Technical Guidelines for Disposal to Land

Appendices

Waste Management Institute New Zealand (WasteMINZ)

August 2018

Table of Contents

List of Tables

List of Figures

Appendix A Legislation

A.1 Relevant Legislation

Health Act 1956

The Health Act is described in Section 2.2.

Resource Management Act 1991

The Resource Management Act 1991 is described in Section 2.3.

Health and Safety at Work Act 2015

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

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

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

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

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

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

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

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

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

Hazardous Substances and New Organisms Act 1996

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

The definition of disposal under HSNO is limited to treatment, discharge to the environment, or export from New Zealand. The controls on disposal also cover the disposal or decontamination of containers that have been used with hazardous substances.

Local Government Act 2002

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

Climate Change Response Act 2002

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

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

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

Waste Minimisation Act 2008

The Waste Minimisation Act 2008 (WMA) is designed to encourage waste minimisation and reduce the quantities of waste disposed.

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

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

The WMA also places a levy on all waste materials disposed of to a disposal facility, as defined in the Act, to be collected by the landfill operator. Fifty percent of the levy funds are provided to Territorial Authorities for spending on waste minimisation initiatives. The remainder, less administration costs, goes into a contestable fund for allocation to waste minimisation projects.

The WMA also provides for product stewardship programmes and established a Waste Advisory Board to provide independent advice to the Minister on waste minimisation matters.

Heritage New Zealand Pouhere Taonga Act 2014

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

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

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

Appendix B Design

B.1 Landfill Liners

Soil Liners

Design Parameters

Parameters that influence the permeability of a soil liner include:

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

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

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

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

Table B-1 Soil Classification Testing

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

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

Construction

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

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

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

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

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

Geosynthetic Clay Liners

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

The advantages and disadvantages of GCLs are summarised in **Table** B-2.

Table B-2 Advantages and Disadvantages of Geosynthetic Clay Liners

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

(Modified from Bouazza, 2002)

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

- **Manufacture:** This includes the selection of the raw materials, the manufacturing of these materials into the GCL and the protection of the rolls of GCL to avoid premature hydration. Compliance testing should be performed to confirm that the material meets the specification requirements.

- **Storage and handling:** Care needs to be taken of the GCL rolls to prevent premature hydration and damage during storage and handling. Once the material reaches the site, its documentation should be checked against the specification requirements.

- **Installation:** The manufacturer's installation procedures should be adopted. The GCL must be protected immediately following placement to prevent damage and premature hydration. Installation should only be performed by an experienced installation contractor and with rigorous quality assurance and quality control procedures in place.

Internationally accepted specifications for GCLs for use in landfill applications have been produced by the Geosynthetic Research Institute (GRI) and it is recommended that these standards are adopted. More information is provided in Section 4.11 and Appendix B4.

Geomembranes

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

- **Manufacture:** This includes the selection of the specific type of geomembrane, its formulation, the manufacturing process and how texturing is applied, if required. Compliance testing should be performed to confirm that the material meets the specification requirements.

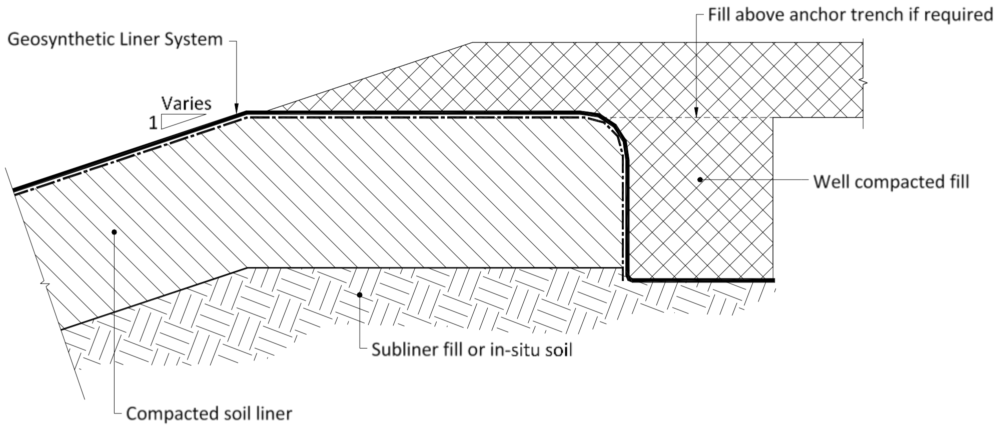
- **Storage and handling:** Care needs to be taken of the geomembrane rolls to prevent damage during storage and handling. Once the material reaches the site, its documentation should be checked against the specification requirements.

- **Installation:** The manufacturer's installation procedures should be adopted. The material should be protected during and following placement to prevent mechanical damage from construction equipment. Consideration should also be given to the temporary ballasting of the liner system to prevent wind damage. Installation should only be performed by an experienced installation contractor and with rigorous quality assurance and quality control procedures in place, including the requirements for test welds, and non-destructive and destructive testing of seams.

- **Anchor trench:** To prevent movement of the geomembrane following placement it needs to be anchored at the top of the slope. The most common form of anchor is a trench backfilled with compacted material. Other forms of anchoring include anchor beams where the geomembrane is welded to a strip of a compatible polymeric material (typically HDPE) cast into a concrete beam. Care must be taken in the design of the anchor trench to ensure that the geomembrane can preferentially pull out of the trench before the geomembrane is ruptured as a result of excessive tensile loads. A typical anchor trench is illustrated in **Figure** B-1, but it is noted that anchor trench dimensions are specific to each case.

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

Figure B-1 Typical Anchor Trench Detail



Internationally accepted specifications for geomembranes for use in landfill applications have been produced by the Geosynthetic Research Institute (GRI) and it is recommended that these standards are adopted. More information is provided in Section 4.11.

Protection Geotextiles

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

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

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

Liner and Global Stability

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

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

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

Waste Settlement

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

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

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

Importance of Uniform Formation and Slope Heights

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

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

B.2 Leachate Management

Leachate Generation

The factors that influence leachate generation at landfills include:

- **Climate:** Leachate generation is typically directly proportional to the amount of rainfall at the site. However, the proportion is influenced by other factors such as cover practices; stormwater and groundwater diversion; humidity; and sunshine hours.

- **Topography:** On- and off-site topography affects the site’s runoff pattern and the amount of water entering and leaving the site. Landfills should be designed to limit leachate generation from areas peripheral to the site by constructing perimeter stormwater drainage systems to divert surface water “run-on” away from the site and by constructing the landfill cover to promote runoff and reduce infiltration. All areas of a landfill should maintain at least a two percent grade over the waste at all times to prevent ponding of surface water. This may mean constructing grades steeper (say 5%) so that suitable drainage grades remain after settlement. Unlined facilities may also be influenced by groundwater flowing into the waste material.

- **Landfill cover:** The cover at the site affects the amount of water percolating into the waste to form leachate. In general, as the permeability of the soil used for final cover increases, leachate production rates increase.

- **Vegetation:** Vegetation plays an integral part in leachate control. It limits infiltration by intercepting precipitation directly (thereby improving evaporation from the surface) and by taking up soil moisture and transpiring it back to the atmosphere. A landfill with poor vegetative cover may experience erosion that cuts gullies through the cover soil and allows precipitation to flow directly into the waste.

- **Type of waste:** The type of waste, the water content of the waste and the form that it is in (bulk, shredded, etc.) affect both the composition and quantity of leachate. Wetter wastes, for example, will generate more leachate.

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

Leachate Generation Estimates

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

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

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

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

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

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

Leachate Collection and Removal Systems

Leachate Collection System Design

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

Base Grade

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

Drainage blanket

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

Collection Pipes

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

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

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

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

Penetrations

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

Sumps

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

Sumps can be inclined or vertical depending on the configuration of the landfill side slope. See **Figure** B-2 Inclined Leachate Collection Sump and Riser Going up the Side Slope and **Figure** B-3 General Arrangement of a Leachate Pumping Chamber.

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

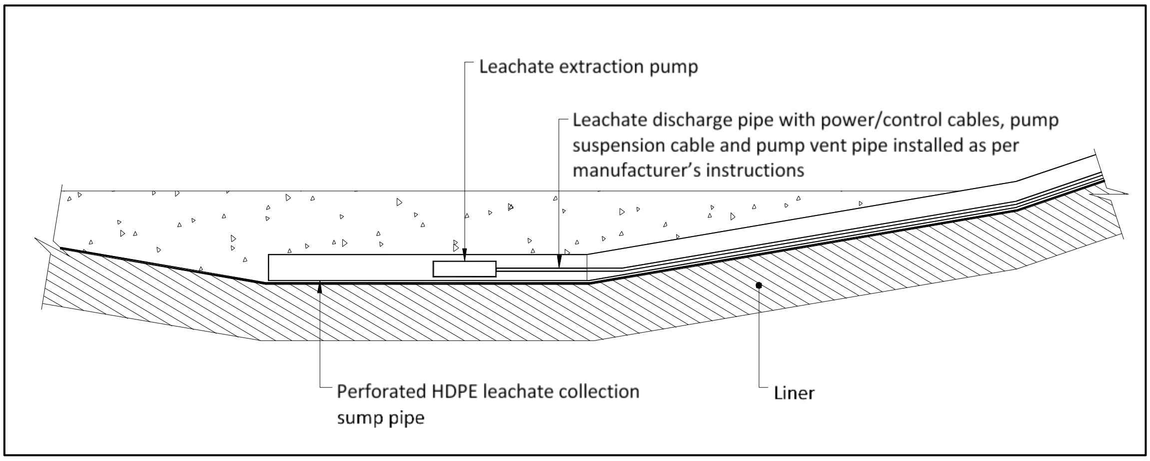
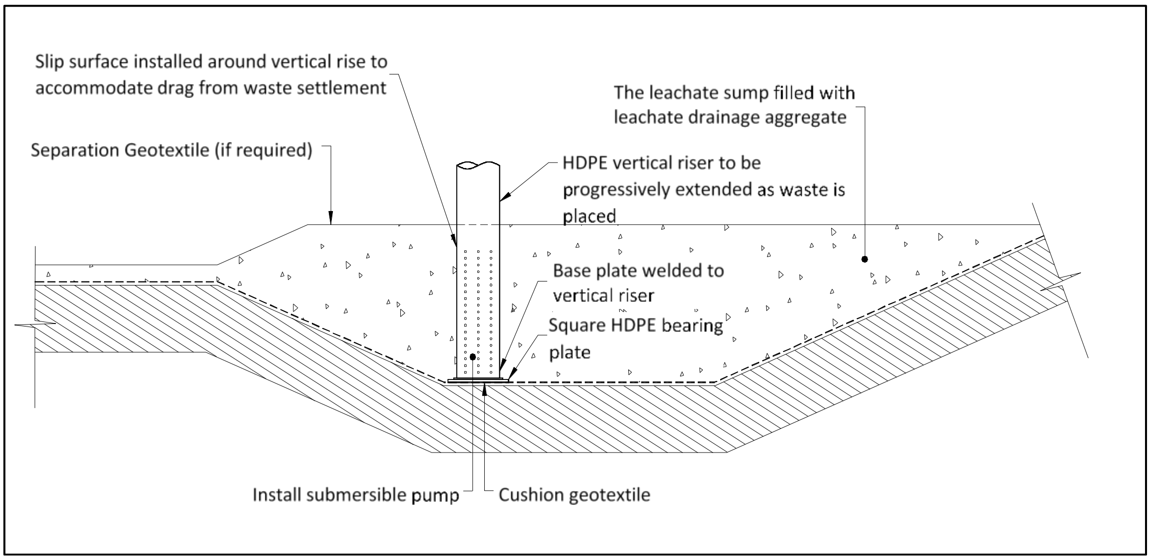


Figure B-3 General Arrangement of a Leachate Pumping Chamber



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

Pumps

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

Maintenance

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

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

Leachate Recirculation

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

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

- Increased concentration of contaminants in the leachate.
- Increased potential for differential settlement.
- Increased potential for odour.

