.

The proposed classification system will separate MSW landfills into two classes. Class A will meet the standard of site selection and design in the CAE Guidelines. Class B will include existing landfills of a lesser standard.

Siting

All classifications outline restrictions or fatal flaws with respect to siting. However, there is a degree of judgement implicit in determining areas that could be unsuitable, or constitute a fatal flaw (for example, in determining unstable areas, sensitive ecological areas, or aquifers vulnerable to pollution).

The CAE Guidelines outline the areas considered to be generally undesirable for landfill siting. However, because they are guidelines, no areas are explicitly restricted or classed as fatal flaws.

Design

All classifications have required, or recommended, prescriptive minimum designs for landfill liners, leachate collection systems and final covers. The New South Wales designs are intended as benchmarks and Germany allows equivalence to the recommended design to be demonstrated.

The United States also has a performance based option whereby proposed liner design must demonstrate compliance with maximum concentration limits (MCLs) for selected contaminants at a compliance point (at the site boundary, or no more than 150 metres from the edge of the landfill).

The CAE Guidelines state that a site specific assessment of effects on the environment must be prepared to characterise the site and local environment, identify environmental receptors and evaluate the potential risks due to the landfill. The Guidelines also recommend three liner designs that have been shown to provide a reasonable level of protection to the receiving environment, for a landfill sited in accordance with the Guidelines.

Operations

All classifications have requirements with respect to the monitoring of waste acceptance and groundwater and surface water monitoring.

The CAE Guidelines make recommendations on waste acceptance monitoring and provide examples of groundwater and surface water monitoring programmes.

All classifications for MSW landfills also set out requirements for the day to day landfill operations in relation to waste handling, and control of nuisances from dust, odour, vermin and vectors. These operational requirements are generally in line with recommended best practice for all landfills.

Table 3-5 - Summary of Overseas Classification Systems

COUNTRY	CLASSIFICATIONS	CRITERIA		
		Siting	**Design**	**Operations**
South Africa	**General** (8 Classes) Based on size and leachate generation **Hazardous** (2 Classes) Based on waste hazard rating Smaller landfills are exempt from many requirements	Areas with fatal flaw are eliminated, including: • flood plains (50yr) • near water bodies; • unstable areas; • sensitive ecological or historical areas; • important aquifers; • important catchment areas; • high groundwater; • incompatible land uses; and • upwind of residential areas.	Based on the type of landfill Small landfills only require a surface drainage system and a leachate detection system. Large and hazardous waste landfills require stormwater diversion (50 yr), leachate collection systems and liners. Liner requirements based on type of landfill with soil liner permeability from $1x10^{-8}$ m/s – $1x10^{-9}$ m/s. Leachate collection system comprising of 150mm of gravel of size between 38-50mm. Active or passive landfill gas management systems may be used.	All landfills must undertake waste acceptance monitoring with larger and hazardous waste landfills required to do an audit every two years. Monitoring of surface and groundwater is required up and downstream before, during and 30years after operation. Collected leachate must be treated to relevant standards with detection systems in place.
Australia (NSW)	Inert (2 Classes) Solid (2 Classes) Industrial	Site must not be within the following areas: • environmentally sensitive; • significant environmental or conservation value; • drinking water catchment; • near dwellings; • near water bodies • near drinking water aquifers • near aquifers vulnerable to pollution; • unstable areas; • floodplains (100yr).	Benchmark techniques are used to provide guidance for solid and hazardous waste landfills No benchmarks given for inert landfills. Solid waste landfills require a clay liner >900mm with permeability <$1x10^{-9}$m/s. Industrial landfills require a flexible membrane liner (>1.5mm with permeability <1x10-11m/s) and a clay liner >900mm with permeability <$1x10^{-9}$m/s. Leachate collection system must comprise 300mm of gravel > 20mm.with permeability	All landfills are required to have waste acceptance procedures and records with industrial landfills using statistically sampling and testing of wastes. A surface water monitoring program must demonstrate that surface water is not polluted by the landfill with upstream and downstream quality monitoring. Any water contaminated by the landfill should be handled as for leachate. Groundwater monitoring (quartile or as demonstrated to be required) should demonstrate that it is not contaminated

			>$1x10^{-3}$ m/s. A gas extraction system should be used to extract and, where possible, combust gas. Industrial waste landfills are required to be double lined with a permeability of >$1x10^{-4}$ m/s in the primary layer and $1x10^{-2}$ m/s in the secondary layer covered with a non-woven filter fabric. Perforated collector pipes should be placed max 50m apart, min 150mm diameter at 1%.	and ensure early detection of any contaminant. Industrial waste landfills should monitor conductivity up and down gradient from the landfill.
USA	Inert Waste Landfill Municipal Solid Waste Landfill (MSWL) (Subtitle D) Hazardous Waste Landfill (HWL) (Subtitle C) Exemptions are made for small landfills with no evidence of groundwater contamination, low rainfall with no alternative.	There are four location restrictions that may or may not apply to all landfills: • floodplains (all landfills); • wetlands (MSWL); • seismic zones (municipal & hazardous); and • unstable areas (municipal & hazardous).	Prescriptive and performance design options for MSWLs: • an approved design that meets the EPA performance standard of maximum contaminant levels; or • a composite liner comprising a synthetic flexible membrane over a >600mm thick layer of soil with hydraulic conductivity <$1x10^{-9}$ m/s; • a leachate collection system must be designed to ensure <300mm depth of leachate. Gas collection and control at sites with capacity in excess of 2.5 million tonnes. HWLs must have two or more liners with a collection and removal system between. Bottom liner must be >900mm of compacted soil with a hydraulic conductivity <$1x10^{-9}$ m/s. Leachate collection system must be designed to ensure <300mm depth of leachate	MSWLs must set up a waste acceptance monitoring procedure with random inspections to detect and prevent disposal of hazardous wastes. HWLs must have a detailed chemical and physical analysis of a representative sample to verify the composition before any waste can be disposed of. Groundwater monitoring must be conducted at MSWLs to assess the quality of upstream and downstream groundwater as MSWLs are monitored twice a year and HWLs as determined statistically. HWLs must ensure leak detection system does not exceed the action detection rate.

Germany	Municipal Solid Waste Landfill (2 Classes) Hazardous Waste Landfill	The following locational restrictions • Karst and fractured areas; • areas for drinking and mineral spring water; • flood plain areas; • wooded areas, nature protection zones and recognized protected areas; • within 300 metres of neighboring residential area; • earthquake areas and active fault zones;	MSWLFs and HWLFs, the following or equivalent: • 750 millimetres with $k < 5 \times 10^{-10}$ m/s (Class 2); • 500 millimetres with $k < 5 \times 10^{-10}$ m/s (Class 1); • 1.5 metres with $k < 5 \times 10^{-10}$ m/s (HWLF); • a synthetic liner layer with a minimum thickness of 2.5mm; • a drainage layer with a minimum thickness of 300 mm with $k > 1 \times 10^{-3}$ metres per second.	Waste acceptance control, monitoring and record keeping. Monitoring of: • groundwater; • settling of the landfill body; • settling of the liner system; • meteorological data; • leachate and other waters; • temperature, at the base of the landfill body.

4.1 Assessment of Classification Systems

It is assumed that two classes of landfill (Class A and Class B) will be instituted, in accordance with the MfE's preferred option, as outlined in Section 1.1.

The three different classification systems, outlined in Section 2.2, and a combination of the systems, are assessed and compared with respect to the following:

- required level of site knowledge, that is, understanding of geology, hydrogeology and surface hydrology;
- requirement for favourable geology;
- requirement for an engineered liner system;
- level of technical robustness, consistency and defensibility;
- clarity and transparency to the public;
- ease of implementation;
- ability to cater for alternative designs and new technology.

Both existing and new landfills are considered. In this case "new" refers to both proposed new landfill sites and lateral expansions of existing landfill sites.

A tiered approach to using the different systems is also discussed.

A summary of the comparison is outlined in Table 4-1.

4.1.1 Prescriptive

A prescriptive system would provide a consistent national approach to landfill classification.

To achieve a Class A classification, a landfill would have to comply with each and every one of the listed requirements. However, in order to provide an appropriate level of requirements with respect to ensuring environmental protection, requirements may be such that many existing landfills, with a high level of security, would not comply with Class A criteria.

A prescriptive system would likely include the following, assuming it were to be based on the CAE Landfill Guidelines (2000):

- location restrictions with respect to landfill siting, for example:
  - high permeability sands or gravels;
  - active faults;
  - geothermal areas;

  - karst geology;
  - minimum distance to groundwater users;
  - minimum distance to surface water bodies;
  - appropriate surrounding land uses;
- minimum design requirements, for example:
  - a liner comprising 900 millimetres of clay or other low permeability soils, compacted in lifts of a maximum of 150 millimetres thick, to achieve a coefficient of permeability not exceeding 1 x 10^{-9} metres per second; or
  - a composite liner comprising a synthetic flexible membrane, 1.5 mm thick, overlying 600 millimetres of clay with a coefficient of permeability not exceeding 1 x 10^{-9} metres per second; or
  - a composite liner comprising a synthetic flexible membrane 1.5 mm thick, overlying a geosynthetic clay liner (GCL), a minimum of 5 millimetres thick, with a coefficient of permeability not exceeding 1 x 10^{-11} metres per second (on expansion), overlying a 600 millimetres thick compacted sub-base layer with a coefficient of permeability not exceeding 1 x 10^{-8} metres per second;
  - maximum design leachate head of 300 millimetres;
  - minimum capacity for stormwater retention based on landfill area;
  - maximum total landfill capacity without a landfill gas collection and disposal system
- minimum operational requirements with respect to:
  - waste acceptance and monitoring;
  - waste compaction;
  - daily and intermediate cover;
  - nuisance control;
  - monitoring.

A prescriptive landfill classification system is likely to be the most straight forward and easiest to implement of the three systems as it has well defined requirements. It would also likely be the most conservative with respect to environmental protection and the degree of redundancy in siting and design.

The required level of site knowledge would be high, as with performance or effects/risk based systems, as detailed characterisation of geology and hydrogeology would still be necessary, to ensure that requirements are met.

Favourable geology would be required, as would an engineered liner. As such, a prescriptive system would likely be the most conservative with respect to a combination of siting and engineered redundancy.

A prescriptive system would be considered to be highly technically robust and defensible. It would be most suited to new landfill sites, where the requirements can be followed, with respect to siting, or incorporated into designs or operating practices. However, it would not be possible to develop landfills to prescriptive criteria in areas where favourable natural site characteristics do not exist or there are no suitable on-site materials for liner construction. A prescriptive system may lead to unnecessary levels of redundancy and cost in areas with good geological and hydrogeological characteristics.

A prescriptive system would not make allowance for alternative designs, or new technology, unless there is a procedure to change the requirements within a reasonable timeframe.

A prescriptive system may result in waste acceptance criteria being less defensible, in terms of effects on the environment, if applied nationally, without regard to site specifics.

Advantages

- nationally consistent;
- easy to implement;
- technically robust;
- clear and transparent.

Disadvantages

- may be conservative, and not allow siting of Class A landfills in some areas;
- may exclude some existing secure landfills from Class A;
- landfill development may involve increased levels of redundancy and cost in some areas;
- may be difficult to cater for alternative designs;
- waste acceptance criteria may be less defensible in terms of effects.

4.1.2 Performance Based

A performance based approach to siting and design, with respect to containment, and operations enables a landfill design flexibility to achieve classification criteria through a combination of natural containment and engineered design. Therefore, a site with less favourable geological characteristics can be improved through engineering, and a site with highly favourable natural characteristics may require little in the way of engineered liner systems. However, it may still be desirable to implement minimum siting exclusions and/or engineering requirements.

There is a need to define a compliance point, at which performance criteria can be determined. This is commonly the site boundary, or a specified distance from the edge of the landfill footprint. The compliance point may not, necessarily, relate to the closest environmental receptor(s).

A more conservative compliance point, for example, at the edge of the landfill footprint, would enable ready comparison between landfill sites and takes into account the following:

- differing substrata underlying the landfill;
- differing hydrogeological conditions;
- the presence of sensitive natural systems adjacent to the landfill.

However, a compliance point at the edge of the landfill footprint may not take into account the natural leachate containment/attenuation characteristics of a site's underlying materials, or the use of a buffer zone with respect to landfill gas and particulate matter.

Use of the site boundary as a compliance point ensures no adverse effects beyond the site boundary. However, site boundaries can move, for example, if land used initially as a buffer is sold or leased.

In order to ensure appropriate provision for use of the underlying characteristics of a site for containment/attenuation and to provide a buffer zone, a combination of the site boundary or a maximum distance from the landfill edge can be used. For example, the USEPA performance criteria (referred to in Section 2.2.2) requires the compliance point to be at the site boundary, or a maximum of 150 metres from the landfill edge.

A performance based system would, likely, include the following:

- maximum contaminant concentrations in groundwater for selected chemical parameters at the compliance point;
- maximum contaminant concentrations in surface/stormwater discharges;
- maximum landfill gas concentration at a compliance point (for example landfill surface);
- minimum landfill gas treatment/disposal system destruction efficiency (if used);
- minimum operational performance requirements with respect to:
  - waste acceptance monitoring;
  - waste compaction;
  - cover;
  - nuisance control;

A performance based landfill classification system is still likely to involve prescriptive requirements with respect to waste acceptance and leachate, groundwater and surface water monitoring.

