Appendix A4.5 Landfill Gas Management Plan

Kerdiffstown Landfill Remediation Project (KLRP)

Kildare County Council (KCC)

Landfill Gas Management Plan

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Kerdiffstown Landfill Remediation Project (KLRP)

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Contents

1. Introduction

1.1 Background

The site of the proposed Project, is located in County Kildare, approximately 3km north-east of central Naas, approximately 400m north-west of Johnstown village and in close proximity to the strategically important M7/N7 corridor. The site is located in close proximity to a number of residential and commercial receptors as well as being a short distance away from the larger settlements of Johnstown and Naas. In addition to the above, the site neighbours a number of recreational land uses, specifically Palmerstown House Estate and Naas Golf Course to the north-east and north-west respectively.

Kerdiffstown Landfill occupies approximately 30 hectares near Johnstown and is a former sand and gravel quarry which was progressively backfilled by a number of operators from the 1950s onwards. In January 2011 a major fire developed in a mound of waste material in the northern part of the site. This required intervention of a number of state agencies including Kildare County Council and the Environmental Protection Agency (EPA). The site was under the control of Kildare Fire Service until late February 2011, when it was handed over to the care of the EPA. Since 2011, measures have been taken to secure the site and limit environmental impact.

In April 2015 the Minister for the Environment, Community and Local Government, Alan Kelly TD, announced that funding would be made available for the remediation of the landfill site, and that Kildare County Council would take control of the site and commence remediation.

The objective in remediating the site in terms of landfill gas management is to:

- Manage and control landfill gases and odours in such a way that they do not constitute a future risk to nearby properties and residents and other identified receptors.

Linked to the overarching objectives of the project is the aim to provide a future landform and end use appropriate for the site and of potential benefit to the local community. To that end, the intended end-use for the site is public access parkland and recreational use.

1.2 Aims and Objectives

This Landfill Gas Management Plan has been prepared in support of a planning application and industrial emissions licence for the remediation and operational (end-use) phases, outlined as follows:

- *Development / Remediation* – The works required to re-profile the site including excavation of waste and other materials for deposition on site to achieve the proposed final landform. The works will also include the installation of landfill infrastructure such as capping, landfill gas, leachate and surface water management. A second stage of remediation will comprise the works required to restore the site to the proposed park end use, including planting and landscaping, installation of sports pitches, changing rooms, car parks and associated services.
- *Operational / Aftercare* – The life cycle stage of the site following the remediation works when the site will be used for public access parkland and recreation. The responsibility for the management of the site and the landfill infrastructure systems as well as park operation and maintenance will be retained by Kildare County Council (KCC).

Due to the significance of risks posed by landfill gas, location of sensitive receptors on and around the site and the proposed end-use, a detailed assessment has been undertaken to determine the risks associated with the site and put in place a framework to ensure that the landfill gas is appropriately controlled and managed throughout the gassing life of the site. These risks will need to be re-assessed and appraised during the stages of site development and operation. This framework is to be referred to and adapted as required by the person or entity responsible for the site during the various stages of development (see Section 1.3 Roles and Responsibilities).

At all stages the aim of the management plan is to:

- Ensure the site is compliant with regulation and best practice at all stages (during development/ remediation and operation/ aftercare);
- Ensure that the management plan is based on the current site operations and development, data arising from the site and foreseen future proposals for changes to the site;
- Prevent lateral gas migration from the site boundary;
- Control emissions of gas to atmosphere to acceptable levels to reduce odour impact;
- Minimise global warming potential from gas emissions;
- Ensure safety of site operatives and contractors working on site;
- Be sufficiently flexible to control gas occurrence throughout different phases of the remediation works;
- Integrate with leachate management and other environmental control systems;
- Be compatible with final restoration and after-use of the site; and
- Reduce potential environmental impact of the site throughout its whole life.

Section 4 of Annex 1 of the 1999 EU Landfill Directive outlines the gas control requirements for all classes of landfills. The specific requirements with regards to treatment and use of landfill gas are:

> *4.2 Landfill gas shall be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and used. If the gas collected cannot be used to produce energy, it must be flared.*
>
> *4.3 The collection, treatment and use of landfill gas under paragraph 4.2 shall be carried on in a manner which minimises damage to or deterioration of the environment and risk to human health.*

This Directive was transposed into Irish law by the Waste Management Licensing Regulations 2004 (SI 395 of 2004) and the Waste Management Act 1996 (as amended). Relevant guidance and best practice documents referred to in the development of this management plan are provided in Appendix A.

1.3 Roles and Responsibilities

This management plan is a live document where site use and operations, monitoring and performance data informs regular updates to the proposals and procedures within the document in order to mitigate the risks posed by landfill gas. These requirements will vary during the lifecycle stages of the site and according the specific works and operations being undertaken on the site.

The following provides definition of some of the terms used within the management plan:

- *Operator* – Kildare County Council, who hold responsibility and liability for the operation and maintenance of the gas management system;
- *Site Manager* – the individual representing the Operator on site during the remediation works and operation of the park/ aftercare of the site; and
- *Designated Representative* – The entity or individual appointed by the Operator to undertake management of the landfill gas system for a defined phase of its lifecycle.

The Operator, Site Manager or Designated Representative will have full responsibility to ensure that landfill gas is properly managed on site in accordance with relevant regulations, guidance and best practice at all times and that all activities are fully documented in the Site File.

2. Landfill Gas Properties

Landfill gas is generated from the breakdown of degradable fractions of wastes. Under typical landfill conditions wastes degrade anaerobically, producing a mixture of methane, carbon dioxide and trace components (which can number two to three hundred different compounds). In some situations, wastes may degrade in the presence of oxygen. Aerobic degradation produces carbon dioxide and trace components. Aerobic break-down usually occurs for a short period immediately following waste emplacement and for a longer period when the wastes are near the end of their degradation potential, and air is able to diffuse into wastes. Aerobic degradation may also occur at sites with active gas extraction, where over-extraction results in significant air ingress to the waste body.

Landfill gas constitutes a hazard as follows:

- Methane is flammable within the range of concentrations 5% to 15% in air. Ignition of a gas mixture within the flammable range in a confined space can result in an explosion. Methane concentrations in air greater than 15% still represent a hazard, since the gas mixture will at some point become diluted within the flammable range. Mixtures of methane in air below 5% by volume cannot ignite.
- Methane has a Global Warming Potential (GWP) estimated to be approximately 21 to 26 times higher than carbon dioxide. Therefore combustion or oxidation of landfill gas will significantly reduce GWP of emitted gas.
- Carbon Dioxide is an odourless, asphyxiant gas. Industrial occupational health levels for carbon dioxide are set at 0.5% for 8 hour exposure and 1.5% for 10 minute exposure for workers.
- Trace Components are variable across landfills, depending on the nature of waste materials deposited and the age of waste degradation. Trace components give rise to odours, some are asphyxiates or poisonous, and some have carcinogenic properties. The landfill gas at Kerdiffstown is odorous. Trace gas analysis has identified a range of odorous constituents, including sulphides and mercaptans, which are typical constituents of trace gases in landfill gas. Gaseous releases such as Hydrogen Sulphide and Carbon Monoxide can pose significant risk at relatively low concentrations.
- Odour thresholds for many trace components, including those above, are low and a large dilution with air (for some compounds of the order of a million times) is required to render the gases odourless (although odour detection is subject to the sensitivity of individuals).
- Some trace components have GWPs orders of magnitudes higher than methane and carbon dioxide, hence require to be oxidised prior to emission to atmosphere.

3. Risk Assessment

3.1 Principles of Risk Assessment

The management plan is based on Source-Pathway-Receptor risk assessment. This risk assessment uses the current understanding of the site for development of a Conceptual Site Model (CSM) based on the available information and data from the site, and proximity of receptors. Identified receptors to the site with respect to landfill gas migration are shown on Drawing Number 32EW5604-00-38. A CSM has been developed for the four key zones on the site, as presented on Drawing Numbers 32EW5604-00-039 to 042 inclusive.

It is recognised that this management plan and risk assessment will evolve in response to on-going investigations and monitoring, and observations on the phasing of the remediation works, for example:

- Data collected from the perimeter monitoring wells, which may provide evidence of migration or preferential pathways;
- Ongoing ground investigation works, including gathering data on wastes and gas production, and installation and monitoring of in-waste and perimeter boreholes;
- The findings of FID survey or other investigations undertaken as remediation works progress;
- General observations from the remediation works, e.g. areas of relatively high biodegradable wastes, areas that are observed to be gassing or odorous, location and extent of wastes;
- Any changes or additions to receptors around the site;
- Gas flows and concentrations from the existing landfill gas wells;
- The as-built details including final remediation landform as, for example, slopes may not be suitable for drilling vertical wells.

As a result review of this gas management plan should be undertaken at regular intervals, and revised on significant change at the site and / or following key stages of delivery of the remediation works. This will be managed on an on-going basis by the Operator.

3.2 Source

3.2.1 Gas Production

The future volume of landfill gas to be generated depends on the composition of materials that have been deposited at the site. The time for which gas will be produced depends on the rate of gas generation. Generation rate is influenced by a number of factors, key of which are the nature of the waste, the physical size of waste components, temperature within the waste body and moisture content of the waste.

Factors influencing landfill gas production:

Nature of wastes	Degradable materials can be categorised by their relative contents of cellulose, hemicellulose and lignin (woody component). Materials with relatively high proportions of cellulose to lignin (such as food) degrade more rapidly than materials with a higher proportion of lignin (such as cloth). It is likely that a large proportion of the highly degradable wastes landfilled will have undergone significant decomposition by this stage. Likely to be left are the more slowly degradable fractions of the waste. Loss on Ignition (LoI) tests for the borehole waste arisings at Kerdiffstown (2011 site investigations on Zone 1) indicated an average value of approximately 13% w/w (dry matter) and a maximum of approximately 35% w/w (dry matter).

Physical Form of Wastes	Notwithstanding the above, small particles of material will generally degrade faster than larger particles of the same material, since smaller particles have a much higher surface area to volume ratio, allowing microbes to be more effective in the degradation process. Therefore shredded paper will degrade faster than whole newspaper, and finely chipped wood will degrade faster than large chunks of wood (which may take thousands of years to achieve complete degradation). A large proportion of the wastes at the site have been through a waste treatment process, where the previous site operator attempted to extract marketable materials from the deposited wastes. These processed wastes are likely to have been reduced physically in size, which may increase the degradation rate, but the waste processing may also have removed some of the biodegradable fraction of the wastes. Review of borehole data in areas where processed wastes are said to be located (e.g. Zone 2B) appear to indicate less biodegradable wastes being present that zones where wastes had not been processed (e.g. Zone 1).
Temperature	The effectiveness of the micro-organisms facilitating breakdown of waste increases with temperature, with maximum effectiveness occurring at approximately 65^{o}C. Above this temperature, the rate of breakdown falls rapidly. If the temperature is too high (approaching 75^{o}C) microbes will die.
Moisture content	Increasing moisture content increases the rate of degradation, with maximum rate achieved when wastes are approaching 100% moisture content provided the wastes remain free draining. Moisture content of waste samples was measured by the UK Water Research Centre (WRC) during waste categorisation investigations when the site was operational. Results ranged from 3.8% to 20% w/w dry residue. Laboratory analyses for moisture content in wastes taken during the 2012 site investigation indicated that the wastes arising had an average of approximately 28% moisture content.

3.2.2 Current Active Gas Extraction

Currently (March 2017) active gas extraction occurs in two areas of the site; the lined cell (Zone 3) where the majority of the currently in place waste has gas extraction well coverage, and the north-western section (Zone 1) where only approximately a quarter of the currently in place waste has gas well coverage.

The aims of the existing landfill gas management measures are to control off-site migration along the north-western boundary of the site (where wastes are deep and close to the edge of the original sand quarry wall, and houses and outbuildings are present within 10m of the site boundary) and reduce emissions to atmosphere to control odours (these two areas of the site were identified in previous studies as being significant for gas emissions to atmosphere and hence odour).

Within the Zone 3 lined cell wastes have been covered with a temporary heavy duty membrane to assist with odour management and to reduce air from being drawn in during gas extraction operations. No formal capping system presently exists on Zone 1.

Gas is removed and burnt in specially manufactured stainless steel high temperature gas flares. There are two flares on site; one with 250 m^3/hr capacity, the second with 500 m^3/hr capacity. Valves are incorporated within pipework which enable gas from Zones 1 and 3 to be directed to a SINGLE flare, or to separate flares, depending on gas yields and quality. Currently, all gas extracted is being burnt at the '250' flare, with the '500' flare acting as standby.