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

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

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

In areas of low to moderate rainfall, the in-situ waste in a landfill is capable of absorbing and storing significant amounts of additional moisture (i.e. the moisture content of the waste mass is typically less than its field capacity[1]). This storage volume can be used to reduce the amount of leachate which needs to be treated by other means.

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

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

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

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

---

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

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

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

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

Leachate Treatment and Disposal

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

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

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

Table B-3 Leachate Treatment Methods and Objectives

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

Modified from Hjelmar et al. (1995).

Land Treatment and Disposal

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

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

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

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

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

Physical/Chemical Pre-treatment

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

Common technologies include:

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

Biological Treatment

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

Common technologies include:

- activated sludge;
- sequencing batch reactors (SBR);
- rotating biological contactor;
- anaerobic treatment; and
- biological nitrogen removal.

Physical/Chemical and Biological Treatment

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

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

- filtration.

Tertiary Treatment Methods

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

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

B.3 Landfill Gas Management

Landfill Gas Generation Models

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

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

First-Order Model

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

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

These parameters are discussed in more detail below.

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

Alternative Landfill Gas Generation Models

Compound First-Order Model

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

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

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

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

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

Zero Order Model

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

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

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

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

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

Methane Generation Potential (L_o)

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

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

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

Table B-4 Methane Yield from Municipal Waste

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

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

Methane Generation Rate Constant (k)

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

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

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

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

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

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

The Ministry for the Environment (MfE, 2001) suggests that typical values of k used in New Zealand range from 0.036 1/year to 0.15 1/year and typically a maximum value of 0.05 1/year is adopted even for wet landfills (high rainfall areas and poor landfill cover).

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

$$k = 0.016\ e^{0.040r}$$

Where r is the average annual rainfall

Table B-5 Typical Methane Generation Rate Constant Values

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

Landfill Gas Collection Efficiency and Fluctuations

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

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

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

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

Landfill Gas Control

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

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

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

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

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

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

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

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

- **Utilisation equipment**: The maximum collected landfill gas throughout the design life of the landfill gas management system.

Active Collection Wells

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

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

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

- **Access for waste placement:** The wells are typically developed in parallel with the waste placement and need to be suitably placed and spaced to enable waste placement.

- **Proximity to the tipping area:** To reduce the potential for odour issues, the wells need to be sited as close as possible to the tipping area; however, if an individual well is too close to an open area, then there will be a tendency to draw in air and the vacuum applied at the well will need to be adjusted accordingly.

- **Capping on platforms and side slopes:** The permeability of a temporary soil cap on platforms and side slopes not currently receiving waste would permit air ingress if high vacuum pressures were applied to an extraction well. Thus during operation of the landfill only relatively low vacuums can be applied to a number of wells thus reducing the collection efficiency. This may necessitate closer well spacing.

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

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

- **Location of any special or liquid wastes:** The wells are located to ensure, as far as practicable, that they do not pass through localised areas of special wastes or liquid waste which might affect well performance.

- **Irregular base formation information:** For older sites there is often limited information of the exact base formation of the landfill. Care must be taken not to compromise the liner system when drilling gas wells, with wells being carefully positioned and targeted to depths at least 5 m above the base liner level.

- **Depth constraints:** Typically the maximum depth a well can be retrospectively drilled into an existing waste mass is in the order of 30 m, which may not be the full depth of the waste column. For deep landfills, consideration should be given to whether well installation should be a combination of retrospective drilling and progressive installation.

Active Extraction Vacuum

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

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

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

Active System Flexibility

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

Extraction Well Design

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

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

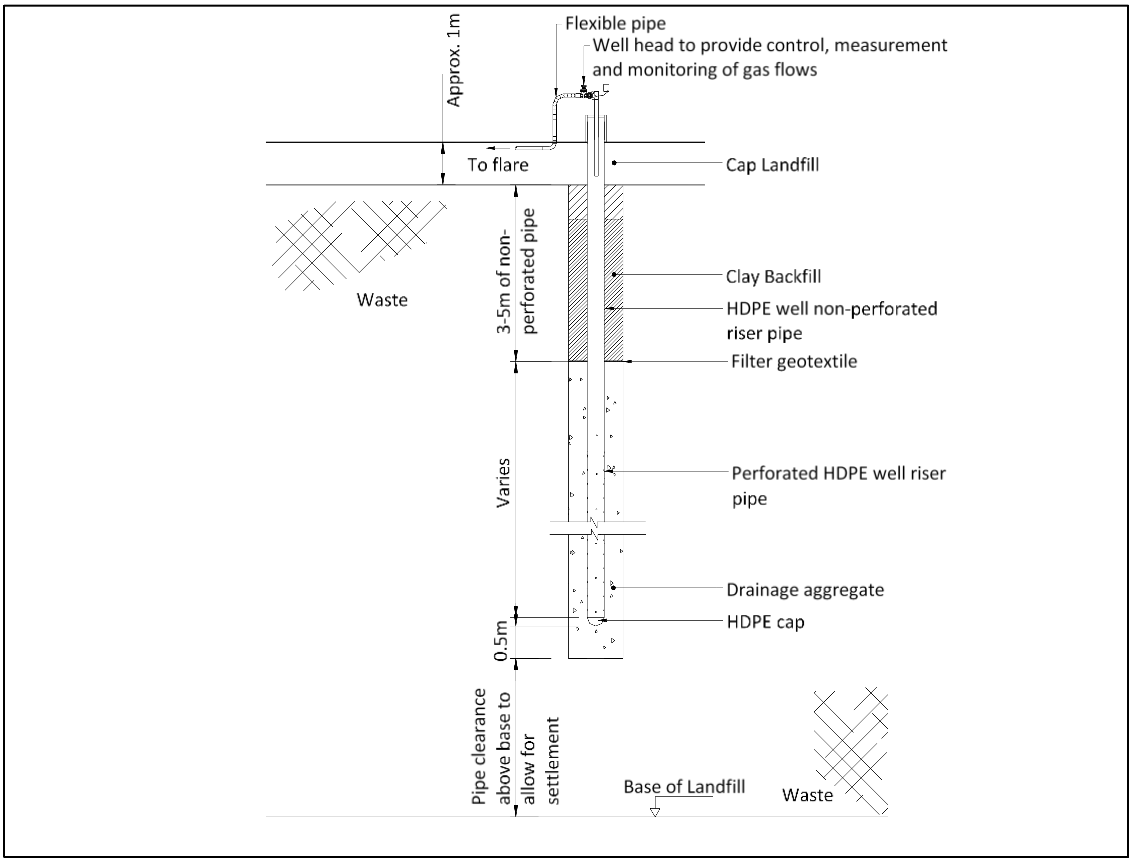
For deep wells, the stability of the open bore during construction is of prime importance. Larger bores are more stable in construction than small bore wells, and the construction of the well can be undertaken without damage to the well structure. For this reason, a large bore size is typically adopted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

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

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

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

Figure B-4 Typical Landfill Gas Well Design



Air Ingress

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

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

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

Well Riser Structure

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

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

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

Wellhead

The design of the wellhead needs to consider:

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

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

- **Open chambers:** These are used where there is no public access. They are shallow in depth to prevent landfill gas collecting and large enough to allow the operators to stand and work within the chamber.

- **Closed chambers:** These are typically used where the public has or may have authorised or unauthorised access. The chambers are small enough to prevent a person entering and have lockable covers.

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

Wellhead Control Equipment

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

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

Prefabricated wellhead units are a simple, reliable option.

Flow Monitoring

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

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

Allowance for Settlement

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

Extraction Network

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

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

- standardising pipe sizes.

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

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

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

Pipeline

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

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

Isolation and Road Crossing Valves

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

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

Condensate Management

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

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

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

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

Landfill Gas Treatment

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

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

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

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

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

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

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

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

Electricity Generation Technologies

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

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

Recent emerging technologies include:

- micro turbines;
- fuel cells; and
- Stirling cycle engines.

Landfill Gas Pre treatment

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

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

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

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

Heat Recovery

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

B.4 Construction Quality Assurance & Quality Control

Geosynthetic Testing Requirements

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

The documents available on their website[2] include internationally recognised specifications for geosynthetics. The specifications cover the majority of geosynthetics used in landfills and provide information on material properties and testing regimes. It is recommended that these specifications form the basis of specification and design development.

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

Soils Testing Requirements

Quality assurance and quality control is required for soil materials, used in the construction of landfill liners and capping layers, to confirm:

- the materials meet the specification requirements;

---

[2] http://www.geosynthetic-institute.org/specifications.htm

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

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

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

Parameter	Test Frequency[1]
In-situ density ("Rapid")	Consider the following: • Rate of testing based on waste and fill material placement from each borrow area. The rate for a borrow may reduce over time depending on consistency of results. Typically one set for every 200-500 cu.m of waste or fill material placed. • Maximum number per day. • Maximum horizontal distance between test locations. • Maximum vertical separation between tests.
In-situ density ("Fully Specified")	• As required to provide confidence that the "rapid method" is giving reliable results. Refer to NZS4407:1991.
Strength (shear vane or scala penetrometer test as appropriate)	Consider the following: • Rate of testing based on waste or fill material placement, typically 1 set per 200 cu.m of fill placed. • Maximum horizontal distance between test locations. • Maximum vertical separation between tests.
Moisture content	1 per in-situ density test
Maximum dry density and overall moisture content determination	Consider the following: • Initial test prior to fill placement. • Rate of testing based on waste or fill material placement from each borrow area or waste or fill material type. Typically 1 test per 10,000 cu.m for a particular borrow source or waste or fill material type.
Permeability (Laboratory Triaxial Test)	Consider the following: • Rate of testing based on waste or fill material placement from each borrow area. Typically 1 test per 500-1000 cu.m. The rate for a borrow may reduce over time depending on confidence from results. • Typically would require at least 1 test per week
Solid density	Consider the following: • Initial testing prior to waste or fill material placement. • Rate of testing based on waste or fill material placement from each borrow area or waste or fill material type. Typically 1 test per 10,000 cu.m for a particular borrow source or waste or fill material type.

Note:

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

B.5 References

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

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

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

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

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

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

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

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

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

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

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

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

New Zealand Ministry for the Environment. 2001. *A Guide for the Management of Closing and Closed Landfills in New Zealand.*

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

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

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

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

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

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

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

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

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

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

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

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

Appendix C Derivation of Waste Acceptance Criteria

C.1 Philosophy and Basis for Waste Acceptance Criteria Development

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

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

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

C.2 Waste Acceptance Criteria Development

Waste acceptance criteria can be expressed as either total concentrations or leachable concentrations.