A performance based landfill classification system is likely to be complex to implement. It would require development of performance criteria for specific discharges of concern (leachate, landfill gas, particulate matter). In addition, it would require development of a methodology to be used to determine if criteria are being, and will continue to be, met (existing landfills) or will be met in the future (new landfills and lateral extensions of existing landfills). Specific models and/or software would need to be prescribed, or developed, to ensure both an appropriate level of assessment with respect to both performance criteria and national consistency.

Models are simplified representations of the real system, and as such, cannot fully reproduce, or predict, all site characteristics. Errors can be introduced as a result of the following:

- simplifying assumptions;
- lack of data;
- uncertainty in data;
- poor understanding of the processes influencing the fate and transport of contaminants;

Modeling for specific contaminants does not take into account the cumulative or synergistic effects on the environment of different contaminants.

Modeling would require review and verification of inputs and outputs, as well as the modeling process.

The required level of site knowledge would be high, as detailed characterisation of geology and hydrogeology would be necessary, but may be less than that needed for an effects/risk based system,.

Favourable geology and hydrogeology could result in an engineered liner not being required for the landfill to meet performance criteria with respect to groundwater contamination.

Favourable geology would not necessarily be required, provided appropriate engineered systems could be developed to compensate for any site deficiencies. Favourable geology would still be desirable to provide a degree of redundancy.

Depending on the location of the compliance point, a performance based system may not be as conservative as a prescriptive system, with respect to a combination of siting and engineered redundancy, but may generally be more conservative than an effects/risk based system. However, there may be instances where detailed effects based assessment is more conservative.

A performance based system would be considered to be highly technically robust and defensible for existing landfills, if a comprehensive monitoring system has been in place for a considerable time and demonstrates compliance with criteria. For new landfill sites it would not be considered as robust due to the dependence on assessment methodology and modeling.

Clarity and transparency would not be as high as a prescriptive system as an understanding of assessment methodology and modeling would be required. For new sites there would likely be extensive requirements for review and verification of assessment and modeling documentation.

A performance based system would allow for alternative designs or new technology.

Advantages

- reduces the level of engineered redundancy within a landfill design;
- takes account of the natural containment characteristics of a site;
- flexibility in terms of siting and design;
- monitoring information can be used in assessing existing landfills;
- may enable cost-effective landfill development throughout the country regardless of geological characteristics of a region.

Disadvantages

- requires complex modeling and therefore subject to associated assumptions and/or errors;
- extensive requirements for review and verification;
- assessment may be expensive.

4.1.3 Effects or Risk Based

An effects/risk based system would be the most complex of the three classification systems. In addition to determining the performance of the natural and engineered containment systems, the environmental receptors with respect to air and water and their sensitivity to the modeled concentrations of contaminants must also be determined. It should be noted that this is a requirement, under the RMA, of the consenting process for any new landfill development.

An effects/risk based approach enables the degree of environmental protection to be determined based on the risk posed to surrounding environmental receptors. Therefore, it is potentially the least conservative approach. As with a performance based approach, an effects/risk based system allows landfill design flexibility to achieve classification criteria through a combination of natural site characteristics and engineered design. However, it is still likely to be desirable to implement minimum siting and/or engineering requirements.

The compliance points with respect to an effects/risk based system are the environmental receptors, as opposed to an arbitrary location for a performance based system. It is usual to consider the most sensitive environmental receptors when undertaking a risk assessment.

An effects/risk based system would likely include the following:

- maximum contaminant concentrations in groundwater and surface water based on the water quality standards/guidelines for the closest/most sensitive receptor (for example drinking water standards or guidelines for protection of aquatic species;
- maximum landfill gas concentration at a receptor;

- minimum landfill gas treatment/disposal system destruction efficiency (if used);
- maximum effect on receptors with respect to:
  - cover;
  - nuisance control.

An effects/risk based landfill classification system is still likely to involve prescriptive requirements with respect to waste acceptance and leachate, groundwater and surface water monitoring.

As with a performance based system, it may be desirable to set minimum siting exclusions and engineering requirements.

An effects/risk based landfill classification system is likely to be the most complex to implement. It would require development of effects criteria for specific discharges of concern and receptors (leachate; landfill gas; particulate matter; people; stock; aquatic fauna) where these do not already exist.

As with a performance based system, it would require development of a methodology to be used to determine if criteria are being, and will continue to be, met (existing landfills) or will be met in the future (new landfills and lateral extensions of existing landfills). Specific models and/software would need to be prescribed, or developed, to ensure both an appropriate level of assessment with respect to both effects criteria and national consistency.

Modeling with respect to effects at existing landfills would, in most cases, be considerably more complex and expensive than for a performance based system. Assessment would need to be undertaken by the classification authority or, because of likely expense, by the landfill owner/operator, for review by the classification authority.

The required level of site knowledge would be higher than that required for a performance based system as detailed characterisation of receiving environments would be required in addition to geology, hydrogeology and surface hydrology. An understanding of the sensitivity of the receiving environment due to seasonal changes would also be required.

As with a prescriptive system, favourable geology and hydrogeology could result in an engineered liner not being required for the landfill to meet performance criteria with respect to groundwater contamination.

Favourable geology would not necessarily be required, provided appropriate engineered systems could be developed to compensate for any site deficiencies. Favourable geology would still be desirable to provide a degree of redundancy.

Previous monitoring information could provide a basis for the assessment of existing landfills.

An effects/risk based system would be considered to be highly technically robust and defensible for existing landfills, if a comprehensive monitoring system has been in place for a considerable time and demonstrates compliance with criteria. For new landfill sites the robustness of the assessment would be dependent on the detail of the methodology for modeling, and verification of the modeling by monitoring.

Clarity and transparency would be similar to a performance based system as an understanding of assessment methodology, modeling and the receiving environments would be required. For new sites there would likely be extensive requirements for review and verification of assessment and modeling documentation, as for any new landfill development.

An effects/risk based system would allow for alternative designs or new technology.

Advantages

- examines the actual effects of the landfill on receiving environment(s);
- potentially reduces the level of engineered redundancy within a landfill design;
- takes account of a sites natural containment characteristics;
- flexibility in terms of siting and design;
- monitoring information can be used in assessing existing landfills;
- may enable cost-effective landfill development throughout the country regardless of geological characteristics of a region.

Disadvantages

- requires complex investigations and modeling and therefore subject to associated assumptions and/or errors;
- requires detailed knowledge of receiving environment;
- extensive requirements for review and verification;
- most expensive assessment system.

4.1.4 Combination Classification System

A classification system could use a combination of prescriptive, performance and effects/risk based criteria for different elements. This would be an attempt to use the most appropriate or logical system for different elements to maximise their advantages, while minimising any undue complexity or cost.

For example, a system could use the following approach:

- prescriptive criteria with respect to minimum operational requirements for:
  - waste compaction;
  - daily and intermediate cover;

  - nuisance control;
  - monitoring;
- prescriptive criteria with respect to minimum siting exclusions;
- prescriptive criteria with respect to minimum requirements for a liner and leachate collection system;
- performance or effects/risk criteria with respect to containment and groundwater contamination;
- effects/risk based criteria with respect to surface water contamination;
- effects/risk based criteria with respect to landfill gas and particulate emissions;

Such a system would enable certainty with respect to key construction and operational issues while enabling the flexibility associated with performance and effects/risk based systems.

The level of site knowledge required would be high and favourable geology desirable. An engineered liner is likely to be required.

While such a system would be technically robust, the complexity associated with modeling would still exist.

4.1.5 Tiered Classification Methodology

This classification methodology would use prescriptive, performance based and effects/risk based classification systems progressively, in a tiered manner. An assessment would initially be undertaken using prescriptive criteria. The siting, design or operations factors that do not meet prescriptive criteria would then be assessed using performance criteria. The remaining siting, design or operations factors that do not meet performance criteria would then be assessed using effects/risk based criteria.

A tiered methodology would likely be less time consuming than a completely performance or effects/risk based classification systems, as performance or effects/risk based criteria would be used only with respect to those factors that did not meet prescriptive criteria. It would retain the flexibility and potential for cost effective landfill development associated with the performance and effects/risk based classification systems. However, it would be subject to the disadvantages associated with complex investigations and modeling, extensive requirements for review and verification and costs when performance or effects/risk based criteria are used.

Table 4-1 - Assessment of Landfill Classification Systems

	Ease of Implementation		Required Level of Site Knowledge		Favourable Geology		Engineered Liner		Technical Robustness		Clarity and Transparency		Alternative Designs or New Technology	
Classification System	Existing	New	Existing	New	Existing	New	Existing	New	Existing	New	Existing	New	Existing	New
Prescriptive eg. Subtitle D, CAE siting criteria	Straight forward	Straight forward	High	High	Required	Required	Required	Required	High	High	High	High	No	No[4]
Performance Based eg. Meet MCL at downgradient site boundary or compliance point	Complex	Complex	High	High	Desired[1]	Desired[1]	May be Required	May be Required	High[2]	Med[1]	Med[1]	Med[3]	Yes	Yes
Site-specific Effects Based Meet effects criteria for most sensitive receptor	Complex	Complex	High	High	Desired[1]	Desired[1]	May be Required	May be Required	High[2]	Med[1]	Med[1]	Med[3]	Yes	Yes
Combination A combination of prescriptive, performance and/or effects based criteria	Complex	Complex	High	High	Desired[1]	Desired[1]	Likely to be Required	Likely to be Required	High	High	Med[1]	Med[3]	Yes	Yes

[1] Site specific and dependent on approach and model used for consistency and robustness.
[2] Dependent on appropriate comprehensive monitoring based assessment.
[3] Significant requirements for documentation, review and verification.
[4] Can have some flexibility if there is a procedure to change the requirements.

5.1 Recommended Classification Methodology

It is recommended that a tiered methodology be used to classify landfills within New Zealand.

As outlined in Section 4.1.5, the methodology would use prescriptive, performance based and effects/risk based classification systems progressively, in a tiered manner. Prescriptive requirements would be used to filter out those elements of siting, design and operations that require further analysis to determine their classification. In this way, landfill sites that comply with the CAE Landfill Guidelines (2000) or best practice with respect to some or all of the relevant siting, design and operations issues would have reduced requirements for further investigation or analysis for their classification to be determined.

The methodology would involve the development of criteria specific to New Zealand (for example, based on the CAE Landfill Guidelines (2000)), or adoption of criteria currently used in overseas countries. Criteria would include appropriate prescriptive, performance based and effects/risk based requirements for siting, design and operations for Class A landfills.

A classification assessment would be undertaken as described below, and outlined diagrammatically in Figure 5-1.

An initial assessment would be undertaken using the prescriptive criteria. If the landfill complies with all criteria then it would be classified as Class A.

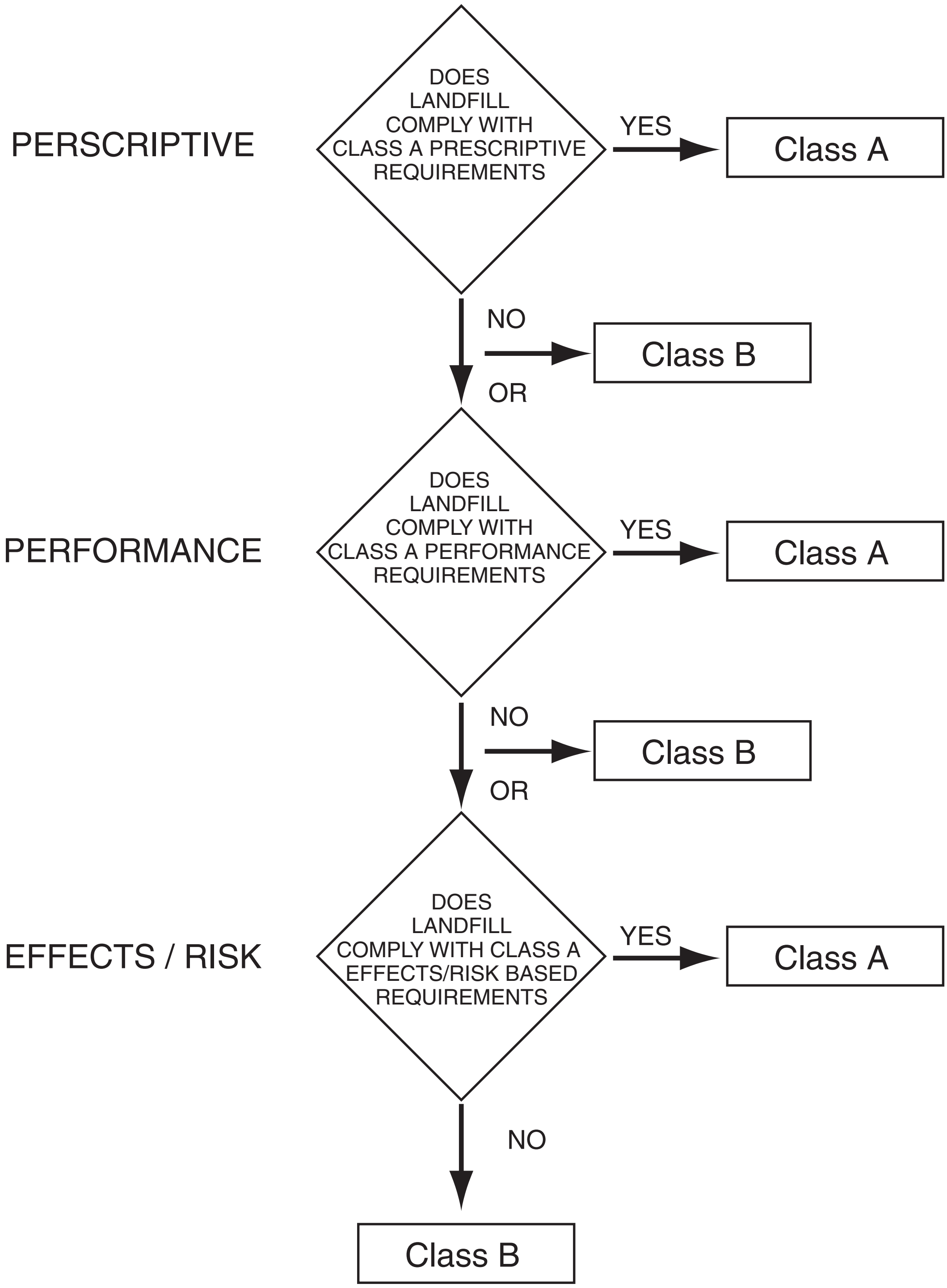
If the landfill does not comply with all criteria then it would be classified as Class B. However, if the owner/operator does not want a Class B classification then it has the opportunity to demonstrate that those elements, which did not comply with prescriptive requirements, can comply with performance based criteria. If it can be demonstrated that the landfill complies with performance based criteria then it becomes a Class A landfill.

