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NORTH KERRY LANDFILLS

TIER 3 RISK ASSESSMENT
HISTORIC LANDFILL AT LISTOWEL, CO. KERRY

Prepared for: Kerry County Council

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Abstract: This report represents the findings of a Tier 3 risk assessment carried out on Listowel Historic Landfill site, Co. Kerry, conducted in accordance with the EPA Code of Practice for unregulated landfill sites. The Tier 3 risk assessment was conducted following a review of findings from earlier Tier 1 and Tier 2 site investigations and risk assessments.

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1. INTRODUCTION

1.1 Overview

Fehily Timoney and Company (FT) was appointed by Kerry County Council to carry out and prepare a Tier 3 risk assessment for Listowel Historical landfill located in Listowel, Co. Kerry. This Tier 3 makes reference to:

- Tier 1 risk assessment findings and classifications (2007).
- Tier 2 Site investigation, testing and risk assessment (2020).

All FT risk assessments were carried out in accordance with the Environmental Protection Agency (EPA) Code of practice (CoP) - Environmental Risk Assessment for Unregulated Waste Disposal Sites guidance document.

1.1 Tier 1 Risk Classification

Kerry County Council initially prepared a Tier 1 risk assessment in 2007. This risk assessment determined that the site was a Moderate (Class B) risk to the receiving environment. Applying the EPA risk assessment tool as per the CoP - Environmental Risk Assessment for Unregulated Waste Disposal Sites yielded risk scores of 44% for source-pathway-receptors (SPR) linkages SPR5 and SPR6.

A summary of the risks are included below in Table 1.1.

Table 1-1 normalised scores for 2007 Tier 1 assessment have been provided for reference purposes to reflect records as per the current (2020) EPA Section 22 register:

Table 1-1: Tier 1 SPR Linkages (2007)

SPR No.	Linkage	Normalised Score	Justification
Leachate migration through combined groundwater and surface water pathways			
SPR1	Leachate => surface water	23%	Groundwater vulnerability was identified as being extreme and the site is predominantly underlain by a regionally important karstified aquifer.
SPR2	Leachate => SWDTE	23%	The nearest groundwater protection zone is located approximately 20 km south-west of the site.
Leachate migration through groundwater pathway			
SPR3	Leachate => human presence	29%	The surrounding area is a town park open to the public and the nearest residential dwellings are located approximately 150m north-east of the site boundary and karstified aquifer presented a pathway for vertical and lateral leachate migration.
SPR4	Leachate => GWDTE	29%	The nearest groundwater protection zone is located approximately 20 km south-west of the site.

SPR No.	Linkage	Normalised Score	Justification
SPR5	Leachate => Aquifer	44%	Aquifer vulnerability is extreme and is classified as being a regionally important aquifer across the majority of the site.
SPR6	Leachate => Public Supply	44%	Nearest public water supply is located over 1km from the site.
SPR7	Leachate => Surface water	29%	Surface water body (River Feale which is part of an SAC) is located directly south (within 25m) of the site boundary.
Leachate migration through surface water pathway			
SPR8	Leachate => Surface Water	0%	There are no visible surface drains located within the site that discharge directly into the River Feale surface water body.
SPR9	Leachate => SWDTE	0%	The nearest groundwater protection zone is located approximately 15.8 km south-west of the site.
Landfill gas migration pathway (lateral & vertical)			
SPR10	Landfill Gas => Human Presence	10%	Residential dwellings are located approximately 150m north-east of the site boundary. The site is also located within a public town park.
SPR11	Landfill Gas => Human Presence	0%	Residential dwellings are located approximately 150m north-east of the site boundary. The site is also located within a public town park.

1.2 Tier 2 Site Investigation

Listowel historic landfill is located adjacent to the River Feale in Listowel and underlies a public park.

Listowel's historic landfill site investigation included the following elements:

- Site walkover.
- 2 No. boreholes by rotary drilling methods.
- 2 No. standpipe installations.
- 8 boreholes by dynamic (windowless) sampling methods.
- 1 No. geophysical survey (2D resistivity, EM31 ground conductivity and seismic refraction profiling).
- Topographical survey.
- Factual reporting.

The Tier 2 assessment produced a comprehensive understanding of the characterisation of the site and facilitated the production of an updated Conceptual Site Model (CSM). The Tier 2 investigation confirmed the landfill contained a mixed commercial and domestic waste deposited within a single infill area, covering an area of approximately 8,900 m^2.

The depth of waste has been estimated from the seismic refraction and 2D-Resistivity surveys. An average thickness of 11 m has been calculated for the landfill material.

The estimate includes capping or natural fill material on top of the main waste body; however, it was noted during the geophysical survey that the low resistivities near the surface indicates that there is no significant fill over the waste material. An initial volume calculation based on geophysical survey estimates an interred waste volume of approximately 98,000 m^3 at the site.

1.3 Tier 2 Risk Classification and Tier 2 SPRs

The Tier 2 risk assessment concluded that the risk rating of the site was Moderate (Class B) as outlined in Table 1.2. The highest risk rating for the site was calculated to be 50% for source-pathway-receptor (SPR) Linkage 3, Linkage 5 and Linkage 7 which referred to leachate migration through a groundwater pathway to human receptors, the underlying aquifer and surface water dependent terrestrial ecosystems, respectively. A risk rating of 50% was also calculated for SPR 8 and SPR1, leachate migration through a surface water pathway and leachate migration through a combined groundwater and surface water pathway, respectively. The SPR linkages examined in this Tier 3 are discussed in further detail below.

Table 1-2: Tier 2 Selected SPR Linkages

SPR No.	Linkage	Normalised Score	Justification
Leachate migration through combined groundwater and surface water pathways			
SPR1	Leachate => surface water	50%	Groundwater vulnerability was identified as being extreme and the site is predominantly underlain by a regionally important karstified aquifer.
SPR2	Leachate => SWDTE	33%	The nearest groundwater protection zone is located approximately 20 km south-west of the site.
Leachate migration through groundwater pathway			
SPR3	Leachate => human presence	50%	The surrounding area is a town park open to the public and the nearest residential dwellings are located approximately 150m north-east of the site boundary and karstified aquifer presented a pathway for vertical and lateral leachate migration.
SPR4	Leachate => GWDTE	33%	The nearest groundwater protection zone is located approximately 20 km south-west of the site.
SPR5	Leachate => Aquifer	50%	Aquifer vulnerability is extreme and is classified as being a regionally important aquifer across the majority of the site. Site investigation data confirms that waste has been placed directly on the underlying bedrock.
SPR6	Leachate => Public Supply	0%	Nearest public water supply is located over 1km from the site.
SPR7	Leachate => Surface water	50%	Surface water body (River Feale which is part of an SAC) is located directly south (within 25m) of the site boundary.
Leachate migration through surface water pathway			
SPR8	Leachate => Surface Water	50%	There are no visible surface drains located within the site that discharge directly into the River Feale surface water body.

SPR No.	Linkage	Normalised Score	Justification
			Leachate breakout was observed to flow into an existing drainage outfall adjacent to the council offices.
SPR9	Leachate => SWDTE	33%	The nearest groundwater protection zone is located approximately 15.8 km south-west of the site.
Landfill gas migration pathway (lateral & vertical)			
SPR10	Landfill Gas => Human Presence	30%	Residential dwellings are located approximately 150m north-east of the site boundary. The site is also located within a public town park.
SPR11	Landfill Gas => Human Presence	0%	Residential dwellings are located approximately 150m north-east of the site boundary. The site is also located within a public town park.

1.3.1 Leachate migration through groundwater pathways to human receptors (SPR3)

A risk rating score of 50% was calculated for the SPR3 linkage. This rating refers to the risk of leachate migration through the underlying aquifer and to human receptors via private groundwater wells. The site is located within the 'Garden of Europe', an award-winning town park situated at the edge of Listowel town. There are no buildings or structures located within the waste footprint area, however the nearest residential dwellings are located approximately 150 m north-east of the boundary area and there is council building < 50 m south of the waste footprint. There are two aquifers underlying the site and have been identified by the GSI as a 'Regionally Important Aquifer – Karstified (diffuse)' and a 'Poor Aquifer – bedrock which is generally unproductive'. The site is predominantly underlain by the 'Regionally Important' aquifer, with a section of the southern area of the site underlain by the 'Poor Aquifer'. The presence of a karst aquifer underlying the majority of the site and the proximity of the closest residential dwellings are contributing factors in the calculated risk that the historical landfill site poses.

1.3.1.1 Leachate Breakout

During the site walkover there was evidence of leachate breakout in the south-eastern section of the site. The leachate seepage was noted bubbling through the ground surface within the Kerry County Council (KCC) works/ storage yard. The leachate was brown/ orange in colour and was noted in two areas within the KCC works yard. A photographic log containing images of the leachate breakout is included in Appendix 4 of the Tier 2 ERA report.

1.3.2 Leachate migration through groundwater pathways to the underlying aquifer (SPR5)

A risk rating score of 50% was calculated for the SPR5 linkage. This rating refers to the risk of leachate migration to the underlying groundwater aquifer. As mentioned in Section 1.3.1 above, the site is underlain by two aquifers; the majority of the site is underlain by a 'Regionally Important Aquifer – Karstified (diffuse)' with a section of the southern part of the site underlain by a 'Poor Aquifer – bedrock which is generally unproductive'. The presence of a karst aquifer underlying the majority of the site is a contributing factor in the calculated risk that the historical landfill poses.

1.3.3 Leachate migration through groundwater pathways to surface water dependent terrestrial ecosystems (SPR7)

A risk rating score of 50% was calculated for the SPR7 linkage. This rating refers to the risk of leachate migration through a groundwater pathway, to surface water dependent ecosystems. The Feale River is located approximately 25 m south of the waste body and is part of the Lower River Shannon SAC (Site Code: 002165). The underlying aquifers comprise a 'Regionally Important Aquifer – Karstified' across the majority of the site with a 'Poor Aquifer' underlying a section in the southern part of the site. The location of the SAC coupled with the karst characteristics of the underlying aquifer are significant factors in the calculated risk that the historical landfill site poses. There is evidence of a connection between the historic landfill boundary and the River Feale where leachate breakout was observed from the foot of the landfill and a discharged to surface drains in the yard to the south . Anecdotal evidence from County Council operatives obtained during the site visit suggested the contaminated surface water runoff discharges to the River Feale. The section of the River Feale directly south of the site is also underlain by a 'Poor Aquifer – bedrock which is generally unproductive'.

1.3.3.1 Surface Water Monitoring

Surface water monitoring was conducted at upstream and downstream locations on the River Feale located just south of the site, as part of the Tier 2 site investigations. Surface water monitoring did not demonstrate any exceedances above surface water quality threshold values or any deterioration in water quality between upstream and downstream monitoring locations. This indicates that the landfill is not having a deleterious effect on the River Feale, as the nearest surface water receptor. However, the River Feale is part of the Lower River Shannon SAC, which should be considered as part of the Tier 3 assessment, due to its sensitivity.

1.3.4 Leachate migration to surface water receptor through a surface water and groundwater pathway (SPR1) (SPR8)

A risk rating score of 50% was calculated for leachate migration through a surface water pathway and combined groundwater and surface water pathway. The River Feale is located approximately 25 m south of the site. There is evidence of a connection between the site and the River Feale through the surface water drainage systems. Leachate was observed to flow from the toe of the park footprint where it adjoins the Council yard, over ground in the council yard into a surface drain within the council yard. This leachate breakout has the potential to flow directly into the River Feale, and so has been considered during the Tier 3 assessment.

1.3.5 Lateral migration of landfill gas (SPR10)

A risk rating score of 30% was calculated for lateral migration of gas within the site. However, monitoring conducted at the site as part of the Tier 2 site investigation indicated that the concentrations of both methane and carbon dioxide were below the threshold values set by the CoP. Due to the presence of a 'Regionally Important – Karstified' aquifer and human receptors in the area, there is potential for gas migration which is reflected in the risk rating score. Although the calculated risk score is low, it was decided to include landfill gas generation calculation as part of this DQRA due to the use of the site as a public space and its location within an urban environment.

2. TIER 3 ASSESSMENT SCOPE OF WORKS

2.1 Tier 3 Overview

The EPA Code of Practice on Environmental Risk Assessment for Unregulated Waste Disposal Sites requires a Tier 3 Quantitative Risk assessment to include some form of quantitative assessment for **Moderate or High-risk sites**, either as a Generic Quantitative Risk Assessment (GQRA) or as a Detailed Quantitative Risk Assessment (DQRA).

This Tier 3 report further examines the Tier 2 (see Table 1-2) linkages in relation to the following:

- SPR1 leachate migration through combined surface and groundwater pathways.
- SPR3 leachate migration through groundwater pathways to human receptors.
- SPR5 leachate migration through groundwater pathways on the underlying aquifer.
- SPR7 leachate migration through groundwater pathways to surface water dependent terrestrial ecosystems.
- SPR8 leachate migration through surface water pathways.
- SPR10 lateral migration of landfill gas.

Based on the outcomes of the GQRA/DQRA, suitable remediation measures and associated costs are determined.

The Tier 2 risk assessment concluded that the Listowel site presents a **moderate risk** therefore a GQRA or a DQRA is required as part of this Tier 3 assessment.

As part of the Tier 3 assessment, a further review of all previous site investigations and environment risk assessments was conducted.

This Tier 3 assessment report uses a DQRA to further assess the risks to surface water and combined groundwater and surface water receptors.

This Tier 3 assessment report uses the following DQRAs to further assess the risks to surface waters, groundwater and gas migration:

- Groundwater contaminant dispersion modelling (EA Remedial Targets Worksheet) was undertaken to quantitatively assess the risks posed to the aquifer.
- An assimilative capacity assessment and a mass balance calculation were carried out to predict the potential impact on surface water quality from a leachate discharge to the adjacent river.
- Predictive landfill gas modelling (LandGEM) was used to assess gas migration risks.

Based on the outcomes of the DQRA, suitable remediation measures and associated costs are presented in Section 5 of this report.

3. DETAILED QUANTITATIVE RISK ASSESSMENT (DQRA)

3.1 Detailed Quantitative Risk Assessment

The detailed quantitative risk assessment addressed the following primary risks:

- Leachate migration through combined surface and groundwater pathways (SPR1).
- Leachate migration through groundwater pathways to human receptors (SPR3).
- Leachate migration through groundwater pathways to the underlying aquifer (SPR5).
- Leachate migration through groundwater pathways to surface water dependent terrestrial ecosystems (SPR7).
- leachate migration through surface water pathways (SPR8).
- Lateral migration of landfill gas (SPR10).

The DQRAs rely on information gathered as part of the Tier 2 site investigations. A summary of the relevant environmental characteristics considered in evaluating the site and carrying out this Tier 3 investigation are discussed below.

3.2 Existing Geological and Hydrogeological Environment

An accurate understanding and rating of the geological and hydrogeological characteristics of the site and environment are directly linked to determining the primary source-pathway-receptor (SPR) linkages and potential impacts/ risks associated with the site.

The Quaternary Geology present within the site is classified as comprising, Tills derived from Namurian Sandstones and Shales, Bedrock outcrop or subcrop and Urban Made Ground. Alluvium deposits are present along the path of the River Feale.

The bedrock beneath to be found on two different formations; Visean Limestones (north-western section of the site) and the Clare Shale Formation (south-eastern section of the site). The boundary between the two formations transects the site in a south-west to north-east direction. GSI mapping indicates that there is bedrock outcrop present within the centre of the site boundary, directly east of the site and along the banks of the River Feale. Bedrock was not encountered during site investigations.

An examination of the national bedrock aquifer map indicates that the Visean Limestones are a ‘Regionally Important Aquifer – Karstified (Diffuse) Bedrock (Rkd’) i.e. dominated by diffuse rather than conduit flow. The Clare Shale Formation is a ‘Poor Aquifer – bedrock which is generally unproductive’.