The overall quantity and quality of gas entering the 250 flare has declined gradually over time with current flows of approximately 100 m^3/hr and gas concentrations recorded at 23% methane, 23% carbon dioxide and 0.3% oxygen. This represents a decrease of more than a half for the gas flows compared to initial gas yields during July/August 2011. The decline in gas yields has been seen to be relatively steady since April 2012 despite weekly monitoring and rebalancing. This is expected as the gas generation will fall as time passes, but may also be symptomatic of a decrease in extraction efficiency from the installed system.

3.2.3 Gas Modelling

Modelling has been completed using GasSim[1] software to determine the landfill gas generation over time (Source) based on the mass of waste deposited and the assessed composition of the waste. A lateral migration risk assessment has been under taken using a qualitative approach due to the limitations of GasSim for gas migration assessment. Air dispersion assessments have been undertaken as detailed in Chapter 8 (Air Quality and Odour) of the EIS.

GasSim relies on estimated inputs of waste tonnages and definition of waste types to determine the biodegradable portion of the wastes for calculation of Source. There are no records of the wastes deposited at the site hence boreholes records have been used to assess the variation of the wastes deposited. The GasSim model has been zoned, as shown on Drawing Number 32EW5604-00-43. The characteristics of the zones are summarised as follows:

Zone	Key Characteristics
1	Wastes deposited in the zone accounts for approximately 65% of the entire estimated volume of waste on site. The wastes in this area are typically unprocessed, highly odorous and principally comprise non-hazardous mixed construction and demolition (C & D) wastes and household wastes. C & D wastes are noted to contain varying amounts of clay, gravel, concrete, brick, wood, textile, plastic, rubber and metal. Wastes in this area of the site are currently uncapped and unlined. Remediation proposals for this zone comprise capping using a geosynthetic system (low permeability geomembrane or similar) with capping soils. End-use proposals will see this area become a public open space.
1A	The north western tip of this zone contains predominantly inert wastes and this section will be engineered to provide a surface water management pond. As there are limited wastes in this area (with further likely to be removed) it will not be subject to active gas management, although extraction wells will be installed on edge of adjacent Zone 1 to minimise the potential for migration off site.
2A	Much of this zone is covered by c.500 mm thick, reinforced concrete pads, which form an impermeable layer over the wastes and prevent direct rainwater ingress. Wastes are recorded to be unprocessed non-hazardous mixed C & D waste with varying amounts of clay, gravel, brick, concrete, wood, textile, paper, plastic, rubber and metal. Domestic waste also present in this area at varying depths mixed in with C & D materials. Zone 2A contains localised areas of biodegradable wastes. Remediation proposals comprise the retention of the concrete pads (with repairs) over which a sports pitch will be located. Outwith the concrete pads low permeable soils will be placed. End-use proposals will see this area become a public open space, incorporating car parking, a sports pitch and a changing rooms building.
2B	Much of this zone is covered by c.500 mm thick, reinforced concrete pads, which form an impermeable layer over the wastes and prevent direct rainwater ingress. Wastes are recorded to be unprocessed non-hazardous mixed C & D waste with varying amounts of clay, gravel, brick, concrete, wood, textile, paper, plastic, rubber and metal. Waste depths are shallower than, and lower in biodegradability than Zone 2A. Remediation proposals comprise the retention of the concrete pads (with repairs) over which a sports pitch will be located. Outwith the concrete pads low permeable soils will be placed. End-use proposals will see this area become a public open space incorporating a sports pitch.

[1] www.gassim.co.uk/

Zone	Key Characteristics
3	A large part of this area is lined with processed waste materials filling 60% of the existing void space. Wastes in this area comprise processed non-hazardous C & D materials with domestic waste mixed through. C & D wastes contain varying amounts of clay, gravel, concrete, brick, wood, textile, plastic, rubber and metal. The remediation proposals comprise infilling using wastes excavated from other areas of the site to create a suitable profile. The cell will be capped with a low permeability geomembrane or similar, covered with soils. End-use proposals comprise this area being a public open space.
4	Area containing large waste stockpiles, redundant infrastructure and concrete tanks/bays/walls. Various stockpiles are located within the zone, comprising both processed and unprocessed non-hazardous mixed C & D and limited household waste. C & D wastes noted to contain varying amounts of clay, gravel, concrete, brick, wood, textile, plastic, rubber and metal. The remediation proposal is to excavate wastes from this area as far as practicable, to create safe slope profiles and placing low permeable soils above. End-use proposals have this area used as a surface water management pond with paths.

Previous zoning of the site included Zone 5, which includes the site entrance and roads. It is considered from review of ground investigation data that no waste is present in this zone and is not subject to gas modelling. Properties adjacent to this zone will be demolished as part of the works at the site, to facilitate a new site access arrangement and construction of a new Landfill Infrastructure Compound.

The development scheme also encompasses a field adjacent to the L2005 Kerdiffstown Road and is bounded by site Zones 1 and 2A. This field is to be developed for a multi-use sports pitch during the Operational Phase of the works. This field is virgin ground, does not contain waste materials and is therefore not subject to gas modelling.

Waste tonnages and waste type to date

The waste tonnage inputs for the model are based on assessment of the depth of the wastes from site investigation borehole data profiling the depths of wastes encountered. AutoCAD analysis and modelling has been used to estimate waste fill volumes for each of the zones. The volume has been translated into tonnage for the model using a simple 1:1 principle i.e. 1 m^3 = 1 tonne of in place waste.

Definition of waste composition

To assess the biodegradability of the wastes within the zones borehole log waste descriptions were used (2011 site investigations) and a representative sample of borehole logs selected based on:

- Representation for waste areas of higher biodegradability (Zone 1), and of lower biodegradability (majority from Zones 2A and 2B);
- Quality of the recorded descriptions of the wastes and strata; and
- Boreholes which did not hit obstructions and terminate early.

The borehole logs provided relatively detailed descriptions of the waste arising including categories such as municipal waste, wood, paper, plastic, textile, cardboard, clay and gravel. Each of these descriptions had been provided with an assessment of the percentage of that material within each depth profile from the borehole e.g. borehole depth 2 to 4m wood 20%, paper 5% etc. These descriptions and percentages were used to calculate (pro-rata) the overall composition of the full depth of the boreholes.

The following groups of waste were modelled as inert waste (i.e. zero degradability) – soils, clays and gravel, metals and wire, plastics, rubber and ash – as they will have no or insignificant gas generation. Although some of these fractions such as plastics will degrade over-time, this is generally over a time period which will become irrelevant to the objectives of the gas modelling, i.e. over 130 or 150 years. The wastes inputs for the model were entered for the start year 2011 as that was the year of the site investigation which the borehole came from and represents the observation at that time.

The initial runs of the GasSim model produced gas generation estimates which were much higher than the actual landfill gas extraction rates from the site would suggest were feasible. GasSim has been developed for mimicking the landfilling of ‘fresh waste’, and is calibrated by empirical data from active landfills rather than older closed landfills under retrospective investigation as is the case at Kerdiffstown. Therefore, a process of model calibration was deemed to be required to adjust the model to provide results broadly in line with the actual extraction data from the site. The model calibration assumed the rapidly degradable proportion of the waste would have already degraded, and that what is left will be the medium rate and slow rate biodegradable fractions. This calibration gave more realistic model output, as presented in Section 3.2.4, which aligns with the actual gas extraction from the site with appreciation of the current limited coverage of extraction wells.

3.2.4 Model Results

Figure 3.1 provides the calibrated GasSim bulk landfill gas output curves for the entire site (all zones collated) and each of the individual zones.

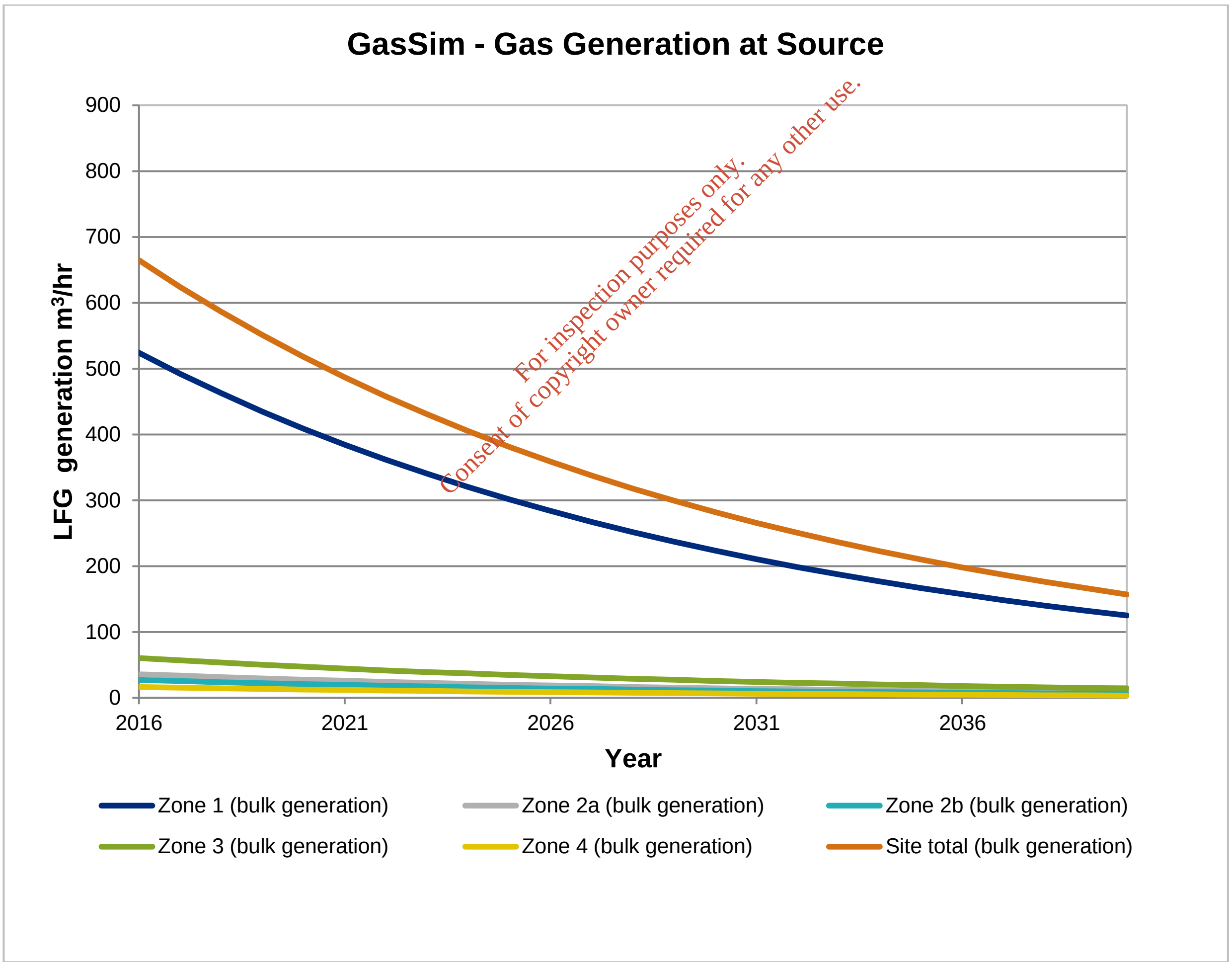

Figure 3.1 : GasSim Gas Output Curves

The majority of the landfill gas is predicted to be produced by Zone 1. This is expected as this zone contains the greatest proportion of the waste (c. 2 million tonnes), and relatively more biodegradable wastes. The next biggest contributor to gas production is Zone 3, which also contains wastes of the higher biodegradability but only contains in the order of 200,000 tonnes of waste.

Zone 1 is currently (2017) extracting approximately 80 m^3/hr of gas from the installed wells from a well coverage area of approximately 25%. Zone 3 is currently (2016) extracting 20 m^3/hr of gas from installed wells which cover all the in-place wastes within that Zone.

The model estimation of approximately 550 m^3/hr (Zone 1 plus Zone 3 for 2017), when compared to actual current on-site extraction rates and current well coverage, is broadly acceptable and potentially provides a slight over-estimation for risk assessment and specification of gas management infrastructure. The extraction efficiency for a site such as Kerdiffstown which does not have full engineered containment across the entire site area is likely to be in the region of 75%. Approximate extrapolation from the above chart suggests that once the full extraction field is installed on Zones 1 and 3 in the order of 400 m^3/hr may be able to be extracted (in 2020 following remediation works).

The GasSim model is provided within Appendix B in hard copy format.