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

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

C.3 Exposure Assessment

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

Waste acceptance criteria have been developed based on existing guideline values.

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

- The **contaminant source or release**. The waste is the source which could release contaminants into various media.
- **Environmental fate and transport**. Once released to the environment, contaminants move through and across different media.
- **Exposure point or area**. The specific point where people or environmental receptors might come into contact with a contaminated medium.
- **Exposure route**. The route is the means by which people physically contact environmental contamination at the exposure point (e.g., by inhalation, ingestion, or dermal contact).
- **Potentially exposed populations**.

Table C-1 Exposure Pathway Assessment

All Classes of Landfills and Fills						Class 1&2		Class 3		Class 4		Class 5	
Exposure path	**Contaminant source**	**Release/ transport/ media**	**Exposure point**	**Exposure route**	**Receptor - operational**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**	**Assessment - operational**	**Assessment - post closure**
1.1	Waste	Direct contact/soil	Onsite	Ingestion	Human health – workers	Incomplete EC	Incomplete EC/IC	**TBC**	**TBC**	Incomplete IC	Incomplete IC	Assessed commercial industrial land use	Assessed - any land use human health
1.2	Waste	Direct contact/soil	Onsite	Ingestion	Human health – public	NA	Incomplete EC			Incomplete IC	Assessed - rural residential/ lifestyle, residential	Assessed commercial industrial land use	Assessed - any land use human health
1.3	Waste	Direct contact/soil	Onsite	Dermal contact	Human health - Workers	Incomplete EC	Incomplete EC/IC			Incomplete IC	Incomplete IC	Assessed commercial industrial land use	Assessed - any land use human health
1.4	Waste	Direct contact/soil	Onsite	Dermal contact	Human health - public	NA	Incomplete EC			Incomplete IC	Assessed - rural residential/ lifestyle, residential	Assessed commercial industrial land use	Assessed - any land use human health
1.5	Waste	Direct contact/soil	Onsite	Ingestion	Wildlife	Incomplete EC	Incomplete EC			Incomplete OC	Incomplete EC	Assessed - ecological effects pathway	Incomplete EC
2.1	Waste	Volatilisation or wind/air or dust	Onsite	Inhalation	Human health - workers	Assessed commercial industrial land use	Incomplete EC			Assessed outdoor air	Assessed outdoor & indoor air	Assessed outdoor air	Assessed Outdoor & Indoor Air
2.2	Waste	Volatilisation or wind/air or dust	Offsite	Inhalation	Human health - residential	Incomplete EC	Incomplete EC			Assessed outdoor & indoor air		Assessed outdoor & indoor air	
3.1	Waste	Erosion or runoff/ dissolved or suspended sediment	Offsite	Ingestion	Aquatic ecosystems	Incomplete EC	Incomplete EC			Assessed - ANZECC	Incomplete EC	Assessed - ANZECC	Incomplete EC

All Classes of Landfills and Fills						Class 1&2		Class 3		Class 4		Class 5	
3.2	Waste	Erosion or runoff/ dissolved or suspended sediment	Onsite	Dermal contact	Contact recreation	Incomplete EC	Incomplete EC			Assessed - ANZECC contact	Incomplete EC	Assessed - ANZECC contact	Incomplete EC
3.3	Waste	Erosion or runoff/ dissolved or suspended sediment	Onsite	Ingestion	Human health - workers	Incomplete EC	Incomplete EC			Assessed commercial industrial land use	Incomplete EC	Assessed commercial industrial land use	Incomplete EC
4.1	Waste	Leaching/ groundwater/ seepage	Offsite	go to 3.1 to 3.3									
4.2	Waste	Leaching/ groundwater/ seepage	Onsite	Ingestion	Human health - workers	Incomplete EC	Incomplete EC			Assessed - GW use	Assessed - GW use	Assessed - GW use	Assessed - GW use
4.3	Waste	Leaching/ groundwater/ seepage	Onsite	Dermal contact	Human health - workers	Incomplete EC	Incomplete EC			Assessed - GW use	Assessed - GW use	Assessed - GW use	Assessed - GW use
4.4	Waste	Leaching/ groundwater/ seepage	Onsite	Ingestion	Aquatic ecosystems	Assessed - ANZECC	Assessed - ANZECC			Assessed - ANZECC	Assessed - ANZECC	Assessed - ANZECC	Assessed - ANZECC
5.1	Waste	Leaching/ groundwater/ GW wells	Offsite	Ingestion	Human health - drinking water	Assessed - GW use	Assessed - GW use			Assessed - GW use	Assessed - GW use	Assessed - GW use	Assessed - GW use
5.2	Waste	Leaching/ groundwater/ GW wells	Offsite	Dermal contact	Human health - drinking water	Assessed - GW use	Assessed - GW use			Assessed - GW use	Assessed - GW use	Assessed - GW use	Assessed - GW use
6.1	Waste	Landfill gas/ air subsurface	Offsite	Inhalation	Human health - residential	Assessed outdoor & indoor air	Assessed outdoor & indoor air			Not applicable	Not applicable	Not applicable	Not applicable
6.2	Waste	Landfill gas/ air subsurface	Offsite	Explosion	Human health - residential	Incomplete OC	Incomplete OC			Not applicable	Not applicable	Not applicable	Not applicable
6.3	Waste	Landfill gas/ air subsurface	Onsite	Inhalation	Human health - recreation	Incomplete OC	Assessed outdoor air			Not applicable	Not applicable	Not applicable	Not applicable
6.4	Waste	Landfill gas/ air subsurface	Onsite	Inhalation	Human health - indoor air	Incomplete IC	Incomplete IC			Not applicable	Not applicable	Not applicable	Not applicable
6.5	Waste	Landfill gas/ air subsurface	Onsite	Explosion	Human health - workers	Incomplete OC	Incomplete OC			Not applicable	Not applicable	Not applicable	Not applicable

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

- Erosion or runoff. Release of waste directly to the environment is controlled by operational and engineering controls such as daily cover and stormwater treatment and is verified by monitoring. These pathways are considered incomplete.
- Leaching to groundwater or seepage. This pathway is mitigated by engineered controls, such as liners and leachate collection systems, but is a primary pathway for exposure to contaminants from waste either as groundwater use or seepage to surface water. These pathways are therefore assessed on the basis of ANZECC criteria or Drinking Water Standards.
- Landfill gas migration both onsite and offsite is potentially a complete pathway. For the offsite pathways, indoor and outdoor air are both potential pathways. The onsite exposure during operations is controlled by management plans and assessment above. Onsite exposure post closure will have institutional controls in terms of constraints on future land use and a post closure management plan, which will control the indoor and maintenance and excavation worker exposure pathways. Only the onsite outdoor air exposure pathway is therefore considered complete post closure.

Class 1 and 2 Landfills

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

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

Class 3 Landfill

TBC.

Class 4 Landfill

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

- Direct contact with waste. These exposure scenarios/pathways would - generally be incomplete during operation of the site, but are potentially complete post closure. The placement of final cover, institutional controls in the form of a site management plan, including measures for maintenance of cover post closure, and limitations on future land use could eliminate these pathways. Ecological receptors are expected to be controlled during operations and, with the establishment of vegetative topsoil cover post closure, these pathways are considered incomplete post closure.

- Inhalation of volatiles. Migration of volatile constituents through the landfill cover is a potential pathway. Consideration is given to workplace exposure standards for volatiles when the site is operating and outdoor and indoor air post closure.
- Erosion or runoff. Release of waste directly to the environment is a potential pathway during operations. Cover placement and closure management controls would prevent waste release and make this pathway incomplete post closure.
- Leaching to groundwater or seepage. This pathway is a primary pathway for exposure to contaminants from waste, either as groundwater use or seepage to surface water. These pathways are therefore assessed.
- Landfill gas migration. Given the absence of significant organic material in this class of landfill these pathways are not evaluated.

Class 5 Landfill

Waste acceptance criteria for these fills are not risk based, but reflective of natural background conditions at the site. For fills without engineered containment (such as Class 5) and unrestricted operation the exposure scenarios and pathways were evaluated as follows:

- Direct contact with waste. These exposure scenarios/pathways would generally be commercial industrial outdoor worker scenarios during operation of the site. Post closure, unrestricted land use for human health effects need to be considered. Ecological receptors could be exposed during operations, but with the establishment of vegetative topsoil cover these pathways are considered incomplete post closure.
- Inhalation of volatiles. Migration of volatile constituents through the fill cover is a potential pathway. Consideration is given to workplace exposure standards for volatiles when the site is operating and outdoor and indoor air post closure.
- Erosion or runoff. Release of waste directly to the environment is a potential pathway during operations. Cover placement and closure management controls would make this pathway incomplete post closure.
- Leaching to groundwater or seepage. This pathway is a primary pathway for exposure to contaminants from waste either as groundwater use or seepage to surface water. These pathways are therefore assessed.
- Landfill gas migration. Given the absence of significant organic material in this class of landfill, these pathways are not evaluated.

C.4 Exposure Scenarios

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

- Class 1 and 2 landfills - operational – "commercial industrial worker outdoor".
- Class 1 and 2 landfills – post closure – the lesser of "recreational/parkland" and "commercial industrial outdoor".
- Class 4 landfills - the potential future land use is assumed to be unrestricted.
- Class 5 landfills - the potential future land use is assumed to be unrestricted.

Where a pathway is limiting in terms of the waste acceptance criteria, and has limited applicability, consideration needs to be given to deriving a site specific exposure scenario. The Contaminated Land Management Guideline (MfE 2011) is applied where guidelines values are not provided for a parameter.

Conversion of water phase criteria to soil phase limits is necessary for Class 4 landfills where waste acceptance criteria are based on total concentrations. The following assumptions are adopted to provide this conversion:

- The groundwater use receptors are located at the down-gradient boundary of the landfill.
- The leaching rate from soil is based on generic partition coefficients to derive a porewater concentration.
- A dilution attenuation factor (DAF) of 20 is adopted as representative of the dilution of leaching porewater that will occur for groundwater located at the down-gradient boundary of the site. The US EPA (May 1996) has adopted a default DAF of 20 based on a weight of evidence approach to screen for soil contaminants in soil porewater that could present a risk to groundwater.
- It is acknowledged that these models have many limitations and site conditions should be evaluated for specific sites.
- A further DAF of 5 is assumed to be the minimum that would occur in groundwater discharging to a freshwater receiving environment.

The onsite ecological receptor pathway is potentially complete for Class 5 landfills when operational. In both class 4 and 5 landfills the establishment of some separation post closure is considered to make the pathway incomplete. Ecological receptor criteria are generally of a similar order to soil background values. The soil background concentrations are therefore adopted for Class 5 sites. In general, Class 3 & 4 sites will have a higher level of operational control in terms of control of vectors and the inspection of all loads (recommended for these sites).

C.5 Leachability Based Criteria

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

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

C.6 Derivation of Leaching Criteria

Waste acceptance criteria for municipal waste landfills are generally based on a dilution and attenuation factor. The US EPA adopts a dilution and attenuation factor of 100 times the drinking water limits. The appropriate dilution and attenuation factor will be subject to a number of variables including the following:

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

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

- waste with a placed permeability of between 1×10^{-3} and 1×10^{-7} m/s, a placed density of 0.7 to 1.6 t/m^3 and an effective porosity between 0.1 and 0.5;
- a landfill cover with a permeability of between 1×10^{-6} and 1×10^{-9} m/s;

- a leachate discharge (liner leakage) to ground of between 10 and 5000 litres per hectare per day;
- a site located within 100 m of the receiving environment or a sensitive receptor; and
- sites where there is not a sustained inward hydraulic gradient and the hydraulic conductivity of the primary pathways for leachate migration is in excess of 1×10^{-5} m/s.