The nearest groundwater protection zone is located approximately 18.5 km north-east of the site near Glin village and is associated with the Glin Public Water Supply, it is noted however that this public water supply is no longer in use. Other groundwater protection zones are located over 20km away from the site.

Groundwater recharge is quite variable within and surrounding the site. Owing to the variation in geology i.e. areas of bedrock, made ground and till subsoils, permeability and recharge will vary.

Effective rainfall for the area ranges from 765 to 785 mm/year. Recharge co-efficient values vary from 20%, 22.5%, 85% yielding recharge rates 153 to 650 mm/year.

The groundwater vulnerability within the site as 'Extreme' with an area of 'Rock at or near the surface'. This facilitates a relatively easy pathway for rainfall and potential leachate to enter the underlying groundwater aquifer.

3.3 River Feale – (Lower River Shannon SAC)

The historic landfill site is located within the Tralee Bay - Feale catchment (Hydrometric Area: 23), Feale_SC_040 sub-catchment and Feale_090 sub-basin. The River Feale is the most significant water feature close to the site, being approximately 25 m south of the site boundary and is part of the Lower Shannon SAC. Following a review of online mapping and site walkovers, it was determined that there may be a direct surface water connection allowing leachate breakout entering County Council's yard drains and to discharge into the River Feale. The River Feale flows in an east – west direction, past Listowel converging with the River Brick and Galey River before eventually discharging to the Atlantic, at Kilmore (south of Ballybunion).

As stated in Section 1.3.4 one of the potential risks associated with the historical landfill site at Listowel, is the potential for leachate from the waste body too break out from the waste body, and discharge via existing surface drainage systems to the River Feale negatively impacting on water quality which could affect any surface water dependent terrestrial ecosystems (SWDTE). The site is underlain by a 'Regionally Important Aquifer – Karstified' in the north and by a 'Poor aquifer – bedrock which is generally unproductive' in the south. The River Feale, located approximately 25 m south of the site boundary, is underlain by the 'Poor Aquifer'.

As described by the GSI, a poor aquifer generally consists of few and poorly connected fractures, fissures and joints. The poor fissure network results in poor aquifer storage, short flow paths and low 'recharge acceptance'. Groundwater discharge to streams is very limited.

3.3.1 Desktop Records – Surface Water Quality

Surface water quality monitoring has historically been conducted at Listowel Bridge approximately 330m downstream of the site. The most recent biological Q-Rating for surface water quality at this location (2017) was Q4 – 'Good' status. Upstream monitoring close to the site has not been historically conducted. The nearest EPA surface water monitoring station is located between 5-6 km upstream of Listowel Bridge, and the most recent Q-Rating assigned was Q4 – 'Good' in 2017.

3.3.1.1 River Feale Flow Information

Flow data was collected from a hydrometric station located on the River Feale directly south of the site location and is presented in Table 3.1.

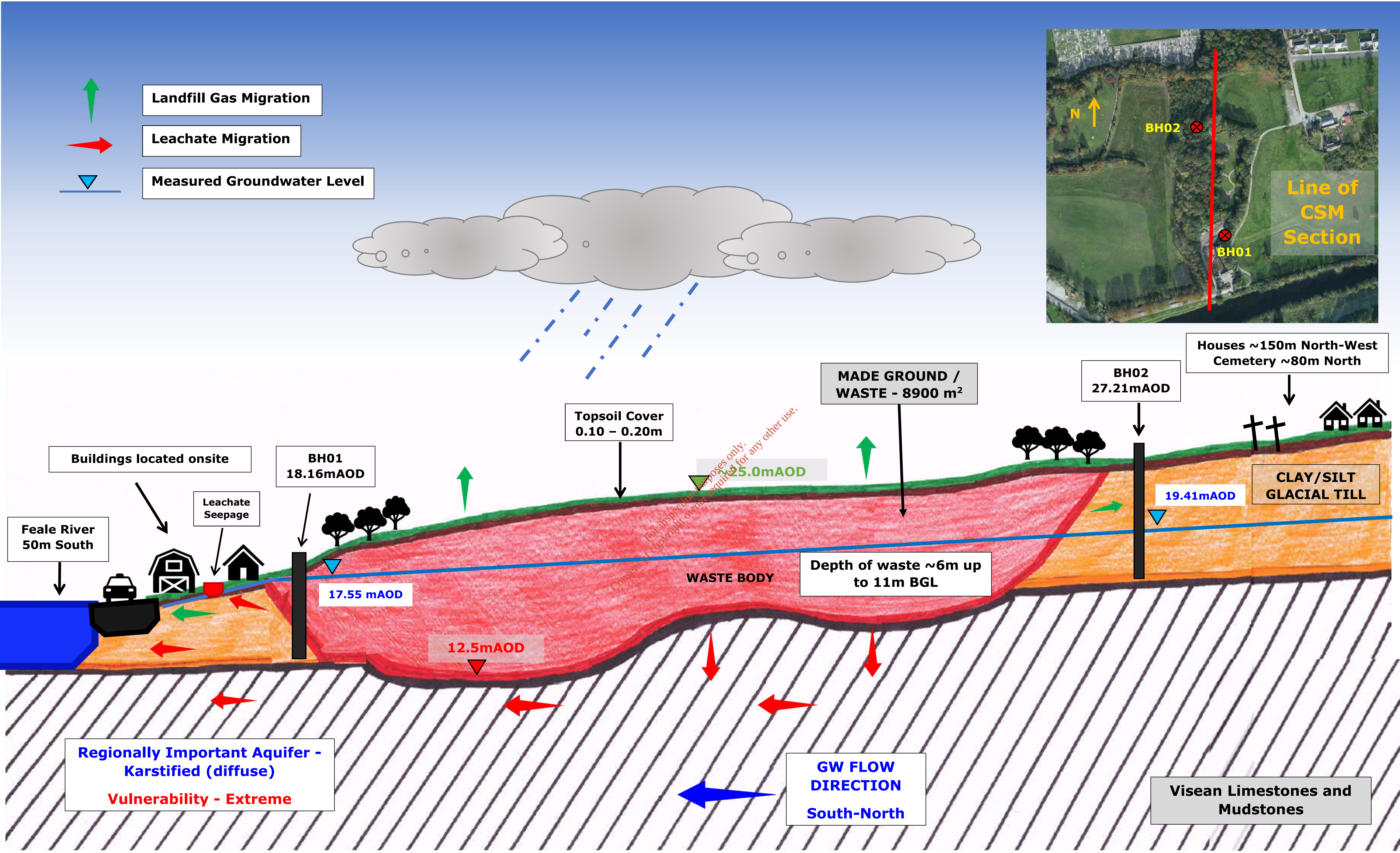
Table 3.1, illustrates the River Feale flow duration percentiles. This table displays the percent of values that specified discharges, were equalled or exceeded.

Table 3-1: River Feale Flow Duration Percentiles (Waterlevel.ie)

Duration Percentiles								
Flows equalled or exceeded for the given percentage of time (m^3/day) (Data derived for the period 1974 to 2013)								
1%	5%	10%	25%	50%	75%	90%	95%	99%
122,607,65	68,151,46	48,815,14	24,721,63	9,180,86	3,504,38	1,787,62	1,363,39	69,120

3.4 Conceptual Site Model (CSM)

Based on a review of the Tier 1 and Tier 2 assessments undertaken for the historic Listowel landfill, an updated conceptual site model has been produced. This CSM is presented in Figure 3.1.



CROSS SECTION NORTH-SOUTH

FIGURE 3.1 Listowel HISTORIC LANDFILL

CONCEPTUAL SITE MODEL

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3.5 Historic Landfill: Contaminants of Concern

Environmental monitoring detected concentrations above the groundwater threshold values for groundwater quality as per the interim guideline values (IGV) contained within the EPA's *Towards Setting Guideline Values for the Protection of Groundwater in Ireland*[1] report and S.I No. 9 of 2010[2] regulations for several parameters within both monitoring wells; BH01 and BH02 adjacent to the site boundary. With respect to the groundwater quality threshold values within S.I No. 9 of 2010 ammoniacal nitrogen concentrations exceeded the threshold value of 0.175 mg/l at BH01 with concentrations of 26.1 mg/l and 0.313 mg/l at BH02. The Tier 2 site investigation and risk assessment concluded that although BH02 (upgradient) concentrations are elevated above the groundwater threshold value the significant increase in concentrations at BH02 (downgradient) does indicate potential contamination of groundwater from the landfill.

The Tier 2 site investigation identified the following chemicals were shown to exceed the groundwater quality Interim Guideline Values from the EPA's *Towards Setting Guideline Values for the Protection of Groundwater in Ireland* report in samples taken from both groundwater wells BH01 and BH02:

- Ammoniacal Nitrogen as N.
- Alkalinity as $CaCO_3$.
- Chloride.
- Manganese.

Elevated alkalinity ($CaCO_3$) is found in both sampling locations and could be influenced by local bedrock hydrochemistry.

3.6 Impact of Leachate on Groundwater

The site location is predominantly underlain by a 'Regionally Important Aquifer – Karstified (diffuse)' in the northern section of the site and a 'Poor Aquifer' in the southern section. The River Feale located approximately 25 m south of the site boundary is part of the Lower Shannon SAC. This section of the River Feale is also underlain by the 'Poor Aquifer'.

3.6.1 Potential Leachate Generation

In quantifying the potential impact that the leachate generated at the historical landfill may have on the underlying groundwater aquifer and on the River Feale, it is important to estimate the quantity of leachate produced at the site. At Listowel, the groundwater level flows through the base of the waste body which, paired with direct rainfall percolating through the waste body, could drive the vertical migration of the leachate through the surface.

The vertical infiltration of rainfall to the underlying groundwater aquifer is determined by the groundwater recharge rate at this site. The recharge rate at the site is defined as 650 mm/year with a recharge coefficient of 85%.

[1] Towards Setting Guideline values For the Protection of Groundwater in Ireland-Interim Report (EPA, 2003)

[2] S.I. No. 9/2010 - European Communities Environmental Objectives (Groundwater) Regulations 2010.

The aquifer recharge volumes within the site boundary has been calculated below:

Rainfall Aquifer Recharge

85% x 765 mm/year = 650.25 mm/year or 0.650 m/year (available rainfall for recharge over the landfill area)

Aquifer Recharge Volume = Recharge x Area of Landfill

Aquifer Recharge Volume = 0.650 m/year x 8,900 m^2

Aquifer Recharge Volume over landfill area = ***5,787 m^3/year [16 m^3/day]***

The potential leachate generation by groundwater flowing through the waste body was calculated using Darcy's Law as set out below.

Groundwater Flow through the Waste Body

$Q = KA\ (\delta H/\delta L)$

Q= Flow Rate m^3/day

K= Permeability m/day

A = Cross sectional Area m^2

$\delta H/\delta L$= Hydraulic Gradient m/m

$Q = (1.29 \times 10^{-5})\ (1650\ m^2)\ (0.0124)$

Q= 0.000264 m^3/day/m

Q= 10 m^3/day

The underlying groundwater aquifers are not used for public water supplies within the area. Based on the calculations above and taking the flow rate of the River Feale into account, it is likely that there is a low potential impact from leachate generated at the historical landfill site on the quality of the groundwater and surface water body in the area.

3.6.2 Leachate Dispersion Modelling and Assessment

To confirm the potential downstream concentration of leachate/ contaminated groundwater generated at the site and the potential risk it may pose to the River Feale surface water body and subsequently any surface water dependent terrestrial environments, a hydrogeological model was utilised.

The Hydrogeological Risk Assessment for Land Contamination – Remedial Targets Worksheet, developed by the UK Environment Agency's Science Group, was utilised to carry out this assessment. This model is generally used to develop remediation targets in soil or groundwater, to ensure a desired downstream concentration at a point, e.g. a well or other receptor. The model allows the user to predict at what point in time and distance, the desired groundwater concentration will be met.

This assessment tool was utilised to predict the potential groundwater concentration for select parameters/ contaminants downstream of the site. The model relies of the following (simplified) inputs:

- Source Characteristics (i.e. Leachate species Concentration, retardation, half-life),
- Aquifer Characteristics (permeability, porosity, hydraulic gradient).

As noted in Section 3.5, ammoniacal nitrogen, chloride and manganese were found to be present in the groundwater samples taken from within the site, in concentrations above the relevant groundwater quality threshold[2]. The Tier 2 investigation did note that the slightly elevated manganese concentration is typical of the local bedrock hydrochemistry however for purpose of this assessment it was included as a potential pollutant.

The UK EA worksheet relies on the input of single values therefore it was necessary to make several assumptions based on the available site-specific data, and typical values obtained from literature and understanding of the site. The values applied for this model are outlined in Table 3.2.

Table 3-2: UK EA Remedial Targets Worksheet Model Inputs

Input Parameter	Unit	Ammoniacal Nitrogen	Chloride	Manganese	Source
Target Concentration	*mg/l*	0.175	30	0.05	S.I No. 9 of 2010 and EPA IGV
Initial contaminant concentration in groundwater at plume core	*mg/l*	26.1	214	1.31	Maximum BH01 groundwater monitoring well concentration (2019)[1]
Half-life for degradation of contaminant in water	*days*	$1x10^9$			Assumed high value (no degradation)
Width of plume in aquifer at source (perpendicular to flow)	*m*	70			Approximate width of site/waste extent based on Site Investigation
Plume thickness at source	*m*	11			Assumed thickness, waste is deposited directly on limestone bedrock
Saturated aquifer thickness	*m*	10			Average aquifer thickness minimum thickness of regionally important aquifer
Bulk density of aquifer materials	*g/cm3*	1.55			Assumed limestone bulk density
Effective porosity of aquifer	*fraction*	0.275			Median value of assumed porosity referenced in Environmental Agency Landsim manual

Input Parameter	Unit	Ammoniacal Nitrogen	Chloride	Manganese	Source
Hydraulic gradient	*fraction*	0.0179			Calculated hydraulic gradient between BH01 and BH02 (S.I. 2019)
Hydraulic conductivity of aquifer	*m/d*	8.64			Assumed single conductivity based on literature values for karst limestone
Distance to compliance point	*m*	150			Distance from site to boundary of River Feale SAC
Time Since Pollutant entered groundwater	*days*	25, 50, 100, 500 and 1000 years [9,125, 18,250, 36,500, 182,500, 365,000 days]			Time intervals selected
Soil Water Partition Co-efficient	*l/kg*	1.25	0	0	Assumed - based on values referenced in Environmental Agency Landsim manual

3.6.3 Results – EA UK Remedial Targets Worksheet

This model was used to estimate the dispersion of ammoniacal nitrogen, chloride and manganese. The groundwater concentration at a range of distances from the source at different time intervals are presented in Table 3.3.

The range of distances are automatically generated by the model based on the percentages of the compliance point distance (150m) i.e. 7.5m [5%], 30m [20%], 60m [40%] and 150m [100%].