3.3 Pathways

3.3.1 Landfill Gas Migration – General

There are three main processes which cause gases to migrate:

- Differences in gas pressure;
- Differences in gas concentration; and
- By dissolving in water or leachate which subsequently migrates from the landfill, with the dissolved gas coming out of solution.

Of these three mechanisms, pressure differential is usually the dominant mechanism. Within a landfill, continuing degradation of wastes replenishes landfill gas, which results in a positive gas pressure inside the site. Gas will move from zones of high pressure (e.g. within the wastes) to zones of lower pressure (e.g. soil surrounding the site or the atmosphere) until the pressure differential is equalised. Thus within an actively degrading landfill, there is a continuous production of landfill gas and potential for gas migration out of the wastes.

Currently there is no engineered capping on the site, hence gas has ability to vent to atmosphere where it is not controlled by the current gas extraction system, or impeded by presence of thick concrete slabs. Following capping, the potential for horizontal gas migration will increase substantively if no gas control measures are installed at the site. There is also potential for enhanced risk of off-site migration during the remediation phase, if materials are temporarily stockpiled on previously free-venting areas of wastes.

A second mechanism of pressure induced migration is created by changes in atmospheric pressure. Low pressure and falling atmospheric pressure encourages migration of gas, whereas high atmospheric pressure has the opposite tendency. Management of the gas control system will need to be responsive to the potential effects caused by sudden and steep falls in atmospheric pressure which can lead to increased gas migration from the wastes.

Gas will also migrate by diffusion between areas of different gas concentration. For a landfill site, this means there is potential for high concentrations of methane and carbon dioxide to move from the wastes to atmosphere and surrounding soils, and for oxygen and nitrogen in the air and surrounding soils to migrate into the landfill. This mechanism for gas migration becomes significant where there is no pressure difference (typically near the end of the gas producing life of the wastes).

Both carbon dioxide and methane are soluble, with carbon dioxide being approximately 90 times more soluble than methane. Landfill gas can dissolve in leachate in the site, and as leachate migrates away the gases can come out of solution. At Kerdiffstown, this will require methane stripping from leachate prior to its discharge to the public sewer network and monitoring of off-site monitoring boreholes for methane adjacent to unlined areas of the site where leachate may be migrating to groundwater.

During migration, reactions can occur which change the composition of landfill gas. Methane can be subject to microbial oxidation. This reaction causes methane and oxygen to be consumed and generates carbon dioxide and water vapour. This is an important mechanism of methane removal which for passive gas control measures which will need consideration near the end of the gas producing life of the wastes. Carbon dioxide can be removed from soil gas by dissolving in water contained in the soil. The result of these mechanisms occurring is that the composition of gas which has migrated from a landfill site can be substantially different from the composition of gas within wastes. Such mechanisms need to be considered when evaluating results of off-site monitoring, since indications of these processes occurring may provide an early warning of gas migration from the site.

3.3.2 Current Monitoring for Gas Migration

Currently there is limited off-site monitoring of landfill gas. Existing perimeter gas monitoring boreholes are shown in Drawing Number 32EW5604-00-43, comprising a total of eight boreholes on the northern boundary and two on the north-west boundary. To date these boreholes have not detected any significant gas migration as may be expected with the site being uncapped.

It is proposed that additional gas monitoring boreholes will be installed during 2017, in order to assess background readings in advance of the remediation works, to then detect and mitigate gas migration.

3.3.3 Lateral Migration Potential

Logs for existing off-site boreholes (gas and groundwater boreholes) show variable sequences of silt, sand, gravel and clay around the site. Gas migration risk is highest along bands of sand and gravel deposits which have lower permeability silts and clays above and below them, thus concentrating gas movement along the sand and gravel layer. Appendix C summarises the ground conditions encountered in off-site boreholes constructed close to the site perimeter, and provides commentary on gas migration risk for each. This information illustrates that much of the natural geology around the site is conducive to gas movement. The variability of the strata and the presence of sand and gravel layers cannot be defined to the level required to consider the risk of migration through specific routes to specific receptors. It must be assumed that due to the absence of a basal and sidewall liner to prevent migration in all zones (other than Zone 3) there is considered to be a high risk of off-site gas migration requiring suitable gas controls to then be installed. Following installation of new gas monitoring boreholes around the site perimeter, anticipated to be undertaken in 2017, an update to the table in Appendix C will be completed.

To the northern border it is considered that there is less risk of landfill gas migration due to the topography which slopes away from the site, and depth of wastes in contact with the natural strata. Also, the Morell River is present in this direction, the alluvial deposits of which transect the water table and this feature is likely to act as a natural barrier to gas migration.These factors will both limit the potential for landfill gas migration and increase the likelihood that any migrating gas is released through the soil surface.

Gas migration from Zone 3 will be limited due the presence of the engineered liner which will be resistant to gas migration. Migration from Zone 2 (A and B) is considered be limited due to the quantity and nature of the wastes within these areas as not likely to build up the gas pressures required for migration. Migration from Zone 4 will be limited as the vast majority of the wastes will be removed from this zone during remediation with limited gassing potential from existing data, with migration more likely to be vertical through the soils cover.

The migration potential for the landfill gas from the zones is shown in the Conceptual Site Models provided on Drawing Numbers 32EW5604-00-039 to 042 inclusive. These cross sections consider the potential for gas migration prior to and after remediation works and on the introduction of gas control measures proposed in Section 4.

3.4 Receptors

The following current receptors are identified on and around the site. Locations are shown on Drawing Number 32EW5604-00-38.

3.4.1 Buildings

The risk to buildings from landfill gas ingress is associated with the flammability and potential explosion risk of methane. Gas present in soils can enter buildings through cracks or holes in the floor slab, or via services which enter buildings below ground if no protection measures have been incorporated into building design.

Buildings and structures on site which will remain during the remediation works and new buildings to be added on-site for the operation/ aftercare phase relevant for the risk assessment are:

Structure	Gas Protection Measures	Note
EPA Site Offices.	Raised floor slab located over thick concrete pad.	Will be removed following the remediation works.
Security Office – Site Entrance.	Raised above ground, not above areas containing waste.	Will be removed as part of the remediation works.
Security Hut – Zone 1.	Raised above ground.	Will be removed as part of the remediation works.
ESB electrical switch room.	Founded on concrete pad. Louvres in doors and permanently operating fan ensures continuous ventilation of building.	Will remain during aftercare phase.
Two houses are located adjacent to the site entrance, bordering the southern boundary of the site.	Unknown finish and therefore assumed to be susceptible to gas migration.	Due to requirements for a new access to the site and construction of a landfill infrastructure compound, it is proposed that these properties will be removed as part of the remediation works.
Changing room associated with development of public park.	Design measures to take account of gassing ground potential	Developed as part of the end-use design.

As well as the buildings on site (within the site boundary) there are houses and outbuildings close to the north-western, western and southern boundaries of the site which could be vulnerable to landfill gas entry due to migration from the site. The nearest off-site house is located approximately 10m from the site boundary. More buildings and outbuildings are present within 50m of the site boundary. The nearest building associated with Kerdiffstown House is present approximately 110m from the site boundary. It is not considered likely that off-site buildings have been fitted with specific gas protection measures to date.

3.4.2 Residents and Occupiers of Off-site Properties

The risks to people within buildings from landfill gas is associated with flammability and potential explosion risk of methane, and asphyxiation arising from accumulation of carbon dioxide and/or reductions in oxygen. Odours can make houses uninhabitable before gas concentrations reach dangerous levels.

Any on-site work is subject to agreement of detailed health and safety risk assessment and method statement for working, which includes precautions for gas accumulation. Presently there is no identified requirement for gas alarms to be installed in these properties. However, this is required to be reviewed routinely as remediation works progress at the site, with updates to this management plan enacted as necessary.

3.4.3 Underground Services

Underground services on-site and off-site are potentially at risk from landfill gas entry and accumulation, unless the services have been designed to prevent gas ingress. The risk to underground services from landfill gas ingress is associated with the flammability and potential explosion risk of methane. In addition, services can act as pathways for gas to migrate into buildings via service entries.

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Locations of known off-site services are outlined on Drawing Number 32EW5604-00-038. The drawing does not show service connections to individual premises. It can be assumed that off-site services do not have specific design features to prevent gas ingress into pipes or surrounding backfill. Locations of surface water drainage and other services on site will be largely amended and augmented during the remediation works.

The remediation and park development proposals incorporate provision of services. This will include electricity supply to the Landfill Infrastructure Compound, the changing rooms building, lights around car parking areas and adjacent paths and floodlights for the sports pitches. Water service connections will be required for the Landfill Infrastructure Compound and the changing rooms building. Gas supplies are not envisaged as being required for these facilities (subject to final design). Any services provided to such site buildings will be designed to limit gas ingress to the service ducts (e.g. surface laid where possible) or designed with measures to prevent gas migration to the buildings (e.g. sealing of ducts prior to entry to facilities).

3.4.4 Utility and Site Workers

The risks to utility workers from landfill gas are associated with flammability and potential explosion risk of methane, and asphyxiation arising from accumulation of carbon dioxide and / or reductions in oxygen. It is likely that practices for working below ground and within buildings will take account of potential risks arising from accumulation of potentially asphyxiant and explosive atmospheres before work commences, although this may not be recognised by individuals working on their own premises.

Any on-site work is subject to agreement of detailed health and safety risk assessment and method statement for working, which includes precautions to be taken against gas accumulation. Any off-site work on utilities and services within the local vicinity of the site should be made aware of the potential risks of migrating gas.

3.4.5 Vegetation

Landfill gas which migrates into soils will tend to displace oxygen from the root zone, and in extreme cases can lead to anaerobic conditions in the soil. This can result in vegetation stress or die off. Deep rooted vegetation is generally more prone to effects of landfill gas presence in soils than shallow rooted.

Currently (2017) there is no evidence to suggest landfill gas is affecting off-site vegetation (along Kerdiffstown Road and within Kerdiffstown House lands).

3.4.6 Summary of Receptor Sensitivity

For the purposes of the development of the gas management plan, the following receptor sensitivities are designated to receptors based on the current situation at the site.

Receptor	Sensitivity	Comments (refer to CSM Drawing Numbers 32EW5604-00-39 to 42)
Buildings on site and occupants and site users	High / Medium	Located directly above, or directly beside source of landfill gas. Likely that there will be migration through the landfill surface, although design of some on-site building such as the site office limits risk.
Grassland / other shallow rooted vegetation (park restoration)	Medium	Likely that there will be migration through the landfill surface. However, relatively high concentrations of migrating gas are required to cause noticeable effects.
Services on-site	High	Located above, or directly beside source of landfill gas, and possibly trenched into waste/capping. Likely that there will be migration through the landfill surface.
Buildings (and occupants) within 50m of site boundary	High	Many buildings located within 50m of site boundary including properties and businesses which abut the boundary. Large thickness of waste along north-western boundary of site giving potential for significant gas movement.
Services within 50m of site	High	Possibility of migrating gases accumulating within services.

Receptor	Sensitivity	Comments (refer to CSM Drawing Numbers 32EW5604-00-39 to 42)
Buildings between 50m and 250m of site perimeter.	Medium	Buildings associated with Kerdiffstown House are approximately 100m from the site boundary, and other properties at this distance. Likelihood of gas migration into this distance is lower as gas likely to be released through soil surface; however, properties will not have been designed with gas protection measures.
Johnstown Garden Centre and Naas Golf Club	Low	Morell River will act as natural barrier to gas migration for Johnstown Garden Centre. Naas Golf Club building is within 250m of the site boundary, but greater than 250m from the waste boundary as the northern tip of Zone 1 which will not contain biodegradable wastes following remediation.
Woodland and individual mature trees, golf course fairways and gardens within 50m of boundary	Low	Trees generally have deeper root penetration than other vegetation, and therefore likely to suffer greater impacts from landfill gas than more shallow rooted species. Relatively high concentrations of migrating gas are required to cause noticeable effects.
Services between 50m and 250m of site perimeter	Medium/ Low	Possibility of migrating gases accumulating within services, lower risk at greater distance.

Measures for mitigating the risk to sensitive receptors are provided in the management plan in Section 4.

3.5 Fugitive Emissions

As well as sub-surface migration there are currently and will be fugitive emissions of landfill gas to atmosphere from the cap and infrastructure, although the proposed gas management will greatly limit these fugitive emissions. Capturing and flaring (thermal treatment) of the landfill gas will provide environmental benefit as it will reduce the global warming potential (GWP) of emitted landfill gas (fugitive methane emissions) to the atmosphere. Methane has a GWP of the order of 21+ times more than carbon dioxide, and during thermal oxidation the methane within the landfill gas will be converted to carbon dioxide. Landfill gas contains other hydrocarbons which will also be treated by the thermal process to deliver management plan improvements.