C.7 Recommended Waste Acceptance Criteria

Class 1 Landfills

The US EPA TCLP criteria are recommended as waste acceptance criteria for Class 1 landfills.

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

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

Class 2 Landfills

The US EPA TCLP tests are recommended as a means of determining leachable concentrations for Class 2 landfills. Threshold minimum total concentrations are provided to indicate the waste concentrations at which TCLP testing should be undertaken.

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

Criteria for Class 2 landfills are based on the US EPA dilution and attenuation factor approach. In deriving waste acceptance criteria, consideration has been given to the following:

- differing level of containment relative to a Class 1 site as noted above;
- nature of the waste received at a Class 2 site will by definition have less organic material (<5%) and hence less concentrated organic acids that result from biodegradation of waste; and
- organic constituents in waste will have less partitioning onto the waste solids given the lower general organic matter content.

A dilution and attenuation factor of 20 is therefore adopted to derive waste acceptance criteria for Class 2 landfills for inorganic constituents (this equates to US EPA TCLP criteria for a Class 1 site divided by 5).

A dilution and attenuation factor of 10 is therefore adopted to derive waste acceptance criteria for Class 2 landfills for organic constituents (this equates to the US EPA TCLP criteria for Class 1 landfills divided by 10).

Class 3 Landfills

TBC

Class 4 Landfills

Waste acceptance criteria for Class 4 landfills are based on total concentrations.

A Class 4 landfill does not include any form of engineered containment. Due to the nature of material received, it has the potential to receive wastes that are above soil background levels. Waste acceptance criteria should therefore be developed for total concentrations that limit the potential for significant adverse effects. These criteria need to be developed in terms of maximum allowable concentrations.

Table C-2 Class 4 Managed Fill Exposure Scenarios shows the exposure pathways that are limiting based on the exposure assessment outlined above and the resultant criteria. Given the uncertainty inherent within the derivation of guideline values it is proposed that the default national soil background values should be adopted as the minimum concentration at which pragmatic waste acceptance criteria can be established.

As discussed in Section 3, Class 4 landfills should not be sited in areas with drinking water aquifers. As a result, the MfE Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites (MfE 2011) groundwater protection numbers are not considered to represent a realistic exposure scenario and the criteria are developed on the same basis as for other constituents (refer Section 3).

In evaluating waste acceptance criteria for Class 4 landfills the ecological receptor values for Auckland that represent minimal risk (Cavanagh 2006) have been considered. This assessment notes that in a number of instances the values are below soil background and therefore the soil background value is adopted. As noted for Class 5 landfills soil background values are treated as region specific and adopting another region’s values is not appropriate. As a result only ecological receptor values that are above default national soil background (i.e. cadmium and mercury) are considered in deriving waste acceptance criteria values for Class 3 landfills.

For organic constituents the waste acceptance criteria are based on exposure assessment outlined above. If site specific criteria are derived, consideration should be given to all the relevant exposure pathways based on Section C3 and potential future land uses.

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

Table C-2 Class 4 Managed Fill Exposure Scenarios

	Receptor/ Exposure Scenario						
Class 4 Landfill	**Human health**		**Ecological receptor**	**Groundwater**	**Aquatic**	**Adopted**	**Limiting pathway/guideline**
(mg/kg)	**(NES rural residential/ lifestyle 25% produce)**	**(Oil industry agricultural use)**	**Cavanagh 2006**	**(DWSNZ x 20 x Kd)**	**(ANZECC x 100 x Kd)**		
Arsenic	17	NGV	Soil background	310	2100	17	Human health -NES RRL 25% produce
Cadmium	0.8	NGV	1.0	40	10	0.8	Human health -NES RRL 25% produce
Chromium	290	NGV	Soil background	6300	630	290	Human health -NES RRL 25% produce
Copper	>10,000	NGV	Soil background	12650	44	>44 & soil background	Greater of Aquatic – ANZECC and soil background
Lead	160	NGV	60	1000	1700	>60 & soil background	Greater of human health - Ecological (Cavanagh 2006) and soil background
Mercury	200	NGV	0.7	160	240	0.7	Human health -Ecological (Cavanagh 2006)
Nickel	NGV	NGV	Soil background	310	870	310	Human health -DWSNZ
Zinc	NGV	NGV	Soil background	15000	400	400	Aquatic - ANZECC
TPH C7 – C9	NGV	120	NGV	NGV	NGV	120	Human health - MfE Oil
TPH C10 – C14	NGV	58	NGV	NGV	NGV	58	Human health - MfE Oil
Benzene	NGV	1.1	NGV	0.2	80	0.2	Human health -DWSNZ
Ethylbenzene	NGV	59	NGV	66	NGV	59	Human health - MfE Oil
Toluene	NGV	82	NGV	50	NGV	50	Human health -DWSNZ
Total Xylene	NGV	59	NGV	30	130	30	Human health –MfE Oil
Benzo(a)pyrene (equivalent*)	6.0	Superceded by NES	0.7	54	NGV	Interim based on soil background = 2	Ecological receptor - CCME
Dieldrin	1.1	NGV	NGV	0.2	NGV	0.2	Human health -DWSNZ
Total DDTs	45.0	NGV	0.7	526	26	0.7	Ecological receptor - CCME

Note: MfE Oil = Ministry for the Environment Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand (2011)

Class 5 Landfills

Waste acceptance criteria for Class 5 landfills are based on total concentrations.

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

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

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

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

Waste acceptance criteria are therefore recommended only for the following synthetic organic compounds:

- total petroleum hydrocarbons (TPH);
- benzene, toluene, ethyl benzene and xylenes (BTEX);
- polycyclic aromatic hydrocarbons (PAH); and
- pesticides (DDT).

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

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

With respect to DDT, the NES for Assessing and Managing Contaminants in Soil to Protect Human Health (MfE 2011) does not consider ecological receptors. Using the Ministry for the Environment Contaminated Land Management Guidelines No. 2 - Hierarchy and Application in New Zealand of Environmental Guideline Values (MfE 2011) hierarchy, the international risk-based criteria adopted for DDT are those in the Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health (CCME 1999) ecological receptor pathway for agricultural use.

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

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

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

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

Table C-3 Class 5 Landfill Exposure Scenarios summarises the basis for selection of guideline values.

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

- Auckland
- Waikato
- Wellington
- Canterbury

Table C-3 Class 5 Landfill Exposure Scenarios

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

Note:

MfE Oil = Ministry for the Environment Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand (2011)

C.8 Site Specific Waste Acceptance Criteria

Class 1 Landfills

Waste acceptance criteria for Class 1 landfills are leachability criteria applied to waste materials.

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

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

Class 2 Landfills

Waste acceptance criteria for Class 2 landfills are leachability based criteria.

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

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

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

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

- Derivation of site specific dilution attenuation factors for leaching from the waste should assume receptors are located at the downgradient extent of the footprint for the fill site.
- Site specific waste acceptance criteria should include limitations on the amount of waste containing the contaminants as a percentage of the total waste stream received at the site. This should typically not exceed 2% of the waste stream.

Class 3 Landfills

TBC

Class 4 Landfills

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

Site specific criteria should only be considered for Class 4 landfills if there are site specific factors that will effectively mitigate the potential for significant adverse effects. Specific situations where derivation of site specific criteria for Class 4 landfills could be considered are:

- Waste acceptance criteria that are based on the human health exposure pathway may vary based on the land use at the site if it is already constrained. The philosophy with waste acceptance criteria derivation is that possible future land uses are not limited. In the case of urban areas where land has a current commercial industrial use, it is conceivable that the land use could change to more sensitive residential use. It is however unlikely to become agricultural land. The least restrictive land use that should be considered for Class 4 landfill waste acceptance criteria is therefore residential (10% produce).
- Waste acceptance criteria for waste material, within the fill mass, that when placed will not be in direct contact with the water table, or within 2 m of the finished fill surface could consider a revised exposure scenario with respect to human health. However the groundwater and aquatic pathways in Table C-3 must be considered as they are likely to be limiting. It is recommended that waste acceptance criteria total concentrations at or exceeding the groundwater and aquatic pathways concentration in Table C-3 should require mandatory testing of leachability (TCLP) as these total concentrations are above the threshold minimum total concentration at which Class 2 landfill waste acceptance criteria could be exceeded (refer Appendix D).

Class 5 Landfills

Waste acceptance criteria for Class 5 landfills should be applied as a maximum total concentration not to be exceeded in any material received at the site.

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

C.9 References

ANZECC Guidelines for Fresh and Marine Water Quality (2000).

Canadian Council of Ministries for the Environment (CCME 1999) Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health.

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

Drinking Water Standards for New Zealand (DWSNZ 2005 revised 2008).

Environment Canterbury Report No. R07/19 (T&T, 2007) – Background Concentrations of Polycyclic Aromatic Hydrocarbons in Christchurch Urban Soils.

J Cavanagh (2006) Comparison of soil guideline values used in New Zealand and their derivations. Landcare Research Contract Report LC0607/025 Prepared for Environment Canterbury.

Ministry for the Environment. 2011. Contaminated Land Management Guidelines No. 2 - Hierarchy and Application in New Zealand of Environmental Guideline Values (2003, Revised 2011)

Ministry for the Environment (2011). Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand (1999, revised 2011).

Ministry for the Environment (2011). Methodology for Deriving Standards for Contaminants in Soil to Protect Human Health (2011) Appendix 6 Natural Background Topsoil Datasets for Arsenic and Cadmium.

Ministry for the Environment User’s Guide for the National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health, (2012).

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

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

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

United States Environmental Protection Agency (1996). Soil Screening Guidance: Technical Background Document, Second Edition. EPA/540/R-95/128, May 1996.

United States Environmental Protection Agency (1997) *Identification And Listing of Hazardous Waste* Title 40, Part 261, Code of Federal Regulations. 40 CFR §261.24.