Table 3-3: Modelled Downstream Concentrations (UK EA Remedial Targets Worksheet)

Ammoniacal Nitrogen (mg/l)			*Groundwater threshold Value (GTV) = 0.175 mg/l*		
Years of Dispersion	**Initial Plume Concentration (mg/l)**	***Conc.at 7.5m (mg/l)***	***Conc. at 30m (mg/l)***	***Conc. at 60m (mg/l)***	***Conc. at 150 m (mg/l)***
25	26.1	26.1	26.1	25.6	21.1
50	26.1	26.1	26.1	25.6	21.1
100	26.1	26.1	26.1	25.6	21.1
500	26.1	26.1	26.1	25.6	21.1
1000	26.1	26.1	26.1	25.6	21.1

Chloride (mg/l)			*Groundwater threshold Value (GTV) = 30 mg/l*		
Years of Dispersion	Initial Plume Concentration (mg/l)	*Conc.at 7.5m (mg/l)*	*Conc. at 20 m (mg/l)*	*Conc. at 60 m (mg/l)*	*Conc. at 150 m (mg/l)*
25	214	214	214	210	173
50	214	214	214	210	173
100	214	214	214	210	173
500	214	214	214	210	173
1000	214	214	214	210	173
Manganese (mg/l)			***Groundwater threshold Value (GTV) = 0.05 mg/l***		
Years of Dispersion	**Initial Plume Concentration (mg/l)**	***Conc.at 7.5m (mg/l)***	***Conc. at 20 m (mg/l)***	***Conc. at 40 m (mg/l)***	***Conc. at 150 m (mg/l)***
25	1.31	1.31	1.31	1.29	1.06
50	1.31	1.31	1.31	1.29	1.06
100	1.31	1.31	1.31	1.29	1.06
500	1.31	1.31	1.31	1.29	1.06
1000	1.31	1.31	1.31	1.29	1.06

3.6.4 Discussion of Results

The model was used to predict downgradient concentrations of the identified pollutants (ammoniacal nitrogen, chloride and manganese) at 7.5 m, 20 m, 40 m and 150 m downstream of the site after the stated number of years of dispersion (25, 50, 100, 500 and 1000 years).

The model conservatively assumes a worst-case scenario of a non-depleting source concentration. The source concentrations applied in the model were based on the groundwater concentrations detected in samples obtained at groundwater monitoring well BH01 as part of the Tier 2 site investigation.

With respect to all contaminants, it is clear that over time, the concentrations will decrease. However, these concentrations are still exceeding the groundwater threshold values. This indicates that even after 1,000 years, the pollutants of concern will be negatively impacting the groundwater quality of the underlying aquifer, if no mitigation measures are put in place.

3.7 Impact of Leachate on Receiving Surface Waters

The potential impact of leachate emissions to the adjacent river located south of the site was identified as being a risk associated with the site. Ammonia concentrations detected in groundwater monitoring boreholes installed at the site were shown to exceed the relevant groundwater quality threshold (0.175 mg/l) with concentrations of 26.1 mg/l at BH01 and 0.313 mg/l at BH02.

Ammonia is a commonly occurring pollutant associated with landfills which may pose a risk to surface waters, where a pathway exists.

Although surface water monitoring did not indicate that the landfill was causing a deterioration in surface water quality, the presence of leachate underlying the site, leachate breakout and potential discharge to the River Feale warrants further assessment to confirm the risk.

The potential impact of the site on this receiving waterbody was assessed by conducting an assimilative capacity assessment and mass balance calculations with ammonia chosen as a representative potential pollutant.

3.7.1 Assimilative Capacity Assessment

Table 3-4 shows the assimilative capacity of receiving waters in relation to Ammonia to be **12.96 kg/day**:

Table 3-4: Surface Water Assimilative Capacity Assessment

Assimilative capacity = (C_{max} – C_{back}) x F95 x 86.4 kg/day		
Where:	Value	Source
C_{max} = maximum permissible concentration (EQS – 95%ile value) (mg/l)	0.14	95%-ile 'good' status threshold as per S.I No. 77 of 2019 - European Union Environmental Objectives (Surface Waters) (Amendment) Regulations 2019
C_{back} = background upstream concentration (mg/l mean value)	0.035	Assumed background concentration
F95 = the 95%ile flow in the river (m^3/s)	1.429	Obtained from online EPA Hydrotool for river segment adjacent to site.
Assimilative Capacity kg/day	**12.96**	AC (kg/day) = (0.14 - 0.035) x 1.429 x 86 .4

3.7.2 Potential Impacts of Leachate Breakouts on Receiving Surface Waters

To determine potential impacts that leachate surface breakouts from the landfill may have on the assimilative capacity of the receiving water body, the mass of ammonia discharging from the site is calculated applying the equation below.

Mass Emission (kg/day) = Discharge Flow (m^3/day) x Concentration (mg/l) /1000

Assumed criteria:

- *Flow range of assumed leachate breakouts:* 1-5 l/s
- *Concentration of ammonia in leachate:* 26.1 mg/l ammoniacal nitrgoen based on BH01 observations
- *Significant pollution threshold if:* > S.I. No. 77 of 2019 ('Good' status mean 0.065 mg/l) or > S.I. No. 77 of 2019 ('Good' status 95%-ile 0.140 mg/l)

A range of assumed discharge flows (1 - 5 litres/second) was applied and the percentage of the assimilative capacity removed following discharge to the receiving water was also calculated (Daily Mass Emission ÷ Assimilative Capacity).

A discharge ammonia concentration of 26.1mg/l (highest ammonia observation from groundwater BH01) was assumed for this calculation. The calculated mass emissions and the impacts on the assimilative capacity, for a range of assumed discharge rates, of the receiving water are shown in Table 3-6.

3.7.3 Mass Balance Assessment

A mass balance calculation was used to determine the potential change in ammonia concentration within the receiving water downstream of the discharge. The following calculation as shown in Table 3-5 was applied:

Table 3-5: Mass Balance Calculation

T = (FC + fc)/(F + f)		
Where:		*Source*
F is the river flow upstream of the discharge (95%ile flow m^3/sec);	1.429	Obtained from online EPA Hydrotool for river segment adjacent to site.
C is the concentration of pollutant in the river upstream of the discharge (mean concentration in mg/l);	0.035	Assumed background concentration
f is the flow of the discharge (m^3/sec);	0.001 to 0.005	Assumed discharge rate
c is the maximum concentration of pollutant in the discharge (mg/l);	26.1	Maximum concentration of ammoniacal nitrogen detected in BH04
T is the concentration of pollutant downstream of the discharge.	Varies 1-5 l/s	Predicted ammonia concentration in receiving water downstream of discharge
Water Quality Standard (mg/l)	0.140	'Good' Status 95%-ile as per S.I No. 77 of 2019
	0.065	'Good' Status Mean as per S.I No. 77 of 2019

Table 3-6: Potential Impacts of Leachate Breakouts on Assimilative Capacity of Receiving Downstream Waters

Assumed Leachate Breakout Flow (l/s)	Assumed Leachate Breakout Flow (m^3/day)	Daily Mass Emission (kg/day) assuming ammoniacal nitrogen concentration 26.1 mg/l	% Impact Breakout has on of Assimilative Capacity (see Note 3)	Estimated Downstream Concentration ammoniacal nitrogen (mg/l)
1	86	2.26	17%	0.053
2	173	4.51	35%	0.071
3	259	6.77	52%	0.090
4	346	9.02	70%	0.108
5	432	11.27	87%	0.126

Note 1: Water quality standard as per S.I. No. 77 of 2019 ('Good' status 95%-ile 0.140 mg/l)
Note 2: Water quality standard as per S.I. No. 77 of 2019 ('Good' status mean 0.065 mg/l)
Note 3: Assimilative capacity assumed to be 12.96 kg/day ammonia (Table 3-3)

Table 3-6 results show that leachate discharge flow rates of 1, 2, 3, 4 and 5 l/s (86, 173, 259, 346 and 432 m3/day) will be compliant with S.I. No. 77 of 2019 ('Good' status 95%-ile 0.140 mg/l).

Tables 3-4 and 3-5 mass balance calculations predicts that leachate breakouts containing of 26.1 mg/l ammoniacal nitrogen will cause downstream concentrations of ammoniacal nitrogen between 0.053 mg/l to 0.126 mg/l for flow rates between 1 and 5 l/s respectively.

3.7.4 Discussion of Results

Site observations showed the presence of leachate breakouts flows discharging into an open drainage system on site are likely to be less than 5 l/s. The outfall location of the site drainage system could not be determined. It was assumed that the leachate/contaminated surface water runoff discharges discharge ultimately into a storm drainage system and into the adjacent river.

The assimilative capacity assessment shows that the discharge of leachate to the River Feale would only have a significant impact on the assimilative capacity of the river (with respect to ammoniacal nitrogen) at a leachate discharge rates >3 l/s (52% of assimilative capacity consumed).

The mass balance calculation did show that predicted downstream concentrations would remain below the 'Good' status 95%-ile ammonia concentration threshold at all assumed leachate discharge flow rates. Review of EPA surface water monitoring data at Listowel Bridge downstream of the site did show that concentrations are consistently below the 'good' status water quality threshold of 0.140 mg/l with a 2014 baseline concentration 0.031 mg/l and a most recent 2018 concentration of 0.062 mg/l ammoniacal nitrogen.

An upward trend in ammoniacal nitrogen concentrations is observed. Although river quality is good the leachate breakout which may be discharging to the River Feale should be mitigated to eliminate any potential impact, therefore remedial measures will be required to mitigate the risk of leachate breakouts contaminating receiving surface waters.

3.8 Landfill Gas Assessment – LandGEM

LandGEM is an excel based screening model developed by the US EPA for estimating the quantity of landfill gases generated during both the operational phase of a landfill and post-closure of the landfill. The model applies a first-order decomposition rate equation to estimate the quantity of landfill gases being produced from decomposing waste present in a landfill.

The model relies on a limited number of inputs, some of which are supplied within the model as a variety of default values and site-specific information provided by the user. A summary of the model inputs used for this Tier 3 assessment are presented in Table 3-7 below.

The results of this model will aid in informing what, if any, remedial measures or control measures should be put in place to mitigate or monitor that risk.

Monitoring for landfill gases emitted from perimeter groundwater monitoring wells (BH01 and BH02), was conducted in October 2019 as part of the Tier 2 site investigation. Both wells yielded trace quantities of methane at 0.6% and 0.4% respectively and carbon dioxide concentrations of 0.4% and 0.3% respectively.

In accordance with the EPA CoP, the trigger level for methane outside the waste body is 1% v/v and for carbon dioxide is 1.5% v/v. As can be seen from Table 3.7 over, concentrations of both CO_2 and CH_4 at both monitoring boreholes BH01 and BH02 were below the threshold values set by the CoP during both monitoring rounds.

Table 3-7: Well Gas Monitoring Results October 2019

Date: 23/10/2019						
Sample Station	CH_4 (% v/v)	CO_2 (% v/v)	O_2 (% v/v)	Atmospheric Pressure (mbar)	Staff Member	Weather
BH01	0.6	0.4	24.5	1005	Emily Archer	Overcast, heavy rain showers, 10-14°C
BH02	0.4	0.3	23.6			

Although the concentrations are low, the site is located within a town park on the edge of Listowel town where human receptors are present close to the site.

Table 3-8: LandGEM Model Inputs

Landfill Characteristics	Input	Source
Landfill Open Year	1968	Landfill operations commenced in 1968 as referenced in the Tier 1 assessment
Landfill Closure Year	1988	Evidence suggests landfilling activities ceased c.1988
Have Model Closure Calculate Closure Year	Yes	
Waste Design Capacity (megagrams/tonnes)	40,000	Tonnage based on of 1,850 tonnes per annum waste intake (An Foras Forbatha records) over an assumed lifespan of 20 years (37,000 tonnes). Rounded to 40,000 tonnes for purpose of modelling.
Determining Model Parameters		
Methane Generation Rate, k ($year^{-1}$)	CAA Conventional – 0.05	Default value – maximum values applied as a conservative worst-case scenario approach
Potential Methane Generation Capacity, L_0 (m^3/Mg)	CAA Conventional – 1070	
NMOC Concentration (ppmv as hexane)	CAA – 4,000	
Methane Content (% by volume)	CAA – 50% by volume	

Landfill Characteristics	Input	Source
Select Gases/pollutants		
Gas/Pollutant #1	Total Landfill Gas	Standard – No other specific gases of concern
Gas/Pollutant #2	Methane	
Gas/Pollutant #3	Carbon Dioxide	
Gas/Pollutant #4	NMOC	
Enter Waste Acceptance Rates (Mg/year)		
1968 - 1988	2,000	Exact waste acceptance quantities per year are unknown. Worst case assumed waste design capacity was filled equally over 1968 to 1988 (20 year) period

Note: Regarding waste tonnage, geophysical survey provided a waste volume estimate of 98,000 m^3. Assuming a waste density of 1.4 tn/m^3 this equates to estimated 137,200 tonnes (3.43 times modelled 40,000 tonnes deposited).

3.8.1 Results - LandGEM

Modelling landfill gas generation in LandGEM generates a series of graphs illustrating the production rate of each specified pollutant.

As an output, LandGEM produces a report on the model inputs and outputs. This report is included in Appendix 3 of this report. LandGEM estimates the mass and volume of landfill gases generated both during the operational/filling phase of the landfill and beyond. The estimated quantity of gas generated for the current year (2019) and after 10 years of further degradation (2029) are presented in Table 3.9.

Table 3-9: Estimated landfill Gases Generated (2019 and 2029)

Gas/Pollutant	Tonnes/year		m^3/year		tonnes/hour		m^3/hour	
	2019	2029	2019	2029	2019	2029	2019	2029
Total Landfill Gas	114.2	69.28	91,460	55,470	0.014	0.009	10.44	6.33
Methane	30.51	18.50	45,730	27,740	0.004	0.002	5.22	3.17
Carbon dioxide	83.71	50.77	45,730	27,740	0.01	0.006	5.22	3.17
NMOC	1.31	0.8	365.8	221.9	0.000	0.000	0.04	0.02

The approximate maximum waste deposition footprint was estimated to be approximately 8,900 m^2. The estimated volume and mass of landfill gas generated in 2019 and potentially released per m^2 of the total landfill area are presented in Table 3-10 over.

Table 3-10: Estimated gases generated/released per m^2 (2019)

Gas/Pollutant	Tonnes/year/m^2	m^3/year/m^2	tonnes/hour/m^2	m^3/hour/m^2
Total Landfill Gas	0.012	10.28	0.000	0.001
Methane	0.003	5.14	0.000	0.001
Carbon dioxide	0.009	5.14	0.000	0.001
NMOC	0.0001	0.04	0.000	0.000

3.8.2 Discussion of Results

The outcome of the LandGEM model predicts a low rate of landfill gas generation in 2019 of 91,460 m^3/year (10.44 m^3/hr). If the higher estimate of 137,200 tonne (6,860 tonnes/year) were applied this would equate to 35.8 m^3/hr.

The EPA guidance document, 'Management of Low Levels of Landfill Gas' prepared by Golder Associates Ireland Ltd outlines readily available flaring technologies that meet EPA requirements on temperature and retention specifications. These technologies generally require gas flow rates ranging from 40 m^3/hr to greater than 2,500 m^3/hr with methane contents ranging from 10 to 50 percent. The lowest methane content referring to Low-CV (Calorific value) flare technology.

As shown in Table 3.9, LandGEM estimated that in the current year (2019) a relatively low quantity, 91,460 m^3/year (10.44 m^3/hr) of landfill gas across the whole site is generated and assuming 50% percent of that flow rate being methane (5.22 m^3/hr). Landfill gas monitoring of groundwater wells conducted in 2019 yielded only trace amounts of methane. The LandGEM model suggests that at the estimated quantity of waste deposited at the site that methane production is still occurring in low quantities and will continue for a number of years.

Figure 3-2 below shows the estimated landfill gas generation rates per year during the assumed operational phase (c.1968 to 1988) and predicted generation rates from 1988 onwards following closure of the site. Note that the model assumes equal production rates for both methane and carbon dioxide and are represented by the pink trendline because the blue line is below the pink line.

If groundwater tables in the waste body are lowered to reduce groundwater contamination, gas production may increase.