If the landfill does not comply with the performance based criteria then it would remain a Class B landfill. However, the owner/operator would then have the opportunity to demonstrate that those elements, which did not comply with performance based criteria, can comply with effects/risk based criteria. If they comply with effects/risk based criteria then the landfill becomes a Class A landfill. If not, it remains a Class B landfill.

Poor operational practices could reduce the overall classification of a well sited and designed landfill from A to B, but good operations could not result in an improved classification for a site which does not meet Class A requirements for siting and design.

An improved design for a lateral expansion may improve the siting and design classification from B to A. An overlay liner on and existing unlined landfill could also improve the design classification from B to A in respect of future disposal at the site.

LANDFILL CLASSIFICATION METHODOLOGY TIERED APPROACH



URS
Woodward Clyde
Dames & Moore

LANDFILL CLASSIFICATION METHODOLOGY
FIGURE 5-1

5.2 Classification Process

5.2.1 Mechanisms for Implementation

It is assumed that if a landfill classification system, with associated waste acceptance criteria, were developed and implemented it would be as either a:

- National Environmental Standard, under the RMA;
- Code of Practice, under the Hazardous Substances and New Organisms Act 1996 (HSNO); or
- Ministry for the Environment Guideline.

These three mechanisms have different requirements and degrees of complexity in development and implementation and the mechanism under which a landfill classification system was to be instituted would, to a large extent, dictate means of implementation.

While a discussion of potential mechanisms for implementation is beyond the scope of this report, the following are addressed below:

- classification criteria and assessment procedure;
- relationship between landfill classification and landfill standards;
- implementation of assessment procedure;
- classification assessor;
- potential classification authorities;
- MfE landfill intervention under the Landfill Management Programme.

5.2.2 Classification Criteria and Assessment Procedure

Prior to the classification methodology being put in place, the classification criteria and assessment procedure would need to be determined. In addition, models and/or software for undertaking assessments would have to be investigated and/or developed and then specified.

The following would need to be established:

- prescriptive criteria for siting, design and operations. These could be based on a combination of:
  - overseas standards;
  - New Zealand landfill guidelines;
  - existing industry standard/best practices;

  - criteria developed as a result of studies undertaken with respect to a New Zealand landfill classification;
- performance and effects/risk based criteria for siting design and operations. These could be based on:
  - overseas performance/effects standards;
  - New Zealand guidelines for human health, stock health and environmental protection (for example, ANZECC Guidelines);
  - overseas guidelines/standards) for human health, stock health and environmental protection (for example, USEPA standards);
  - New Zealand Standards Association Standards, where applicable (for example, noise standards);
  - existing industry standard practices;
  - criteria developed as a result of studies undertaken specifically for a New Zealand landfill classification;
  - HSNO regulations relating to environmental exposure limits (EELs) and tolerable exposure limits (TELs) for humans;
- appropriate models to estimate contaminant discharges and concentrations in the surrounding environment. These could include:
  - existing models, (for example HELP and LANDSIM for leachate production and discharges, MODFLOW and WinTran for groundwater contaminant transport and the USEPA LandGEM (landfill gas generation), AUSPLUME (dispersion) and a human health risk assessment methodology for air discharges);
  - developing models specifically for a New Zealand landfill classification assessment;
- appropriate systems for verification and review of modeling inputs and outputs;
- minimum prescriptive requirements for siting, design and operations to be used in conjunction with performance/effects based criteria, if appropriate.

Appropriate leachate concentrations of contaminants would need to be set, for use with performance and effects/risk based criteria, in order to estimate contaminant concentrations at a compliance point or receiving environment. These could be based on leachable concentrations for acceptance criteria.

It is assumed that the Ministry for the Environment would be responsible for the development of assessment criteria and determining any associated procedures, models or software to be used in determining a landfill's classification. However, a significant portion of this work could be undertaken through external contract.

5.2.3 Relationship Between Landfill Classification and Landfill Standards

As stated in Section 1.3, the classification methodology is not intended to be used to set standards for landfill siting, design or operations, but rather to define those landfills with the appropriate siting, design and operational characteristics for different waste acceptance criteria.

In New Zealand there are no binding standards for landfill siting, design, operations or monitoring. All such requirements are determined on a site specific basis, in accordance with the RMA, by the appropriate consent authority, or the Environment Court. However, a landfill classification system would assist in the process of determining appropriate waste acceptance criteria.

This report has assumed that Class A landfills will be sited, designed and operated in accordance with the recommendations in the CAE Landfill Guidelines (2000) and Class B landfills would be those developed to a lesser standard.

A number of existing landfills would be unlikely to meet Class A requirements, when classified. In addition, it is possible that new landfills may receive resource consents and yet not meet Class A requirements. In these cases the classification system and associated acceptance criteria would determine acceptance limits for specific wastes with hazardous properties, but not the landfill's ability to receive municipal solid waste. Waste acceptance criteria, for waste with hazardous properties, would be set at the more restrictive limits for Class B landfills.

In all cases it would be accepted that the municipal solid waste stream contains small quantities of wastes with hazardous properties, for which it would be impractical to screen at landfills.

5.2.4 Implementation of Assessment Procedure

It is assumed that all landfills would be classified using Class B as the default classification, until Class A status is demonstrated.

The assessment procedure, to classify a landfill, could be undertaken at the following times:

- during the resource consent application process (new landfills);
- during the resource consent review process (existing landfills);
- at a time specified for compliance with a national standard or guideline in respect of waste acceptance criteria (existing landfills).

Resource Consent Application Process

The information required to determine the classification of a new landfill would be presented as part of the resource consent application documentation. The consent authority would review the information and classification, and thereby the waste acceptance criteria, would be finalised at the time consents are considered.

This approach would ensure that all new landfills, or existing landfills seeking new consents, would be classified prior to receiving waste. However, existing landfills would continue to operate with their existing waste acceptance criteria, which may be at variance with the classification criteria. This could lead to wastes with hazardous properties being disposed of at landfills with a lower level of containment, but less restrictive acceptance criteria.

Resource Consent Review Process

At the time of consent review, initiated by either the consent holder or consent authority in accordance with review conditions, the classification information would be presented. The consent authority would then review the information and finalise classification.

A number of landfill resource consents also have a condition requiring review of waste acceptance criteria in response to the introduction of a national definition of hazardous waste or standard or guideline relating to waste acceptance criteria.

This approach would ensure that all existing landfills would be classified within a timeframe of approximately five years (the usual time period between consent reviews). However, as with the previous option, existing landfills would continue to operate with their existing waste acceptance criteria, which may be at variance with the classification criteria. This could lead to wastes with hazardous properties being disposed of at landfills with a lower level of containment, but less restrictive acceptance criteria.

Specified Time

At the same time as a classification system is instituted a time, by which all landfills must be classified, could be specified. This approach would ensure that all landfills were classified within a short timeframe, thereby reducing the potential for movement of wastes with hazardous properties to inappropriate sites.

5.2.5 Classification Assessor

There are two options with respect to the party that could undertake the classification procedure to assess landfills, namely;

- the landfill owner/operator; or
- a separate classification authority.

Landfill Owner/Operator

In this case the landfill owner/operator would undertake an assessment and apply to the classification authority for an “A” classification on the basis of those results. The owner/operator would provide supporting technical information in much the same way as occurs with resource consent applications.

The classification authority would review the information, which may include requesting additional information or assessment, and then make a determination on the classification.

It would be incumbent on the landfill owner/operator to demonstrate that an "A" classification is justified. The classification would be made on technical grounds only, and not involve a formal hearing process.

Classification Authority

In this case a classification authority would undertake an initial assessment using prescriptive criteria and classify the landfill accordingly.

Information on which to base a landfill's classification could be obtained from the following sources:

- supporting documentation for resource consent applications;
- resource consents;
- ongoing monitoring of site operations, groundwater and surface water;
- specific investigations to provide sufficient information by which to undertake an assessment.

If the landfill owner/operator is then dissatisfied with the classification it could apply for a re-assessment based on performance and/or effects/risk based criteria. It would have to supply supporting information, to the classification authority, as in the case above.

5.2.6 Potential Classification Authorities

There are a number of options for agencies, or bodies that could carry out landfill classifications. These include:

- regional councils;
- Ministry for the Environment, or a central classification authority;
- accredited organisations or individuals.

Regional Councils or Consent Authorities

Regional councils would be a logical choice as they administer landfill resource consents under the RMA.

It is acknowledged that standards/requirement for landfills differ from region to region. However, as classification criteria and assessment requirements would be technical and dictated by MfE, it is not expected that classification standards would vary significantly across the country.

Standards could vary if there was a significant subjective component to the classification methodology.

The degree of technical knowledge required would be relatively high, due to the likely complex nature of the assessment procedures. The appropriate expertise may not be available within some regional councils. However, this could be overcome by contracting outside expertise.

Ministry for the Environment, or Central Classification Authority

The Ministry for the Environment could undertake the role of classification authority if a centralised authority was desired. However, this may been seen as a departure from the Ministry's core functions.

As with regional councils, the appropriate expertise may not be available within the organisation. However, this could be overcome by contracting outside expertise.

Accredited Organisations or Individuals

Appropriately qualified and experienced organisations and/or individuals could be accredited by the Ministry for the Environment as classification authorities, or as appropriate outside experts for contracting by regional councils or the Ministry.

This would likely provide a small number of qualified people and help ensure consistency throughout the country.

5.2.7 MfE Landfill Intervention Under the Landfill Management Programme

If a landfill classification system, and associated waste acceptance criteria, were developed as an MfE Guideline it is likely that consent authorities, applicants and submitters would have regard to it. It could result in classification being undertaken by the applicant or consent authority as part of the consent application or review process.

The MfE, as part of it's purchase agreement with the Minister, is required to monitor all landfill consent applications and determine if intervention is appropriate. The Ministry could continue to review consent applications and consent reviews, as part of the Landfill Management Programme, taking the Landfill Classification Guideline into considertion. As it has done previously, the Ministry could then make a submission to the consent application/review process for consideration by the consent authority, or undertake negotiations with the parties involved in the process, as appropriate.

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Landfill Classification Focus Group

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Dave Hadfield – Gisborne District Council

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Barry Strong – Wellington Regional Council

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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.

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).

Background level The ambient level of a contaminant in the local area of the site under consideration.

Bio-accumulation Accumulation within the tissues of living organisms.

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

Cleanfill A cleanfill is any landfill that accepts only cleanfill material as defined below.

Cleanfill material Material that when buried will have no adverse effect on people or the environment. Cleanfill material includes virgin natural materials, such as clay, soil and rock, and other inert materials, such as concrete or brick that are free of:

- combustible, putrescible, degradable or leachable components
- hazardous substances
- any products or materials derived from hazardous waste treatment, hazardous waste stabilisation or hazardous waste disposal practices
- materials that may present a risk to human or animal health such as medical and veterinary waste, asbestos, or radioactive substances
- liquid waste.

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

Co-disposal The disposal of hazardous waste by mixing, in an informed and predetermined manner, with municipal refuse, so as to use the attenuation and biochemical processes operating within the landfill to reduce the environmental impact from the mixed waste to an insignificant level.