Appendix D Class 1 Landfill Waste Acceptance Criteria

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

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

Table D-1 Class 1 Waste Acceptance Criteria for Inorganic and Organic Elements[3]

Contaminant of concern	Unit	Maximum allowable TCLP concentration
Arsenic	mg/L	5
Barium	mg/L	100
Benzene	mg/L	0.5
Cadmium	mg/L	1
Carbon Tetrachloride	mg/L	0.5
Chlordane	mg/L	0.03
Chlorobenzene	mg/L	100
Chloroform	mg/L	6
Chromium	mg/L	5
Endrin	mg/L	0.02
m-Cresol	mg/L	200
o-Cresol	mg/L	200
p-Cresol	mg/L	200
Total cresol	mg/L	200
1,4-Dichlorobenzene	mg/L	7.5
1,2-Dichloroethane	mg/L	0.5
1,1-Dichloroethylene	mg/L	0.7
2,4-Dinitrotoluene	mg/L	0.13
2,4-Dichlorophenoxyacetic acid	mg/L	10
Heptachlor	mg/L	0.008
Hexachloro – 1,3-butadiene	mg/L	0.5
Hexachlorobenzene	mg/L	0.13
Hexachloroethane	mg/L	3
Lead	mg/L	5
Lindane	mg/L	0.4

---

[3] US EPA Chapter 40 CFR

Contaminant of concern	Unit	Maximum allowable TCLP concentration
Mercury	mg/L	0.2
Methoxychlor	mg/L	10
Methyl ethyl ketone	mg/L	200
Nitrobenzene	mg/L	2
Pentachlorophenol	mg/L	100
Pyridine	mg/L	5
Selenium	mg/L	1
Silver	mg/L	5
Tetrachloroethylene	mg/L	0.7
Toxaphene	mg/L	0.5
Trichloroethylene	mg/L	0.7
2,4,5-Trichlorophenol	mg/L	400
2,4,5-Trichlorophenoxypropionic acid	mg/L	1
2,4,6-Trichlorophenol	mg/L	2
Vinyl chloride	mg/L	0.2
Sulfides	ppm	50
Cyanides	ppm	50
Total halogenated compounds	ppm	1,000
Total synthetic non-halogenated compounds	ppm	10,000
Polychlorinated biphenyls	ppm	50

Table D-2 Class 1 Waste Acceptance Criteria for Inorganic and Organic Elements[4]

Contaminant of concern	Unit	Maximum allowable TCLP concentration
Aluminium	ppm	40
Aniline	ppm	0.2
Antimony	ppm	0.6
Beryllium	ppm	10
Boron	ppm	20
Bromodichloromethane	ppm	1
Bromoform	ppm	10
Carbon disulphide	ppm	3
2 Chlorophenol	ppm	0.05
Copper	ppm	5.0
1,2 Dibromo-3-chloropropane	ppm	0.2
Dibromochloromethane	ppm	10

---

[4] Module 2: Hazardous Waste Guidelines MfE 2004

Contaminant of concern	Unit	Maximum allowable TCLP concentration
1,2 Dichlorobenzene	ppm	0.2
1,2 Dichloroethene	ppm	10
Dichloromethane	ppm	2
2,4 Dichlorophenol	ppm	0.05
1,2 Dichloropropane	ppm	1
1,3 Dichloropropene	ppm	2
Diethylphthalate	ppm	100
Dimethylphthalate	ppm	400
Ethyl benzene	ppm	50
Fluoride	ppm	200
Lithium	ppm	20
Molybdenum	ppm	10
Naphthalene	ppm	10
Nickel	ppm	10
Phenol	ppm	40
1,1,2,2 Tetrachloroethane	ppm	50
Tin	ppm	1000
Toluene	ppm	100
Tributyltin oxide (TBTO)	ppm	3
1,1,1 Trichloroethane	ppm	200
1,1,2 Trichloroethane	ppm	500
Vanadium	ppm	2.0
Xylene (m,o,p)	ppm	100
Zinc	ppm	10.0

Appendix E Class 2 Landfill Waste Acceptance Criteria

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

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

Table E-1 Class 2 Waste Acceptance Criteria for Inorganic and Organic Elements [5]

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Unit	Total concentration above which TCLP tests required
Arsenic	mg/L	1	mg/kg	20
Barium	mg/L	20	mg/kg	400
Benzene	mg/L	0.05	mg/kg	1
Cadmium	mg/L	0.2	mg/kg	4
Carbon Tetrachloride	mg/L	0.05	mg/kg	1
Chlordane	mg/L	0.003	mg/kg	0.06
Chlorobenzene	mg/L	10	mg/kg	200
Chloroform	mg/L	0.6	mg/kg	12
Chromium	mg/L	1	mg/kg	20
Endrin	mg/L	0.002	mg/kg	0.04
m-Cresol	mg/L	20	mg/kg	400
o-Cresol	mg/L	20	mg/kg	400
p-Cresol	mg/L	20	mg/kg	400
Total cresol	mg/L	20	mg/kg	400
1,4-Dichlorobenzene	mg/L	0.75	mg/kg	15
1,2-Dichloroethane	mg/L	0.05	mg/kg	1
1,1-Dichloroethylene	mg/L	0.07	mg/kg	1.4
2,4-Dinitrotoluene	mg/L	0.013	mg/kg	0.26
2,4-Dichlorophenoxyacetic acid	mg/L	1	mg/kg	20
Heptachlor	mg/L	0.0008	mg/kg	0.016

---

[5] Module 2: Hazardous Waste Guidelines MfE 2004

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Unit	Total concentration above which TCLP tests required
Hexachloro – 1,3-Butadiene	mg/L	0.05	mg/kg	1
Hexachlorobenzene	mg/L	0.013	mg/kg	0.26
Hexachloroethane	mg/L	0.3	mg/kg	6
Lead	mg/L	1	mg/kg	20
Lindane	mg/L	0.08	mg/kg	1.6
Mercury	mg/L	0.04	mg/kg	0.8
Methoxychlor	mg/L	1	mg/kg	20
Methyl ethyl ketone	mg/L	20	mg/kg	400
Nitrobenzene	mg/L	0.2	mg/kg	4
Pentachlorophenol	mg/L	10	mg/kg	200
Pyridine	mg/L	0.5	mg/kg	10
Selenium	mg/L	0.2	mg/kg	40
Silver	mg/L	1	mg/kg	20
Tetrachloroethylene	mg/L	0.07	mg/kg	1.4
Toxaphene	mg/L	0.05	mg/kg	1
Trichloroethylene	mg/L	0.07	mg/kg	1.4
2,4,5-Trichlorophenol	mg/L	40	mg/kg	800
2,4,5-Trichlorophenoxypropionic acid	mg/L	0.1	mg/kg	2
2,4,6-Trichlorophenol	mg/L	0.2	mg/kg	4
Vinyl chloride	mg/L	0.02	mg/kg	0.4
Sulfides	ppm	10	mg/kg	NA
Cyanides	ppm	10	mg/kg	NA
Total halogenated compounds	ppm	100	mg/kg	NA
Total synthetic non-halogenated compounds	ppm	1000	mg/kg	NA
Polychlorinated biphenyls	ppm	5	mg/kg	NA

Note: NA = not applicable

Table E-2 Class 2 Waste Acceptance Criteria for Inorganic and Organic Elements[6]

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Unit	Total concentration above which TCLP tests required
Aluminium	ppm	4	ppm	80

---

[6] Module 2: Hazardous Waste Guidelines MfE 2004

Contaminant of concern	Unit	Maximum allowable TCLP concentration	Unit	Total concentration above which TCLP tests required
Aniline	ppm	0.02	ppm	0.4
Antimony	ppm	0.06	ppm	1.2
Beryllium	ppm	1	ppm	20
Boron	ppm	2	ppm	40
Bromodichloromethane	ppm	0.1	ppm	2
Bromoform	ppm	1	ppm	20
Carbon disulphide	ppm	0.3	ppm	6
2 Chlorophenol	ppm	0.005	ppm	0.1
Copper	ppm	0.5	ppm	10
1,2 Dibromo-3-chloropropane	ppm	0.02	ppm	0.4
Dibromochloromethane	ppm	1	ppm	20
1,2 Dichlorobenzene	ppm	0.02	ppm	0.4
1,2 Dichloroethene	ppm	1	ppm	20
Dichloromethane	ppm	0.2	ppm	4
2,4 Dichlorophenol	ppm	0.005	ppm	0.1
1,2 Dichloropropane	ppm	0.1	ppm	2
1,3 Dichloropropene	ppm	0.2	ppm	4
Diethylphthalate	ppm	10	ppm	200
Dimethylphthalate	ppm	40	ppm	800
Ethyl benzene	ppm	5	ppm	100
Fluoride	ppm	20	ppm	400
Lithium	ppm	2	ppm	40
Molybdenum	ppm	1	ppm	20
Naphthalene	ppm	1	ppm	20
Nickel	ppm	1	ppm	20
Phenol	ppm	4	ppm	80
1,1,2,2 Tetrachloroethane	ppm	5	ppm	100
Tin	ppm	100	ppm	2000
Toluene	ppm	10	ppm	200
Tributyltin oxide (TBTO)	ppm	0.3	ppm	6
1,1,1 Trichloroethane	ppm	20	ppm	400
1,1,2 Trichloroethane	ppm	50	ppm	1000
Vanadium	ppm	0.2	ppm	4
Xylene (m,o,p)	ppm	10	ppm	200
Zinc	ppm	1	ppm	20

---

[5] Module 2: Hazardous Waste Guidelines MfE 2004

Appendix F Class 3 Landfill Waste Acceptance Criteria

TBC

Appendix G Class 4 Landfill Waste Acceptance Criteria

Table G-1 Class 4 Waste Acceptance Criteria for Inorganic and Organic Elements

Contaminant of concern	Unit	Maximum allowable total concentration
Arsenic	mg/kg	17[a]
Cadmium	mg/kg	0.8[a]
Chromium	mg/kg	290[b]
Copper	mg/kg	Greater of 44 and soil background[a]
Lead	mg/kg	Greater of 60 and soil background[a]
Inorganic Mercury	mg/kg	0.7[c]
Nickel	mg/kg	310[d]
Zinc	mg/kg	400[e]
TPH C7 – C9	mg/kg	120[f]
TPH C10 – C14	mg/kg	58[f]
Benzene	mg/kg	0.2[d]
Ethylbenzene	mg/kg	59[f]
Toluene	mg/kg	50[d]
Total Xylene	mg/kg	30[f]
Benzo(a)pyrene (equivalent*)	mg/kg	Interim = 2[a]
Dieldrin	mg/kg	0.2[d]
Total DDTs	mg/kg	0.7[g]

Note:

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

a) Interim value until National Soil Background value or region-specific values become available.

b) Derived from Ministry for the Environment User's Guide for the National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health, 2012. Table B2 Soil contaminant standards for health for inorganic substances, rural residential/lifestyle block 25 % produce.

c) Based on J Cavanagh (2006) Ecological receptor values for Auckland.

d) Derived using dilution attenuation factor applied to DWSNZ (2008) MAV values.

e) Derived using dilution attenuation factor applied to ANZECC Guidelines for Fresh and Marine Water Quality 2000.

f) Derived from Ministry for the Environment Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand 1999, revised 2011. Table 4.13 Tier 1 soil acceptance criteria for TPH, agricultural use, all pathways.

g) Based on ecological receptor from Canadian Council of Ministries for the Environment (CCME 1999) Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health.

Appendix H Class 5 Landfill Waste Acceptance Criteria

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

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

Note:

NA – Not available

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

Table H-2 Class 5 Waste Acceptance Criteria for Organic Elements

Contaminant of concern	Unit	Maximum allowable total concentration
TPH C7 – C9	mg/kg	120[a]
TPH C10 – C14	mg/kg	58[a]
Benzene	mg/kg	0.0054[b]
Ethylbenzene	mg/kg	1.1[b]
Toluene	mg/kg	1.0[b]
Total Xylene	mg/kg	0.61[b]
Benzo(a)pyrene (equivalent*)	mg/kg	Interim = 2[c]
Total DDT	mg/kg	0.7[d]

Note:

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

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

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

c) TBD National soil background to be determined.

d) US EPA (2006) ecological receptors.