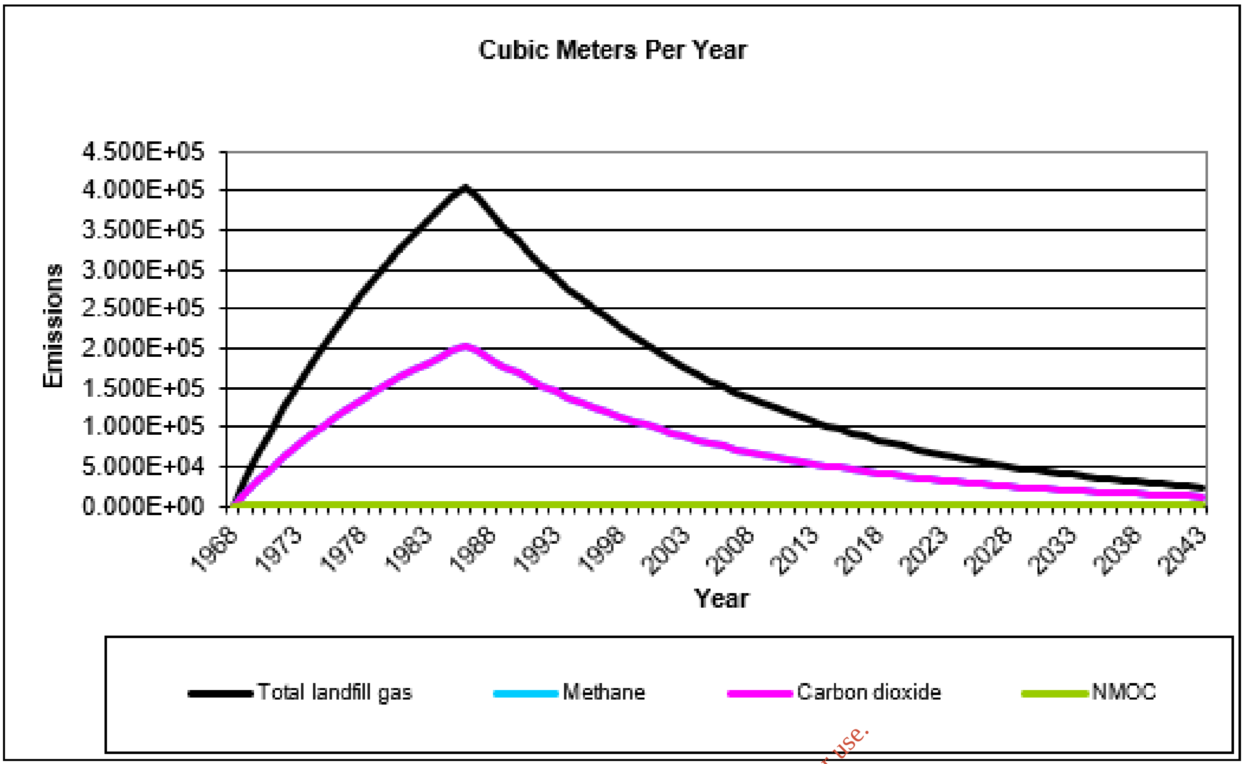


Figure 3-2: LandGEM Landfill Gas Volume Generation Rate

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary Findings

This Tier 3 assessment:

- Reviewed the findings of the Tier 1 risk assessment (determined the site to be of Moderate risk (highest score 44%).).
- Reviewed the findings of the Tier 2 site investigation and risk assessment (determined the site to be Moderate risk (highest score 50%)).
- Assessed and determined the overall risk the site may pose to the receiving environment.
- Determined appropriate measures to mitigate or eliminate that risk.

The Tier 2 risk assessment determined that stormwater runoff drainage outfalls intercepting leachate may discharge untreated leachate to the River Feale presenting a potential risk to surface water quality.

Intrusive site investigations showed that the site comprises a cap typically 1.0 m thick albeit that investigation logs show evidence of C&D materials present in the cap.

The classification of the underlying groundwater aquifer as 'Regionally Important' in the northern section of the site indicates that the underlying aquifer should be protected.

The River Feale is also part of the Lower Shannon SAC.

4.1.1 Groundwater

The UK EA Remedial Targets Worksheet model was used to examine the potential impacts on aquifer/groundwater quality. This model demonstrated that leachate generated at the landfill site has the potential to have a negative impact on groundwater quality downstream of the site. Ammoniacal nitrogen, chloride and manganese downstream concentrations were estimated using this model and it was shown that for all parameters, groundwater concentrations were above groundwater quality thresholds (at 21.1 mg/l, 173 mg/l and 1.06 mg/l respectively) at the designated compliance point, in this case the edge of the River Feale SAC.

4.1.2 Surface Water

Whilst leachate breakouts from the landfill were observed to enter County Council site's surface drains and potentially discharge to receiving surface waters no evidence of contamination in the River Feale was observed.

An assimilative capacity assessment and mass balance calculations on the River Feale indicates that potential discharge of leachate breakouts may increase the concentration of nutrients such as ammoniacal nitrogen within the River, downstream of the site. However, it was demonstrated that at high leachate discharge rates (5 l/s) downstream concentrations will remain below the 'Good' status 95%-ile threshold value, but above the 'Good' mean threshold value at discharge rates >1 l/s. This assessment does assume worst-case scenario (low river flow) conditions and EPA monitoring of the River Feale downstream of the site has shown total ammonia concentrations to be within the 'good' status threshold values.

4.1.3 Landfill Gas

The output from LandGEM indicates that landfill gas will continue to be generated for several years although in minimal quantities. If an upper estimated waste quantity of 137,200 tonnes were applied landfill gas generation would increase but Is still considered to be a low generation rate. Although the risk from landfill gas is relatively low, the concentrations of gas detected during the monitoring process, and the indication that gas will continue to be produced, it is recommended that landfill gas control measures should be installed at the site and in adjacent County Council buildings to monitor for evidence of landfill gas migration. All wells installed on the site should be allowed to vent passively to atmosphere to mitigate the risk of landfill gas migration.

Following installation of the proposed remediation measures the gas monitoring results should be reviewed monthly and following a period of 12 months (post installation of all remediation works) the gas management testing program and oxidation philosophy should be reviewed. Whilst available evidence does not warrant pump tests at the moment, in the event that gas production increases the need or other for a gas pump test may need to be re-considered.

Appropriate control measures shall be selected in accordance with the EPA Guidance document: *Management of Low Levels of Landfill Gas.* These appropriate control measures are further discussed in Section 5 below.

4.2 Recommendations

The primary objectives of the proposed remedial capping works will be to mitigate:

- The risk of leachate contaminating ground and surface waters.
- Mitigate the risk of landfill gas impacting nearby receptors via lateral migration.

Further details regarding the proposed landfill cap are discussed in Section 5 below.

5. REMEDIAL ACTION PLAN

5.1 Overview of the Risks

5.1.1 Tier 3 Summary Findings

The existing site has an established amenity grass/vegetative cover and is used by the public as a park. Site walkovers and Tier 2 and 3 risk assessments showed:

- An in-situ landfill cap that is compliant with regards to cap thickness with the Landfill Directive and Environmental Protection Agency (EPA) publication landfill manual - Landfill Site Design.
- Evidence of:
  - In-situ MSW
  - Low-level landfill gas emissions.
- Evidence that leachate has potential to contaminate receiving surface and groundwaters.
- Proximity to buildings and adjacent permeable road formations presents a risk of landfill gas migration.

Please refer to Appendix 4 for Remediation Plan Drawing P1766-0102l-0001. Based on the findings of the modelling exercises and quantitative risk assessment there are a number of measures proposed to mitigate the identified risks to groundwater, surface water and from landfill gas migration.

The existing site has a basic soil cap with an established amenity park grass cover used by the public.

5.1.2 Primary Risks

The primary environmental risks are:

- Leachate contamination of surface and groundwaters.
- Landfill gas migration.

Measures are required to:

- Monitor and ensure appropriate operating protocols are in place to support management of landfill gas
- Intercept and remove leachate arisings currently discharging over and through the surface of the adjacent County Council yard.

Whilst the Tier 3 Risk assessment shows evidence that groundwater flows through the base of the historic waste body have potential to contaminate downstream surface and groundwaters and consideration should therefore be given to managing the groundwater, measures to lower, contain and or otherwise treat groundwater table below the site are not recommended for the following reasons:

- Lowering groundwater within the waste may increase landfill gas production. Following removal of saturated conditions anaerobic breakdown of organic matter as may be present may result in increased landfill gas production.
- The site was developed as a dilute and disperse landfill and has been operating as such for decades. Retrospective groundwater management actions may not improve groundwater quality owing to extensive flushing having taken place in the intervening years and such actions may also have unforeseen environmental consequences if water flows are directed elsewhere.

5.2 Remediation Plan

5.2.1 Proposed Engineering Solution

The proposed remediation plan to address these risks shall:

- Require landfill gas management infrastructure
- Infrastructure to monitor and remove leachate from the site
- Establishment of routine environmental measures

The preliminary remediation design is presented in Appendix 4 on drawing:

- P1766-0102-0001

5.2.2 Landfill Gas Management

The current (LandGEM) estimated landfill gas generation rate is extremely low and onsite monitoring has not measured gas concentration nearing emissions limit values. Although the calculated SPR risk scores were determined to be low and below the threshold values set out by the EPA CoP, the presence of landfill gas requires remediation due to the location and every-day use of the site. The site is a public town park adjacent to:

- Permeable road and service infrastructure.
- County Council offices.

Future developments on the site may also require development of below ground infrastructure (which would be designated as a confined space) and buildings (which would need continuous gas monitoring).

Landfill gas related management will therefore be required to eliminate the potential impacts of landfill gas causing harm to human receptors.

Landfill gas migration under the prevailing conditions is unlikely to be a problem as there is a well-drained vegetated cap and such landfill gas as maybe present gas will most likely vent to atmosphere or be oxidized by the parks cover materials.

Landfill gas production may however increase if leachate elevations in the landfill were to be lowered.

The recommended landfill gas remedial solution is to support passive venting of landfill gas and to develop landfill gas management working protocols to protect personnel and to ensure that landfill gas migration does not occur.

It is recommended that KCC develops a gas management plan. This will require:

- Landfill gas risk assessments and method statements addressing public access and park related activities.
- Deep passive venting multipurpose wells that can be used for regular monitoring of landfill gas within the waste body (and extracting leachate if required).
- A network of shallow passive perimeter wells at 50m centres to be monitored regularly.
- An ATEX review of site equipment and operations.
- Reviews and updates as required to standard operating procedures to ensure that the risks associated with operating in confined spaces and in areas where landfill gas may be present are fully documented.
- Installation of continuous gas monitoring equipment in current County Council (or future) buildings on and immediately adjacent to the site.

Development of the gas management plan will require evidence of landfill gas concentrations under a range of atmospheric conditions. Following installation of the proposed boreholes and perimeter wells, it is recommended that KCC monitor wells weekly for a period of 12 months under a range of atmospheric conditions.

Following a review of gas observations over a period not less than 12 months, the landfill gas risk assessments and summary recommendation should be reviewed and updated as required.

It is recommended that KCC develops landfill gas risk assessments with reference to the following CIRA publications:

- R149 Protecting Development from Methane.
- R151 Interpreting Measurements of Gas in the Ground.
- R152 Risk Assessments for Methane and Other Gases from the Ground.
- C735 Good Practice on the Testing and Verification of Protection Systems for Buildings Against Hazardous Ground Gases.

5.2.3 Leachate Management Infrastructure

The SPR linkages advise the risk of leachate contaminating surface and groundwater is moderate. The Remedial Targets Worksheet showed there will be on-going groundwater quality exceedances associated with ammoniacal nitrogen, chloride and manganese and there was visual evidence of overland flows of leachate discharging over ground from the toe of the landfill/park side slopes on the southern park boundary into the Council depot surface drainage system and thereafter possibly entering the River Feale immediately south of the landfill footprint.

At the entrance to the park a pump house exists that was used in the past to pump water to a water treatment plant. In the event that this station is recommissioned in the future to pump surface water, KCC will need to carry out risk assessments to evaluate the potential impacts of pumped water being contaminated by leachate within 25 m of this pump station.

Remediation measures will also be required to mitigate the risk of leachate breakouts and contaminated shallow groundwater impacting receiving ground or surface waters.

The proposed remediation measures are:

- To construct a vertical cutoff (gravity) interceptor drain with storage as may be required on the southern boundary of the park within the council yard.
- Discharge leachate as may be collected in the interceptor drain to a licensed waste water treatment facility.
- Install vertical leachate wells within the Park to monitor leachate elevations within the park. If leachate elevations within the waste are ever lowered, design risk assessment will need to consider the implications on gas production.

Layout locations of the proposed remediation design proposals are presented on Drawing P1766-0102-001.

5.3 Proposed Monitoring

5.3.1 Surface Water, Groundwater and Leachate Monitoring

The EPA Landfill Monitoring landfill manual outlines recommended, minimum monitoring requirements for surface water, groundwater and leachate. These parameters are shown in Table 5-1 below and are as presented in Table C.2 of the EPA's *Landfill Manuals - Landfill Monitoring, 2nd Edition (2003).*

Table 5-1: Parameters for Monitoring of Groundwater, Surface Water and Leachate

Monitoring Parameter[3] See Footnote	Frequency*	Surface Water	Groundwater	Leachate
Level	Monthly+	-	✓	✓
Flow Rate		-	-	✓
Temperature		✓	✓	✓
Dissolved Oxygen		✓	-	-
pH		✓	✓	✓
Electrical Conductivity[4]		✓	✓	✓
Total suspended solids		✓	-	-
Total dissolved solids		-	✓	
Ammonia (as N)		✓	✓	✓
Total oxidized nitrogen (as N)		✓	✓	✓
Total organic carbon		-	✓	-
Biochemical Oxygen Demand		✓	-	✓
Chemical Oxygen Demand		✓	-	-
Metals[5]		✓	✓	✓
Total Alkalinity (as $CaCO_3$)		✓	✓	-
Sulphate		✓	✓	✓
Chloride		✓	✓	✓
Molybdate Reactive Phosphorous[6]		✓	✓	✓
Cyanide (Total)		✓	✓	✓
Fluoride		✓	✓	✓

[3] Tables D.1 and D.2 of the EPA Landfill Monitoring manual recommend guideline minimum reporting values for parameters

[4] Where saline influences are suspected, a salinity measurement should also be taken

[5] Metals for analysis should include: calcium, magnesium, sodium, potassium, iron, manganese, cadmium, chromium (total), copper, nickel, lead, zinc, arsenic, boron and mercury.

[6] Total Phosphorus should be measured in leachate samples where colorimetric interference is likely.

Monitoring Parameter[3] See Footnote	Frequency*	Surface Water	Groundwater	Leachate
Trace organic substances[7]	Annually	✓	✓	✓
Faecal and Total Coliforms[8]		-	✓	-
Biological assessment	-	-	-	-

*Note: Parameters proposed should initially be monitored monthly for a duration of 12-months to establish baseline conditions.

The proposed well locations and monitoring works shall be cognisant of the site use.

5.3.1.1 Groundwater Monitoring Locations

Groundwater samples shall be taken from existing groundwater monitoring boreholes BH01 and BH02, and proposed groundwater pumping wells BH03, BH04 and BH05.

The suite of tests required for groundwater monitoring shall be as per Table 5-1:

5.3.1.2 Leachate Monitoring Locations

It is proposed that KCC extract leachate from groundwater wells and discharge it to the proposed leachate balance/storage tank on site.

Leachate levels and quality shall be monitored as per Table 5-1.

Control of drawdown levels and associated control systems shall be subject to detailed design.

5.3.1.3 Surface Water Monitoring Location

It is proposed that surface water monitoring be conducted at or immediately downstream of the redundant pump station in the River Feale adjacent to the park entrance.