Contaminant	Any substance (including gases, liquids, solids, and micro-organisms) or energy (excluding noise) or heat, that either by itself or in combination with the same, similar, or other substances, energy or heat: a) when discharged into water, changes or is likely to change, the physical, chemical, or biological condition of water; or b) when discharged onto or into land or into air, changes or is likely to change, the physical, chemical, or biological condition of the land or air onto or into which it is discharged.
Corrosivity	The ability of a substance to corrode metals or to cause severe damage by chemical action when in contact with living tissue.
Designation	A provision made in a district plan to give effect to a requirement made by a requiring authority under section 168 or 168A, or clause 4 of the First Schedule of the RMA.
Diffusion	Migration of dissolved substances within a fluid due to random movement of particles (this is significant when flows are low).
Down-gradient	In the direction of decreasing water level (i.e. in groundwater this is following the hydraulic gradient)
Discharge	Includes emit, deposit and allow to escape.
Discharge permit	A consent to do something that otherwise would contravene section 15 of the RMA.
Down-gradient	In the direction of decreasing water level (in groundwater this is following the hydraulic gradient).
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment, interacting as a functional unit.
Ecotoxic	Capable of causing ill health, injury, or death to any living organism.
Environment	Includes: a) ecosystems, including people and communities b) all natural and physical resources c) those qualities and characteristics of an area that contribute to the community's reasonable enjoyment d) the cultural, economic, aesthetic, and social conditions that affect the above.

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

Geologic formation An assemblage of rocks which have some characteristics in common, whether of origin, age or composition. Normally used to refer to an identifiable rock unit within a particular area.

Geomembrane A polymeric sheet material that is impervious to liquid as long as it maintains its integrity.

Geosynthetic clay liner (GCL)
A relatively thin layer of processed clay (typically bentonite), either bonded to a geomembrane or fixed between two sheets of geotextile.

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

Groundwater All water 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.

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

- explosiveness
- flammability
- capacity to oxidise
- corrosiveness
- toxicity
- ecotoxicity.

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

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.

Industrial or trade premises

a) Any premises used for industrial or trade purposes; or

b) any premises used for the storage, transfer, treatment, or disposal of waste materials or for other waste management purposes, or used for composting organic materials; or

c) any other premises from which a contaminant is discharged in connection with any industrial or trade process, and includes any factory farm, but does not include production land.

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

Industrial waste landfill
An industrial waste landfill is any landfill that accepts industrial waste.

Infiltration The entry of water, usually as rain or melted snow, into soil or a landfill.

Land use consent A consent to do something that otherwise would contravene sections 9 or 13 of the RMA.

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

Landfill gas Gas generated as a result of the decomposition processes on biodegradable materials deposited in a landfill. It consists principally of methane and carbon dioxide, but includes minor amounts of other components.

Leachate Liquid that has percolated through or emerged from solid waste, and that contains dissolved and/or suspended liquids and/or solids and/or gases.

Monitoring A continuous or regular periodic check to determine the ongoing nature of the potential hazard, conditions along environmental pathways and environmental impacts of landfill operations to ensure that the landfill is performing according to design.

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

Municipal solid waste landfill
A municipal solid waste landfill is any landfill that accepts municipal solid waste.

Natural attenuation Natural processes which reduce the concentration of contaminants in groundwater.

NMOC Non-methane organic compound

Oxidise The ability to cause or contribute to the combustion of other material by yielding oxygen.

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”.

Plume An ellipsoidal volume of water containing elevated levels of contaminants, emanating from a point or line source of those contaminants.

Receptor A resource (including humans) that may be affected by a contaminant, via a pathway.

Resource consent A coastal permit, discharge consent, land use consent or water permit granted under the RMA. It includes all conditions to which the consent is subject.

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.

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.

Surface water Any accumulation of water on the ground surface including puddles, ponds, lakes, wetlands, drains, ditches, springs, seepages, streams and rivers.

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 after exposure to the toxin, and chronic toxicity means the effects that occur either after prolonged exposure or an extended period after initial exposure.

Transfer station A facility where wastes are transferred from smaller vehicles (cars, trailers, trucks) into larger vehicles for transport to a disposal site.

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

Upgradient In the direction of increasing hydraulic head (i.e. 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.

Waste	Any material, whether it is liquid, solid or contained gas, that is unwanted and unvalued and discarded or discharged by its holder.
Water permit	A consent to do something that otherwise would contravene section 14 of the RMA.

Appendix A
Project Brief

Appendix A
Project Brief

CONTRACT BRIEF – INVITATION FOR DETAILED PROPOSAL

Basis for Landfill Classification System

The Ministry for the Environment invites proposals from selected consultants for a contract to prepare a report entitled ***"The Basis for Landfill Classification Within New Zealan*d"**.

The report will outline what extent landfill design, siting criteria, and operational management procedures should be considered during the development of a landfill classification system. The Ministry will use the report during the undertaking of a cost/benefit analysis on landfill classification and waste acceptance criteria for wastes with hazardous properties.

The closing date for proposals is **Wednesday 16th May 2001.**

Background

During April 2001 the Ministry for the Environment released an Issues and Options report entitled "Landfill Acceptance Criteria for Wastes with Hazardous Properties". The report notes that a nationally consistent approach to waste acceptance criteria is required.

A preferred option is identified within the report. This involves the development of a landfill classification system together with prescriptive lists defining what concentration thresholds are acceptable for disposal in the differing classes of landfill.

The preferred option proposes landfills be classified according to the degree of environmental protection they offer, the basis for the division being whether the landfill meets the design standards and siting criteria recommended in the Centre for Advanced Engineering 2000 Landfill Guidelines, that is:

- Class A ("designed landfills) – landfills meeting site selection and design standards outlined in the CAE 2000 Landfill Guidelines
- Class B ("yesterday's old tips and dumps") – waste disposal facilities not meeting site selection and design standards outlined in the CAE 2000 Landfill Guidelines).

However, the recommended design and siting criteria contained within the Landfill Guidelines are a mixture of prescriptive, performance and site-specific based criteria. For example, the Landfill Guidelines recommend three liner designs that have shown to adequately protect the environment. However, the Landfill Guidelines also note that other liner designs could be suitable at some sites after taking into account specified site-specific factors (e.g. landfill size, favourable geological conditions).

The basis for dividing landfills into differing classes must be robust and transparent to provide clarity and certainty. Yet it must also be flexible enough to allow the incorporation of alternative designs that meet acceptable performance standards, the adoption of advances in technology and increased understanding of landfill processes.

The outputs of this contract will be an essential component when considering future policy options on the disposal of hazardous waste. Therefore, even if submissions on the Issues and Options report overwhelmingly oppose the development of a landfill classification system, and/or further analysis by the Ministry concludes in not proceeding with a classification system, this contract still needs to undertaken.

A separate contract is being tendered to develop the prescriptive lists defining what concentration thresholds are acceptable for disposal in the differing classes of landfill. This work will consider the most suitable method of testing, as well as defining actual concentration limits.

Associated Project – "Guide to Managing Cleanfills"

The landfill classification system considered in this contract focuses on a system to manage the disposal of *wastes with hazardous properties*. It does not extend to define the boundaries between cleanfill material and standard municipal waste.

This is being covered by a guide currently being prepared for the Ministry entitled "Guide to Managing Cleanfills". An important aspect of this guide is developing a definition of cleanfill and waste acceptance criteria for cleanfill sites. The cleanfill definition will determine what wastes are cleanfill or inert, wastes not meeting this definition will be unsuitable for disposal at a cleanfill site and will have to be disposed of at a landfill accepting municipal wastes.

Cleanfill operators will use the definition as the basis for deciding what wastes are acceptable at their site, it will therefore act as a generic form of waste acceptance criteria for cleanfill sites. The document will also set recommended siting and design standards, as well as recommended operational and management practices.

Beca Steven is preparing this guide. A first draft has been prepared, and is available to tenderers upon request.

Project Requirements and Specifications

The report will be used by the Ministry as the basis for detailing how landfills will be classified for the purpose of acceptance criteria for wastes with hazardous properties. The report will need to address the extent to which the following factors should, if at all, be considered when classifying landfills:

- Landfill liner design
- Landfill siting
- Any other aspects of landfill design – e.g. leachate collection system, landfill gas collection system
- Alternative landfill designs
- Landfill operations
- Any other factors not listed above.

An important part of the report will be the development of a table or matrix, which will summarise the factors that need to be considered in a landfill classification system.

The Ministry will consider the mechanics of who would undertake landfill classification and how they would do it. However we are interested in obtaining viewpoints on:

- Who should undertake the classification – a national body, or, undertaken regionally following national sourced guidelines
- Process for reassessing landfill classifications, for example upgrading of landfills.

It is important to note that an analysis of the overall framework proposed within the Issues and Options report, i.e. the division of landfills into two classes – Class A and Class B is not part of the contract.

The Ministry will be setting up a "Landfill Classification Focus Group". The purpose of this group is to act as peer reviewers during the production of this report. An important part of the development of the report will be presenting a draft of the report to the focus group. The focus group will comprise members of district councils, regional councils, private landfill operators, hazardous waste generators and treaters, and other interested parties.

The Outputs (with timeline) Required Include:

1. The Ministry for the Environment invites detailed proposals by **Wednesday 16th May** 2001 for a contract to prepare a report entitled ***"The Basis for Landfill Classification Within New Zealand"***.
2. Ministry for the Environment will select consultancy by **Friday 25th May** 2001.
3. First draft must be prepared in consultation with the Landfill Classification Focus Group. One or two meetings will need to be held with the Focus Group. Submit first draft to Landfill Classification Focus Group by **Friday 20th July 2001.**
4. Second draft of report to be prepared by **Friday 24th August 2001**. Submit to Ministry for the Environment and the Landfill Classification Focus Group. All peer review comments must be considered and assessed.
5. Final draft of report to be submitted to Ministry for the Environment and Landfill Classification Focus Group by **Friday 14th September 2001.**
6. Any alterations to be completed by **Friday 28th September 2001**. Changes to be made by consultancy. Three hard copies and two electronic copies (in rich text format) are to be provided to the Ministry for the Environment by **Friday 5th October 2001.**

The Ministry will retain ultimate ownership and copyright over the report.

Peer Review and Quality Requirements

As previously mentioned the report will need to be developed in conjunction with Ministry for the Environment and the Landfill Classification Focus Group.

Early drafts of the report are also likely to be circulated to the Ministry's Hazardous Waste Technical Review Group and members of the Landfill Review Group.

Reporting and Liaison Arrangements

The Ministry will require progress reports once a month to be sent to the Project Manager. The Ministry expects that the successful consultant(s) will remain in close contact with the Ministry's Project Manager during the development of the Guide, and that any difficulties will be reported as soon as they arise.

Payment of Fee

It is proposed that three payments will be made. Each payment will be made once the following are successfully completed:

7. Consultant(s) selected by Ministry for the Environment – May 2001 – initial payment of 20% of value of contract.

8. First draft document completed in consultation with Landfill Classification Focus Group – further 35% of contract.

9. Final copies of Guide (hard and electronic) supplied to Ministry September 2001 – remaining 45% of contract.

Penalties will be applied if the final report is not satisfactorily completed by the agreed date.

Detailed Proposal

A detailed proposal for this contract is invited by **Wednesday 16th May 2001.** The proposal should include a description of the competence of the people who will be developing the report. The successful consultancy will have:

- Proven written and communication skills.
- Detailed knowledge of landfill/environmental engineering practices, siting criteria and landfill management.
- Detailed knowledge of landfill/environmental science.
- Environmental management and science qualifications.
- Practical understanding of New Zealand landfills. Background knowledge of the types of wastes disposed of in New Zealand landfills.
- Good understanding of the Resource Management Act 1991.
- An understanding of the implications of the HSNO Act on hazardous waste management practices.
- Referees.

The proposal should detail the methodology and the proposed structure (Table of Contents) of the document including a discussion on the content of each chapter. It should also include a total price (with detailed break down of fees and expenses) and proposed timetable. The Ministry encourages joint proposals from prospective tenderers.

Appendix A
Project Brief

Project Manager

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Appendix B
Processes Controlling Sub-surface Contaminant Transport

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Processes Controlling Sub-surface Contaminant Transport

Physical Processes

Advection

Advection is the process by which solute contaminants are transported by the overall motion of flowing ground water. A non-reactive solute will be transported at the same rate and in the same direction as ground water flow. Advective transport is chiefly a function of the subsurface hydraulic conductivity distribution, porosity, and hydraulic gradients.

Hydraulic conductivity is a measure of the ability of geologic media to transmit fluids. It is a function of the size and arrangement of water-transmitting openings (pores and fractures) in the media and of the characteristics of the fluids (density, viscosity, etc.). Spatial variations in hydraulic conductivity are referred to as heterogeneities. A variation in hydraulic conductivity with the direction of measurement is referred to as anisotropy.

Variable hydraulic conductivity of the geologic formation may cause ground-water flow velocities to vary spatially. Variations in the rate of advection may result in non-uniform plume spreading. The changes in aquifer properties that lead to this variability in hydraulic conductivity may be three-dimensional. If the geologic medium is relatively homogeneous, it may be appropriate, in some instances, to assume that the aquifer properties also are homogeneous.

Secondary porosity in rock may be caused by the dissolution of rock (for example, karst) or by regional fracturing (for example, greywacke). In soils, secondary porosity may be caused by desiccation cracks or fissures. Fractures or macropores respond quickly to rainfall events and other fluid inputs and can transmit water rapidly along unexpected pathways. Secondary porosity can result in localized high concentrations of contaminants at significant distances from the facility. The relative importance of secondary porosity to hydraulic conductivity of the subsurface depends on the ratio of fracture hydraulic conductivity to intergranular hydraulic conductivity. For scenarios in which fracture flow is dominant, the relationships used to describe porous flow (Darcy's Law) do not apply.