Zones 2A and 2B are proposed to have passive venting measures due to the anticipated low levels of landfill gas generation within these zones following remediation. Wastes present in Zone 4 suggest minimal landfill gas generation potential, and remediation works comprise the removal of significant quantities of materials from this zone. The quantity of landfill gas generated by these zones is therefore modelled to be relatively low. However, the application of low permeability soils may adjust the degree to which generated landfill gas will laterally migrate to be emitted through discrete structures such as the perimeter venting zones is not fully understood at this stage. These emissions could carry an exposure or explosion risk to site operatives and park users. Therefore, monitoring of the site capping and venting structures for fugitive emissions is proposed within the management plan and, should high emissions be detected, further assessment should be made as to the risk posed action to be taken. The management plan proposals ensure that the design of this passive venting infrastructure provides flexibility for gas management with bio-oxidation or connection to the active gas extraction system being possible.

3.6 Combustion Products

The operation of the flare will lead to point source emissions of combustion products. The emissions to air will disperse into the atmosphere which can act as a pathway to potential receptors. The risk assessment for combustion products is contained within the Air Dispersion Risk Assessment Chapter 8 (Air Quality and Odour) of the EIS.

4. Gas Management Plan

The GasSim estimation of gas generation has been used for broad appreciation of landfill gas management. Details of the proposed landfill gas management and control systems for the aftercare phase are shown on Drawing Number 32EW5604-00-43. These control measures have been developed on a zone specific basis for the site to take account of the differing gassing potential of each zone and their final end-use following remediation works. The current control measures are summarised as follows:

Zone 1 (excl Zone 1A)

- Engineered capping system (geosynthetics);
- Vegetated soils above cap; and
- In-waste vertical landfill gas extraction wells linked to active extraction / landfill gas flaring.

Zones 2A and 2B

- Gas drainage layer overlain by low permeability cap (soils);
- Perimeter gas venting trenches (adaptable to active extraction system if required);
- Park end-use infrastructure designed for gas risk e.g. buildings freely venting, sealed services; and
- Vegetated soils above cap.

Zone 3

- Engineered low permeability basal and sidewall lining system;
- Engineered capping system (geosynthetics);
- Vegetated soils above cap; and
- In-waste vertical landfill gas extraction wells linked to active extraction / landfill gas flaring.

Zone 4

- Low permeability soils; and
- Vegetated soils.

Data will continue to be generated from ground investigations, ongoing monitoring and future pumping trials / operational gas extraction data to be gathered as part of the remediation scheme. As a result the above proposals may be adjusted accordingly, on the basis of further risk assessment and design justification. The gas management proposals will be periodically reviewed to check their suitability and validity, under the responsibility of the Operator.

Other methods for determination of specific landfill gas risk and development of mitigation proposals may be required for all or parts of the site to complement the management plan e.g. detailed design of on-site buildings, public access arrangements and compliance with the ATEX Directive. The detailed design phase will be required to take cognisance of all relevant guidance in this regard and the management plan updated to reflect the risk assessment and mitigation proposed.

4.1 Active Extraction System – Zones 1 and 3

Zones 1 and 3 will continue to generate significant quantities of landfill gas. The GasSim model predicting potential for approximately 400 m^3/hr of bulk gas extraction for Zone 1 and Zone 3 in 2020 and this landfill gas will require active extraction and management. Drawing Number 32EW5604-00-043 shows an indicative layout of the active extraction system, as described in the following sections.

4.1.1 Gas Extraction Wells

Vertical landfill gas extraction wells will be installed in Zone 1 and Zone 3 according to the design shown in Detail 1 on Drawing Number 32EW5604-00-043. It is currently assumed the wells will be installed at minimum 40m spacings towards borders with Kerdiffstown Road and Kerdiffstown House lands, and elsewhere on the zones at maximum 60m spacings. The final well spacings and distribution may change following a pumping trial conducted during the remediation works on Zone 1 and / or gas extraction operational data, offering information on extractable gas yield and the typical zone of influence. Information obtained during the remediation works, to include on-site observations, gas extraction performance data and pumping trial findings should be assessed routinely during the remediation works and inform revisions to the management plan.

It is envisaged that where remediated slope gradients are greater than 1v:3h such as on the northern slope of Zone 1 gas extraction wells will not be able to be installed. In such areas pin wells may be used. Pin wells, were they to be employed, in the management of gas from this part of the site, would typically be installed at 20m spacings as the shallower installation depth of pin wells (c.6m) would not provide as wide a zone of extraction influence as the gas extraction wells. The inclusion of such will be assessed dependent on the actual slopes achieved, gas potential (from pumping trial or operational data) and available and safe drilling methods.

4.1.2 Connecting Pipework

The vertical gas wells will be connected individually to manifolds. The connecting pipework will be designed to ensure that a high velocity is maintained to aid condensate management. As gas generation rates and flows are expected to be relatively low 63mm pipe is likely to be used, but this should be re-assessed based on the pumping trials and gas system operational data.

Connecting pipework is to be laid to maximise falls from the well to the manifold and contra flow conditions i.e. condensate and gas flowing in different directions should be avoided. Pipeline falls shall be a minimum of 1 in 25 where possible. Further review of design proposals to accommodate aspects such as capping stability on the steeper slopes of Zone 1 which may affect the orientation of pipework runs will be required at the detailed design stage for inspection and confirmation during the remediation works.

Connecting pipes are to be joined at the manifold with inlet valves for primary balancing and isolation purposes. Connecting pipe is to be black MDPE to SDR 17.6. Jointing shall be electro-fusion and butt fusion to give strong joints that will not fail.

4.1.3 Manifolds

A manifold system has been chosen as this has the advantage of making gas balancing easier and quicker. The number and location of the manifolds will be subject to the final detailed design once the full number and location of extraction wells has been confirmed. The manifolds will be installed above the capping layer in areas zoned to prevent public access.

The manifolds will be equipped with a gas balancing valve for each gas well, and an isolation valve on the connection to the gas main. Manifolds will include pumped condensate removal where located down gradient from the wells. The manifold chambers will include surface water drain, and ventilation to prevent build-up of landfill gases.

4.1.4 Perimeter Carrier Mains

The carrier mains are proposed to be 250mm diameter MDPE PN10 pipework, which assuming the low flows anticipated from the site (e.g. Zone 1 = c. 400 m^3/hr), will provide flows less than 2 m/s. This will be subject to assessment during pumping trials and the design criteria for all carrier mains is to keep all flows below 6 m/s. Pressure loss calculations should be completed during the final design, to check they are within acceptable levels, dependent on the final extraction system and design.

The mains will be buried or surface laid depending on location and potential for future public access, and laid with suitable falls. Table 4.1 provides a list of ground conditions and required falls for carrier mains.

	Minimum pipework fall
Stable ground, fall and gas flow in same direction	1 in 100
Stable ground, fall and gas flow in opposite direction	1 in 50
Over fill, fall and gas flow in same direction	1 in 50
Over fill, fall and gas flow in opposite direction	1 in 25

Table 4.1 : Ground conditions and recommended pipe falls

4.1.5 Condensate Pumping System

At low points within the carrier mains condensate knock out pots will be installed comprising a water sealed chamber with condensate removal pneumatic pumps, sized and specified for the flow of gas and anticipated condensate quantity. The air supply system for the pumps will be separate from the leachate pumping system. Condensate will either be discharged within Zone 3 (lined cell) or to the leachate treatment system.

4.2 Passive System – Zones 2A and 2B

Zones 2A and 2B have varying depths of waste materials which have relatively lower biodegradability than the wastes within Zones 1 and 3 and are therefore predicted to produce lower quantities of landfill gas. The GasSim model predicts approximately 34 m^3/hr bulk gas production for Zone 2A and 25 m^3/hr for Zone 2B in 2017. These volumes of landfill gas are similar to that for Zone 3, but wastes in these areas are relatively shallow and dispersed over a wider area, hence active gas extraction from these areas would be problematic.

Proposals for passive management fits with outline proposals within the EPA's guidance on the Management of Low Levels of Landfill Gas. This guidance concludes the lower threshold for flaring (low-cal) to be in the region of 25 to 50 m^3/hr at 15 to 30% methane. Site data from drillers borehole logs issued following ground investigations in 2011 record variable and generally low methane content from Zones 2A and 2B with only two exceeding 20% methane. This indicates that extractable gas from these Zones is unlikely to support use of a gas flare and may also negatively impact on the gas extracted from Zones 1 and 3 due to dilution.

The passive system for Zones 2A and 2B includes a gas drainage blanket under low permeability (soils) capping. This gas drainage blanket would comprise a gravel / stone layer to convey any migrating gas to the edges of the zones where it will be vented via trenches. It is proposed that the vent trenches have vertical collection pipework installed at maximum 50m spacing, with perforated pipework extending under the capping, to assist conveyance of gas.

Monitoring is ongoing to enhance the background data for the presence of gas in these zones. This data will be used to further determine the gas generation rate under passive conditions predominantly for informing the detailed design of the changing rooms building and provide appreciation of the suitability of passive venting measures for these zones. The passive venting systems have been designed with adaptability to allow them to be converted to bio-oxidation vents, or a system with slight extraction pressure using rotating aspiromatic cowls, further enhancing to active extraction if data was to support this option in the future.

4.3 Zone 4

Following remediation works Zone 4 will have very limited waste materials left within its footprint. The GasSim model predicts less than 15 m^3/hr of landfill gas production in 2020, and this is based on a worst case assumption of the amount of wastes to remain within this zone. The remediation works comprise placement of low permeable soils which will provide a certain degree of natural biological oxidation for the anticipated low levels of fugitive gas release which may pass through the soils layer.

4.4 Perimeter Monitoring Boreholes

There is currently a limited number of existing perimeter gas monitoring boreholes located around the site. It is proposed to install boreholes specifically for gas monitoring, to be located at or near the site boundary and in proximity to off-site receptors. Provisional locations are shown on Drawing Number 32EW5604-00-043.

The locations and spacings of the boreholes is based on consideration of potential risk from the different zones of the site, the geological setting which is generally conducive to gas migration (refer to Section 3.3.3), the sensitivity of the receptors and their distance from the site boundary. In general the boreholes are shown at 20m spacings on the boundaries with residential properties and Kerdiffstown House, and at 50m spacings at other sections. No additional boreholes are proposed for the site boundaries towards the Morell River as the river limits potential for gas migration, with monitoring continuing on the existing boreholes.

4.5 Landfill Gas Flaring

It is currently proposed to use flaring for the treatment of the landfill gas extracted from the site. Once the site has been remediated and the full gas extraction field is operational it may be possible to install a small scale utilisation scheme at the site. However, presently there is limited certainty on actual extractable gas yield and quality to conclude feasibility and viable economics to support such a scheme. This would be further assessed in the future as technologies develop and a greater understanding of gas yield at the site is determined through the pumping trials.

The existing gas flares at the site will be maintained during the remediation works. As the 250 flare is skid mounted it can be moved around the site to support key extraction areas, to reduce emissions and odour if observed during the remediation works.

The GasSim modelling indicates a flare of approximately 600 m^3/hr capacity will ultimately be required post-remediation works. This presents a slight over-specification of the flare based on the modelling but it is a better approach to assume a larger capacity at this stage. It is also proposed to install a back-up flare unit to maintain control of gas risk should the primary flare be offline for any reason. Post remediation works the gas flares will be located within the landfill infrastructure compound.

Landfill gas wells and extraction field will be progressively installed as the remediation works progress and the flow and quality of extracted gas will be monitored on an on-going basis, as will pumping trials to ascertain sustainable extractable gas quantity and quality. It is envisaged that once the early stages of capping are initiated in Zone 1 and new gas wells installed it should be possible to predict with greater accuracy the actual landfill gas flow and quality which can be extracted from the whole zone. At this stage the flaring system will be constructed within the landfill infrastructure compound.

The primary gas flare will be of an enclosed design providing high temperature flaring, which may or may not be of low-calorific design dependent on the extractable gas yield and quality. The flare will be lined with refractory material on the interior and the flare will be contained within a self-contained unit. The emissions standards the flare shall achieve are set out in Table 4.2 below.