[7] Table D.2 of the EPA Landfill Monitoring manual recommends trace organic substances that should be included in the determination. Surface water should be analysed for the pesticide sand solvents listed in the Water Quality (dangerous Substances) Regulations (S.I No. 12 of 2001).

[8] Required for drinking water supplies within 500m of the landfill.

5.3.2 Proposed Gas Monitoring Regime

5.3.2.1 Site Gas Monitoring

It is recommended that:

- KCC develop a gas management plan to mitigate the risk of off-site landfill gas migration and to determine need or other to vent and or oxidise such landfill gas as may be present.
- Perimeter gas monitoring boreholes be installed at distances not exceeding 50 m round the park perimeter.
- Gas monitoring be carried out at boreholes holes BH01 through BH05 and at all proposed perimeter wells and at any future oxidation or venting outlet monthly following installation for a period of 12 months after which time the gas management plan should be updated.
- Prior to monitoring, well vents should be closed for a period of at least 24 hours to allow representative sampling. During the first 12 months of monitoring all gas wells valves should be sealed.
- Vertical gas monitoring well vent locations be mounted not less than 4 m above ground level and capped to prevent ingress of cigarettes or other ignition sources.

Gas sampling should be carried out during the first 12 months weekly using a calibrated gas analyser for the following parameters:

- Methane.
- Carbon dioxide.
- Oxygen.
- Carbon monoxide.
- Temperature.

5.3.2.2 Building Gas Monitoring

It is recommended that continuous landfill gas monitors are installed in the County Council buildings located adjacent to the site.

5.3.2.3 Methane Oxidation

Following a review of gas productivity over a range of atmospheric conditions at the end of 12 months it is recommended that:

- A review for the need or other for a gas pump test be reviewed in light of more detailed information, ;
- A review of the need or other for oxidation of landfill gas as may be present to be carried out
- If oxidation is required selection of the most appropriate oxidation methodology.
- A review of the need or other to passively vent from existing or proposed (deep) vertical wells.

5.4 Remediation Cost Estimate

Table 5-2 outlines the potential costs associated with the remediation of the site. The costs estimate is limited to “once-off” civil and mechanical and electrical works.

Long term costs associated with maintenance, license compliance and environmental liabilities are not considered.

Table 5-2: Engineers Cost Estimate

Item	Quantity	Unit	Rate, €	Cost
Design				
Allowance for Additional Site Investigation works	0	Rate	€25,000	€0
Detailed Design and Supervision	1	Rate	€40,000	€40,000
12 months monitoring	1	Rate	€20,000	€20,000
General Site Clearance and Demolition Works	***0.1***	***ha***		
General Site Clearance	0.1	ha	€20,000	€2,000
Safety	1	Rate	€20,000	€20,000
Leachate Interception Trench (Southern Boundary)				
Excavation of Existing Waste Materials	300	m^3	€4	€1,200
Disposal of Waste Offsite	480	tonnes	€50	€24,000
Lining of Interception Trench	1200	m^2	€15	€18,000
Backfill with 16-23mm Rounded Washed Drainage Stone	300	m^3	€15	€4,500
225mm Slotted SDR 17 Drainage Pipe	100	m	€40	€4,000
Leachate Collection Sump	1	Sum	€2,500	€2,500
Intermediate Inspection Chambers	3	No.	€1,500	€4,500
Mechanical and Electrical	1	Sum	€15,000	€15,000
Wells				
Mobilisation		Sum	€3,500	€0
Groundwater Well ex. M&E, inc. piping and backfill	3	No.	€50	€150
Landfill Gas Well ex. M&E, inc. piping and backfill	14	No.	€2,500	€35,000
Well Heads	17	No.	€1,000	€17,000
Supporting Infrastructure	17	Sum	€2,000	€34,000
Design, Supervision and Interpretation	1	Sum	€15,000	€15,000
Biological filters	3.0	No.	€10,000	€30,000

Item	Quantity	Unit	Rate, €	Cost
Leachate Management Infrastructure				
Leachate Storage Tank/rising main	1	Sum	€100,000	€100,000
Leachate Handling Yard	1	Sum	€75,000	€75,000
Mechanical and Electrical				
Continuous Emissions Monitor Control Panel	1	No.	€2,200	€2,200
Methane Detection Unit	10	No.	€230	€2,300
Carbon Dioxide Detection Unit	10	No.	€730	€7,300
Audio Visual Alarm Mounted	10	No.	€70	€700
Installation	1	Sum	€5,000	€5,000
Commissioning and Testing	1	Sum	€1,500	€1,500
Sub-Total 1				**€480,850**
Add 10% Contractor Prelims	10.0%			€48,085
Sub-Total 2				**€528,935**
Add 7.5% Contingency	7.5%			€39,670
Grand Total (excl VAT)				**€568,605**

FT in making this Engineers Estimate advises the following:

- FT used rates over the period 2018 to 2019 for similar tendered works items where possible and has used engineering judgement to estimate rates & sums where similar rates were not available.
- Management of hazardous materials was not allowed for.
- Pricing was based on a concept design, no detailed designs were prepared.
- The cost estimate assumes that materials to be imported are readily available from local sources.
- The cost estimate excludes VAT.
- The cost estimate excludes in/deflation.
- The estimate includes for a level of contingency as indicated.
- Excludes landfill gas pump trial.

Prices may change subject to prevailing market conditions.

FEHILY TIMONEY
30 YEARS

CONSULTANTS IN ENGINEERING, ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX 1

EA UK Remedial Targets Worksheet

R&D Publication 20 Remedial Targets Worksheet, Release 3.2

Environment Agency

Level 3 - Groundwater

See Note

Input Parameters (using pull down menu)

	Variable	Value	Unit	Source
Contaminant		Manganese		from Level 1
Target Concentration	C_T	5.00E-02	mg/l	from Level 1

Select analytical solution (click on brown cell below, then on pull-down menu)

Domenico - Steady state — Equations in HRA publication

Approach for simulating vertical dispersion: Simulate vertical dispersion in 1 direction

Select nature of decay rate (click on brown cell below, then on pull-down menu)

Approach for simulating degradation of pollutants: Apply degradation rate to pollutants in all phases (e.g. field derived valu

	Variable	Value	Unit	Source of parameter value
Initial contaminant concentration in groundwater at plume core	C_0	1.31E+00	mg/l	
Half life for degradation of contaminant in water	$t_{1/2}$	1.00E+99	days	*Assumed high value (no degradation)*
Calculated decay rate	λ	6.93E-100	$days^{-1}$	
Width of plume in aquifer at source (perpendicular to flow)	Sz	7.00E+01	m	*Approximate width of site/ waste extent based on SI*
Plume thickness at source	Sy	1.10E+01	m	*Assumed thickness from Geophysics*
Saturated aquifer thickness	da	1.00E+01	m	
Bulk density of aquifer materials	ρ	1.55E+00	g/cm^3	*Assumed limestone density*
Effective porosity of aquifer	n	2.75E-01	fraction	
Hydraulic gradient	i	1.79E-02	fraction	
Hydraulic conductivity of aquifer	K	8.64E+00	m/d	
Distance to compliance point	x	1.50E+02	m	
Distance (lateral) to compliance point perpendicular to flow direction	z		m	
Distance (depth) to compliance point perpendicular to flow direction	y		m	
Time since pollutant entered groundwater	t	3.65E+05	days	*time variant options only*

Parameters values determined from options

	Variable	Value	Unit	Source
Partition coefficient	Kd	0.00E+00	l/kg	*see options*
Longitudinal dispersivity	ax	1.50E+01	m	*see options*
Transverse dispersivity	az	1.50E+00	m	*see options*
Vertical dispersivity	ay	1.50E-01	m	*see options*

Dispersed plume thickness exceeds aquifer thickness! Reduce vertical dispersivity

Calculated Parameters

	Variable	Value	Unit
Groundwater flow velocity	v	5.62E-01	m/d
Retardation factor	Rf	1.00E+00	fraction
Decay rate used	λ	6.93E-100	d^{-1}
Rate of contaminant flow due to retardation	u	5.62E-01	m/d
Contaminant concentration at distance x, assuming one-way vertical dispersion	C_{ED}	1.06E+00	mg/l
Attenuation factor (one way vertical dispersion, CO/CED)	**AF**	**1.23E+00**	

Remedial Targets

Remedial Target	**6.17E-02**	**mg/l**	For comparison with measured groundwater concentration.
Domenico - Steady state			
Distance to compliance point	**150**	**m**	
Concentration of contaminant at compliance point C_{ED}/C_0	**1.06E+00**	**mg/l**	Domenico - Steady state

Care should be used when calculating remedial targets using the time variant options as this may result in an overestimate of the remedial target.
The recommended value for time when calculating the remedial target is 9.9E+99.

Select Method for deriving Partition Co-efficient (using pull down menu)

User specified value for partition coefficient

Entry if specify partition coefficient (option)

Soil water partition coefficient	Kd	0.00E+00	l/kg

Entry for non-polar organic chemicals (option)

Fraction of organic carbon in aquifer	foc		fraction
Organic carbon partition coefficient	Koc		l/kg

Entry for ionic organic chemicals (option)

Sorption coefficient for related species	$K_{oc,n}$		l/kg
Sorption coefficient for ionised species	$K_{oc,i}$		l/kg
pH value	pH		
acid dissociation constant	pKa		
Fraction of organic carbon in aquifer	foc		fraction
Soil water partition coefficient	Kd	0.00E+00	l/kg

Define dispersivity (click brown cell and use pull down list)

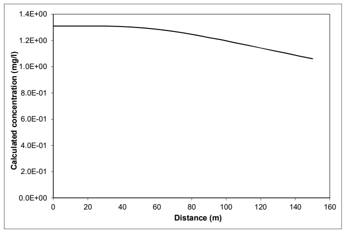
Dispersivities 10%, 1%, 0.1% of pathway length

		Enter value	Calc value	Xu & Eckstein	m
Longitudinal dispersivity	**ax**	5.00E+00	1.50E+01	5.42E+00	m
Transverse dispersivity	**az**	4.00E+01	1.50E+00	5.42E-01	m
Vertical dispersivity	**ay**	9.50E+01	1.50E-01	5.42E-02	

Note values of dispersivity must be > 0

For calculated value, assumes ax = 0.1 *x, az = 0.01 * x, ay = 0.001 * x

Xu & Eckstein (1995) report $ax = 0.83(\log_{10}x)^{2.414}$; az = ax/10, ay = ax/100 are assumed



Note graph assumes plume disperses vertically in one direction only. An alternative solution assuming the centre of the plume is located at the mid-depth of the aquifer is presented in the calculation sheets.

Note

This sheet calculates the Level 3 remedial target for groundwater, based on the distance to the receptor or compliance located down hydraulic gradient of the source. Three solution methods are included, the preferred option is Ogata Banks.

By setting a long travel time it will give the steady state solution, which should be used to calculate remedial targets.

The measured groundwater concentration should be compared with the Level 3 remedial target to determine the need for further action.

Note if contaminant is not subject to first order degradation, then set half life as 9.0E+99.

This worksheet should be used if pollutant transport and degradation is best described by a first order reaction. If degradation is best desribed by an electron limited degradation such as oxidation by O2, NO3, SO4 etc than an alternative solution should be used

Site being assessed:	Listowel
Completed by:	EA
Date:	########
Version:	1

Calculated concentrations for distance-concentration graph

Domenico - Steady state
From calculation sheet

Distance	**Concentration**
	mg/l
0	**1.3E+00**
7.5	**1.31E+00**
15.0	**1.31E+00**
22.5	**1.31E+00**
30.0	**1.31E+00**
37.5	**1.31E+00**
45.0	**1.30E+00**
52.5	**1.30E+00**
60.0	**1.29E+00**
67.5	**1.27E+00**
75.0	**1.26E+00**
82.5	**1.24E+00**
90.0	**1.22E+00**
97.5	**1.20E+00**
105.0	**1.18E+00**
112.5	**1.16E+00**
120.0	**1.14E+00**
127.5	**1.12E+00**
135.0	**1.10E+00**
142.5	**1.08E+00**
150.0	**1.06E+00**

FEHILY TIMONEY 30 YEARS

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APPENDIX 2

Surface Water Assimilative Capacity Assessment

Listowel

Assimilative capacity = (Cmax – Cback) x F95 x 86.4 kg/day — **Ammonia**

Where:

C_{max} = maximum permissible concentration (EQS – 95%ile value) (mg/l)	0.14
C_{back} = background upstream concentration (mg/l mean value)	0.035
F95 = the 95%ile flow in the river (m^3/s)	1.429

Note: (60x60x24)/1000 = 86.4

AC kg/d	=	**(Cmax**	**-**	**Cbak)**	**x**	**F95**	**x**	**86.4**
	=	0.14	-	0.035	x	1.429	x	86.4
	=		0.105		x	1.429	x	86.4
AC kg/d	=	**12.96 kg/day**						

Emission Concentration (mg/l) 26.1

Flow (m3/day)	Daily Mass Emission (kg/day)	%-age of AC
86.4	2.255	17%
172.8	4.510	35%
259.2	6.765	52%
345.6	9.020	70%
432	11.275	87%

Mass balance Equation:

$$T = \frac{FC + fc}{F + f}$$

$$f(m^3/sec) = \frac{f\left(\frac{m^3}{day}\right) \div 24hours}{3600\ seconds}$$

F =	1.429	m^3/sec
C =	0.035	mg/l
f =	86.4	m^3/day
	0.005	m^3/sec
c =	26.100	mg/l

where:

- F is the river flow upstream of the discharge (95%ile flow m^3/sec);
- C is the concentration of pollutant in the river upstream of the discharge (mean concentration in mg/l);
- f is the flow of the discharge (m^3/sec);
- c is the maximum concentration of pollutant in the discharge (mg/l)
- T is the concentration of pollutant downstream of the discharge.

T = $\frac{F \times C + f \times c}{F + f}$

1 $\frac{1.429 \times 0.035 + 0.005 \times 26.100}{1.429 + 0.005}$

2 $\frac{0.050015 + 0.131}{1.4340}$

3 $\frac{0.181}{1.434}$

4 **T = 0.126 mg/l** — 0.14 *95%-ile EQS*

FEHILY TIMONEY

30 YEARS

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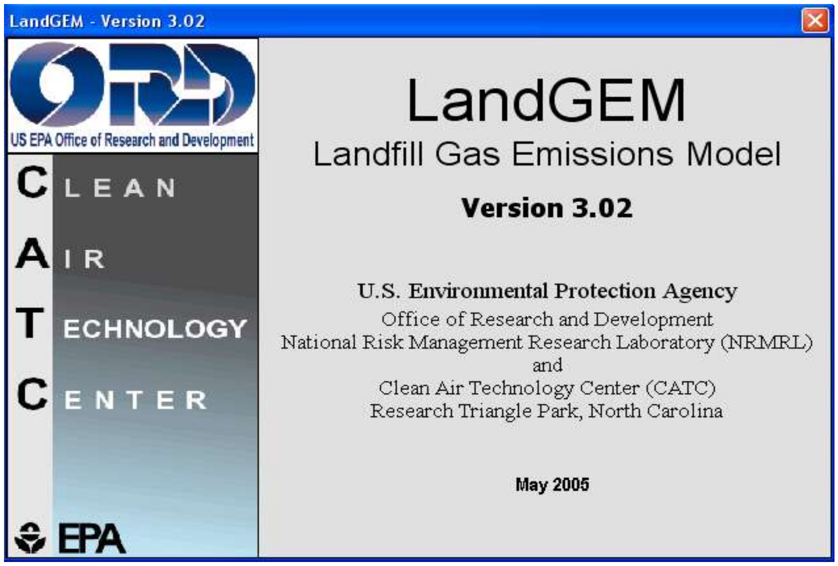
ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX 3

LandGEM Model Summary Report



Summary Report

Landfill Name or Identifier:

Date: Monday 13 July 2020

Description/Comments:

About LandGEM:

First-Order Decomposition Rate Equation:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_o \left(\frac{M_i}{10} \right) e^{-k t_{ij}}$$

Where,

Q_{CH4} = annual methane generation in the year of the calculation *(m^3/year)*

i = 1-year time increment

n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1-year time increment

k = methane generation rate (*$year^{-1}$*)

L_o = potential methane generation capacity (*m^3/Mg*)

M_i = mass of waste accepted in the i^{th} year (*Mg*)

t_{ij} = age of the j^{th} section of waste mass M_i accepted in the i^{th} year (*decimal years*, e.g., 3.2 years)

LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste (MSW) landfills. The software provides a relatively simple approach to estimating landfill gas emissions. Model defaults are based on empirical data from U.S. landfills. Field test data can also be used in place of model defaults when available. Further guidance on EPA test methods, Clean Air Act (CAA) regulations, and other guidance regarding landfill gas emissions and control technology requirements can be found at http://www.epa.gov/ttnatw01/landfill/landflpg.html.