Dispersion

Hydrodynamic dispersion is a non-steady, irreversible mixing process by which a contaminant plume spreads as it is transported through the subsurface. Dispersion results from the effects of two components operating at the microscopic level: mechanical dispersion and molecular diffusion.

Mechanical dispersion results from variations in pore velocities within the soil or aquifer and may be more significant than molecular diffusion in environments where the flow rates are moderate to high.

Molecular diffusion occurs as a result of contaminant concentration gradients; chemicals move from high concentrations to low concentrations. At very slow ground-water velocities, as occur in clays and silts, diffusion can be an important transport mechanism.

Appendix B
Processes Controlling Sub-surface Contaminant Transport

Mechanical Filtration

Mechanical filtration removes contaminants from groundwater that are larger than the pore spaces of the soil. Thus, the effects of mechanical filtration increase with decreasing pore size within a medium. Filtration occurs over a wide range of particle sizes. The retention of larger particles may effectively reduce the permeability of the soil or aquifer.

Physical Sorption

Physical sorption is a function of Van der Waals forces, and the hydrodynamic and electrokinetic properties of soil particles. Sorption is the process by which contaminants are removed from solution in ground water and adhere, or cling, to a solid surface. The distribution of a contaminant between the solution and the solid phase is called partitioning.

Multiphase Fluid Flow

Multiphase fluid flow occurs because many solvents and oils are highly insoluble in water and may migrate in the subsurface as a separate liquid phase. If the viscosity and density of a fluid differ from that of water, the fluid may flow at a different rate and direction than the ground water. If the fluid is more dense than water it may reach the bottom of the aquifer (top of an aquitard) and alter its flow direction to conform to the shape and slope of the aquitard surface.

Chemical Processes

Precipitation/dissolution

Precipitation/dissolution reactions can control contaminant concentration levels. The solubility of a solid controls the equilibrium state of a chemical. When the soluble concentration of a contaminant in leachate is higher than that of the equilibrium state, precipitation occurs. When the soluble concentration is lower than the equilibrium value, the contaminant exists in solution. The precipitation of a dissolved substance may be initiated by changes in pressure, temperature, pH, concentration, or redox. Precipitation of contaminants in the pore space of an aquifer can decrease aquifer porosity. Precipitation and dissolution reactions are especially important processes for trace metal migration in soils.

Chemical Sorption

Chemical adsorption/desorption is the most common mechanism affecting contaminant migration in soils. Solutes become attached to the solid phase by means of adsorption. Like precipitation/dissolution, adsorption/desorption is a reversible process. However, adsorption/desorption generally occurs at a relatively rapid rate compared to precipitation reactions.

Appendix B
Processes Controlling Sub-surface Contaminant Transport

The dominant mechanism of organic sorption is the hydrophobic attraction between a chemical and natural organic matter that exists in some aquifers. The organic carbon content of the porous medium, and the solubility of the contaminant, are important factors for this type of sorption.

There is a direct relationship between the quantity of a substance sorbed on a particle surface and the quantity of the substance suspended in solution. Predictions about the sorption of contaminants often make use of sorption isotherms, which relate the amount of contaminant in solution to the amount adsorbed to the solids. For organic contaminants, these isotherms are usually assumed to be linear and the reaction is assumed to be instantaneous and reversible. The linear equilibrium approach to sorption may not be adequate for all situations.

Redox Reactions

Oxidation and reduction (redox) reactions involve the transfer of electrons and occur when the redox potential in leachate is different from that of the soil or aquifer environment. Redox reactions are important processes for inorganic compounds and metallic elements. Together with pH, redox reactions affect the solubility, complexing capacity, and sorptive behavior of constituents, and thus control the presence and mobility of many substances in water. Microorganisms are responsible for a large proportion of redox reactions that occur in ground water. The redox state of an aquifer, and the identity and quantity of redox-active reactants, are difficult to determine.

Hydrolysis

Hydrolysis is the chemical breakdown of carbon bonds in organic substances by water and its ionic species H^+ and OH^-. Hydrolysis is dependent on pH and Eh and is most significant at high temperatures, low pH, and low redox potential. For many biodegradable contaminants, hydrolysis is slow compared to biodegradation.

Ion Exchange

Ion exchange originates primarily from exchange sites on layered silicate clays and organic matter that have a permanent negative charge. Cation exchange balances negative charges in order to maintain neutrality. The capacity of soils to exchange cations is called the cation exchange capacity (CEC). CEC is affected by the type and quantity of clay mineral present, the amount of organic matter present, and the pH of the soil. Major cations in leachate (Ca, Mg, K, Na) usually dominate the CEC sites, resulting in little attenuation in soils of trace metals in the leachate.

A smaller ion exchange effect for anions is associated with hydrous oxides. Soils typically have more negatively charged clay particles than positively charged hydrous oxides. Therefore, the transport of cations is attenuated more than the transport of anions.

Appendix B
Processes Controlling Sub-surface Contaminant Transport

Complexation

Complexation involves reactions of metal ions with inorganic anions or organic ligands. The metal and the ligand bind together to form a new soluble species called a complex. Complexation can either increase the concentration of a constituent in solution by forming soluble complex ions or decrease the concentration by forming a soluble ion complex with a solid.

It is often difficult to distinguish among sorption, solid-liquid complexation, and ion exchange. Therefore, these processes are usually grouped together as one mechanism.

Appendix C
CAE Landfill Guidelines

Appendix C
CAE Landfill Guidelines

The following summarises the key aspects of landfill siting, design and operations in the CAE Landfill Guidelines 2000.

Siting

The Guidelines detail the key issues, which need to be considered when:

(i) identifying potential landfill sites; and

(ii) planning site investigations and assessing the suitability of a site for landfilling.

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

The following criteria are the most relevant with respect to landfill classification.

Geology

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

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

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

Site Stability

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

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

- areas subject to instability, except where the instability is of a shallow or surface nature that can be overcome, in perpetuity, by engineering works;
- active geological faults;
- areas of geothermal activity; and/or

- karst terrain - regions with highly soluble rocks, sinks and caverns (for example, limestone areas).

Hydrogeology

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

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

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

Surface Hydrology

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

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

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

Environmentally Sensitive Areas

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

- significant wetlands;
- inter-tidal areas;
- significant areas of native bush including the Forest Park and areas able to comply with the requirements for Q.E.II Trust status;

- recognised wildlife habitats;
- national/regional and local parks and reserve lands (for example, cemeteries);
- any areas where release of contaminants from the site could severely affect fish/wildlife/aquatic resources.

Landfill Gas Management

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

Design

Leachate Retention and Liner Systems

The Guidelines state that the following three liner designs are recommended as they have been shown to provide a suitable level of protection to the receiving environment for landfills sited in accordance with the Guidelines:

- 900 millimetres of clay or other low permeability soils compacted in layers a maximum of 150 millimetres thick, to achieve a coefficient of permeability not exceeding 1 x 10^{-9} metres per second.
- a composite liner comprising a synthetic flexible membrane, 1.5 mm thick, overlying 600 millimetres of clay with a coefficient of permeability not exceeding 1 x 10^{-9} metres per second.
- a composite liner comprising a synthetic flexible membrane 1.5 mm thick, overlying a geosynthetic clay liner (GCL), a minimum of 5 millimetres thick, with a coefficient of permeability not exceeding 1 x 10^{-11} metres per second, overlying a 600 millimetres thick compacted sub-base layer with a coefficient of permeability not exceeding 1 x 10^{-8} metres per second.

A leachate collection and removal system is placed at the base of the landfill above the liner system. The functions of the leachate collection and removal system are as follows:

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

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

- a high-permeability drainage layer constructed of either natural granular materials (sands and gravels) or a synthetic drainage material (Geonet). The drainage layer is generally placed directly on the liner;
- perforated leachate collection pipes and/or boulder drains within the high-permeability drainage layer to collect the leachate and carry it rapidly to a collection sump;

- sump(s) at low points within the system from where leachate can be collected; and
- graded filter layers, as appropriate, over the high-permeability drainage layer and collection pipes and/or boulder drains to prevent physical clogging of the material.

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

Landfill Gas Management

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

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

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

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

Operations

The key operational issues with respect to landfill classification are:

- waste acceptance criteria and implementation of that criteria;
- cover;
- nuisance control for litter, dust and odour;
- stormwater management;
- landfill gas control.

Appendix C
CAE Landfill Guidelines

Waste Acceptance Criteria

Waste acceptance criteria should be determined during the resource consent process, based on landfill siting and design of retention, leachate collection and treatment/disposal systems.

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

The co-disposal, or joint disposal, of untreated hazardous wastes with municipal wastes is no longer considered an appropriate management practice.

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

Specific policies and procedures for notifying of customers of waste acceptance criteria are discussed below.

Cover

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

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

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

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

In addition, a final cover system can also include a granular gas drainage blanket, or a geosynthetic membrane below a subsoil drainage layer. Final cover material should be placed as soon as practicable over finished areas of the landfill above the previously placed intermediate cover, when weather conditions are suitable.

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

Nuisance Control

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

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

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

The landfill operator needs to take appropriate good housekeeping steps to prevent the production of odours. The size of the working face should be kept to a minimum and the use of daily cover and immediate attention to odorous waste loads will minimise the transmission of odours off-site.

Stormwater Control

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

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

A regular programme of preventative maintenance for stormwater control systems should be undertaken.

Landfill Gas Control

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

- sub-surface migration control, to reduce or eliminate the risk of explosion on or off the site

- odour control, to eliminate odour nuisance that can affect neighbours and site personnel
- landfill gas to energy by electricity generation or direct gas use
- greenhouse gas emission control, to reduce the methane discharge to atmosphere

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

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Overseas Landfill Classifications

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Overseas Landfill Classifications

Republic of South Africa

Introduction

A series of waste management documents have been written by the Department of Water Affairs and Forestry regarding minimum requirements for waste management. These requirements are implemented and enforced by the landfill site permit which is required by the Environment Conservation Act 1989 (Section 20(1)). The aim of the minimum requirements is to ensure consistency across South Africa and flexibility by requiring landfill classification, graded requirements and objective driven requirements.

The International Solid Waste Association (IWSA) Working Group on Sanitary Landfills has recognised the minimum requirements approach in their document on landfilling in developing countries.

To ensure practical and affordable environmental protection, graded requirements are applied to different classes of landfill. The landfill class is determined from the waste type, size of operation and potential for significant leachate generation. Where significant leachate is generated, leachate management is mandatory and where hazardous waste is involved the most stringent minimum requirements are applicable. Liquid waste may be co-disposed with solid waste provided there is no free liquid on the surface and no more than 200 millimetres of leachate is generated per year.

The permit holder is primarily accountable for the landfill and any effect it may have on the receiving environment. However the permit holder may appoint a Responsible Person (qualified to the satisfaction of the department) such as an operator or a consultant to ensure the minimum requirements are applied throughout the landfill life.

Landfill Classification

The landfill classification was developed as the basis for setting graded minimum requirements for cost effective selection, investigation, design, operation and closure of landfills. The landfills are grouped according to:

- type of waste;
- size of waste stream; and
- potential for leachate generation.

This leads to ten different classes of landfill. Site specific factors such as the sensitivity of the receiving environment are addressed during site selection, investigation and environmental impact assessment.

The ten different classes are summarised in the table below. Refer to the individual sections for details of how each class is determined.

Appendix D
Overseas Landfill Classifications

Table D-1 - Republic of South Africa Landfill Classes

G General Waste								H Hazardous Waste	
C Communal		S Small		M Medium		L Large		H:h Hazardous Rating 3&4	H:H Hazardous Rating 1-4
B-	B+	B-	B+	B-	B+	B-	B+		

Waste Class

Waste types are grouped into two classes:

- General Waste: Waste that does not pose a significant threat to public health or the environment if properly managed. It may have insignificant quantities of hazardous waste such as batteries and insecticides. General waste may be disposed of in any permitted landfill; and
- Hazardous Waste: Waste which can, even in low concentrations, have a significant adverse effect on the environment because of its inherent chemical or physical characteristics. Hazardous wastes are grouped into nine classes based on international danger groups and given a rating from 1 (extreme hazard) to 4 (low hazard) based on acute mammalian toxicity, ecotoxicity, environmental fate, chronic toxicity and other criteria.

Hazardous waste landfills are then divided into two types according to the hazard rating of the material they can accept. H:H landfills can accept waste with hazard ratings of 1-4 and H:h landfills can only accept the waste with lower hazards with ratings 3 and 4.

Size of Waste Stream

General waste classes are further classified according to the size of the waste stream and consequently the size of operation, not the ultimate size of the landfill. The size of the waste stream is determined from the Maximum Rate of Deposition (MRD), which is calculated from the projected maximum average annual rate of waste deposition over the expected life of the landfill. The landfill is then classified according to the following MRD's:

- Communal (C): Less than 25 tonnes per day;
- Small (S):25-150 tonnes per day;
- Medium (M): 15-500 tonnes per day;
- Large (L): greater than 500 tonnes per day.

Hazardous waste landfills do not take into account the size of the operation.

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Overseas Landfill Classifications

Potential for Significant Leachate Generation

General waste landfills are further classified in terms of their potential to generate leachate and the need for leachate management. All hazardous waste landfills are assumed to require leachate management systems.