Determinand[2]	Emission standard (mg/m^3)[1]
NOx	150
CO	50
Total VOCs	10

[1] These limits are based on normal operating conditions and load. Temperature: 0^oC (273K); pressure: 101.3 KPa; and oxygen: 3%(dry gas)

[2] NOx expressed as NO_2

Table 4.2 : Typical Gas Flare Emissions Standards

The flare will be situated within the new Landfill Infrastructure Compound. The flare will be fitted with telemetry systems to inform of shutdowns. The flare stack height will be suitable to achieve the required air dispersion of the emissions products (at this stage assumed to be 11m). The compound will be securely fenced and locked to prevent public access. The compound will be screened by landscaping, planted shrubs and trees with their distance from the flare, and the other building within the compound considered for potential heat wash effects, with radiative effects typically evident within a 10m zone from a flare, dependent on height. The compound access and sizing has been developed in consideration of the potential need for emergency vehicle access, and access for flare management and maintenance. The indicative compound layout is presented on Drawing Number 32EW5604-00-032.

4.6 Construction Quality Assurance

The outline design principles for the landfill gas management system are provided herein. Detailed design of future landfill gas management infrastructure will be undertaken following pumping trials and detailed topographical surveys to determine appropriate gradients and alignments for pipe routes and manifold locations.

The installation of the requisite management measures will be subject to Construction Quality Assurance and Control. This will provide assurance that the landfill gas infrastructure was constructed as specified in the design and will include inspections, verifications, audits and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility.

To enable overall quality management works to the surface water management system will be governed by a comprehensive Construction Quality Assurance (CQA) Plan, prepared for submission to and review by the EPA. CQA is defined as a planned system of activities that provide assurance that the materials used meet design specifications and infrastructure is constructed in accordance with the contract and technical specifications. The CQA Plan will set out:

- Construction quality control (CQC) procedures;
- Technical specification and the conditions of contract drawn up by the designer; and
- Roles and responsibilities for the works. The Construction Environmental Management Plan (CEMP) may also inform and be informed by the CQA Plan.

On completion of the infrastructure works a CQA Report will be prepared, to demonstrate that the system(s) and associated components comply with the specification as set out in the CQA Plan. To align with phasing of the remediation works CQA of landfill gas infrastructure may be embraced within an overarching Remediation CQA Plan, subject to confirmation of procurement approach and detailed design.

4.7 Operations and Maintenance

4.7.1 General

The landfill gas management system will be subject to an operational, preventative maintenance and servicing programme in accordance with the manufacturer's recommendations.

Procedures detailing all the operational and maintenance requirements for the permanent gas flare and utilisation plant will be contained within the operational and maintenance manual, which will be retained in the Site Office. The operational and maintenance manual will include the following:

- System description (construction, process and operational parameters) including full as built drawings, together with a record of all subsequent changes;
- Commissioning measurement data;
- Operating instructions;
- Commissioning into service and out of service procedures;
- Specification for routine operational monitoring;

- Specification for routine field balancing;
- Register of all routine adjustments;
- Record of all non-routine incidents;
- Health and safety instructions for routine operation and further guidance on procedures to adopt in the event of an accident or emergency;
- Detailed inspection programme with inventories and frequencies (including responsibilities for monitoring, inspection and maintenance, daily, weekly and monthly requirements, documentation and recording procedures, procedures for implementing corrective actions);
- Register of fault conditions and corrective actions taken to overcome faults;
- Details of routine repairs and replacements;
- Review requirements for fault conditions and repairs; and
- Inventory of replacement parts and contact details for relevant suppliers and manufacturers.

Personnel responsible for the operation and maintenance of the gas management system are required to be fully conversant with the operational procedures and safety and maintenance programmes.

4.7.2 Flare Maintenance Programme

It is anticipated that flare maintenance will be undertaken via an annual contract by the flare supplier or other qualified maintenance contractor according to the flare manufacturer's recommendations. Routine inspection and maintenance of the installed flare(s) will be undertaken in accordance with manufacturer's recommendations, with an indicative programme set out below.

Task	Monthly	Quarterly*	Annually
Check electrical control panel	X		
Check temperature control loop components		X	
Check control of ignition electrode	X		X
Clean UV lamp	X		
Replace UV lamp			X
Check/clean filter in inlet knockout pot		X	
Check/clean/replace filters in gas sampling lines		X	
Check operation of all alarm functions		X	
Check operation of telemetry system		X	
Check flame arrestors		X	
Check/clean motorised valves			X
Check condition of air throttle or damper	X		
Check thermocouples		X	
Check condition of terminal boxes	X		
Check condition of thermal insulation		X	

In the event of a problem being encountered with the operation of the flare, the Site Manager will attempt to identify the problem using the manufacturer's recommendations on troubleshooting. Should the problem not be rectified through this route, the Site Manager will call out a maintenance contractor to correct the problem, normally within 24 hours of the problem occurring.

4.7.3 General Observations and Landfill Settlement

During monitoring rounds, and at a minimum monthly frequency, a visual assessment of the landfill gas infrastructure should be undertaken and recorded. This should encompass the general condition of the gas management system and site that may affect the efficiency of the system, including:

- The flare and infrastructure located within the Compound;
- The landfill gas wells (including any issues observed during monitoring of wells);
- Perimeter boreholes;
- Manifolds;
- Condensate system;
- Manhole covers;
- Fencing; and
- Surface condition (i.e. signs of settlement).

The assessment and observations should provide detail of the condition of the gas system, listing issues which require attention and maintenance; for example vandalised wells, missing gas taps, corrosion on the compound infrastructure etc.

The observation should include a qualitative assessment of the on-going settlement of the capping profile of the site. Landfills are subject to differential settlement due to the degradation of the waste mass. This settlement can cause issues for landfill gas management including damaging wells and causing the development of low points within the collection pipework which can become flooded with condensate and limit gas extraction. Consolidation and / or scouring of capping soils may also have similar effects or allow preferential pathways to open up for the release of landfill gases through the capping and should also be noted during the assessment. The general observation of the settlement of the site will be supported by an annual topographical survey of the site.

Suitable actions and timescales should be set for corrective action for the above, particularly where it may impact on management and increase landfill gas risk.

4.8 Sampling and Monitoring Plan (Aftercare Phase)

The following section provides proposals for routine monitoring of the site to ensure the performance of the gas management systems. These monitoring proposals are for the aftercare phase once the remediation works are completed where the site and management systems have entered a 'steady state'[2]. Monitoring considerations for the phased remediation of the site are detailed in Section 5.

Provisional monitoring locations, parameters and frequencies are provided in Table 4.3. However, the actual monitoring should be based on the prevailing risk and site behaviour of the site at any particular time.

Monitoring	Location	Frequency	Parameters
In-waste monitoring and gas field balancing	Landfill gas wells/manifolds – includes balancing of wells	Monthly – or as risk defines	CH_4, CO_2, O_2, N_2 and gas balance H_2S CO (note: 50 ppm to be used as trigger for potential fire risk) Relative pressure

[2] Steady State – assuming that no significant gas migration is occurring from the site, and the gas extraction systems are operating full-time without significant downtime for the flare.

Monitoring	Location	Frequency	Parameters
	Landfill gas extraction system for representative sample from each of Zone 1 and Zone 3.	Annual	Trace gases in accordance with English EA guidance LFTGN04
	Leachate extraction well (at least one in Zone 1 and one in Zone 3 for gas monitoring under static conditions).	Monthly	CH_4, CO_2, O_2, N_2 and gas balance H_2S CO (note: 50 ppm to be used as trigger for potential fire risk) Relative pressure
Perimeter	Perimeter boreholes	Monthly – or as risk defines	CH_4, CO_2, O_2, N_2 and gas balance Flow Relative pressure Atmospheric pressure
Flare	Inlet	Automated continuous monitoring	Temperature, CH_4, CO_2, O_2, and gas flow rate
Flare	Inlet	Manual monitoring (monthly)	Inlet pressure CH_4, CO_2, O_2, N_2 and gas balance, H_2S and CO.
	Output	Annual emissions monitoring	NOx, CO and Total VOCs, plus any other species identified by air dispersion assessment. Monitoring in line with EPA Guidance Note on Landfill Flare and Engine Management and Monitoring (AG7)
Surface emissions*	Site wide – capping integrity, edge effects, and vent trenches	Bi-annual – or as risk defines, or in response to observations or complaints	CH_4 with FID If high CH_4 emissions are identified (>100 ppmv over capping or 1,000 ppmv at discrete infrastructure), flux box analysis and trace gas analysis should also be considered to check for exposure risk.
Gas Alarms	As installed – TBC, e.g. compound building	Automated continuous monitoring	CH_4, CO_2, H_2S and CO (or gases identified through risk assessment)
Within buildings on site	e.g. changing room and landfill infrastructure compound buildings if gas alarms not installed	Weekly	CH_4 with FD CO_2, H_2S and CO with GA5000
Topography	Whole site to determine areas of settlement	Annual	Topographical survey.

* refer to UK EA LFTGN07 Guidance for Monitoring Surface Emissions for procedure. Walkover stage only required unless there is a requirement to quantify emissions through flux box analysis.

Table 4.3 : Provisional gas monitoring locations, parameters and frequencies

5. Future Gas Management

5.1 Remediation Phase

The remediation works to be undertaken at the site are likely to be in the order of three to four years duration. During this period, there will be excavation and movement of some wastes to achieve the agreed planning landform. At this stage high level outline remediation phasing plans (Drawing Numbers 32EW5604-00-27 and 32EW5604-00-028) have been developed for achieving the remediation of the site and as such only outline gas management proposals have been developed for this, as the scope and the phasing may change.

During the works additional or replacement interim gas controls may need to be installed to:

- Ensure risk of lateral off-site migration is not increased; and
- Minimise emissions of gas to atmosphere to minimise risk of increasing off-site odours.

The proposals for gas monitoring will need to be bespoke for the remediation works in order to assess the changing nature of the site and associated impacts from gas migration.

Each phase and stage of remedial works will require the contractor appointed to undertake the remediation works to produce a detailed method statement of working which will include assessment of potential environmental, health and safety risks and details of measures to mitigate the gas risks. This will include full development of a detailed phased gas management plan to be approved by the Operator prior to any work taking place. Once approved the Designated Representative will have the responsibly to communicate the method statements and plan to the relevant people involved with the works and ensure compliance with the plan and the method statements. Mitigation measures will need to fulfil the following interconnected objectives:

- Reduce likelihood of increased lateral off-site migration of landfill gas;
- Control gas emissions to air (and hence odours);
- Minimise dust emissions from the site;
- Reduce potential to contaminate surface water run-off with leachate and suspended solids; and
- Minimise attraction of insects such as flies and scavenging birds to the site.

In general with respect to further control of lateral gas migration during remedial works, the following options are available:

- Reduce migration risk by (where possible) not covering existing uncapped areas of wastes with materials, thus preventing risk of increased gas migration from occurring (if feasible, use existing areas of concrete hardstanding as temporary storage areas for materials);
- Conduct regular balancing and adjustment of existing well field to ensure extraction wells are providing sufficient control adjacent to areas where there is a risk of increasing lateral migration of gas;
- If coverage with existing gas wells is determined to be inadequate (for example if FID surveys detect emissions or migration is occurring), install new temporary wells and connecting pipework to existing flare to increase gas capture. Dependent on the issue push wells/pin wells may be able to be deployed rather than full depth wells; and
- Increase frequency of monitoring of off-site boreholes within zone of risk during the particular stage of remedial works, to monitor any changes in off-site migration.

Throughout the period of remediation works monitoring of all off-site boreholes should be conducted at least monthly. During active remedial works, or where materials are moved on to uncapped areas of wastes for temporary storage, more frequent monitoring of off-site boreholes adjacent to affected areas is likely to be required. Frequency will be determined by the risk assessment for each phase of works and incorporated within the method statement for working.

In broad terms the outline gas management approach to be undertaken during remediation works is set out in Table 5.1. Reference should be made to the final proposed gas management scheme in Drawing Number 32EW5604-00-043, and the Outline Remediation Phasing Drawings 32EW5604-00-27 and 32EW5604-00-028.