LandGEM is considered a screening tool — the better the input data, the better the estimates. Often, there are limitations with the available data regarding waste quantity and composition, variation in design and operating practices over time, and changes occurring over time that impact the emissions potential. Changes to landfill operation, such as operating under wet conditions through leachate recirculation or other liquid additions, will result in generating more gas at a faster rate. Defaults for estimating emissions for this type of operation are being developed to include in LandGEM along with defaults for convential landfills (no leachate or liquid additions) for developing emission inventories and determining CAA applicability. Refer to the Web site identified above for future updates.

Input Review

LANDFILL CHARACTERISTICS

Landfill Open Year	**1968**	
Landfill Closure Year (with 80-year limit)	**1987**	
Actual Closure Year (without limit)	***1987***	
Have Model Calculate Closure Year?	**Yes**	
Waste Design Capacity	**40,000**	*megagrams*

MODEL PARAMETERS

Methane Generation Rate, k	**0.050**	*$year^{-1}$*
Potential Methane Generation Capacity, L_o	**170**	*m^3/Mg*
NMOC Concentration	**4,000**	*ppmv as hexane*
Methane Content	**50**	*% by volume*

GASES / POLLUTANTS SELECTED

Gas / Pollutant #1:	**Total landfill gas**
Gas / Pollutant #2:	**Methane**
Gas / Pollutant #3:	**Carbon dioxide**
Gas / Pollutant #4:	**NMOC**

WASTE ACCEPTANCE RATES

Year	Waste Accepted		Waste-In-Place	
	(Mg/year)	*(short tons/year)*	*(Mg)*	*(short tons)*
1968	2,000	2,200	0	0
1969	2,000	2,200	2,000	2,200
1970	2,000	2,200	4,000	4,400
1971	2,000	2,200	6,000	6,600
1972	2,000	2,200	8,000	8,800
1973	2,000	2,200	10,000	11,000
1974	2,000	2,200	12,000	13,200
1975	2,000	2,200	14,000	15,400
1976	2,000	2,200	16,000	17,600
1977	2,000	2,200	18,000	19,800
1978	2,000	2,200	20,000	22,000
1979	2,000	2,200	22,000	24,200
1980	2,000	2,200	24,000	26,400
1981	2,000	2,200	26,000	28,600
1982	2,000	2,200	28,000	30,800
1983	2,000	2,200	30,000	33,000
1984	2,000	2,200	32,000	35,200
1985	2,000	2,200	34,000	37,400
1986	2,000	2,200	36,000	39,600
1987	2,000	2,200	38,000	41,800
1988	0	0	40,000	44,000
1989	0	0	40,000	44,000
1990	0	0	40,000	44,000
1991	0	0	40,000	44,000
1992	0	0	40,000	44,000
1993	0	0	40,000	44,000
1994	0	0	40,000	44,000
1995	0	0	40,000	44,000
1996	0	0	40,000	44,000
1997	0	0	40,000	44,000
1998	0	0	40,000	44,000
1999	0	0	40,000	44,000
2000	0	0	40,000	44,000
2001	0	0	40,000	44,000
2002	0	0	40,000	44,000
2003	0	0	40,000	44,000
2004	0	0	40,000	44,000
2005	0	0	40,000	44,000
2006	0	0	40,000	44,000
2007	0	0	40,000	44,000

WASTE ACCEPTANCE RATES (Continued)

Year	Waste Accepted		Waste-In-Place	
	(Mg/year)	*(short tons/year)*	*(Mg)*	*(short tons)*
2008	0	0	40,000	44,000
2009	0	0	40,000	44,000
2010	0	0	40,000	44,000
2011	0	0	40,000	44,000
2012	0	0	40,000	44,000
2013	0	0	40,000	44,000
2014	0	0	40,000	44,000
2015	0	0	40,000	44,000
2016	0	0	40,000	44,000
2017	0	0	40,000	44,000
2018	0	0	40,000	44,000
2019	0	0	40,000	44,000
2020	0	0	40,000	44,000
2021	0	0	40,000	44,000
2022	0	0	40,000	44,000
2023	0	0	40,000	44,000
2024	0	0	40,000	44,000
2025	0	0	40,000	44,000
2026	0	0	40,000	44,000
2027	0	0	40,000	44,000
2028	0	0	40,000	44,000
2029	0	0	40,000	44,000
2030	0	0	40,000	44,000
2031	0	0	40,000	44,000
2032	0	0	40,000	44,000
2033	0	0	40,000	44,000
2034	0	0	40,000	44,000
2035	0	0	40,000	44,000
2036	0	0	40,000	44,000
2037	0	0	40,000	44,000
2038	0	0	40,000	44,000
2039	0	0	40,000	44,000
2040	0	0	40,000	44,000
2041	0	0	40,000	44,000
2042	0	0	40,000	44,000
2043	0	0	40,000	44,000
2044	0	0	40,000	44,000
2045	0	0	40,000	44,000
2046	0	0	40,000	44,000
2047	0	0	40,000	44,000

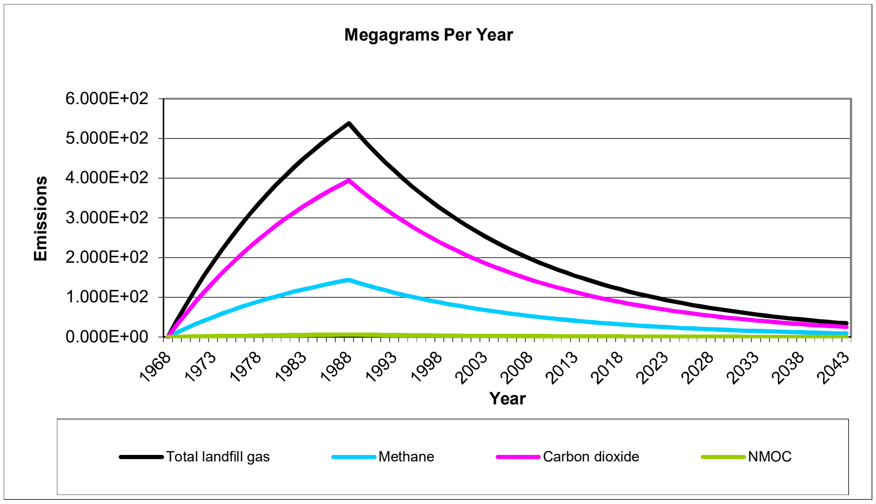
Pollutant Parameters

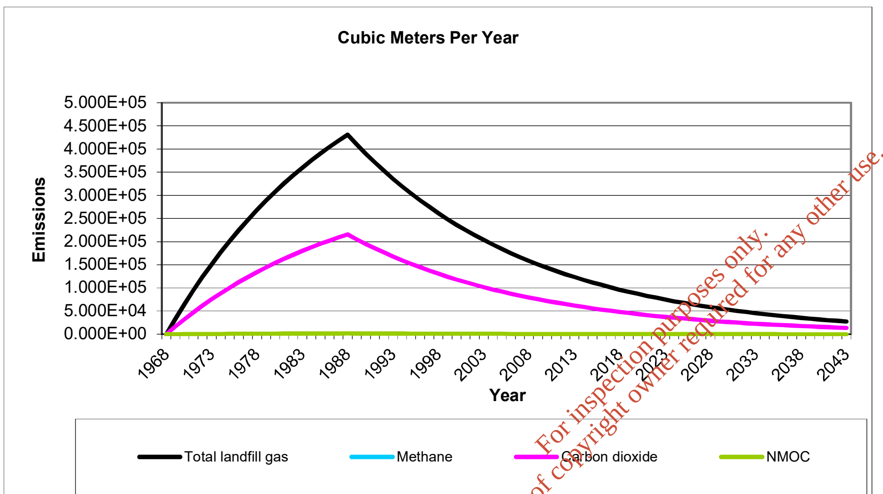
	Compound	Gas / Pollutant Default Parameters: Concentration (*ppmv*)	Molecular Weight	User-specified Pollutant Parameters: Concentration (*ppmv*)	Molecular Weight
Gases	Total landfill gas		0.00		
	Methane		16.04		
	Carbon dioxide		44.01		
	NMOC	4,000	86.18		
Pollutants	1,1,1-Trichloroethane (methyl chloroform) - HAP	0.48	133.41		
	1,1,2,2-Tetrachloroethane - HAP/VOC	1.1	167.85		
	1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	2.4	98.97		
	1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	0.20	96.94		
	1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	0.41	98.96		
	1,2-Dichloropropane (propylene dichloride) - HAP/VOC	0.18	112.99		
	2-Propanol (isopropyl alcohol) - VOC	50	60.11		
	Acetone	7.0	58.08		
	Acrylonitrile - HAP/VOC	6.3	53.06		
	Benzene - No or Unknown Co-disposal - HAP/VOC	1.9	78.11		
	Benzene - Co-disposal - HAP/VOC	11	78.11		
	Bromodichloromethane - VOC	3.1	163.83		
	Butane - VOC	5.0	58.12		
	Carbon disulfide - HAP/VOC	0.58	76.13		
	Carbon monoxide	140	28.01		
	Carbon tetrachloride - HAP/VOC	4.0E-03	153.84		
	Carbonyl sulfide - HAP/VOC	0.49	60.07		
	Chlorobenzene - HAP/VOC	0.25	112.56		
	Chlorodifluoromethane	1.3	86.47		
	Chloroethane (ethyl chloride) - HAP/VOC	1.3	64.52		
	Chloroform - HAP/VOC	0.03	119.39		
	Chloromethane - VOC	1.2	50.49		
	Dichlorobenzene - (HAP for para isomer/VOC)	0.21	147		
	Dichlorodifluoromethane	16	120.91		
	Dichlorofluoromethane - VOC	2.6	102.92		
	Dichloromethane (methylene chloride) - HAP	14	84.94		
	Dimethyl sulfide (methyl sulfide) - VOC	7.8	62.13		
	Ethane	890	30.07		
	Ethanol - VOC	27	46.08		

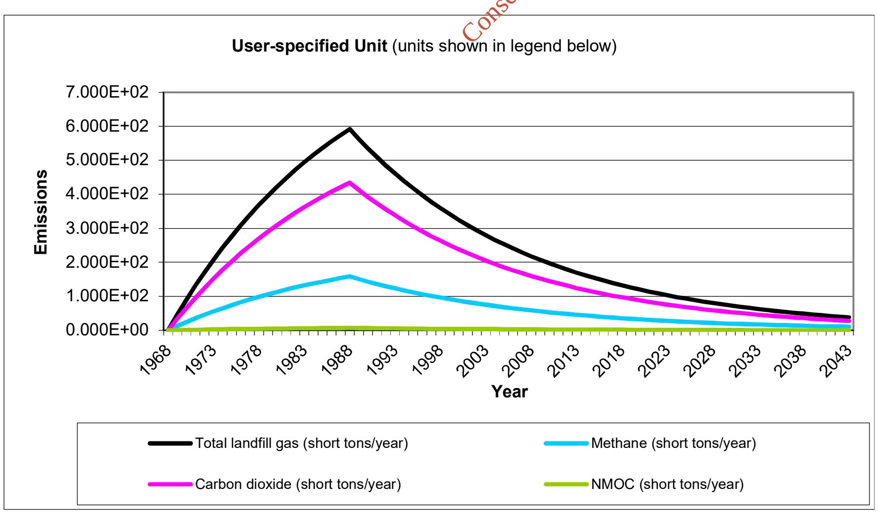
Pollutant Parameters (Continued)

		Gas / Pollutant Default Parameters:		User-specified Pollutant Parameters:	
	Compound	Concentration (*ppmv*)	Molecular Weight	Concentration (*ppmv*)	Molecular Weight
Pollutants	Ethyl mercaptan (ethanethiol) - VOC	2.3	62.13		
	Ethylbenzene - HAP/VOC	4.6	106.16		
	Ethylene dibromide - HAP/VOC	1.0E-03	187.88		
	Fluorotrichloromethane - VOC	0.76	137.38		
	Hexane - HAP/VOC	6.6	86.18		
	Hydrogen sulfide	36	34.08		
	Mercury (total) - HAP	2.9E-04	200.61		
	Methyl ethyl ketone - HAP/VOC	7.1	72.11		
	Methyl isobutyl ketone - HAP/VOC	1.9	100.16		
	Methyl mercaptan - VOC	2.5	48.11		
	Pentane - VOC	3.3	72.15		
	Perchloroethylene (tetrachloroethylene) - HAP	3.7	165.83		
	Propane - VOC	11	44.09		
	t-1,2-Dichloroethene - VOC	2.8	96.94		
	Toluene - No or Unknown Co-disposal - HAP/VOC	39	92.13		
	Toluene - Co-disposal - HAP/VOC	170	92.13		
	Trichloroethylene (trichloroethene) - HAP/VOC	2.8	131.40		
	Vinyl chloride - HAP/VOC	7.3	62.50		
	Xylenes - HAP/VOC	12	106.16		

Graphs


Megagrams Per Year
Emissions
6.000E+02
5.000E+02
4.000E+02
3.000E+02
2.000E+02
1.000E+02
0.000E+00
1968 1973 1978 1983 1988 1993 1998 2003 2008 2013 2018 2023 2028 2033 2038 2043
Year
Total landfill gas
Methane
Carbon dioxide
NMOC


Cubic Meters Per Year
Emissions
5.000E+05
4.500E+05
4.000E+05
3.500E+05
3.000E+05
2.500E+05
2.000E+05
1.500E+05
1.000E+05
5.000E+04
0.000E+00
1968 1973 1978 1983 1988 1993 1998 2003 2008 2013 2018 2023 2028 2033 2038 2043
Year
Total landfill gas
Methane
Carbon dioxide
NMOC


User-specified Unit (units shown in legend below)
Emissions
7.000E+02
6.000E+02
5.000E+02
4.000E+02
3.000E+02
2.000E+02
1.000E+02
0.000E+00
1968 1973 1978 1983 1988 1993 1998 2003 2008 2013 2018 2023 2028 2033 2038 2043
Year
Total landfill gas (short tons/year)
Methane (short tons/year)
Carbon dioxide (short tons/year)
NMOC (short tons/year)