A distinction is drawn between general landfills that generate significant leachate requiring a proper leachate management system and those that generate sporadic leachate and would not require a costly leachate management system. In determining whether significant leachate will be generated a climatic water balance is first undertaken to determine if the climate in which the landfill is located will cause it to generate significant leachate. After that site specific factors are taken into account.

The climatic water balance (B) is defined as the difference in rainfall and evaporation and is calculated for the wettest year on record and then recalculated for successively drier years. If B is positive less than one year in five it is considered that there will be no significant leachate generation and the site is classed as B- which does not require a leachate management system. If B is positive for more than one year in five the site is classed as B+ and a leachate management system is required. However if a borderline situation develops a full detailed water balance using a programme such as HELP is required.

Site Selection

Site selection requirements apply to all classes of landfills. In determining a site for a new landfill several candidate sites must be identified to ensure due consideration of alternatives is given. All interested and affected parties (IAPs) must be notified for all landfill classes and consulted through out the site selection process. Once the general location of the site and size of the site is determined the elimination of areas with fatal flaws (outline below) is undertaken.

The following situations may present fatal flaws, that is they may prohibit the development of an environmentally acceptable waste facility except at excessive cost:

- areas below the 1 in 50 year flood line;
- areas in close proximity to significant water bodies;
- unstable areas, for example fault zones, seismic zones, steep gradients and dolomitic or karst areas;
- sensitive ecological or historical areas;
- important catchment areas;
- areas with insufficient unsaturated zones. This is 2 metres for communal landfills and B- small landfills and as determined for larger and hazardous sites;
- groundwater recharge areas;
- areas overlaying or adjacent to important aquifers (aquifers are classed into 5 categories and waste facilities should only be sited on poor aquifers that are of poor quality or are low yielding) ;

- areas with incompatible land uses;
- areas immediately upwind of residential areas in the prevailing wind direction;
- areas where adequate buffer zones are not possible. Buffer zones differ with different classes of landfills;
  - 200 metres for communal landfills;
  - 400 metres for small landfills; and
  - as determined for larger and hazardous sites.

The sites are ranked depending on environmental impact, safety risk, social impact and costs and presented to IAPs. The top site is then subject to a feasibility study involving preliminary geohydrological and environmental impact assessments to confirm the site has no fatal flaws, or in the case of an existing landfill whether the site should be permitted for ongoing operation or closure.

Once it is determined the site has no fatal flaws a more in-depth investigation is done, the complexity of which depends on the class of landfill.

Landfill Design

If the best available site is sub-optimal, the site design must compensate for this. If there is a higher environmental risk the design must be upgraded in excess of the minimum requirements. In the case of existing landfills, design upgrading may be required.

The amount of design detail required depends on the landfill classification. The least amount of design requirement is specified for Communal Landfills. These only require a surface drainage design, a leachate detection system and a shaped and compacted surface with a layer of topsoil as capping on closure.

Larger and hazardous waste facilities require a range of design details, as listed below:

- adequate cover volume;
- surface drainage and stormwater diversion drains which keep unpolluted and polluted separated able to divert or contain a storm with a 50 year return period;
- a minimum separation of 2 metres between the waste body and the highest groundwater level;
- liners are required in all landfills. Liner requirements with leachate management systems, increase for larger and hazardous waste landfills, as discussed below;
- leachate collection system for B+ and Hazardous Landfills;
- leachate detection system consisting of rudimentary liners with toe drains for B- Landfills;

- monitoring systems for surface and groundwater for B+ Landfills, medium to large landfills and Hazardous Waste Landfills;
- testing of soils, construction material and waste such as soil permeability, compaction properties of soil for lining or capping, shear strength tests and/or geomembrane liner tests (must comply with SABS spec. 1526) as determined by an expert or departmental representative as needed.

Liners

Liners are required in all B+ and Hazardous Waste Landfills. Clay liners must be compacted to a minimum density of 95 percent Standard Proctor maximum dry density at a water content of +2 percent of proctor optimum. Information is also required on the results of particle analysis, hydrometer tests, Atterberg limits, shear strength and permeability. The maximum leakage rates in clay liners depend on the class of landfill as follows:

- G:B+: Less than0.3 metres per year or permeability k of 1 x 10^{-8} metres per second;
- H:h: Less than 0.1 metres per year or permeability k of 3 x 10^{-9} metres per second;
- H:H: Less than 0.03 metres per year or permeability k of 1 x 10^{-9} metres per second.

Performance must be validated by field tests with double ring infiltrometers once liner has been constructed.

Leachate Collection

A leachate collection layer is required for all larger B+ and Hazardous Waste Landfills and should consist of 150 millimetre single sized gravel or crushed stone have a size between 38 and 50 millimetres.

In all landfills the base must be sloped so that any leachate formed is directed to a control point. The collected leachate must be treated to a quality standard that complies with relevant legislation. All ponds and drains used to carry or convey leachate must be adequately lined.

Leakage detection systems are required for all B+ medium and large Landfills and Hazardous Waste Landfills where any leachate that passes the barrier of the upper liner is directed to separate leakage detection sumps.

The level of leachate treatment required depends on the leachate composition.

Landfill Gas

Active or passive landfill gas management systems may be used. If the gas from an active system is not used for energy or chemical feedstock it must be flared off. The gas from a passive system may be flared or passed through filters to remove odour. If there is a need for gas management, the system and its design must be agreed with the Department.

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Overseas Landfill Classifications

Landfill Operation

Waste Acceptance Monitoring

Prior to waste being accepted at general sites it must be inspected by qualified staff with the transporter confirming that it is general waste and the operating at the working face ensuring that no hazardous wastes are disposed of.

At Hazardous Waste Landfills all new enquiries for disposal must be submitted to the responsible person with representative samples and a completed waste information sheet. Each subsequent load must be sampled and tested for correlation with the original enquiry and if it does not conform, be properly identified with laboratory testing.

Hazardous Waste and large General Landfills must have a landfill monitoring committee with IAPs and have an external audit done every two years.

Water Quality Monitoring

Before installation of a monitoring system, a risk assessment must be undertaken to determine the risk of water becoming polluted. Water quality monitoring is then required before commissioning of the landfill, during operation and 30 years after the closure of the landfill for certain landfill classifications. Surface and ground water monitoring is required upstream and downstream of the landfill every six months for a comprehensive range of leachate indicator parameters as shown in table 13.1. The quality and quantity from toe seepages should be analysed monthly.

Closure

The most common end use of the landfill is as open space for sport or recreation apart from hazardous landfills where no public access is permitted. A closure investigation is required for all landfills to identify any existing problems and remedial work required with a closure report written detailing the work needed to be done before closure can be accepted. Ongoing inspections are then required at six or twelve month intervals with regard to integrity of cover, drainage systems, subsidence, vegetation and security.

Capping

All landfills require a shaped and compacted waste surface with a 200 millimetre thick layer of topsoil. Other layers that may be required depending on the landfill classification include:

- 150 millimetre compacted soil cap layer which must meet plasticity, particle size and density requirements;
- geotextile layer; and

- a gas venting layer.

Australia (New South Wales)

Introduction

New South Wales has a state-wide scheme for licensing waste activities to ensure that appropriate controls apply to the handling, storage, treatment and disposal of wastes that pose a threat to the environment.

Landfill environmental issues are mainly dealt with in two documents: Environmental Guidelines: Solid Waste Landfills (1996) and Environmental Guidelines: Industrial Waste landfilling (Draft, 1998), and in the Environmental Impact Statement Guide (1996). The purpose of the guidelines is to ensure landfill occupiers are aware of their risks to the environment and the community and their responsibility for managing these risks in the most effective way possible. This is done by giving a clear outline of environmental issues to be managed and a system for regulating landfills.

A license is required for facilities:

- that dispose of hazardous and industrial wastes;
- rural landfills that accept over 5000 tonnes of solid waste per year;
- rural landfills that accept over 20,000 tonnes of any waste per year;
- any landfill in an environmentally sensitive area;
- in extended metropolitan except if it receives less than 20,000 tonnes of inert waste over a lifetime or if it is on a residential or farming property and only receives waste generated on that property.

The approach used in regulating landfills is described as performance based, used to provide a consistent and environmentally responsible approach to achieve the best environmental outcomes allowing flexibility and rewards for careful site selection, design and innovated management. The emphasis of the performance based and integrated environmental approach is on achieving the most environmentally beneficial outcome using effect treatment and disposal of the wastes. Benchmark techniques, which set techniques that should be considered in developing a landfill, are used. Each benchmark is related to a primary environmental goal and any deviations from the benchmarks will have to proved capable of still meeting the environmental goals and has either been proved to work effectively elsewhere or verified by appropriate field tests.

The performance outcomes are defined as environmental goals which. These are:

- preventing, detecting and remediation of water pollution;
- preventing, detecting and remediation of landfill gas emissions;

- assuring quality in the design, construction and operation of the landfill;
- assuring quality and recording of the nature and quantity of wastes and that the landfill only receives waste which it is licensed to;
- using landfill space optimally;
- preventing degradation of local amenity from litter, odour, dust, vermin, weeds and noise;
- minimising hazards through preventing unauthorised entry, adequate fire fighting capacity and staff training;
- adequate post closure for proper remediation and beneficial final use by the community.

In meeting the environmental goals it is recognised that the most effective and affordable method will be influence by the quantity and type of waste and in such the landfills are classified as inert, solid and industrial. Hazardous waste must be treated before it is suitable for landfill disposal, or stored until a suitable treatment technology becomes available. Disposal of liquid waste at landfills was banned from 1 July 2001.

Landfill Classification

All licensed landfill facilities will be in one of six classes:

- Inert (Class 1 or Class 2);
- Solid (Class 1 or Class 2);
- Industrial;
- Hazardous.

Each class or subclass has its own specific waste acceptance criteria. The waste acceptance criteria defining waste as inert, solid or industrial is specified in two ways:

- specific contaminant concentration (SCC), measured as the total concentration of any chemical contaminant in the waste;
- leachable concentration, obtained by subjecting the waste to the Toxicity Characteristics Leaching Procedure (TCLP).

Solid waste has criteria concentrations ten times higher than for inert waste. Industrial waste criteria has concentration limits four times higher than for solid waste.

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Inert Waste Landfills

An Inert Waste Landfill is only able to accept inert wastes. These are defined as wastes that do not undergo environmentally significant physical, chemical or biological transformation and have no potentially hazardous contents once landfilled. Inert Waste Landfills are divided into two classes:

- Class 1: All inert wastes including stabilised asbestos cement and physically, chemically or biologically fixed, treated or processed waste in accordance with any special requirements that may be set by the EPA;
- Class 2: All inert wastes except stabilised asbestos cement or physically, chemically or biologically fixed, treated or processed waste.

Solid Waste Landfills

A solid waste landfill is only able to accept solid waste and inert waste. Solid waste is defined as wastes that are non-hazardous, solid or degradable and as such are more likely to release higher quantities of greenhouse gases or contaminated leachates. Solid wastes landfills are divided into two classes:

- Class 1: All solid waste including putrescible waste and other wastes approved by the EPA;
- Class 2: All solid waste excluding putrescible waste and other wastes approved by the EPA.

It should be noted that the New South Wales Government envisages banning garden wastes in the near future.

Industrial Waste Landfills

An Industrial Waste Landfill is able to accept industrial, solid and inert waste. Inert waste is defined as stabilised asbestos waste, asbestos fibre and dust waste, any non-liquid radio active that emits ionising radiation spontaneously and has a specific activity ratio that is greater than one. Industrial Waste Landfills will also generally have a license condition prohibiting the disposal of putrescible waste in order to keep the quantity and quality of the leachate generated low.

Industrial waste may also be disposed of in cells within other landfills that are isolated from the rest of the landfill by leachate barriers with separate leachate management systems. Dedicated industrial landfills or industrial waste cells are usually required to have double liners.

Hazardous Waste Landfills

There is no such thing as a Hazardous Waste Landfill. Hazardous wastes need to treated in order to be disposed of in an industrial waste landfill or stored appropriately.

Appendix D
Overseas Landfill Classifications

Site Selection

The site selection procedure is the same for all categories of landfills and it is recognised that careful location of a landfill is the single most effective environmental management tool, avoiding the need for impact mitigation and ongoing management.

The procedure used for site selection does not discuss the need to assess alternative locations but rather seeks alternative sites if the potential site does not conform for one of the following reasons:

- site is inconsistent with any existing plans or strategies;
- proposed land use is prohibited on the site;
- high environmental sensitivity;
- incompatible with surrounding land use (adequate buffer areas from residential areas, surface waters, groundwater charge areas and environmentally sensitive areas are determined on a case specific basis);
- initial site investigations indicate the site is fundamentally unsuitable.

The following areas are considered inappropriate for landfilling due to their environmental sensitivity:

- within 250metres of an area of significant environmental or conservation value identified under relevant legislation including national parks, world heritage areas, wilderness areas and marine reserves.
- identified sensitive locations within a drinking water catchment;
- within 250 metres of a residential zone or dwelling;
- within 40 metres of a water body or in an area overlapping an aquifer which contains drinking water quality groundwater which is vulnerable to pollution;
- site located within a karst region of with substrata which are prone to land slip or subsidence;
- sites within a floodway that may be subject to washout during a 1 in 100 year flood event.