Activity	Gas Management Proposals
Prior to remediation works.	• Installation of perimeter boreholes. • On-going monitoring of all perimeter wells. Perimeter monitoring data to be collated and used as baseline for detection of migration and increased risk e.g. determination of trends. • Continued extraction from the site via the existing temporary flare system and installed wells.
Works to site entrance and access area, including construction of new Landfill Infrastructure Compound.	• Continued extraction from Zones 1 and 3 via the existing temporary flare system and installed wells. • Continue perimeter borehole monitoring at agreed frequency. • Wells within Zone 3 should be left intact where possible during filling of Zone 3, and extraction maintained on those wells. • Increased perimeter borehole monitoring adjacent to areas where substantial stockpiles have been placed. • Additional temporary extraction to be installed within Zone 3 should monitoring indicate unacceptable risk.
Remediation of slopes in Zone 4, including the removal of wastes. Clean materials to be stockpiled on Zones 2A and 2B for re-use within Zone 4 or elsewhere on site. Waste materials to be disposed of within Zone 3 or Zone 1. Remediation and capping of Zone 1A working progressively onto Zone 1.	• Continued extraction from the site via the existing temporary flare system and all installed operational wells. • Wells within Zone 3 should be left intact where possible during filling and re-profiling of Zone 3, and extraction maintained on those wells. • Increased perimeter borehole monitoring on Zones 2A and 2B adjacent to areas where substantial stockpiles have been placed, as this may increase migration risk. • Additional temporary extraction to be installed within Zone 3 should monitoring indicate unacceptable risk. • Consideration of installation of temporary extraction to be installed within Zones 2A and 2B should monitoring indicate an unacceptable risk. • Installation of extraction wells on completed capping on Zone 1, connected to temporary flare. • Increased monitoring frequency of perimeter boreholes along the L2005 Kerdiffstown Road, adjacent to capping works.
Capping of Zone 3, continued progressive capping of Zone 1 and capping of Zone 4 and formation of surface water ponds.	• Continued extraction from the site via the existing temporary flare system and all installed operational wells. • Continued phased installation of extraction wells within Zone 1 on completion of capping. • Increased monitoring frequency of perimeter boreholes along the L2005 Kerdiffstown Road, adjacent to capping works. • As soon as practical, after capping Zone 3, installation of permanent gas extraction wells to support retained existing wells. Wells to be connected to existing temporary extraction system.

Activity	Gas Management Proposals
	• Pipework installed to allow future changeover to the new extraction system and flare in the landfill infrastructure compound. • Continue increased perimeter borehole monitoring on Zones 2A and 2B adjacent to areas where substantial stockpiles have been placed. • Consideration of installation of temporary extraction to be installed within Zones 2A and 2B should monitoring indicate an unacceptable risk. • First phases of wells in Zone 1 and 3 to be monitored under active extraction via a pumping trial to ascertain achievable long-term extractable yield.
Continued phased capping of Zone 1 and progressive capping of 2B beyond extents of concrete slabs.	• Continued extraction from the site via the existing temporary flare system and all installed operational wells. • Install perimeter venting trenches and associated pipework prior to capping of Zone 2B. Capping with gas drainage layer progressively installed and tied into perimeter vent trench for Zone 2B. • Zone 1: installation of the perimeter extraction mains and manifolds. • Capping to be installed in phases, requiring the corresponding phased decommissioning of currently installed extraction wells to permit cap system installation. • New gas extraction wells to follow as soon as practicable in phases. • Connection of extraction wells to manifolds and perimeter mains. • Pumping trial data to be used to inform capacity and specification of final permanent flare (consider low-calorific flare if suitable). • Final installation and commissioning of permanent flare or operation of temporary flare within compound, pending certainty over extractable yield. • Increased monitoring frequency for all perimeter boreholes. • Consideration of conversion of vertical vents within vent trench to vertical cowls or installation of temporary extraction within Zones 2A and 2B should monitoring indicate an unacceptable risk. • Monitoring of vent trench with FID to check emissions within acceptable levels. • Conversion of vent trench to include bioxidation if venting emissions deemed at an unacceptable level. • Walkovers of installed capping with FID to ensure engineering integrity and acceptable emissions, particularly edge effects where tying in capping with concrete platforms and other infrastructure features.
Final profile and capping for Zone 1 and capping of Zone 2A.	• Continued extraction from the site to the landfill gas compound from all installed operational wells, with connection to permanent flare within landfill infrastructure compound once commissioned. • Continue FID walkover surveys on capped areas to monitor for effects of installation of capping on Zone 1, including tie-ins to Zones 2A and 2B.

Activity	Gas Management Proposals
Final site works – final installation of park infrastructure and planting.	• Connection of extraction system to permanent flare in landfill infrastructure compound if not undertaken in previous phase. • Reduce monitoring frequency back to monthly if appropriate i.e. extraction system operating effectively, gas extraction stable without major fluctuations and no gas migration issues being detected. • FID surveys for cap, infrastructure, vent trenches to check for gas issues. • Site enters Aftercare Phase for gas management, and monitoring schedule in Section 4.8.

Table 5.1 : Remediation Phase activities and gas management proposals

5.2 Operational Phase

Gas management proposals for the Operational Phase at the site are likely to follow that identified for the Remediation Phase, augmented by the addition of the new gas management system and requirements of specific guidance on flares and surface emissions. This will be informed by the added background data, confirmation of detailed design, pumping trials, operational data and IED Licence. This section will be updated accordingly.

6. Action Plan

The following Action Plan provides the outline for processes to be followed when incidents associated with the gas management system arise.

Incident	Actions
Landfill gas detected in perimeter boreholes above trigger levels (1% methane and 1.5% carbon dioxide)	• Report incident to Site Manager. • Consider results in relation to gas risk to receptors. • Consider emergency response and evacuation if situation presents unacceptable risk. • Increase monitoring frequency of subject borehole and neighbouring boreholes. • Check adjacent gas management infrastructure (extraction wells or vent trench) for issues. • Check service ducts and service access points within vicinity for gas (be mindful of risks of confined spaces). • Check replenishing rate - concentration and flow after evacuating borehole. • Increase suction on neighbouring extraction wells to see if linkage, and if this resolves the problem (over sufficient time). • Consider installation of additional gas extraction (Zone 1 and 3) wells in area affected if problem persists. • Consider modifications to gas management (Zones 2A and 2B) e.g. aspiramatic cowls or connection to active extraction if migration is detected from passive zones. • If problem persists, or if gas monitoring indicates increasing trend then undertake FID survey of properties, evacuating property if found to be unacceptable risk. • Install gas monitoring and alarms within properties affected once issue resolved.
Gas Flare Shut Down	• Report incident to Site Manager. • Back-up flare should be operated. • Check cause of failure and re-ignite if possible. • Set to vent mode (if available) and re-balance site wells, or re-balance using back-up flare if issue due to poor gas quality or flow. • Check extraction systems for air ingress issues during balancing, shut off sections subject to unacceptable air ingress, then re-ignite. • Monitor perimeter boreholes, and other related infrastructure for migration effects from flare shut-down or adjustment to gas field • Monitoring gas internal and external to site on a daily basis if flare shut down persists for more than a day, call flare supplier to trouble shoot, modifications or repairs to flare as required. • Once issue is fixed re-balance site.

Incident	Actions
Gas extraction system compromised (gas wells, manifolds or carrier mains)	• Report incident to Site Manager. • Isolate leak via the extraction system valves. • Mark out and fence off safety zone, consider restricting public access to area of the site. • Rectify cause with supplies and tools on site if possible, if not order relevant parts or specialist contractor assistance to fix. • Increase perimeter monitoring frequency on adjacent perimeter monitoring wells to check for migration. • Consider increasing suction on adjacent gas extraction wells to alleviate any issues. • Once issue is fixed re-balance site.
Capping compromised (gas emissions detected during FID survey, air ingress or gas escape noted, settlement, or erosion issues etc.)	• Report incident to Site Manager. • Mark out and fence off safety zone, consider restricting public access to area of the site. • Balance site in affected area to allow maximum suction without drawing in excess air (Zones 1 and 3). • Arrange for repair of the cap. • Once issue is fixed re-balance site.
Landfill fire detected (trigger 100ppm CO)	• Report incident to Site Manager and emergency services if appropriate. • Only take the following steps if safe to do so: • Mark out and fence off safety zone, consider restricting public access to area of the site. • Take laboratory sample to confirm analysis. • Check extraction pressures of wells within local vicinity, and gas concentrations of extracted gases. Refer to UK Industry Code of Practice Management and Prevention of Sub-Surface fires (C&P Environmental) for guidance. • If confirmed fire then restrict gas extraction from affected area. • Increase monitoring and balancing in the affected area to see if the issue can be alleviated. Balance affected area of site to keep oxygen levels as low as possible. Note: high CO results may persist in the waste mass after the fire is extinguished. • Change balancing approach to ensure similar problems do not occur in future and that oxygen is not drawn into the site where the fire was located.

Following incidents occurring at the site the Action Plan should be updated to ensure that the document is kept relevant.

Appendix A. Relevant Guidance Documents

Below is a non-exhaustive list of guidance. Review of this and prevailing best practice should be made on future updates to this Management Plan:

Guidance	Year
Guidance Note on Landfill Flare and Engine Management and Monitoring (AG7)	2012
Policy: Monitoring of Stack Emissions at EPA Licensed Sites	2012
Basic Air Monitoring Checklist for Licensees	2011
Management of Low Levels of Landfill Gas	2011
Guidance Note on Site Safety Requirements for Air Emissions Monitoring (AG1)	2010
Odour Impact Assessment Guidance for EPA Licensed Sites (AG5)	2010
Air Guidance Note - Surface VOC Emissions Monitoring on Landfill Facilities (AG6)	2010
Climate Change Research Programme (CCRP) 2007-2013: Report Series No. 3 - Estimates of Methane Recovery in Landfill Gas Flaring and Utilisation	2009
Summary Report - Independent Assessment of Landfill Gas Emissions and Management Systems at 29 EPA Licensed Landfills in the Republic of Ireland	2009
Air Guidance Note on the Implementation of I.S. EN 14181 (AG3)	2008
Annual Surveillance test (AST) Report summary format - AG3	2008
Air Emissions Monitoring Guidance Note #2 (AG2)	2007
Landfill Manual - Guidance note of Landfill Monitoring	2003
Landfill Manuals Landfill Monitoring	2003
Landfill Site Design	2000
Landfill Manuals Investigations for Landfills	1995
Landfill Manuals Landfill Operational Practices	1997
Landfill Manuals Landfill Restoration and Aftercare	1999
The Safety, Health and Welfare at Work (Construction) Regulations 2013 SI 291	2013
The Safety, Health and Welfare at Work Act	2005
ATEX 1999/92/EC Directive, the Worker Protection Directive (also known as the 'ATEX 137' Directive), concerned with the "minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres"	1999
ATEX 94/9/EC Directive, the ATEX 'Product' Directive, concerned with the manufacture of equipment and protective systems designed for use in potentially explosive atmospheres	1994

The UK landfill industry has also developed a series of Industry Codes of Practice (ICoPs), comprising guidelines on compliance with ATEX regulations with respect to landfill gas, leachate, drilling and general landfill operations, including the undertaking of area classifications / zoning around landfill infrastructure.

Available [Online] from www.esauk.org/reports_press_releases/esa_reports/dsear_guidance.html [accessed 9 December 2016].

Appendix B. GasSim Model

[Refer to Hard Copy for CD Rom]

Project Details

Project Name	**Kerdiffstown Landfill**
Client	Kildare County Council
Model	c:\users\scooke\documents\kerdiffs data\final gassim\kerdiff 2016 v4.gss
Model Date	09/03/2017 13:47:07
Comments	Start Year 2011 Operation Period 7 Simulation Period 150 Iterations 100 Confined Migration Pathway

Waste Composition

Year	***Composition***
2011	Kerdiffstown half degradability
Newspapers	
User Defined 1	SINGLE(5.0)
User Defined 2	SINGLE(1.5)
User Defined 3	SINGLE(5.0)
Water (%)	SINGLE(30.0)
Cellulose (%)	SINGLE(48.5)
Hemi-Cellulose (%)	SINGLE(9.0)
Decomposition (%)	SINGLE(17.5)
Magazines	
Water (%)	SINGLE(30.0)
Cellulose (%)	SINGLE(42.3)
Hemi-Cellulose (%)	SINGLE(9.4)
Decomposition (%)	SINGLE(46.0)
Other paper	
Domestic	SINGLE(18.2)
Civic Amenity	SINGLE(3.3)
Commercial	SINGLE(28.8)
Industrial	SINGLE(8.8)
User Defined 1	SINGLE(5.0)
User Defined 2	SINGLE(1.5)
User Defined 3	SINGLE(5.0)
Water (%)	SINGLE(30.0)
Cellulose (%)	SINGLE(87.4)
Hemi-Cellulose (%)	SINGLE(8.4)
Decomposition (%)	SINGLE(49.0)
Liquid cartons	
Water (%)	SINGLE(30.0)
Cellulose (%)	SINGLE(57.3)
Hemi-Cellulose (%)	SINGLE(9.9)
Decomposition (%)	SINGLE(64.0)
Card packaging	
Water (%)	SINGLE(30.0)
Cellulose (%)	SINGLE(57.3)
Hemi-Cellulose (%)	SINGLE(9.9)
Decomposition (%)	SINGLE(64.0)
Other card	
Water (%)	SINGLE(30.0)
Cellulose (%)	SINGLE(57.3)
Hemi-Cellulose (%)	SINGLE(9.9)
Decomposition (%)	SINGLE(64.0)
Wood	
Domestic	SINGLE(2.8)
Civic Amenity	SINGLE(11.2)
Commercial	SINGLE(3.3)
Industrial	SINGLE(5.0)
User Defined 1	SINGLE(31.0)
User Defined 2	SINGLE(11.0)
User Defined 3	SINGLE(31.0)
Water (%)	SINGLE(20.0)
Cellulose (%)	SINGLE(21.0)
Hemi-Cellulose (%)	SINGLE(11.0)
Decomposition (%)	SINGLE(37.5)
Textiles	
Domestic	SINGLE(1.8)
Civic Amenity	SINGLE(2.3)
Commercial	SINGLE(1.1)
Industrial	SINGLE(0.3)
User Defined 1	SINGLE(11.0)
User Defined 2	SINGLE(2.0)
User Defined 3	SINGLE(11.0)
Water (%)	SINGLE(25.0)