Results

Year	Total landfill gas			Methane		
	(Mg/year)	(m^3/year)	(short tons/year)	(Mg/year)	(m^3/year)	(short tons/year)
1968	0	0	0	0	0	0
1969	4.152E+01	3.325E+04	4.567E+01	1.109E+01	1.662E+04	1.220E+01
1970	8.101E+01	6.487E+04	8.912E+01	2.164E+01	3.244E+04	2.380E+01
1971	1.186E+02	9.496E+04	1.304E+02	3.167E+01	4.748E+04	3.484E+01
1972	1.543E+02	1.236E+05	1.698E+02	4.122E+01	6.179E+04	4.534E+01
1973	1.883E+02	1.508E+05	2.071E+02	5.030E+01	7.540E+04	5.533E+01
1974	2.206E+02	1.767E+05	2.427E+02	5.894E+01	8.834E+04	6.483E+01
1975	2.514E+02	2.013E+05	2.765E+02	6.715E+01	1.007E+05	7.387E+01
1976	2.807E+02	2.247E+05	3.087E+02	7.497E+01	1.124E+05	8.247E+01
1977	3.085E+02	2.470E+05	3.393E+02	8.240E+01	1.235E+05	9.064E+01
1978	3.350E+02	2.682E+05	3.685E+02	8.947E+01	1.341E+05	9.842E+01
1979	3.602E+02	2.884E+05	3.962E+02	9.620E+01	1.442E+05	1.058E+02
1980	3.841E+02	3.076E+05	4.225E+02	1.026E+02	1.538E+05	1.129E+02
1981	4.069E+02	3.258E+05	4.476E+02	1.087E+02	1.629E+05	1.196E+02
1982	4.286E+02	3.432E+05	4.714E+02	1.145E+02	1.716E+05	1.259E+02
1983	4.492E+02	3.597E+05	4.941E+02	1.200E+02	1.798E+05	1.320E+02
1984	4.688E+02	3.754E+05	5.157E+02	1.252E+02	1.877E+05	1.377E+02
1985	4.875E+02	3.903E+05	5.362E+02	1.302E+02	1.952E+05	1.432E+02
1986	5.052E+02	4.045E+05	5.557E+02	1.349E+02	2.023E+05	1.484E+02
1987	5.221E+02	4.181E+05	5.743E+02	1.395E+02	2.090E+05	1.534E+02
1988	5.381E+02	4.309E+05	5.920E+02	1.437E+02	2.155E+05	1.581E+02
1989	5.119E+02	4.099E+05	5.631E+02	1.367E+02	2.050E+05	1.504E+02
1990	4.869E+02	3.899E+05	5.356E+02	1.301E+02	1.950E+05	1.431E+02
1991	4.632E+02	3.709E+05	5.095E+02	1.237E+02	1.854E+05	1.361E+02
1992	4.406E+02	3.528E+05	4.847E+02	1.177E+02	1.764E+05	1.295E+02
1993	4.191E+02	3.356E+05	4.610E+02	1.119E+02	1.678E+05	1.231E+02
1994	3.987E+02	3.192E+05	4.385E+02	1.065E+02	1.596E+05	1.171E+02
1995	3.792E+02	3.037E+05	4.171E+02	1.013E+02	1.518E+05	1.114E+02
1996	3.607E+02	2.889E+05	3.968E+02	9.635E+01	1.444E+05	1.060E+02
1997	3.431E+02	2.748E+05	3.774E+02	9.165E+01	1.374E+05	1.008E+02
1998	3.264E+02	2.614E+05	3.590E+02	8.718E+01	1.307E+05	9.590E+01
1999	3.105E+02	2.486E+05	3.415E+02	8.293E+01	1.243E+05	9.123E+01
2000	2.953E+02	2.365E+05	3.249E+02	7.889E+01	1.182E+05	8.678E+01
2001	2.809E+02	2.250E+05	3.090E+02	7.504E+01	1.125E+05	8.254E+01
2002	2.672E+02	2.140E+05	2.940E+02	7.138E+01	1.070E+05	7.852E+01
2003	2.542E+02	2.036E+05	2.796E+02	6.790E+01	1.018E+05	7.469E+01
2004	2.418E+02	1.936E+05	2.660E+02	6.459E+01	9.681E+04	7.105E+01
2005	2.300E+02	1.842E+05	2.530E+02	6.144E+01	9.209E+04	6.758E+01
2006	2.188E+02	1.752E+05	2.407E+02	5.844E+01	8.760E+04	6.429E+01
2007	2.081E+02	1.667E+05	2.289E+02	5.559E+01	8.333E+04	6.115E+01
2008	1.980E+02	1.585E+05	2.178E+02	5.288E+01	7.926E+04	5.817E+01
2009	1.883E+02	1.508E+05	2.071E+02	5.030E+01	7.540E+04	5.533E+01
2010	1.791E+02	1.434E+05	1.970E+02	4.785E+01	7.172E+04	5.263E+01
2011	1.704E+02	1.364E+05	1.874E+02	4.551E+01	6.822E+04	5.007E+01
2012	1.621E+02	1.298E+05	1.783E+02	4.329E+01	6.489E+04	4.762E+01
2013	1.542E+02	1.235E+05	1.696E+02	4.118E+01	6.173E+04	4.530E+01
2014	1.467E+02	1.174E+05	1.613E+02	3.917E+01	5.872E+04	4.309E+01
2015	1.395E+02	1.117E+05	1.535E+02	3.726E+01	5.586E+04	4.099E+01
2016	1.327E+02	1.063E+05	1.460E+02	3.545E+01	5.313E+04	3.899E+01
2017	1.262E+02	1.011E+05	1.389E+02	3.372E+01	5.054E+04	3.709E+01

Results (Continued)

Year	Total landfill gas			Methane		
	(Mg/year)	(m^3/year)	(short tons/year)	(Mg/year)	(m^3/year)	(short tons/year)
2018	1.201E+02	9.615E+04	1.321E+02	3.207E+01	4.808E+04	3.528E+01
2019	1.142E+02	9.146E+04	1.256E+02	3.051E+01	4.573E+04	3.356E+01
2020	1.086E+02	8.700E+04	1.195E+02	2.902E+01	4.350E+04	3.192E+01
2021	1.033E+02	8.276E+04	1.137E+02	2.761E+01	4.138E+04	3.037E+01
2022	9.831E+01	7.872E+04	1.081E+02	2.626E+01	3.936E+04	2.889E+01
2023	9.351E+01	7.488E+04	1.029E+02	2.498E+01	3.744E+04	2.748E+01
2024	8.895E+01	7.123E+04	9.785E+01	2.376E+01	3.562E+04	2.614E+01
2025	8.462E+01	6.776E+04	9.308E+01	2.260E+01	3.388E+04	2.486E+01
2026	8.049E+01	6.445E+04	8.854E+01	2.150E+01	3.223E+04	2.365E+01
2027	7.656E+01	6.131E+04	8.422E+01	2.045E+01	3.065E+04	2.250E+01
2028	7.283E+01	5.832E+04	8.011E+01	1.945E+01	2.916E+04	2.140E+01
2029	6.928E+01	5.547E+04	7.621E+01	1.850E+01	2.774E+04	2.036E+01
2030	6.590E+01	5.277E+04	7.249E+01	1.760E+01	2.638E+04	1.936E+01
2031	6.268E+01	5.020E+04	6.895E+01	1.674E+01	2.510E+04	1.842E+01
2032	5.963E+01	4.775E+04	6.559E+01	1.593E+01	2.387E+04	1.752E+01
2033	5.672E+01	4.542E+04	6.239E+01	1.515E+01	2.271E+04	1.667E+01
2034	5.395E+01	4.320E+04	5.935E+01	1.441E+01	2.160E+04	1.585E+01
2035	5.132E+01	4.110E+04	5.645E+01	1.371E+01	2.055E+04	1.508E+01
2036	4.882E+01	3.909E+04	5.370E+01	1.304E+01	1.955E+04	1.434E+01
2037	4.644E+01	3.719E+04	5.108E+01	1.240E+01	1.859E+04	1.364E+01
2038	4.417E+01	3.537E+04	4.859E+01	1.180E+01	1.769E+04	1.298E+01
2039	4.202E+01	3.365E+04	4.622E+01	1.122E+01	1.682E+04	1.235E+01
2040	3.997E+01	3.201E+04	4.397E+01	1.068E+01	1.600E+04	1.174E+01
2041	3.802E+01	3.044E+04	4.182E+01	1.016E+01	1.522E+04	1.117E+01
2042	3.617E+01	2.896E+04	3.978E+01	9.660E+00	1.448E+04	1.063E+01
2043	3.440E+01	2.755E+04	3.784E+01	9.189E+00	1.377E+04	1.011E+01
2044	3.272E+01	2.620E+04	3.600E+01	8.741E+00	1.310E+04	9.615E+00
2045	3.113E+01	2.493E+04	3.424E+01	8.315E+00	1.246E+04	9.146E+00
2046	2.961E+01	2.371E+04	3.257E+01	7.909E+00	1.186E+04	8.700E+00
2047	2.817E+01	2.255E+04	3.098E+01	7.523E+00	1.128E+04	8.276E+00
2048	2.679E+01	2.145E+04	2.947E+01	7.157E+00	1.073E+04	7.872E+00
2049	2.549E+01	2.041E+04	2.803E+01	6.808E+00	1.020E+04	7.488E+00
2050	2.424E+01	1.941E+04	2.667E+01	6.476E+00	9.706E+03	7.123E+00
2051	2.306E+01	1.847E+04	2.537E+01	6.160E+00	9.233E+03	6.776E+00
2052	2.194E+01	1.757E+04	2.413E+01	5.859E+00	8.783E+03	6.445E+00
2053	2.087E+01	1.671E+04	2.295E+01	5.574E+00	8.354E+03	6.131E+00
2054	1.985E+01	1.589E+04	2.183E+01	5.302E+00	7.947E+03	5.832E+00
2055	1.888E+01	1.512E+04	2.077E+01	5.043E+00	7.559E+03	5.547E+00
2056	1.796E+01	1.438E+04	1.976E+01	4.797E+00	7.191E+03	5.277E+00
2057	1.708E+01	1.368E+04	1.879E+01	4.563E+00	6.840E+03	5.020E+00
2058	1.625E+01	1.301E+04	1.788E+01	4.341E+00	6.506E+03	4.775E+00
2059	1.546E+01	1.238E+04	1.700E+01	4.129E+00	6.189E+03	4.542E+00
2060	1.470E+01	1.177E+04	1.617E+01	3.928E+00	5.887E+03	4.320E+00
2061	1.399E+01	1.120E+04	1.539E+01	3.736E+00	5.600E+03	4.110E+00
2062	1.330E+01	1.065E+04	1.464E+01	3.554E+00	5.327E+03	3.909E+00
2063	1.266E+01	1.013E+04	1.392E+01	3.381E+00	5.067E+03	3.719E+00
2064	1.204E+01	9.640E+03	1.324E+01	3.216E+00	4.820E+03	3.537E+00
2065	1.145E+01	9.170E+03	1.260E+01	3.059E+00	4.585E+03	3.365E+00
2066	1.089E+01	8.723E+03	1.198E+01	2.910E+00	4.361E+03	3.201E+00
2067	1.036E+01	8.297E+03	1.140E+01	2.768E+00	4.149E+03	3.045E+00
2068	9.856E+00	7.893E+03	1.084E+01	2.633E+00	3.946E+03	2.896E+00

Results (Continued)

Year	Total landfill gas			Methane		
	(Mg/year)	(m^3/year)	(short tons/year)	(Mg/year)	(m^3/year)	(short tons/year)
2069	9.376E+00	7.508E+03	1.031E+01	2.504E+00	3.754E+03	2.755E+00
2070	8.918E+00	7.141E+03	9.810E+00	2.382E+00	3.571E+03	2.620E+00
2071	8.483E+00	6.793E+03	9.332E+00	2.266E+00	3.397E+03	2.493E+00
2072	8.070E+00	6.462E+03	8.877E+00	2.156E+00	3.231E+03	2.371E+00
2073	7.676E+00	6.147E+03	8.444E+00	2.050E+00	3.073E+03	2.255E+00
2074	7.302E+00	5.847E+03	8.032E+00	1.950E+00	2.923E+03	2.145E+00
2075	6.946E+00	5.562E+03	7.640E+00	1.855E+00	2.781E+03	2.041E+00
2076	6.607E+00	5.291E+03	7.268E+00	1.765E+00	2.645E+03	1.941E+00
2077	6.285E+00	5.032E+03	6.913E+00	1.679E+00	2.516E+03	1.847E+00
2078	5.978E+00	4.787E+03	6.576E+00	1.597E+00	2.394E+03	1.757E+00
2079	5.687E+00	4.554E+03	6.255E+00	1.519E+00	2.277E+03	1.671E+00
2080	5.409E+00	4.332E+03	5.950E+00	1.445E+00	2.166E+03	1.589E+00
2081	5.145E+00	4.120E+03	5.660E+00	1.374E+00	2.060E+03	1.512E+00
2082	4.895E+00	3.919E+03	5.384E+00	1.307E+00	1.960E+03	1.438E+00
2083	4.656E+00	3.728E+03	5.121E+00	1.244E+00	1.864E+03	1.368E+00
2084	4.429E+00	3.546E+03	4.872E+00	1.183E+00	1.773E+03	1.301E+00
2085	4.213E+00	3.373E+03	4.634E+00	1.125E+00	1.687E+03	1.238E+00
2086	4.007E+00	3.209E+03	4.408E+00	1.070E+00	1.604E+03	1.177E+00
2087	3.812E+00	3.052E+03	4.193E+00	1.018E+00	1.526E+03	1.120E+00
2088	3.626E+00	2.903E+03	3.989E+00	9.685E-01	1.452E+03	1.065E+00
2089	3.449E+00	2.762E+03	3.794E+00	9.213E-01	1.381E+03	1.013E+00
2090	3.281E+00	2.627E+03	3.609E+00	8.764E-01	1.314E+03	9.640E-01
2091	3.121E+00	2.499E+03	3.433E+00	8.336E-01	1.250E+03	9.170E-01
2092	2.969E+00	2.377E+03	3.266E+00	7.930E-01	1.189E+03	8.723E-01
2093	2.824E+00	2.261E+03	3.106E+00	7.543E-01	1.131E+03	8.297E-01
2094	2.686E+00	2.151E+03	2.955E+00	7.175E-01	1.075E+03	7.893E-01
2095	2.555E+00	2.046E+03	2.811E+00	6.825E-01	1.023E+03	7.508E-01
2096	2.431E+00	1.946E+03	2.674E+00	6.492E-01	9.731E+02	7.141E-01
2097	2.312E+00	1.851E+03	2.543E+00	6.176E-01	9.257E+02	6.793E-01
2098	2.199E+00	1.761E+03	2.419E+00	5.874E-01	8.805E+02	6.462E-01
2099	2.092E+00	1.675E+03	2.301E+00	5.588E-01	8.376E+02	6.147E-01
2100	1.990E+00	1.593E+03	2.189E+00	5.315E-01	7.967E+02	5.847E-01
2101	1.893E+00	1.516E+03	2.082E+00	5.056E-01	7.579E+02	5.562E-01
2102	1.801E+00	1.442E+03	1.981E+00	4.810E-01	7.209E+02	5.291E-01
2103	1.713E+00	1.372E+03	1.884E+00	4.575E-01	6.858E+02	5.033E-01
2104	1.629E+00	1.305E+03	1.792E+00	4.352E-01	6.523E+02	4.787E-01
2105	1.550E+00	1.241E+03	1.705E+00	4.140E-01	6.205E+02	4.554E-01
2106	1.474E+00	1.180E+03	1.622E+00	3.938E-01	5.902E+02	4.332E-01
2107	1.402E+00	1.123E+03	1.543E+00	3.746E-01	5.615E+02	4.120E-01
2108	1.334E+00	1.068E+03	1.467E+00	3.563E-01	5.341E+02	3.919E-01

Results (Continued)