A preliminary site investigation is then required to evaluate the site in terms of waste management, engineering and environmental factors. The levels of detail of the initial investigation should be in line with the scale and type of proposal and potential environmental sensitivity of the area. The site investigation should include an assessment of:

- operation requirements such as sufficient land area, easy access, distance to waste generation;
- geological and soil assessments on underlying strata and suitability of soil for cover material;
- hydrological assessment of surface and groundwater;
- topographical and meteorological assessment such as rainfall patterns and wind direction;

- flora and fauna assessment;
- community issues such as compatible land uses, health risks, heritage areas and aesthetics.

If the site is deemed suitable an environmental impact assessment is required and is tailored to the specific proposal and focuses on key issues.

Landfill Design

The landfill design is based on benchmark techniques that provide guidance on possible solutions for effectively achieving environmental goals. There are different benchmarks for solid waste landfills and industrial waste landfills. There are no benchmarks for inert waste landfills.

Liners

The primary goal of this benchmark is *to prevent pollution of water by leachate*. The liner should be designed and installed in accordance with the quality requirements specified in an approved design, construction and management quality assurance program. It shall contain the leachate over the period that the waste poses a environmental risk with an impervious barrier between the groundwater/soil/substrata and the waste.

The liner in an industrial waste landfill should comprise of a:

- flexible membrane line (FML) of a minimum thickness of 1.5mm with a permeability to water of less than $1x10^{-11}$ metres per second overlaid with protective soil with all joins and repairs full tested; and
- a foundation layer of recompacted clay or modified soil of at least 900 millimetres with a permeability of less than $1x10^{-9}$ metres per second with successive compatible layers scoured and sides with a slope not greater than 1:3.

A liner in a solid waste landfill should be the same without the FML unless the landfill is located in an area of poor hydrological conditions, in which case it should have a FML as well.

Where natural geology of the site is proposed to be used as the leachate barrier system an extensive hydrogeological and geotechnical investigation should be undertaken on the permeability and integrity of the soil.

Once the surface of the liner is formed and settling has finished the upper surface must exhibit a transverse gradient of greater than three percent and a longitudinal gradient of greater than two percent.

Leachate Collection

An acceptable design of leachate collection systems for Solid Waste Landfills is a drainage layer of thickness greater than 300 millimetres designed to prevent a build up of no more than 300 millimetres with a permeability of greater than 1 x 10^{-3} metres per second.

Industrial Waste Landfills are required to be double lined each with a drainage layer as for solid waste landfills. The primary layer should have a permeability of greater than 1 x 10^{-4} metres per second and the secondary layer a permeability of greater than 1 x 10^{-2} metres per second.

The drainage material for both types of landfills shall be selected to have sufficiently large pore space to prevent crustation with the gravel ideally having a smooth rounded surface, with a relatively uniform grain size of greater than 20 millimetres. In the case of industrial landfills it must be covered with a non-woven filter fabric. Geotextiles should not be used where their low porosity could result in blockage of the drainage system.

Perforated collector pipes should be placed within the drainage layer at intervals of not more than 50 metres, which should be a minimum of 150 millimetres diameter, of adequate strength, have a minimum longitudinal gradient of 1 percent and be capable of being rinsed and monitored. In order to facilitate the movement of leachate the occupier should puncture or remove the daily cover.

Landfill Gas

Landfill gas generated in the landfill should be contained by benchmark techniques relating to the leachate barrier system, site capping and revegetation and covering of waste.

A gas extraction system should be used to extract and, where possible, combust gas.

Landfill Operation

Waste Acceptance Monitoring

The landfill occupier should have in place waste acceptance and screening procedures in order to meet the environmental goal of assuring quality of incoming waste with recording of wastes received. The complexity of the screening procedure will depend on the type of landfill with it increasing where certain types of waste are to be kept out of the landfill. Industrial Landfills require waste acceptance, inspection, sampling and analysis procedures to ensure that prohibited hazardous waste is not accepted, to verity the waste generators description and ensure the health and safety of personnel.

Generally the following practices will be applied:

- for Industrial Landfills the occupier should ensure that the assessment and classification of the waste received has been made in accordance with the Waste Guidelines;

- signs clearly show what is and is not accepted at the point of entry;
- there should be a program of inspection for incoming waste loads. This may involve directing selected loads to a separate area for examination. For industrial landfills the sampling and testing of loads needs to be statistically reliable;
- all industrial waste or waste sludges should have appropriate documentation prior to acceptance;
- soil or inert waste must not contain any single amount of hazardous waste greater than 200mL/tonne or 200g/tonne and procedures should be in place to screen out this waste;
- records of inspection should be kept for at least four years for a solid waste landfill or for the operating life of an industrial landfill;
- supervision of the tipping activity at the tip face.

Industrial waste landfills must also maintain detailed records of the quantity, composition, source, disposal location on site in Australian Map Grid and altitude in metres above principal datum of each incoming waste load. This is to ensure that any waste disposed of can be accurately located (within 5m) on site for future retrieval if it is identified as causing a problem, if technology emerges that is capable of treating the waste or if the waste becomes a useful resource.

Leachate Management

The primary goal of this benchmark is to prevent pollution of water by leachate. Leachate management involves the collection, storage, treatment and disposal of the leachate.

Once collected the leachate should be tested for aromatics, volatiles, halocarbons and extractable organic contaminants that could be detected by methods 8260 and 8270 (USEPA 1992). Industrial waste landfill leachate will also need to be tested for heavy metals as well with additional quarterly testing for all contaminants and daily monitoring of inflow rates from the secondary leachate collection system for the action leakage rate and the rapid and large leakage rate.

The action leakage rate is a low level leak rate that would indicate the presence of a small hole or defect in the top liner. The rapid and large leakage rate is the maximum design leakage rate that the secondary layer can accept, it is site specific and is a high level danger trigger that would indicate a serious malfunction and therefore warrant immediate action. Both are site specific and if exceeded, the leak response action plan should be implemented. A leak response action plan is required for the operation of all industrial waste landfills and should describe all measures to be taken for most likely leakage scenarios.

The leachate can be disposed of by one of the following methods:

- discharge to sewer in accordance with the water authorities requirements (industrial landfills may require treatment first);

- treated to an acceptable quality and discharged to open waters or land in accordance with the conditions of the license;
- assessed and classified in accordance with the Waste Minimisation and Management Regulation 1996 followed by transport to a licensed liquid waste treatment facility;
- in the case of solid waste landfills only it may be applied to completed areas of the landfill or injected back into the landfill.

Surface Water Management

Surface water controls for all landfill types shall follow the following principles:

- all water that has entered waste-filled areas, and water that has been contaminated by leachate, should be handled and treated in the same manner as leachate;
- all surface water that has been collected from cleared surfaces should be treated in accordance with the *stormwater manual*;
- exposed or cleared areas should be minimised at all times and topsoil set aside for revegetation purposes.

A surface water monitoring program must be able to demonstrate that surface water is not polluted by the landfill. Survey monitoring points should be located upstream and downstream of discharge points from the landfill and monitored quality for the indicators shown in table 2 of the appendix and for suspended solids. If water pollution is detected the occupier should follow the procedures outlined in the water contamination remediation plan.

Groundwater Management

The design, number and location of wells or lysimeters in a groundwater monitoring network should be able to demonstrate that groundwater or subsoil is not contaminated, and ensure early detection of any contamination.

For industrial waste landfills only, electrodes should be installed beneath the leachate collection sump and in at least one in both the upgradient and downgradient groundwater monitoring wells to continuously monitor electrical conductivity to give an early indication of possible groundwater contamination. The frequency will depend on the rainfall patterns.

The groundwater should be monitored on a quarterly basis for a range of parameters. The sampling frequency may need to be increased if the strata is highly permeable of the groundwater highly vulnerable or may be relaxed if the occupier can demonstrate there are no seasonal effects and the results are statistically constant for at least five consecutive years. The parameters may be varied by the occupier as long as it is justified how the limits for the indicators adopted will provide an indication that pollution may have occurred.

If the groundwater monitoring program detects a possible failure of the leachate containment system, a groundwater assessment program should be established to determine the extent of the failure with a groundwater assessment plan prepared if contamination is confirmed.

Site Closure

In order to meet the environmental goal of remediating the landfill after closure, a post-closure monitoring plan (leachate collection monitoring and reporting remains the same as before closure) and a maintenance plan is required to ensure integrity of the landfill until it does not pose a threat to the environment. When there is sufficient evidence that the landfill is stable and non-polluting (gas levels <1% at perimeter, leachate contains low levels of contamination, groundwater monitoring indicates the liner has not failed and capping is stable), the occupier may then seek to complete all obligations.

Capping and Revegetation

Site capping and revegetation is needed in order to meet the environmental goal of remediating the landfill after closure. It should ensure that the final surface provides a barrier to the migration of water into the waste, controls emissions to water and atmosphere and prevents hazards and protects amenity. It would include the following points:

- capping will commence capping 30 days after completion of landfilling in an area;
- for solid waste landfills the capping should comprise of five parts:
  - a seal bearing surface of a properly designed and engineered layer of material;
  - a gas drainage layer with minimum thickness of 300 millimetres;
  - a sealing layer of at least 500 millimetres thick having a permeability less than $1x10^{-8}$ m/s;
  - a infiltration drainage layer not less than 300 millimetres of permeability not less than $1x10^{-5}$ metres per second;
  - a revegetation layer of depth not less than 1000 millimetres with plants with roots that will not penetrate beyond the vegetation layer;
- for industrial waste landfills the capping should comprise of three parts:
  - a composite liner system of a geosynthetic clay layer of permeability of less than $1x10^{-11}$ metres per second laid over a foundation layer of recompacted clay or modified soil of at least 600 millimetres thickness and a permeability of less than $1x10^{-9}$ metres per second with a final slope of not less than 2 percent;
  - a middle drainage layer with a permeability of greater than $1x10^{-4}$ metres per second of not less than 300 millimetres depth of gravel of the same specifications as the leachate drainage system;
  - a revegetation layer of depth not less than 1000 millimetres with plants with roots that will not penetrate beyond the vegetation layer;

- industrial landfills should also implement a site settlement monitoring program that surveys the capping regularly.

United States of America

Introduction

The Code of Federal Regulations (CFR) Title 40, *The Protection for the Environment* allows for the regulation of solid waste under the Resource Conservation and Recovery Act (RCRA). It contains many parts regarding the management of solid waste including Criteria for the Classification of Solid Waste Disposal Facilities and Practices (257), Criteria for Municipal Solid Waste Landfills (258) and Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities (264). The purposes of these regulations is to establish minimum national criteria under the RCRA to ensure protection of human health and the environment.

The regulations have been written to allow flexibility in both technical requirements and their implementation. They are considered to establish a cost effective and practical system for managing the nation's wastes by specifying safe design and management practices that will prevent releases of contaminants to ground water, specify operating practices that will protect human health and by having careful closure procedures.

Under the authority of the Resource and Recovery Act (RCRA) as amended, the EPA issued "Solid Waste Disposal Criteria Technical Manual" as a companion to Part 258, the purpose of which is to assist owners/operators of municipal solid waste landfills (MSWL) in achieving compliance with the regulation. Owners/operators that do not meet the criteria will be considered to be engaging in open dumping in violation of the RCRA.

It is intended that the state governments maintain the lead role in implementing and enforcing the Criteria through approved state permit programs by the EPA. Having an approved permit program allows for the use of flexible performance standards that are established in Part 258. This provides owner/operators flexibility in satisfying the criteria and means consideration of site-specific conditions in designing the MSWL at the lowest cost possible while ensuring protection of human health and the environment.

There are six categories that MSWL must comply with. These are location, operation, design, groundwater monitoring and corrective action, closure and post closure and financial assurance which are outlined below.

Classification

There is no specific landfill classification that the United States stipulates in text but rather separate parts of the CFR which deal with the different types of landfills with different requirements for landfills accepting municipal solid waste and landfills accepting hazardous waste.

Appendix D
Overseas Landfill Classifications

Part 257 Criteria for the Classification of Solid Waste Disposal Facilities and Practices was the initial regulation for all non-hazardous landfills which determined if disposal facilities pose a reasonable probability of adverse effects on the environment or human health. Part 258 Criteria for Municipal Solid Waste Landfills revised this regulation for solid waste landfills that receive municipal waste.

Part 257 is now intended to be used for all other non-hazardous facilities that receive inert material only such as construction and demolition debris, tires or non-hazardous industrial waste. This means that Inert Waste Landfills do not have any requirements on design or operation but rather dictate that they should not be in floodplains, contribute to threatened species, discharge pollution to surface water or contaminate drinking water beyond the boundary in order not to pose a threat to the environment or human health.

Part 264 of the CFR, Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities deals with hazardous waste. Note the Land Disposal Restrictions program, Disposal Prohibition states that before a hazardous waste can be land disposed, treatment standards specific to that waste must be met and that the waste can not be diluted or stored indefinitely.

Exemptions from these regulations are made for small landfills receiving less than 20 tonnes of municipal solid waste per day averaged annually (these generally serve populations of less than 10,000 people) with no evidence of groundwater contamination from the landfill, to provide some relief from the more costly requirements of design, groundwater monitoring and corrective action requirements. To qualify the landfill must also receive less than 635 millimetres of rainfall per year and have no practical waste management alternative or have no ready access to a regional facility due to an interruption in transportation for at least three consecutive months.