Appendix I Prohibited Wastes

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

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

Characteristics

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

Waste Types which may exhibit the above Characteristics

Cyanides, surface treatment and heat treatment	
A100	Cyanide containing waste from treatment of metals
A110	Cyanide containing waste
A120	Complexed cyanides
A130	Other cyanides
Acids	
B100	Sulfuric acid
B110	Hydrochloric acid
B120	Nitric acid
B130	Phosphoric acid
B140	Chromic acid

B150	Hydrofluoric acid
B160	Sulfuric/hydrochloric acid mixtures
B170	Other mixed acids
B180	Organic acids
Alkalis	
C100	Caustic soda, potash, alkaline cleaners
C110	Ammonium hydroxide
C140	Other (hazardous substances must be specified)
Inorganic chemicals	
D100	Metal carbonyls
D120	Mercury
D280	Alkali metals
D330	Sulfur
Reactive chemicals	
E100	Oxidising agents
E110	Reducing agents
E120	Explosives
E130	Highly reactive chemicals
Paints, lacquers, varnishes, inks, dyes, pigments, adhesives	
F200	Uncured adhesives or resins
Organic solvents	
G100	Ethers
G110	Non-halogenated (FP>61°C), n.o.s
G130	Halogenated (FP>61°C), n.o.s
G140	Halogenated (FP>61°C), n.o.s
G150	Halogenated n.o.s
G160	Wastes from the production and formulation of organic solvents
G180	Others (hazardous substances must be specified)
Pesticides	
H100	Inorganic, organometallic pesticides
H110	Organophosphorus pesticides
H180	Organic wood preserving compounds
H120	Nitrogen-containing pesticides
H130	Halogen-containing pesticides
H140	Sulfur-containing pesticides
H150	Mixed pesticide residues

H160	Copper-chrome-arsenic (CCA)
H170	Other inorganic wood preserving compounds
Oils, hydrocarbons, emulsions	
J100	Waste mineral oils unfit for their original intended use (lubricating, hydraulic)
J110	Waste hydrocarbons
J120	Waste oils/water, hydrocarbon/water mixtures, emulsions (mainly oil and or hydrocarbons, i.e. >50%)
J130	Waste oils/water, hydrocarbon/water mixtures, emulsions (mainly water, i.e. >50%)
J140	Transformer fluids (excluding PCBs)
J150	Other (cutting, soluble oils)
J160	Tars and tarry residues (including tarry residues arising from refining)
Putrescible, organic wastes	
K100	Liquid animal effluent (poultry and fish processing)
K150	Liquid vegetable oils and derivatives
K170	Liquid animal oils and derivatives
K180	Abattoir effluent
K200	Food processing effluent
Industrial washwaters, effluents	
L100	Truck, machinery washwaters with or without detergents
L101	Car wash waters with or without detergents
L120	Cooling tower washwater
L130	Fire wastewaters
L140	Textile effluent
L150	Other industrial plant washdown water
Organic chemicals	
M100	Polychlorinated biphenyls (PCBs) and/or polyterphenyl (PCTs) and/or polybrominated biphenyls (PBBs)
M110	Equipment containing PCBs and/or PCTs

	and/or PBBs
M120	Solvents and materials contaminated with PCBs and/or PCTs and/or PBBs
M150	Phenols, phenol derivatives including chlorophenols
M160	Halogenated compounds n.o.s.
M170	Any congener of poly-chlorinated dibenzofuran
M180	Any congener of poly-chlorinated dibenzop-dioxin
M210	Organic cyanides
M250	Liquid surfactants and detergents
Chemical and pharmaceutical wastes	
R100	Infectious substances
R110	Pathogenic substances
R130	Cytotoxic substances
Miscellaneous	
T100	Waste chemical substances arising from research and development or teaching activities, which are not identified

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

Characteristics

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

Waste Types which may exhibit the above Characteristics

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

K100	Animal residues (poultry and fish processing wastes)
K101	Scallop processing residues
K120	Grease interceptor trap waste – domestic
K130	Bacterial sludge (septic tank)
K132	Sewage sludge and residues
K140	Tannery wastes not containing chromium
K150	Vegetable oil derivatives
K160	Vegetable wastes
K170	Animal oil derivatives (e.g. tallow)
K180	Abattoir residues
K190	Wool scouring wastes
Organic Chemicals	
M130	Non-halogenated (non-solvent) n.o.s.
M140	Heterocyclic organic compounds
M190	Organic phosphorus compounds
M200	Organic sulfur compounds
M220	Organic isocyanates
M230	Amines and other nitrogen compounds (aliphatic)
M240	Amines and other nitrogen compounds (aromatic)
M260	Highly odorous (eg. mercaptans, acrylate)
M270	Methacrylate compounds
M280	Other
Solid/sludge requiring special handling	
N100	Drums which have contained hazardous substances (and which have been triple rinsed)

N110	Containers and bags which have contained hazardous substances (hazardous substances must be specified)
N120	Contaminated soils (hazardous substances must be specified)
N130	Spent catalysts (contaminants must be specified)
N140	Fire debris
N150	Fly ash
N160	Encapsulated wastes
N170	Chemically fixed wastes
N180	Solidified or polymerised wastes
N190	Ion-exchange column residues
N200	Industrial waste treatment sludges and residues n.o.s.
N210	Residues from pollution control operations
N220	Asbestos (refer to the Management and Removal of Asbestos Approved Code of Practice, WorkSafe New Zealand, November 2016)
N230	Synthetic mineral fibres
Clinical and pharmaceutical wastes	
R120	Pharmaceutical and residues
R140	Wastes from the production and preparation of pharmaceutical products
Miscellaneous	
T120	Scrubber sludge
T130	Photographic chemicals which do not contain silver
T140	Inert sludges/slurries (eg. clay, ceramic suspensions)
T150	Used tyres/tyre wastes
T190	Other (hazardous substances must be specified)

Appendix J Hazardous Activities and Industries List (MfE, 2011)

A. Chemical manufacture, application and bulk storage

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

B. Electrical and electronic works, power generation and transmission

19. Batteries including the commercial assembling, disassembling, manufacturing or recycling of batteries (but excluding retail battery stores)
20. Electrical transformers including the manufacturing, repairing or disposing of electrical transformers or other heavy electrical equipment
21. Electronics including the commercial manufacturing, reconditioning or recycling of computers, televisions and other electronic devices
22. Power stations, substations or switchyards

C. Explosives and ordinances production, storage and use

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

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

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

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

31. Asbestos products manufacture or disposal including sites with buildings containing asbestos products known to be in a deteriorated condition
32. Asphalt or bitumen manufacture or bulk storage (excluding single-use sites used by a mobile asphalt plant)
33. Cement or lime manufacture using a kiln including the storage of wastes from the manufacturing process
34. Commercial concrete manufacture or commercial cement storage
35. Coal or coke yards
36. Hydrocarbon exploration or production including well sites or flare pits

37. Mining industries (excluding gravel extraction) including exposure of faces or release of groundwater containing hazardous contaminants, or the storage of hazardous wastes including waste dumps or dam tailings

F. Vehicle refuelling, service and repair

38. Airports including fuel storage, workshops, washdown areas, or fire practice areas
39. Brake lining manufacturers, repairers or recyclers
40. Engine reconditioning workshops
41. Motor vehicle workshops
42. Port activities including dry docks or marine vessel maintenance facilities
43. Railway yards including goods-handling yards, workshops, refuelling facilities or maintenance areas
44. Service stations including retail or commercial refuelling facilities
45. Transport depots or yards including areas used for refuelling or the bulk storage of hazardous substances

G. Cemeteries and waste recycling, treatment and disposal

46. Cemeteries
47. Drum or tank reconditioning or recycling
48. Landfill sites
49. Scrap yards including automotive dismantling, wrecking or scrap metal yards
50. Waste disposal to land (excluding where biosolids have been used as soil conditioners)
51. Waste recycling or waste or wastewater treatment

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

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

Appendix K Landfill Monitoring

K.1 Scope of Monitoring

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

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

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

Monitoring

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

- **Leachate.** Understanding the character of the leachate will enable the appropriate interpretation of potential risks which the discharge of the leachate may have on the receiving environment. Certain parameters are generally present in leachate, but the relative concentrations of these parameters will vary depending on the nature of the waste and the age of the landfill. In a landfill with an engineered liner and leachate collection system, the leachate can generally be sampled directly. This is the most appropriate location at which to test for trace toxicants, as they will be present here at the highest concentrations and hence are more likely to be detected in the leachate itself. In landfills without such systems, the leachate may need to be sampled via bores, after it has mixed with the underlying groundwater.

- **Stormwater**. Stormwater is rainfall which has fallen onto the landfill and is shed. Generally, stormwater that falls on the active areas of the landfill and hence is potentially contaminated by waste is managed with the leachate. Rainfall on peripheral and closed areas of the landfill is generally considered to be uncontaminated but may contain sediment which requires management. An understanding of the stormwater catchment area of each landfill site activity will identify the nature of the potential contamination which should be monitored. It should be noted that leachate seeps can result in the stormwater network receiving leachate, and the potential for this to occur should be assessed.

- **Gas**. Landfills receiving organic waste produce landfill gas, which may constitute a hazard and can migrate off site. This migration of gas and its spatial pattern and concentration will need to be monitored. Larger landfills may have a landfill gas collection system, via which the composition of the gas can be monitored. However, the migration of the gas needs to be monitored through other means as discussed in Section J4.

- **Groundwater**. Leakage from a fully engineered lined landfill may occur, resulting in a discharge into groundwater to some extent. In a fully engineered landfill with a leachate collection system, the extent of this discharge will be minimal, whereas in unlined landfills, the leachate will be discharging into the ground or groundwater under the site. In the first instance, monitoring is to verify that leachate is being adequately contained and is not escaping into the underlying aquifer(s). In the latter case, monitoring is focused towards determining the extent of the leachate plume and whether any sensitive receivers are being impacted. The extent of the groundwater bore network needed to meet these objectives depends upon the nature of the hydrogeology and the sensitivity of the use of the aquifer.

- **Surface water**. If there is a surface water body in the vicinity of the landfill, then monitoring of it should be considered. However, the potential route for contamination should be carefully assessed. Leachate seepage from the landfill surface, or failure of above ground leachate pipes or storage facilities, may result in leachate discharge to the stormwater management system. Otherwise, if the surface water and groundwater are not connected, then there is minimal potential for leachate contamination to be transmitted to the surface water and any impact is probably restricted to sediment impacts from stormwater discharges, with monitoring targeted appropriately.

- **Sediment**. Contaminants which are associated with particulates may accumulate in the sediments of an impacted surface water body. Therefore, if the landfill could potentially discharge contaminants into a surface water body, then monitoring of the sediment in depositional areas of the water body may indicate any accumulation of contaminants, particularly trace metals and synthetic organic constituents.

- **Ecosystem monitoring.** Whilst chemical monitoring can indicate the potential for a discharge to have an impact on an ecosystem, monitoring of the ecosystem itself provides a direct measure of any impact. This can include monitoring of the speciation and abundance of elements of the ecosystem, for example benthic organisms, macroinvertebrates, and periphyton. Standard methodologies have been developed for the monitoring of these aspects. The receiving environment should be assessed to determine whether appropriate ecosystem indicators are present to which these methodologies can be reliably applied. This monitoring will indicate the general status of the ecosystem, which is generally inherently highly variable. Careful design of the programme is required if analysis of effects specifically from the landfill are required.