Cellulose (%)	SINGLE(20.0)
Hemi-Cellulose (%)	SINGLE(20.0)
Decomposition (%)	SINGLE(25.0)
Disposable nappies	
Domestic	SINGLE(2.3)
Civic Amenity	SINGLE(2.9)
Water (%)	SINGLE(20.0)
Cellulose (%)	SINGLE(25.0)
Hemi-Cellulose (%)	SINGLE(25.0)
Decomposition (%)	SINGLE(50.0)
Other misc. combustibles	
Domestic	SINGLE(7.1)
Civic Amenity	SINGLE(4.2)
Commercial	SINGLE(10.4)
Industrial	SINGLE(17.7)
User Defined 2	SINGLE(1.0)
Water (%)	SINGLE(20.0)
Cellulose (%)	SINGLE(25.0)
Hemi-Cellulose (%)	SINGLE(25.0)
Decomposition (%)	SINGLE(50.0)
Garden waste	
Domestic	SINGLE(14.2)
Civic Amenity	SINGLE(32.1)
Commercial	SINGLE(9.8)
Industrial	SINGLE(4.7)
Water (%)	SINGLE(65.0)
Cellulose (%)	SINGLE(25.7)
Hemi-Cellulose (%)	SINGLE(13.0)
Decomposition (%)	SINGLE(62.0)
Other putrescible	
Domestic	SINGLE(19.8)
Civic Amenity	SINGLE(14.8)
Commercial	SINGLE(10.4)
Industrial	SINGLE(6.8)
Water (%)	SINGLE(65.0)
Cellulose (%)	SINGLE(55.4)
Hemi-Cellulose (%)	SINGLE(7.2)
Decomposition (%)	SINGLE(76.0)
10mm fines	
Domestic	SINGLE(5.4)
Civic Amenity	SINGLE(1.2)
Commercial	SINGLE(1.9)
Industrial	SINGLE(0.5)
Water (%)	SINGLE(40.0)
Cellulose (%)	SINGLE(25.0)
Hemi-Cellulose (%)	SINGLE(25.0)
Decomposition (%)	SINGLE(50.0)
Sewage sludge	
Sewage Sludge	SINGLE(100.0)
Water (%)	SINGLE(70.0)
Cellulose (%)	SINGLE(14.0)
Hemi-Cellulose (%)	SINGLE(14.0)
Decomposition (%)	SINGLE(75.0)
Composted organic material	
Composted Organic Material	SINGLE(100.0)
Water (%)	SINGLE(30.0)
Cellulose (%)	UNIFORM(7.47, 9.59)
Hemi-Cellulose (%)	UNIFORM(7.47, 9.59)
Decomposition (%)	SINGLE(57.0)
Incinerator ash	
Commercial	SINGLE(0.2)
Industrial	SINGLE(25.5)
Incinerator Ash	SINGLE(100.0)
Water (%)	SINGLE(30.0)
Cellulose (%)	TRIANGULAR(0.5, 0.7, 1.5)
Hemi-Cellulose (%)	TRIANGULAR(0.5, 0.7, 1.5)
Decomposition (%)	SINGLE(57.0)
Non degradable	
Domestic	SINGLE(28.4)
Civic Amenity	SINGLE(28.0)
Commercial	SINGLE(34.1)
Industrial	SINGLE(30.7)
Inert	SINGLE(100.0)
User Defined 1	SINGLE(48.0)
User Defined 2	SINGLE(83.0)

User Defined 3	SINGLE(48.0)	
Water (%)	SINGLE(0.0)	
Cellulose (%)	SINGLE(0.0)	
Hemi-Cellulose (%)	SINGLE(0.0)	
Decomposition (%)	SINGLE(0.0)	
Calcium Sulphate (%)		
Domestic	TRIANGULAR(0.2, 0.35, 2.3)	
Civic Amenity	TRIANGULAR(0.2, 0.35, 2.3)	
Composted Organic Material	TRIANGULAR(0.2, 0.35, 2.3)	
Incinerator Ash	TRIANGULAR(0.2, 0.35, 2.3)	
Residues from MRF	TRIANGULAR(0.2, 0.35, 2.3)	
Recycling Schemes	TRIANGULAR(0.2, 0.35, 2.3)	
Chemical Sludge	TRIANGULAR(0.2, 0.35, 2.3)	
Industrial Liquid Waste	TRIANGULAR(0.2, 0.35, 2.3)	
Iron (%)		
Domestic	TRIANGULAR(0.3, 4.8, 8.2)	
Civic Amenity	TRIANGULAR(0.3, 4.8, 8.2)	
Commercial	TRIANGULAR(0.3, 4.8, 8.2)	
Industrial	TRIANGULAR(0.3, 4.8, 8.2)	
Inert	TRIANGULAR(0.3, 4.8, 8.2)	
Liquid Inert	TRIANGULAR(0.3, 4.8, 8.2)	
Sewage Sludge	TRIANGULAR(0.3, 4.8, 8.2)	
Composted Organic Material	TRIANGULAR(0.3, 4.8, 8.2)	
Incinerator Ash	TRIANGULAR(0.3, 4.8, 8.2)	
Residues from MRF	TRIANGULAR(0.3, 4.8, 8.2)	
Recycling Schemes	TRIANGULAR(0.3, 4.8, 8.2)	
Chemical Sludge	TRIANGULAR(0.3, 4.8, 8.2)	
Industrial Liquid Waste	TRIANGULAR(0.3, 4.8, 8.2)	
User Defined 1	TRIANGULAR(0.3, 4.8, 8.2)	
User Defined 2	TRIANGULAR(0.3, 4.8, 8.2)	
User Defined 3	TRIANGULAR(0.3, 4.8, 8.2)	
2012	Kerdiffstown half degradability	
2013	Kerdiffstown half degradability	
2014	Kerdiffstown half degradability	
2015	Kerdiffstown half degradability	
2016	Kerdiffstown half degradability	
2017	Kerdiffstown half degradability	
Justification:	[Changed]	Not Justified

Trace Gases

No Combustion Products Selected

Zone 1

Infiltration	SINGLE(720.0)	
Justification:	[Changed]	Not Justified

Waste Input

Year	Amount Depositied (t)	
2011	SINGLE(2.15E+06)	
Justification:	[Changed]	Not Justified

Waste Breakdown

2011

User Defined 1	SINGLE(100.0)	
Justification:	[Default]	Default Value

Trace Gases

No Trace Gases Selected

Waste Moisture Content

Degradation rate - Filling Phase	Average	
Justification:	[Changed]	Not Justified
Degradation rate - after change	Average	
Justification:	[Changed]	Not Justified
Waste Density	UNIFORM(0.8, 1.2)	
Justification:	[Default]	Default Value
Leachate Head	SINGLE(1.0)	
Justification:	[Default]	Default Value
Hydraulic Conductivity	LOGUNIFORM(1.00E-09, 1.00E-05)	
Justification:	[Default]	Default Value

Engineered Controls

Cap Composite		
First Layer:		
Cap Thickness	SINGLE(0.6)	
Cap Hydraulic Conductivity	SINGLE(1.00E-09)	
Second Layer:		
Cap 2 Thickness	SINGLE(0.03)	
Cap 2 Hydraulic Conductivity	SINGLE(1.00E-09)	
Justifications		
Cap	[Changed]	Not Justified

Cap Thickness	[Changed]	Not Justified
Cap Hydraulic Conductivity	[Changed]	Not Justified
Liner	None	
Justifications		
Liner	[Default]	Default Value
Liner Thickness	[Changed]	Not Justified
Liner Hydraulic Conductivity	[Changed]	Not Justified
Justification:	[Default]	Default Value
Methane Oxidation %	SINGLE(10.0)	
Justification:	[Default]	Default Value
Land Raise Depth	SINGLE(20.0)	

Geosphere

Ground Surface (mAOD)	100
Water Table (mAOD)	80
Geosphere Moisture Content	SINGLE(5.0)
Geosphere Porosity	SINGLE(10.0)

Zone 2a

Infiltration	SINGLE(720.0)
Justification:	[Changed] Not Justified

Waste Input

Year Amount	Depositied (t)	
2011	SINGLE(4.12E+05)	
Justification:	[Changed]	Not Justified

Waste Breakdown

2011

User Defined 2	SINGLE(100.0)	
Justification:	[Default]	Default Value

Trace Gases

No Trace Gases Selected

Waste Moisture Content

Degradation rate - Filling Phase	Average	
Justification:	[Changed]	Not Justified
Degradation rate - after change	Average	
Justification:	[Changed]	Not Justified
Waste Density	UNIFORM(0.8, 1.2)	
Justification:	[Default]	Default Value
Leachate Head	SINGLE(1.0)	
Justification:	[Default]	Default Value
Hydraulic Conductivity	LOGUNIFORM(1.00E-09, 1.00E-05)	
Justification:	[Default]	Default Value

Engineered Controls

Cap	*SINGLE* Clay	
Cap Thickness	SINGLE(0.6)	
Cap Hydraulic Conductivity	SINGLE(1.00E-09)	
Justifications		
Cap	[Changed]	Not Justified
Cap Thickness	[Changed]	Not Justified
Cap Hydraulic Conductivity	[Changed]	Not Justified
liner	None	
Justifications		
Liner	[Default]	Default Value
Liner Thickness	[Changed]	Not Justified
Liner Hydraulic Conductivity	[Changed]	Not Justified
Justification:	[Default]	Default Value
Methane Oxidation %	SINGLE(10.0)	
Justification:	[Default]	Default Value
Land Raise Depth	SINGLE(5.0)	

Geosphere

Ground Surface (mAOD)	100
Water Table (mAOD)	80
Geosphere Moisture Content	SINGLE(5.0)
Geosphere Porosity	SINGLE(10.0)

Zone 2b

Infiltration	SINGLE(720.0)
Justification:	[Changed] Not Justified

Waste Input

Year	Amount Depositied (t)
2011	SINGLE(3.12E+05)
Justification:	[Changed] Not Justified

Waste Breakdown

2011

User Defined 2	SINGLE(100.0)

Justification:	[Default]	Default Value

Trace Gases

No Trace Gases Selected

Waste Moisture Content

Degradation rate - Filling Phase	Average	
Justification:	[Changed]	Not Justified
Degradation rate - after change	Average	
Justification:	[Changed]	Not Justified
Waste Density	UNIFORM(0.8, 1.2)	
Justification:	[Default]	Default Value
Leachate Head	SINGLE(1.0)	
Justification:	[Default]	Default Value
Hydraulic Conductivity	LOGUNIFORM(1.00E-09, 1.00E-05)	
Justification:	[Default]	Default Value

Engineered Controls

Cap	*SINGLE* Clay	
Cap Thickness	SINGLE(0.6)	
Cap Hydraulic Conductivity	SINGLE(1.00E-09)	
Justifications		
Cap	[Changed]	Not Justified
Cap Thickness	[Changed]	Not Justified
Cap Hydraulic Conductivity	[Changed]	Not Justified
liner	None	
Justifications		
Liner	[Default]	Default Value
Liner Thickness	[Changed]	Not Justified
Liner Hydraulic Conductivity	[Changed]	Not Justified
Justification:	[Default]	Default Value
Methane Oxidation %	SINGLE(10.0)	
Justification: [Default] Default Value		
Land Raise Depth	SINGLE(5.0)	