Site Selection

There are 4 location restrictions relating to the environment that apply to the landfills:

- floodplains. No landfill located in 100-year floodplains can restrict the flow of the 100-year flood, reduce the temporary water storage capacity of the floodplain, or allow the washout of solid waste;
- wetlands. In general, owners/operators of new or expanding municipal landfills may not build or expand in wetlands. However, states or tribes with EPA-approved permitting programs can make exceptions for units able to show: No siting alternative is available, construction and operation will not (1) violate applicable state/tribal regulations on water quality or toxic effluent; (2) jeopardize any endangered or threatened species or critical habitats; or (3) violate protection of a marine sanctuary, the unit will not cause or contribute to significant degradation of wetlands and steps have been taken to achieve no net loss of wetlands;
- seismic impact zones. When any municipal or hazardous new or laterally expanding landfill is located in a seismic impact zone, its containment structures (liners, leachate collection systems, surface-water control systems) must be designed to resist the effects of ground motion due to earthquakes;

- unstable areas. All owners/operators of municipal or hazardous landfills must show that the structure of their landfills will not be compromised during "destabilizing events," including, debris flows resulting from heavy rainfall, fast-forming sinkholes caused by excessive ground-water withdrawal, rockfalls set off by explosives or sonic booms, the sudden liquefaction of the soil after a long period of repeated wetting and drying.

Landfill Design

Municipal Solid Waste Landfills

The criteria for landfill design apply to new landfills and lateral expansions of existing landfills . (Existing landfills are not required to retrofit liner systems.) The criteria give owners/operators two basic design options for municipal waste landfills.

First, in states and tribal areas with EPA-approved programs, owners/operators may build their landfills to comply with a design approved by the state/tribal director. In approving the design, the director must ensure that it meets the EPA performance standard, that Maximum Contaminant Levels (MCLs) will not be exceeded in the uppermost aquifer at a "relevant point of compliance." This point is must be no farther than 150 meters from the landfill unit boundary and on land owned by the landfill owner. Refer to Table 2-1, in Section 2, for the MCL's. In reviewing these performance-based designs, approved states and tribes also must consider other factors, such as the hydrogeologic characteristics of the facility and surrounding land, the local climate, and the amount and nature of the leachate.

The second option is a design developed by EPA that consists of a composite liner and a leachate collection system. In general, landfills in states or tribal jurisdictions without EPA-approved programs must use this design. The composite liner system combines an upper liner of a synthetic flexible membrane and a lower layer of soil at least 600 millimetres with a hydraulic conductivity of no greater than 1×10^{-9} metres per second. The leachate collection system must be designed to keep the depth of the leachate over the liner to less than 300 millimeters.

Landfills with a capacity in excess of 2.5 million tonnes are required to have a well designed and well operated gas collection system and a control device capable of reducing NMOCs in the collected gas by 98 weight percent.

Hazardous Waste Landfills

Hazardous waste landfills must be designed and operated to minimise the possibility of a fire, explosion, or any unplanned release of hazardous waste which could affect human health or the environment. The landfill must have two or more liners and a collection and removal system above and between the liners as shown below or an alternative design as approved that prevents migration of hazardous constituents into the groundwater and allows detection of leaks through the top liner. The liner system must include:

- A top liner designed and constructed of materials (eg a geomembrane) to prevent the migration of hazardous constituents into such liner; and
- A composite bottom liner consisting of at least two components. The upper component must be designed and constructed of materials (eg a geomembrane) to prevent the migration of hazardous constituents into such liner. The lower component must be designed and constructed of materials to minimise the migration of hazardous constituents if a breach in the upper component were to occur. The lower component must be constructed of at least (900 millimetres of compacted soil with a hydraulic conductivity of no more than $1x10^{-9}$ metres per second.

The leachate, collection and removal system above the top liner must be designed to ensure the depth does not exceed 300 millimetres. The leachate collection and removal system between liners and above the bottom liner will act as a leak detection system which shall have:

- a bottom slope of one percent;
- granular drainage materials with a hydraulic conductivity of $1x10^{-5}$ metres per second or more with a thickness of 300 millimetres or more, or a synthetic or geonet drainage material with a transmissivity of $3x10^{-5}$ cubic metres per second or more;
- sumps and liquid removal methods of sufficient size to collect and remove liquids to prevent liquids backing up into the drainage layer. Each unit must have its own sump and measuring device for recording the volume of liquid.

Landfill Operation

Groundwater Monitoring

Generally, groundwater monitoring must be conducted at all Municipal Solid Waste Landfills. Owners/operators must install enough ground-water monitoring wells in the appropriate places to accurately assess the quality of the uppermost aquifer beneath the landfill before it has passed the landfill boundary (to determine background quality) and at a relevant point of compliance (downgradient). Owners/operators should consider the specific characteristics of the sites when establishing their monitoring systems, but a qualified ground-water scientist or the director of an EPA-approved state/tribal program must certify the systems as adequate. During detection monitoring, owners/operators must take ground-water samples and analyze them at least twice a year for specific constituents (as defined in the federal regulations or by the director of an approved state/tribal program).

Owner/operators of hazardous waste landfills must ensure that hazardous constituents detected in the ground water do not exceed specified concentration limits. The frequency of the sampling will be determined by the statistical method employed to evaluate background levels. Each landfill shall have an action detection rate which is the maximum design flow rate that the leak detection system can remove without the fluid head on the bottom liner exceeding one foot.

Surface Water Management

All landfills must be operated in a way that ensures they do not release pollutants that violate the Clean Water Act, which protects surface waters.

The owner/operator must build and maintain a control system designed to prevent storm waters from running on to the active part of the landfill. The run-on control system must be able to handle water flows as heavy as those expected from the worst storm the area might undergo in 25 years.

The owner/operator also must build and maintain a surface water run-off control system that can collect and control, at a minimum, the surface water volume that results from a 24-hour, 25-year storm. Run-off waters must be managed according to the requirements of the Clean Water Act, particularly with regard to the restrictions on the discharge of pollutants into water bodies and wetlands.

Waste Acceptance Monitoring

The owner/operator of Municipal Solid Waste Landfills must set up a program to detect and prevent disposal of regulated quantities of hazardous wastes and polychlorinated biphenyl (PCB) wastes. The program must include procedures for random inspections, record keeping, training of personnel to recognize hazardous and PCB wastes, and notification of the appropriate authorities if such waste is discovered at the facility.

Before an owner/operator of a hazardous waste landfill can dispose of waste, a detailed chemical and physical analysis of a representative sample is required to verify the composition. This information may be supplied through laboratory analysis or through acceptable knowledge. Operating records must be kept detailing a description and quantity of the hazardous waste received, date of disposal and location of disposal in the landfill.

Site Closure

The criteria establish specific standards for all owners/operators to follow when closing a landfill and setting up a program of monitoring and maintenance during the post-closure period. The final cover must be designed and constructed to have a permeability less than or equal to the bottom liner system or natural subsoils, or a permeability no greater than $1x10^{-2}$ metres per second, whichever is lower. Thus, the regulation is in the form of a performance standard that must be achieved by the owner/operator.

When a landfill's bottom liner system includes a flexible membrane or synthetic liner, the addition of a flexible liner in the infiltration layer cover will generally be the only design that will allow the final cover design to achieve a permeability less than or equal to the bottom liner. The infiltration layer must also be composed of a minimum of 450 millimetres of earthen material to minimise the flow of water into the closed landfill. The cover must also contain an erosion layer to prevent the disintegration of the cover. The erosion layer must be composed of a minimum of 150 millimetres of earthen material capable of sustaining plant growth.

The director of an approved state or tribe may approve an alternative final cover design that achieves an equivalent reduction in infiltration and protection from erosion as the design described above. For 30 years after closure, the owner/operator is responsible for maintaining the integrity of the final cover, monitoring ground water and methane gas, and continue leachate management (Hazardous Waste Landfills need to continue leachate collection and removal until leachate is no longer detected. (Approved states/tribes may vary this interval.).

Germany

Classification

Germany has two principal classes of landfill:

- Municipal Solid Waste Landfill (MSWLF), TASiedlungsabfall requirements; and
- Hazardous Waste Landfill, (HWL), TAAbfall requirements.

MSWLFs are further separated into two classes, Class 1 and Class2, based on the wastes chemical composition.

Site Selection

The general requirements for the siting of new MSWLFs do not permit landfills in the following areas:

- Karst areas and areas with a high proportion of fissures and fractures in the geologic subsurface;
- areas currently used, planned or potentially designated for the extraction of drinking water and mineral spring water;
- within existing or planned flood plain area;
- within a quarry, where a discharge of free-flowing leachate to a drainage system to an area outside of the landfill area is not possible;
- within existing and/or planned wooded areas, nature protection zones and areas classified as a recognized protected area;
- the landfill site must be located at a minimum distance of 300 metres to any neighboring residential area;
- the landfill site is not permitted in earthquake areas, active fault zones, areas imminent of landslide or surface lowering following former mining activities. Geologic and hydrogeologic surveys are required to adequately describe the geologic and hydrogeologic conditions on site;
- generally, the ground must be stable enough to prevent damage to the liner system and to ascertain the stability of the landfill body;

- after natural settling and under the load of the landfill body the bottom of the permanent disposal area must be laid out at least 1.0 metre above the expected maximum level of a confined or unconfined water table.

Landfill Design

MSWLFs are required to be equipped with a liner and leachate collection system.

It is recommended that the bottom liner system for a Class II landfill site consist of the following layers (starting from the bottom):

- a layer of mineral/earthen material with a minimum thickness of 750 millimetres and a total permeability (k) of equal or less than 5×10^{-10} metres per second.
- a synthetic liner layer with a minimum thickness of 2.5 millimetres. Appropriate measures must be taken to protect the liner from damage due to overlying weight. After settling processes the lateral slope is required to be at least 3 percent and the slope lengthways to be at least 1 percent.
- a drainage layer with a minimum thickness of 300 millimetres. The draining material must be spread out evenly showing a permeability (k) of at least 1×10^{-3} metres per second.

Vertical penetration of the liner system is not permitted. If a different liner system is used, equivalent containment characteristics must be maintained.

For Class I landfill sites the same combination of layers is recommended. The minimum thickness of the mineral layer is required to be 500 millimetres.

A Hazardous Waste landfill must have a liner comprising the following layers (starting from the bottom):

- a layer of mineral/earthen material with a minimum thickness of 1.50 metres and a minimum permeability value (k) of 5×10^{-10} metres per second;
- a synthetic liner layer with a minimum thickness of 2.5 millimetres. Suitable measures must be taken to protect it from load-related damage.
- a drainage layer with a minimum thickness of 300 millimetres. The drainage system must have a permeability (k) of at least1 $\times 10^{-3}$ metres per second.

Landfill Operations

The competent authority to approve a plan for the construction and operation of a MSWLF. As part of the plan approval process, the local authorities must individually determine the types of wastes permitted for disposal for each MSWLF.

Waste Acceptance Monitoring

A separate control unit must be established as part of the organizational structure of the MSWLF. Control procedures must be established by the control unit to ensure that the various types of waste to be disposed of comply with the criteria set for the landfill site. The control unit is responsible for registering and recording the quantity and type of delivered waste material identified with a waste number. The following procedures are required:

- sight control procedures, consisting of appearance, consistency, color and odor control
- control analysis, consisting of the collection and analysis of samples from waste material. It is only required if there is evidence that waste requirements are not being met. The parameters to be analysed depend on the type of waste sampled. Duplicate samples must be collected and preserved for a minimum of one month. Control analysis must also be conducted as spot checks. The results of these analyses must be recorded in the operational log of the landfill.

The landfill operator must maintain an operational log containing the following information:

- records of delivered domestic waste;
- declarations of acceptance, confirmations of disposal and approval record books;
- records of received substances;
- results of environmental investigations and chemical analyses.

Monitoring

The installation and regular inspection of the following monitoring systems/programs for Class II landfill sites is required (monitoring systems/programs for Class I landfill sites the are determined according to local conditions):

- a groundwater monitoring system;
- a monitoring system for the settling of the landfill body;
- a monitoring system for the settling of the liner system;
- meteorological data, including precipitation, temperature, wind and evaporation (alternatively the meteorological data of a neighboring measuring station may be used);
- a water monitoring program to establish a water inventory;
- a monitoring program for determining the quality of leachate and other waters
- temperature monitoring at the base of the landfill body

A gas monitoring system must be installed, if there is evidence that landfill gas may be generated from the landfill body.

Site Closure

Following the closure of a landfill site, or closure of an individual landfill cell, a cover system and must be installed. The final cover system must consist of the following layers (starting from the bottom):

- a compacted layer consisting of homogeneous material with a thickness of at least 500 millimetres. If gas generation is expected, additional requirements apply;
- an impermeable layer consisting of mineral/earthen material for a Class I landfill and a combination of mineral material and synthetic layers for a Class II landfills;
- a drainage layer with a thickness of at least 300 millimetres. The drainage material must be spread evenly with a permeability of at least $k = 1 \times 10^{-3}$ metres per second.
- A final vegetative layer of at least 1000 millimetres.

During the post closure period, long term security measures must be established and maintained, and monitoring of the landfill site must be continued and documented. The duration of the post-closure period depends upon the approval of the local authorities.