Parameters Analysed

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

- **Leachate Indicators**. Leachate typically contains elevated concentrations of a number of parameters, primarily chemical oxygen demand (COD), conductivity and ammoniacal nitrogen. Should consistent sampling indicate elevated levels of these three parameters, leachate is likely present. Generally, an elevated concentration of a single parameter is not sufficient to indicate leachate contamination but elevation of a number of them provides a useful indication. This parameter group is useful for groundwater or surface water where the purpose is to determine if leachate is present and the degree to which contamination is occurring. It can also indicate the extent to which the waste in the landfill has decomposed and what stage that landfill is at. [Objective 2].

- **Physico-chemical Parameters**. These parameters, such as temperature, conductivity and pH, indicate the general condition of the water sample. They determine the general characteristics of the water sample and can be used to indicate the source of the water. These parameters can affect the way in which the results are interpreted, especially the potential toxicity of the sample. [Objective 3]

- **Cation/Anion**. These are the major cations and anions in the water sample. These characteristics can be used to determine if samples from different locations have been collected from the same aquifer or water source, as water from the same source will have similar cation/anion characteristics. Analysis for these parameters can be useful to clarify that samples are being collected from the same aquifer, and also the degree of connectivity between groundwater and surface water. [Objective 1 and 3].

- **Nutrients**. The primary nutrients of concern are nitrogen (N) and phosphorus (P), and, to a lesser extent, potassium (K). Leachate is a significant source of N in the form of ammoniacal N, and can contain P. Therefore, a landfill can contribute to the general nutrient balance in a catchment. N and P can exist in a variety of forms and can change between these forms in the environment. Therefore, if nutrients are a concern in the receiving environment, analysis for the range of forms may be appropriate, especially if there are a number of background sources of nutrients. [Objective 1 and 3].

- **Trace Metals**. Leachate can contain trace metals, which can be toxic at higher concentrations. Any discharge of leachate can thus increase the concentration of these metals in the receiving environment. However, when deciding which parameters to analyse and in interpreting the results, it should be noted a number of these metals are present naturally in the environment (for example aluminium is present in a number of clays). Therefore, elevated metal concentrations may not necessarily be due to leachate, especially if the primary leachate indicators are not elevated. [Objective 2].

- **Synthetic Organics**. Dependent upon the nature of the waste in the landfill, leachate can contain synthetic organic contaminants such as pesticides, herbicides, plasticisers etc. Generally these are present at low concentrations, even in the leachate, and are less than the detection limits. Monitoring for these parameters should focus upon the leachate to determine their presence, as they are unlikely to be detected in groundwater except in a concentrated plume. [Objective 2].

- **Landfill Gas Constituents.** Typically CO_2, CH_4, H_2S and O_2 in the landfill gas collection system and in migration monitoring wells.

A single parameter may fall into a number of these groups.

Trigger Values

As outlined in section 7.4 of the Guidelines, trigger levels consist of specified numerical values or narrative descriptors for the protection of groundwater and surface water resources that require response by the landfill operator.

Trigger values would typically not be set for all parameters that are monitored but would be determined for a suite of parameters that will act as the indicators for the site.

Different trigger values would be set for the different components of the monitoring programme. For example, different trigger values could be set for groundwater than for surface water. Significantly different values will be set for leachate and stormwater, as these are potential contaminant discharges prior to mixing.

Appropriate trigger values for environmental effects should be set based on the receptors identified for a certain site. If the surrounding land use includes provision of drinking water for surface and groundwater, human health indicators should be considered. The New Zealand Drinking Water Standards[7] provide guideline values for human health.

Guideline values which protect ecosystem health should be sourced from the ANZECC 2000 Guidelines[8]. These guidelines include a wide variety of guidance for various uses of the water, including ecosystem protection, both for general stressors and toxicity; stock water; irrigation; and other primary industrial uses.

The ANZECC 2000 guidelines provide values for 80%, 90%, 95% and 99% protection levels. The level of modification of the surrounding environment will determine the protection level used. A 99% protection level is appropriate for highly pristine, unmodified ecosystems, while 80% protection level is appropriate for highly modified environments with little ecological significance or value (again not often used). The most common guideline level used is 95% protection level which is suitable for modified ecosystems.

For sites which are used for contact recreation, reference should be made to the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MfE, 2003)[9].

The location at which the trigger values are imposed should be considered carefully, and should be as close as possible to either edge of the area within the allowed mixing zone, or at or just upstream of the site of the sensitive receiver. They should be assessed across all sites. An assessment of the background (upstream or upgradient) concentrations should also be made.

To be able to evaluate compliance of monitoring data with surface water performance standards or trigger levels, it is necessary to specify what an exceedance is. The statistical function that will be used to determine compliance needs to be clearly defined, and should be consistent with the derivation of the trigger value.

Examples of this are:

- for continuous (i.e. half-hourly) measurements of turbidity and conductivity, compliance with trigger levels can be assessed by using running averages calculated over 12 successive measurements (i.e. 6 hours total);
- for fortnightly monitoring data, compliance can be assessed using running averages over three successive sampling occasions. Also, non-compliance

---

[7] Ministry of Health, 2005: Drinking Water Standards for New Zealand

[8] ANZECC, 2000: Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters. Australia and New Zealand Environment and Conservation Council.

[9] Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MfE, 2003)

can be deemed to have occurred if more than one of the three data points exceeds the trigger level; and

- for quarterly and annual monitoring data, compliance with trigger levels can be assessed using individual data points.

Errors

There are two types of errors inherent in any monitoring programme which must be taken into account in the design of the programme. These two error types, Type I and Type II, are:

> *'The situation where we conclude that an important change has happened when, in fact it has not, is technically referred to as a Type I error. Conversely, many indicators are very variable naturally and intensive sampling may be essential to detect ecologically important changes in the indicator. If the sampling intensity is too small and the important change is missed, then a Type II error is committed'.* (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, 2000, pp. 3.1-21)[10].

When designing a monitoring programme, these two error types should be considered and an explicit acceptance of the extent to which these two errors will occur should be made. This will enable the selection of appropriate programme design.

Detection Limits

Detection limits are considered in Section 7.4 of the Guidelines.

Sampling and Analytical Requirements

As outlined in section 7.4 of the Guidelines, the collection of representative samples and the achievement of a subsequent unbiased analysis of results can present considerable challenges for monitoring programmes.

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

- **Sample replication**. The number (replicates) of samples to be collected at any time needs to be specified. The collection of replicates allows an understanding of the inherent variability in the water body. Ideally, the number of samples is determined by an acceptable level of uncertainty specified at the 95% confidence level. However, due to the high costs incurred by replication, this guideline is seldom achieved. Rather, the

---

[10] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, 2000, pp. 3.1-21

approach taken to reduce the uncertainty of monitoring data is to average them over time or space.

- **Sampling Methods and Equipment.** In general, the fewer disturbances that a sample receives before capture in a sample bottle, the more likely it is to retain its integrity. The sampling methods should be selected to achieve the minimum of sample disturbance, and should be standardised such that variability in the results between sites is not introduced through different sample collection methods. Also, access to the various sites should be considered, especially if pumps and associated batteries or generators are required to collect the sample.

- **Sample Collection Protocols**. Care should be taken to ensure that the sample as collected is as representative as possible of the water body from which it is collected. For groundwater sample collection, the well should be purged of stagnant water before taking a sample. Normal practice is to purge three to five well volumes and monitor key indicators to determine that the sample extracted has stabilised. The procedures given in A National Protocol for State of the Environment Groundwater Sampling in New Zealand (MfE 2006)[11] provide useful guidance. However, for wells which do not recharge rapidly, an alternative approach of draining the well, then sampling from the water which refills the well, may have to be employed. Micro-purging[12] is an alternative method, usually undertaken at pumping rates of less than 1 L/min, that can avoid highly turbid samples (and the need for pre-filtering) and large purge volumes.

- **Field Filtering.** Whether to undertake field filtering should be carefully considered, with the relative risks of field contamination of the sample weighed against the potential for the partitioning of the parameters to change during transport to the laboratory. In some cases, laboratory pre-filtering may be more practical if samples are highly turbid and transit time to the laboratory is short.

- **Collection and recording of field data.** Ambient conditions in the water body sampled (i.e. aquifer, surface water, leachate pond etc.) should be recorded through visual observations, field measurements, sample collection and analytical testing. Standard field sheets should be used to ensure that all required information is collected. Adequate photographic evidence should be collected to adequately describe the conditions under which each sample is collected; the general conditions of the site; and any specific issues which may affect the interpretation of the results. There are a number of

---

[11] A National Protocol for State of the Environment Groundwater Sampling in New Zealand (MfE 2006)

[12] Stone WJ, 1997: Low Flow Ground Water Sampling – Is it a Cure-All? *Groundwater Monitoring and Remediation*, Vol XV11 No 2

references which may be used for this purpose, including APHA 2012[13], Hellawell 1978[14], Metcalfe-Smith 1992[15] and Standards Association of Australia, 1987[16]. A full range of references is provided in ANZECC 2000[17]. Protocols should be passed on to external contractors involved in the monitoring programme.

- **Sample Storage and Transport.** The use of laboratory supplied bottles and transport containers is usually the most secure and quality assured sample holding method. A comprehensive chain of custody procedure is required to ensure that samples are received and analysed as required.

- **Sample Analysis Protocols.** Selection of analysis methods needs to consider factors including likely parameter concentrations, detection limits, regulatory requirements, and cost. More details of analytical methods can be found in Standard Methods, APHA 2012. The portion of the sample that should be analysed needs to be identified (the dissolved, acid soluble or total digestible portion). This applies to metals but also to other parameters which may be affected by solids in the sample, such as COD and total nutrients. The ability to collect a clean sample free from sediment, along with the manner in which trigger values were derived, will impact upon which portion of the sample is analysed.

- **QA/QC Requirements.** Quality assurance and quality control (QA/QC) requirements vary depending on elements of the monitoring programme. Some standardisation is possible but specific plans are required for each site. All QA/QC protocols and results should be documented in a manner that enables them to pass regulatory authority scrutiny. Approximately 10 to 15% of the sampling effort should be devoted to QA/QC[18]. Plans should cover:

    - cleaning and decontamination of sampling equipment;
    - maintenance and calibration of instrumentation;
    - requirements for field blanks, bottle blanks, and replicate samples;
    - laboratory safeguards including reagent blanks, duplicates and reference materials;

---

[13] APHA, 2012: *Standard methods for the examination of water and wastewater*. 22nd edition. American Public Health Association, Washington.

[14] Hellawell, J M, 1978: *Biological surveillance of rivers*. Water Research Centre, Stevenage, United Kingdom.

[15] Metcalfe-Smith, J.L. 1992: Biological water quality assessment of rivers based on macroinvertebrate communities. In: *Rivers Handbook*, edited by Calow, P and Petts, G E. Blackwell Scientific Publications, Oxford.

[16] Standards Association of Australia, 1987: AS2031 – The selection of containers and preservation of water samples for chemical and microbiological analyses. Standards Association of Australia, Canberra.

[17] Australia and New Zealand Environment and Conservation Council, 2000: Australian water quality guidelines for fresh and marine waters. Canberra, Australia.

[18] ANZECC, 2000: Australian Water Quality Guidelines for Fresh and Marine Waters. Australia and New Zealand Environment and Conservation Council.