Geosphere

Ground Surface (mAOD)	100	
Water Table (mAOD)	80	
Geosphere Moisture Content	SINGLE(5.0)	
Geosphere Porosity	SINGLE(10.0)	
Zone 3		
Infiltration	SINGLE(720.0)	
Justification:	[Changed] Not Justified	

Waste Input

Year	Amount Depositied (t)	
2011	SINGLE(2.49E+05)	
Justification:	[Changed]	Not Justified

Waste Breakdown

2011		
User Defined 3	SINGLE(100.0)	
Justification:	[Default]	Default Value

Trace Gases

No Trace Gases Selected

Waste Moisture Content

Degradation rate - Filling Phase	Average	
Justification:	[Changed]	Not Justified
Degradation rate - after change	Average	
Justification:	[Changed]	Not Justified
Waste Density	UNIFORM(0.8, 1.2)	
Justification:	[Default]	Default Value
Leachate Head	SINGLE(1.0)	
Justification:	[Default]	Default Value
Hydraulic Conductivity	LOGUNIFORM(1.00E-09, 1.00E-05)	
Justification:	[Default]	Default Value

Engineered Controls

Cap	Composite	
First Layer:		
Cap Thickness	SINGLE(0.6)	
Cap Hydraulic Conductivity	SINGLE(1.00E-09)	
Second Layer:		
Cap 2 Thickness	SINGLE(0.03)	
Cap 2 Hydraulic Conductivity	SINGLE(1.00E-09)	
Justifications		
Cap	[Changed]	Not Justified
Cap Thickness	[Changed]	Not Justified
Cap Hydraulic Conductivity	[Changed]	Not Justified

liner	*SINGLE* Liner	
Liner Thickness	SINGLE(0.03)	
Liner Hydraulic Conductivity	SINGLE(1.00E-09)	
Justifications		
Liner	[Changed]	Not Justified
Liner Thickness	[Changed]	Not Justified
Liner Hydraulic Conductivity	[Changed]	Not Justified
Justification:	[Default]	Default Value
Methane Oxidation %	SINGLE(10.0)	
Justification:	[Default]	Default Value
Land Raise Depth	SINGLE(8.0)	

Geosphere

Ground Surface (mAOD)	100
Water Table (mAOD)	80
Geosphere Moisture Content	SINGLE(5.0)
Geosphere Porosity	SINGLE(10.0)

Zone 4

Infiltration	SINGLE(720.0)	
Justification:	[Changed]	Not Justified

Waste Input

Year	Amount Depositied (t)	
2011	SINGLE(1.92E+05)	
Justification:	[Changed]	Not Justified

Waste Breakdown

2011

User Defined 2	SINGLE(100.0)	
Justification:	[Default]	Default Value

Trace Gases

No Trace Gases Selected

Waste Moisture Content

Degradation rate - Filling Phase	Average	
Justification:	[Changed]	Not Justified
Degradation rate - after change	Average	
Justification:	[Changed]	Not Justified
Waste Density	UNIFORM(0.8, 1.2)	
Justification:	[Default]	Default Value
Leachate Head	SINGLE(1.0)	
Justification: [Default] Default Value		
Hydraulic Conductivity	LOGUNIFORM(1.00E-09, 1.00E-05)	
Justification:	[Default]	Default Value

Engineered Controls

Cap	*SINGLE* Clay	
Cap Thickness	SINGLE(0.6)	
Cap Hydraulic Conductivity	SINGLE(1.00E-06)	
Justifications		
Cap	[Changed]	Not Justified
Cap Thickness	[Changed]	Not Justified
Cap Hydraulic Conductivity	[Changed]	Not Justified
liner	None	
Justifications		
Liner [Default] Default Value		
Liner Thickness	[Changed]	Not Justified
Liner Hydraulic Conductivity	[Changed]	Not Justified
Justification:	[Default]	Default Value
Methane Oxidation %	SINGLE(10.0)	
Justification:	[Default]	Default Value
Land Raise Depth	SINGLE(2.0)	

Geosphere

Ground Surface (mAOD)	100
Water Table (mAOD)	80
Geosphere Moisture Content	SINGLE(5.0)
Geosphere Porosity	SINGLE(10.0)

Site Characteristics

Proportion to CO2 [%]	SINGLE(50.0)	
Justification: [Default] Default Value		
Proportion to CH4 [%]	SINGLE(50.0)	
Justification:	[Default]	Default Value

Cellulose Decay Rates

	Slow	Moderate	Fast
Dry	SINGLE(0.013)	SINGLE(0.046)	SINGLE(0.076)
Average	SINGLE(0.046)	SINGLE(0.076)	SINGLE(0.116)
Wet	SINGLE(0.076)	SINGLE(0.116)	SINGLE(0.694)

Saturated	SINGLE(0.013)	SINGLE(0.046)	SINGLE(0.076)
User Defined 1	SINGLE(0.046)	UNIFORM(0.046, 0.076)	UNIFORM(0.076, 0.116)
User Defined 2	UNIFORM(0.046, 0.076)	UNIFORM(0.076, 0.116)	UNIFORM(0.116, 0.694)
Justification:	[Default]	Default Value	

Gas Plant

No Flares/Engines in use

Engine/Flare Order	[Default]	Default Value

Trace Gas Plant

No Trace Gases Selected

Justification:	[Default]	Default Value

Global Impact

Bulk Gases

Global Warming Potential

Carbon Dioxide [t]:	1	
Methane [t carbon dioxoide]:	21	
Hydrogen [t carbon dioxide]:	0	
Justification:	[Default]	Default Value

Ozone Depletion Potential

Carbon Dioxide [t trichlorofluoromethane]:	0	
Methane [t trichlorofluoromethane]:	0	
Hydrogen [t trichlorofluoromethane]:	0	
Justification:	[Default]	Default Value

Lateral Migration

Bulk Gases

Air Diffusion Coefficients

CO2 Dispersivity	SINGLE(0.1613)	
CH4 Dispersivity	SINGLE(0.2192)	
H2 Dispersivity	#UNDEFINED?	
Justification:	[Default]	Default Value

Geosphere

Cell Zone 1		
Geosphere Moisture Content	SINGLE(5.0)	
Geosphere Porosity	SINGLE(10.0)	
Cell Zone 2a		
Geosphere Moisture Content	SINGLE(5.0)	
Geosphere Porosity	SINGLE(10.0)	
Cell Zone 2b		
Geosphere Moisture Content	SINGLE(5.0)	
Geosphere Porosity	SINGLE(10.0)	
Cell Zone 3		
Geosphere Moisture Content	SINGLE(5.0)	
Geosphere Porosity	SINGLE(10.0)	
Cell Zone 4		
Geosphere Moisture Content	SINGLE(5.0)	
Geosphere Porosity	SINGLE(10.0)	
Justification:	[Changed]	Not Justified

Appendix C. Perimeter Borehole Log Summary

Borehole	Strata Description	Gas Generation Potential
EMW01	Clay to 7.3 metres.	Low permeability will inhibit gas movement.
EMW02	Clay to 4.0 metres, sand from 4.0 to 5.5 metres, clay to end of borehole at 6.0 metres.	Confined sand layer has potential to allow gas migration, although sand layer is likely to be saturated so gas migration other than by dissolution is unlikely.
EMW03	Sand and gravel to 4.0 metres, clay to 14.0 metres, gravel from 14.0 to 16.5 metres, clay from 16.5 metres to end of borehole at 17.5 metres.	Sand and gravel layers will allow migration of gas. Gas migrating through the upper layer has ability to dissipate to atmosphere. The lower sand layer is confined but below the water table, so gas migration other than by dissolution is unlikely.
EMW04	Sand and gravel to 3.4 metres, clay to base of borehole at 7.0 metres.	Sand and gravel layers will allow migration of gas. Gas migrating through the upper layer has ability to dissipate to atmosphere.
EMW05	Clay to 2.0 metres, sand and gravel from 2.0 metres to 3.5 metres, clay from 3.5 metres to base of borehole at 6.0 metres.	The sand and gravel layer will allow movement of gas. The sand layer is confined, so there is greater potential for horizontal movement of gas although sand layer is likely to be saturated so gas migration other than by dissolution is unlikely.
EMW06	Sand and gravel to 5.9 metres, clay from 5.9 metres to base of borehole at 7.3 metres.	Sand and gravel layers will allow migration of gas. Gas migrating through the upper layer has ability to dissipate to atmosphere.
EMW07	Clay to 3.0 metres, sand and gravel from 3.0 to base of borehole at 6.0 metres.	The sand and gravel layer will allow movement of gas. The sand layer is confined, so there is greater potential for horizontal movement of gas although sand layer is likely to be saturated so gas migration other than by dissolution is unlikely.
EMW08	Sand to 1.0 metres, clay from 1.0 to 2.0 metres, sand and gravel from 2.0 metres to base of borehole at 5.0 metres.	Sand and gravel layers will allow migration of gas. Gas migrating through the upper layer has ability to dissipate to atmosphere. The lower sand layer is confined but likely to be saturated, so gas migration other than by dissolution is unlikely.
EMW09	Sand and gravel to 19.0 metres. Boulders or weathered bedrock from 19.0 metres to base of borehole at 20.5 metres.	A large thickness of sand and gravel will allow migration of landfill gas through a wide cross-sectional area. Migrating gas will tend to dissipate throughout the volume of sand and gravel, rather than migrating along discrete confined layers.
EMW10	Gravel to 2.3 metres, sand and gravel from 2.3 metres to base of borehole at 20.5 metres.	A large thickness of sand and gravel will allow migration of landfill gas. Migrating gas will tend to dissipate throughout the volume of sand and gravel, rather than migrating along discrete confined layers, although the top clay layer will impede dissipation to atmosphere and encourage further lateral migration of gas.
EMW18	Sandy Gravelly clay to 3.2 metres, fine to coarse sandy gravel with occasional cobbles to base of borehole at 6.2.	A large thickness of sand and gravel will allow migration of landfill gas through a wide cross-sectional area. Migrating gas will tend to dissipate throughout the volume of sand and gravel, rather than migrating along discrete confined layers.
EMW19	Clay to 2.0 metres, gravelly clay to 3.0 metres, sandy gravel to 3.9 followed by sand to 8.0, gravelly clay to 8.7 metres, boulder to 9.3 metres followed	The sand and gravel layer will allow movement of gas. The lower sand layer is confined, so there is greater potential for horizontal movement of gas but likely to be saturated, so gas migration other than by dissolution is unlikely.

Borehole	Strata Description	Gas Generation Potential
	by sandy gravel to 10.0 metres. Returns of rock to base of borehole at 15.4 metres.	
EMW20	Fine to coarse sandy gravel with occasional cobbles to base of borehole at 6.1 metres	A large thickness of sand and gravel will allow migration of landfill gas through a wide cross-sectional area. Migrating gas will tend to dissipate throughout the volume of sand and gravel, rather than migrating along discrete confined layers.
EMW21	Made ground to 2.4 metres followed by sandy gravelly clay to 4.9 metres, fine to coarse Sandy gravel with occasional cobbles to base of borehole at 6.7 metres	A large thickness of sand and gravel will allow migration of landfill gas through a wide cross-sectional area. Migrating gas will tend to dissipate throughout the volume of sand and gravel, rather than migrating along discrete confined layers.
EMW22	Sandy slightly gravelly clay with some cobbles to 3.6 metres very sandy slightly gravelly clay with some cobbles and boulders to 15.5 metres, boulders to 16.0 metres followed by returns of sandy gravel to 19.5 metres with bedrock to base of borehole at 24.6 metres	A large thickness of sand and gravel will allow migration of landfill gas through the wide cross-sectional area. Migrating gas will tend to dissipate throughout the volume of sand and gravel, rather than migrating along discrete confined layers. Sand and gravel layer is confined at base by bedrock.
EMW23	Clay to 1.8 metres, Sandy gravel to 10.5 metres, Sand from 10.5 to 11.2 metres followed by sandy gravel to 14.8 metres	The sand and gravel layer will allow movement of gas. The lower sand layer is confined, so there is greater potential for horizontal movement of gas.
EMW29	Soft clay to 0.8 metres followed by sandy gravel to 4.5 metres. Sandy gravelly clay to base of borehole at 8.0 metres	The sand and gravel layer will allow movement of gas, although groundwater is close to ground surface at this location, which limits the extent of unsaturated zone through which gas can move.
EMW30	Sandy gravelly clay to 1.8 metres followed by gravelly sand to 10.0 metres followed by sandy gravel to base of borehole at 14.0 metres	A large thickness of sand and gravel will allow migration of landfill gas through a wide cross-sectional area. Migrating gas will tend to dissipate throughout the volume of sand and gravel, rather than migrating along discrete confined layers.