- requirements for independent certification of the laboratory test method;
- checks by independent third parties;
- checking of analysis results by comparison with previous measurements; and
- chain of custody requirements.

K.2 Groundwater Monitoring

Determining Number and Location of Monitoring Points

As outlined in section 7.6 of the Guidelines, appropriate positioning of monitoring points in a groundwater monitoring network is a key aspect of any monitoring programme.

Sensitivity of the surrounding environment is an important factor in monitoring well network selection. In shallow aquifers with a water table where the environmental risk is low, a basic monitoring well system could comprise one well hydraulically up-gradient and at least two wells hydraulically down-gradient of the landfill.

For large scale landfill facilities, 20 to 50 monitoring/investigation wells may be required. As a minimum for landfill sites which cover only a small area, it is recommended that at least one up-gradient and two down-gradient groundwater monitoring wells (possibly screened at different depths) be installed.

Key factors for selecting well sites include:

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

Pathways for movement of contaminants can be affected by:

- background concentrations of contaminants;
- aquifer numbers and characteristics;
- locations of recharge and discharge areas;
- location of any pumping influences such as local wells;
- nature of the unsaturated zone;
- presence of perched aquifers;
- fractured or porous aquifers;
- soil and geological characteristics;
- geological formation boundaries;
- bedding and tilting of strata;
- geological faults;
- groundwater divides;
- seasonal and short term climatic influences; and
- preferential pathways.

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

- Hydraulic conductivity, K
  - Very slow $K < 10^{-8}$m/s
  - Slow $10^{-6} > K > 10^{-4}$ m/s
  - Medium $10^{-4} > K > 10^{-6}$ m/s
  - Rapid $K > 10^{-4}$ m/s
- Effective porosity
- Hydraulic gradient
- Soil/rock/leachate species interaction as given by the Distribution Coefficient, K_d
  - Very mobile $K_d < 1$ ml/g
  - Mobile $1 < K_d > 100$ ml/g
  - Immobile $K_d > 100$ ml/g

Design Requirements for Monitoring Wells

The purpose of monitoring wells is to provide ‘representative’ samples of the groundwater in terms of its physical and chemical properties. Most wells are also used to monitor groundwater level. The design needs to consider the potential configuration and nature of the contaminants in the groundwater, the potential for chemical alteration of the samples and the sampling techniques to be used.

Wells can use single or multiple monitoring facilities. Multilevel installations, where two or more casing/screen units are placed in the same borehole at different levels, can offer cost savings but introduce the risk of cross-leakage. Post-construction testing is necessary to confirm the integrity of seals.

Well design should cover:

- **Screen Length and Position.** Screens are normally 1m to 3m long. Longer screens lose detection sensitivity to vertically variable water quality and provide only a gross measure of contamination. Screens should be positioned on main flow pathways and intersect the water table, where immiscible floating contaminants such as petrol, and some solvents are likely to be found, if present.

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

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

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

- **Filter Pack and Annular Seals for Screened Zones.** Filter materials selected for packing screens should be nonreactive to the groundwater environment. Geotextile sheaths can be appropriate for fine grained formation materials but are susceptible to clogging and no data on the adsorption of organics and other compounds is available. Annular seals using cement should not be used in screen zones to avoid leached residues from the cement impacting water quality.

- **Surface Completion.** Security of the well head from surface water ingress and external damage are prime design considerations.

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

Monitoring Parameters

Contaminants that enter groundwater systems undergo various degrees of transformation depending on their chemical composition and the nature of the groundwater environment. Factors such as soil/rock geochemistry, redox state and background groundwater quality can affect the evolution of groundwater chemistry along flow paths. Parameters selected for groundwater monitoring programmes need to:

- characterise the overall background chemistry of the natural groundwater;
- characterise the range of contaminant sources likely to be at the landfill; and
- be measured consistently, quickly and cost-effectively.

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

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

K.3 Surface Water Monitoring

Table K-1 provides an example of a surface water monitoring strategy.

Table K-1 Example Surface Water Monitoring Strategy

Monitoring tier	Frequency/description of parameters	
Baseline	Monthly to quarterly monitoring of general water and sediment quality and biological parameters	Establishes the status of existing surface water resources at selected monitoring stations before commencement or a change in landfill operations.
Indicator	Continuous record of flow	Automatic flow meter installed at one or more stations to record catchment and landfill runoff and identify the need for flow-related controls.
	Continuous record of conductivity	Automatic meter installed at one or more stations to pick up any escapes of leachate to surface waters.

	Continuous record of turbidity	Automatic meter installed above and/or below stormwater ponds to check treatment efficiency and measure compliance.
	Daily visual inspections	Visual inspection of stormwater control systems and surface waters downstream of landfill.
	Fortnightly water quality sampling	Short list of parameters aimed at checking general water quality and picking up leachate contaminants.
	Contingency	Long list of parameters to be sampled only when indicator monitoring data indicates regulatory exceedance.
Comprehensive	Quarterly sampling	Long list of parameters checking general water quality and a wide range of possible contaminants (same parameters used as for baseline monitoring).
	Yearly sampling	Selected parameters including organic screening tests, sediment and biological sampling, WET tests (optional).

K.4 Landfill Gas Monitoring

Subsurface Gas Monitoring

As outlined in section 7.8 of the Guidelines, where developments are within 250 m of a landfill site, or underlying geology makes migration likely, landfill gas should be monitored using installed probes around the site boundary.

Permanent monitoring probes should consist of a length of pipe made from an inert material, such as PVC, with a perforated section over the required sampling length. The pipe is usually installed in a gravel pack and appropriately sealed over the upper 1 m. A sampling point should be installed in the capped top of the probe to enable measurement of landfill gas without having to open the sampling probe. Probe depths should generally be at least 3 m, although deeper probes may be required in areas of low groundwater tables, where deep unsaturated permeable layers/fissures exist, or where waste depths are high and water levels low.

At some sites it may be necessary to install stacked probes which incorporate several pipes with screens at discrete depths (corresponding to differing strata/fissures) with seals between each screen.

Monitoring of the probes is preferable during low and falling barometric pressures as these conditions provide closer to “worst case” results in terms of gas migration. A systematic procedure should be used for monitoring the probes to ensure consistency and should include:

- recording barometric pressure and ground pressure; and
- measurement of concentrations of methane, carbon dioxide, and oxygen; taken after purging the probe of at least twice the probe volume using an intrinsically safe vacuum pump to provide a representative gas sample.

The probe should remain sealed between monitoring periods. Opening of the probe cap (to obtain water table levels etc.) should only be done at the completion of a monitoring procedure.

The number and locations of monitoring probes depends on site-specific factors (see section 7.8). Probe spacing and depths will be site specific and should be determined only after a detailed review of site conditions.

Monitoring Frequency

Probe monitoring frequencies will vary depending on site circumstances. Where site conditions change (e.g. extraction rates, surrounding land use, or water table), the frequency of monitoring should be increased until gas concentrations are found to stabilise.

As a minimum, monitoring of each probe should be carried out six monthly until probe gas concentrations have stabilised below 1% by volume methane and 1.5% by volume carbon dioxide.

More frequent monitoring will be required where gas is found in close proximity to properties. In the case of residential properties, permanent gas monitoring equipment may be necessary.

Surface Gas Monitoring

Several techniques exist for monitoring surface emissions from a landfill. It is unlikely that all techniques will be required for any one landfill. However, they have been listed below for completeness:

- **Visual inspection.** Although not adequate in itself as a means of monitoring, visual inspection can provide useful information as to potential areas of elevated landfill gas emissions. Key indicators are areas of distressed vegetation, capping cracking, discernible landfill gas odours and gas bubbles in puddles after periods of rain. Findings from a visual inspection should be confirmed using instantaneous surface monitoring.

- **Instantaneous surface monitoring (ISM).** An ISM is conducted over a prescribed or random walk pattern across a site using a flame ionisation detector (FID). Methane is sampled via a wand with a funnelled inlet held 50mm to 100mm above the ground surface. Site conditions should be dry and wind velocities less than 15 km/hr on average. During the monitoring the technician makes recordings at regular intervals and includes any areas of elevated emission levels.

- **Integrated surface sampling (ISS).** An ISS is similar to instantaneous surface monitoring with the exception that gas collected during the walk pattern is pumped to a non-contaminating sample bag. The methane reading in the bag can then be measured, giving an average concentration over the walk pattern. Trace constituents can also be measured from the gas sample. Extreme care is required using this system in order to obtain representative results.

- **Ambient air sampling**. Ambient air up-wind and down-wind of a site is collected via integrated ambient air samplers into non-contaminating bags. This form of sampling is usually focused on measuring total non-methane hydrocarbons and trace pollutants, and is likely to be required only in exceptional and specific circumstances.

- **Flux box testing**. Flux boxes are containers (typically drums cut lengthways) with the open end embedded approximately 2 cm into the landfill surface. A small hole is formed in the side of the container to allow venting. A flux box testing programme requires a specific design to ensure that a dependable outcome is achieved.

- **Portable accumulation chamber surveys.** Accumulation chamber surveys can be used to measure the flux (rate) of CO_2, CH_4 or H_2S at the land surface at a given point. The method is non-invasive and through measurement of sufficient points, can be used to assess the total emissions from a site as well as to represent the spatial pattern in landfill gas flux across the surface (Rissmann et al., 2011[19]). An accumulation chamber survey requires a specific design and employs multivariate statistical methods, such as stochastic simulation, to provide a measure of the uncertainty of the emission rate.

Where surface emissions may present a risk to a site, or create an odour nuisance, visual inspections and ISM surveys should be carried out to assess areas requiring remedial work. Other techniques may be utilised in specific situations. For sites with active gas extraction, ISM results can also provide useful information for optimising the effectiveness of the extraction system and capping maintenance.

---

[19] Rissmann, C.; Clark, S.; Bloomberg, S.; Milke, M.: (2011). Direct Measurement of Landfill Gas Emissions - Current Practices and Quantifying Measures of Uncertainty. *WasteMINZ* Conference, Rotorua, 2011. http://www.wasteminz.org.nz/pubs/direct-measurement-of-landfill-gas-emissions-incorporating-measures-of-uncertainty/

Monitoring in Buildings

Where a building is determined to be at potential risk, based on probe monitoring results or other monitoring information, the building should be regularly monitoring to check for the presence of landfill gas. During the monitoring, a portable gas sampler should be used to measure methane and carbon dioxide concentrations in all voids and areas in the basement and/or ground floor and wall cavities of the building. If possible, measurements should be made in each location before allowing ventilation to occur (e.g. measure under a door before opening).

If landfill gas is detected, the cause should be remedied as soon as practically possible. Generally if methane in excess of 10% lower explosive limit (LEL) is detected, gas control measures will be required. If concentrations are found to exceed 1% by volume methane or 1.5% by volume carbon dioxide, the building should be evacuated, all ignition sources (including electricity) switched off, and remedial work carried out as soon as possible under an approved health and safety plan prior to reoccupation.

Monitoring frequencies will vary depending on the level of risk to the building and/or occupiers. Generally monitoring should be carried out at least every six months and stopped only if risks can be demonstrated to be low. For higher risk situations it is advisable to install a permanent gas monitor, an alarm system and to establish clear protocols in the event of an alarm activating.