Year	Carbon dioxide			NMOC		
	(Mg/year)	(m^3/year)	(short tons/year)	(Mg/year)	(m^3/year)	(short tons/year)
1968	0	0	0	0	0	0
1969	3.043E+01	1.662E+04	3.347E+01	4.767E-01	1.330E+02	5.244E-01
1970	5.937E+01	3.244E+04	6.531E+01	9.301E-01	2.595E+02	1.023E+00
1971	8.691E+01	4.748E+04	9.560E+01	1.361E+00	3.798E+02	1.498E+00
1972	1.131E+02	6.179E+04	1.244E+02	1.772E+00	4.943E+02	1.949E+00
1973	1.380E+02	7.540E+04	1.518E+02	2.162E+00	6.032E+02	2.378E+00
1974	1.617E+02	8.834E+04	1.779E+02	2.533E+00	7.067E+02	2.787E+00
1975	1.843E+02	1.007E+05	2.027E+02	2.886E+00	8.053E+02	3.175E+00
1976	2.057E+02	1.124E+05	2.263E+02	3.222E+00	8.990E+02	3.545E+00
1977	2.261E+02	1.235E+05	2.487E+02	3.542E+00	9.881E+02	3.896E+00
1978	2.455E+02	1.341E+05	2.700E+02	3.846E+00	1.073E+03	4.230E+00
1979	2.640E+02	1.442E+05	2.903E+02	4.135E+00	1.154E+03	4.548E+00
1980	2.815E+02	1.538E+05	3.097E+02	4.410E+00	1.230E+03	4.851E+00
1981	2.982E+02	1.629E+05	3.280E+02	4.672E+00	1.303E+03	5.139E+00
1982	3.141E+02	1.716E+05	3.455E+02	4.920E+00	1.373E+03	5.412E+00
1983	3.292E+02	1.798E+05	3.621E+02	5.157E+00	1.439E+03	5.673E+00
1984	3.436E+02	1.877E+05	3.779E+02	5.382E+00	1.502E+03	5.921E+00
1985	3.573E+02	1.952E+05	3.930E+02	5.597E+00	1.561E+03	6.156E+00
1986	3.703E+02	2.023E+05	4.073E+02	5.800E+00	1.618E+03	6.380E+00
1987	3.826E+02	2.090E+05	4.209E+02	5.994E+00	1.672E+03	6.593E+00
1988	3.944E+02	2.155E+05	4.338E+02	6.178E+00	1.724E+03	6.796E+00
1989	3.752E+02	2.050E+05	4.127E+02	5.877E+00	1.640E+03	6.465E+00
1990	3.569E+02	1.950E+05	3.926E+02	5.590E+00	1.560E+03	6.150E+00
1991	3.395E+02	1.854E+05	3.734E+02	5.318E+00	1.484E+03	5.850E+00
1992	3.229E+02	1.764E+05	3.552E+02	5.058E+00	1.411E+03	5.564E+00
1993	3.072E+02	1.678E+05	3.379E+02	4.812E+00	1.342E+03	5.293E+00
1994	2.922E+02	1.596E+05	3.214E+02	4.577E+00	1.277E+03	5.035E+00
1995	2.779E+02	1.518E+05	3.057E+02	4.354E+00	1.215E+03	4.789E+00
1996	2.644E+02	1.444E+05	2.908E+02	4.142E+00	1.155E+03	4.556E+00
1997	2.515E+02	1.374E+05	2.766E+02	3.940E+00	1.099E+03	4.334E+00
1998	2.392E+02	1.307E+05	2.631E+02	3.747E+00	1.045E+03	4.122E+00
1999	2.275E+02	1.243E+05	2.503E+02	3.565E+00	9.945E+02	3.921E+00
2000	2.164E+02	1.182E+05	2.381E+02	3.391E+00	9.460E+02	3.730E+00
2001	2.059E+02	1.125E+05	2.265E+02	3.225E+00	8.998E+02	3.548E+00
2002	1.959E+02	1.070E+05	2.154E+02	3.068E+00	8.559E+02	3.375E+00
2003	1.863E+02	1.018E+05	2.049E+02	2.918E+00	8.142E+02	3.210E+00
2004	1.772E+02	9.681E+04	1.949E+02	2.776E+00	7.745E+02	3.054E+00
2005	1.686E+02	9.209E+04	1.854E+02	2.641E+00	7.367E+02	2.905E+00
2006	1.603E+02	8.760E+04	1.764E+02	2.512E+00	7.008E+02	2.763E+00
2007	1.525E+02	8.333E+04	1.678E+02	2.389E+00	6.666E+02	2.628E+00
2008	1.451E+02	7.926E+04	1.596E+02	2.273E+00	6.341E+02	2.500E+00
2009	1.380E+02	7.540E+04	1.518E+02	2.162E+00	6.032E+02	2.378E+00
2010	1.313E+02	7.172E+04	1.444E+02	2.057E+00	5.738E+02	2.262E+00
2011	1.249E+02	6.822E+04	1.374E+02	1.956E+00	5.458E+02	2.152E+00
2012	1.188E+02	6.489E+04	1.307E+02	1.861E+00	5.192E+02	2.047E+00
2013	1.130E+02	6.173E+04	1.243E+02	1.770E+00	4.938E+02	1.947E+00
2014	1.075E+02	5.872E+04	1.182E+02	1.684E+00	4.698E+02	1.852E+00
2015	1.022E+02	5.586E+04	1.125E+02	1.602E+00	4.468E+02	1.762E+00
2016	9.726E+01	5.313E+04	1.070E+02	1.524E+00	4.251E+02	1.676E+00
2017	9.251E+01	5.054E+04	1.018E+02	1.449E+00	4.043E+02	1.594E+00

Results (Continued)

Year	Carbon dioxide			NMOC		
	(Mg/year)	*(m^3/year)*	*(short tons/year)*	*(Mg/year)*	*(m^3/year)*	*(short tons/year)*
2018	8.800E+01	4.808E+04	9.680E+01	1.379E+00	3.846E+02	1.516E+00
2019	8.371E+01	4.573E+04	9.208E+01	1.311E+00	3.658E+02	1.442E+00
2020	7.963E+01	4.350E+04	8.759E+01	1.247E+00	3.480E+02	1.372E+00
2021	7.574E+01	4.138E+04	8.332E+01	1.187E+00	3.310E+02	1.305E+00
2022	7.205E+01	3.936E+04	7.925E+01	1.129E+00	3.149E+02	1.242E+00
2023	6.854E+01	3.744E+04	7.539E+01	1.074E+00	2.995E+02	1.181E+00
2024	6.519E+01	3.562E+04	7.171E+01	1.021E+00	2.849E+02	1.123E+00
2025	6.201E+01	3.388E+04	6.822E+01	9.715E-01	2.710E+02	1.069E+00
2026	5.899E+01	3.223E+04	6.489E+01	9.241E-01	2.578E+02	1.017E+00
2027	5.611E+01	3.065E+04	6.172E+01	8.790E-01	2.452E+02	9.669E-01
2028	5.338E+01	2.916E+04	5.871E+01	8.362E-01	2.333E+02	9.198E-01
2029	5.077E+01	2.774E+04	5.585E+01	7.954E-01	2.219E+02	8.749E-01
2030	4.830E+01	2.638E+04	5.313E+01	7.566E-01	2.111E+02	8.322E-01
2031	4.594E+01	2.510E+04	5.054E+01	7.197E-01	2.008E+02	7.917E-01
2032	4.370E+01	2.387E+04	4.807E+01	6.846E-01	1.910E+02	7.530E-01
2033	4.157E+01	2.271E+04	4.573E+01	6.512E-01	1.817E+02	7.163E-01
2034	3.954E+01	2.160E+04	4.350E+01	6.194E-01	1.728E+02	6.814E-01
2035	3.761E+01	2.055E+04	4.137E+01	5.892E-01	1.644E+02	6.482E-01
2036	3.578E+01	1.955E+04	3.936E+01	5.605E-01	1.564E+02	6.165E-01
2037	3.403E+01	1.859E+04	3.744E+01	5.332E-01	1.487E+02	5.865E-01
2038	3.237E+01	1.769E+04	3.561E+01	5.072E-01	1.415E+02	5.579E-01
2039	3.080E+01	1.682E+04	3.387E+01	4.824E-01	1.346E+02	5.307E-01
2040	2.929E+01	1.600E+04	3.222E+01	4.589E-01	1.280E+02	5.048E-01
2041	2.786E+01	1.522E+04	3.065E+01	4.365E-01	1.218E+02	4.802E-01
2042	2.651E+01	1.448E+04	2.916E+01	4.152E-01	1.158E+02	4.567E-01
2043	2.521E+01	1.377E+04	2.773E+01	3.950E-01	1.102E+02	4.345E-01
2044	2.398E+01	1.310E+04	2.638E+01	3.757E-01	1.048E+02	4.133E-01
2045	2.281E+01	1.246E+04	2.509E+01	3.574E-01	9.970E+01	3.931E-01
2046	2.170E+01	1.186E+04	2.387E+01	3.400E-01	9.484E+01	3.740E-01
2047	2.064E+01	1.128E+04	2.271E+01	3.234E-01	9.022E+01	3.557E-01
2048	1.964E+01	1.073E+04	2.160E+01	3.076E-01	8.582E+01	3.384E-01
2049	1.868E+01	1.020E+04	2.055E+01	2.926E-01	8.163E+01	3.219E-01
2050	1.777E+01	9.706E+03	1.954E+01	2.783E-01	7.765E+01	3.062E-01
2051	1.690E+01	9.233E+03	1.859E+01	2.648E-01	7.386E+01	2.912E-01
2052	1.608E+01	8.783E+03	1.768E+01	2.518E-01	7.026E+01	2.770E-01
2053	1.529E+01	8.354E+03	1.682E+01	2.396E-01	6.683E+01	2.635E-01
2054	1.455E+01	7.947E+03	1.600E+01	2.279E-01	6.357E+01	2.507E-01
2055	1.384E+01	7.559E+03	1.522E+01	2.168E-01	6.047E+01	2.384E-01
2056	1.316E+01	7.191E+03	1.448E+01	2.062E-01	5.752E+01	2.268E-01
2057	1.252E+01	6.840E+03	1.377E+01	1.961E-01	5.472E+01	2.158E-01
2058	1.191E+01	6.506E+03	1.310E+01	1.866E-01	5.205E+01	2.052E-01
2059	1.133E+01	6.189E+03	1.246E+01	1.775E-01	4.951E+01	1.952E-01
2060	1.078E+01	5.887E+03	1.185E+01	1.688E-01	4.710E+01	1.857E-01
2061	1.025E+01	5.600E+03	1.128E+01	1.606E-01	4.480E+01	1.766E-01
2062	9.751E+00	5.327E+03	1.073E+01	1.528E-01	4.262E+01	1.680E-01
2063	9.275E+00	5.067E+03	1.020E+01	1.453E-01	4.054E+01	1.598E-01
2064	8.823E+00	4.820E+03	9.705E+00	1.382E-01	3.856E+01	1.520E-01
2065	8.393E+00	4.585E+03	9.232E+00	1.315E-01	3.668E+01	1.446E-01
2066	7.983E+00	4.361E+03	8.782E+00	1.251E-01	3.489E+01	1.376E-01
2067	7.594E+00	4.149E+03	8.353E+00	1.190E-01	3.319E+01	1.309E-01
2068	7.224E+00	3.946E+03	7.946E+00	1.132E-01	3.157E+01	1.245E-01

Results (Continued)

Year	Carbon dioxide			NMOC		
	(Mg/year)	*(m^3/year)*	*(short tons/year)*	*(Mg/year)*	*(m^3/year)*	*(short tons/year)*
2069	6.871E+00	3.754E+03	7.558E+00	1.076E-01	3.003E+01	1.184E-01
2070	6.536E+00	3.571E+03	7.190E+00	1.024E-01	2.857E+01	1.126E-01
2071	6.217E+00	3.397E+03	6.839E+00	9.740E-02	2.717E+01	1.071E-01
2072	5.914E+00	3.231E+03	6.506E+00	9.265E-02	2.585E+01	1.019E-01
2073	5.626E+00	3.073E+03	6.188E+00	8.813E-02	2.459E+01	9.694E-02
2074	5.351E+00	2.923E+03	5.887E+00	8.383E-02	2.339E+01	9.222E-02
2075	5.090E+00	2.781E+03	5.599E+00	7.974E-02	2.225E+01	8.772E-02
2076	4.842E+00	2.645E+03	5.326E+00	7.585E-02	2.116E+01	8.344E-02
2077	4.606E+00	2.516E+03	5.067E+00	7.216E-02	2.013E+01	7.937E-02
2078	4.381E+00	2.394E+03	4.819E+00	6.864E-02	1.915E+01	7.550E-02
2079	4.168E+00	2.277E+03	4.584E+00	6.529E-02	1.821E+01	7.182E-02
2080	3.964E+00	2.166E+03	4.361E+00	6.210E-02	1.733E+01	6.832E-02
2081	3.771E+00	2.060E+03	4.148E+00	5.908E-02	1.648E+01	6.498E-02
2082	3.587E+00	1.960E+03	3.946E+00	5.619E-02	1.568E+01	6.181E-02
2083	3.412E+00	1.864E+03	3.753E+00	5.345E-02	1.491E+01	5.880E-02
2084	3.246E+00	1.773E+03	3.570E+00	5.085E-02	1.419E+01	5.593E-02
2085	3.087E+00	1.687E+03	3.396E+00	4.837E-02	1.349E+01	5.320E-02
2086	2.937E+00	1.604E+03	3.231E+00	4.601E-02	1.284E+01	5.061E-02
2087	2.794E+00	1.526E+03	3.073E+00	4.376E-02	1.221E+01	4.814E-02
2088	2.657E+00	1.452E+03	2.923E+00	4.163E-02	1.161E+01	4.579E-02
2089	2.528E+00	1.381E+03	2.781E+00	3.960E-02	1.105E+01	4.356E-02
2090	2.405E+00	1.314E+03	2.645E+00	3.767E-02	1.051E+01	4.144E-02
2091	2.287E+00	1.250E+03	2.516E+00	3.583E-02	9.996E+00	3.941E-02
2092	2.176E+00	1.189E+03	2.393E+00	3.408E-02	9.509E+00	3.749E-02
2093	2.070E+00	1.131E+03	2.277E+00	3.242E-02	9.045E+00	3.566E-02
2094	1.969E+00	1.075E+03	2.166E+00	3.084E-02	8.604E+00	3.392E-02
2095	1.873E+00	1.023E+03	2.060E+00	2.934E-02	8.184E+00	3.227E-02
2096	1.781E+00	9.731E+02	1.959E+00	2.791E-02	7.785E+00	3.070E-02
2097	1.694E+00	9.257E+02	1.864E+00	2.654E-02	7.405E+00	2.920E-02
2098	1.612E+00	8.805E+02	1.773E+00	2.525E-02	7.044E+00	2.777E-02
2099	1.533E+00	8.376E+02	1.687E+00	2.402E-02	6.701E+00	2.642E-02
2100	1.458E+00	7.967E+02	1.604E+00	2.285E-02	6.374E+00	2.513E-02
2101	1.387E+00	7.579E+02	1.526E+00	2.173E-02	6.063E+00	2.391E-02
2102	1.320E+00	7.209E+02	1.452E+00	2.067E-02	5.767E+00	2.274E-02
2103	1.255E+00	6.858E+02	1.381E+00	1.966E-02	5.486E+00	2.163E-02
2104	1.194E+00	6.523E+02	1.313E+00	1.871E-02	5.219E+00	2.058E-02
2105	1.136E+00	6.205E+02	1.249E+00	1.779E-02	4.964E+00	1.957E-02
2106	1.080E+00	5.902E+02	1.188E+00	1.693E-02	4.722E+00	1.862E-02
2107	1.028E+00	5.615E+02	1.131E+00	1.610E-02	4.492E+00	1.771E-02
2108	9.776E-01	5.341E+02	1.075E+00	1.531E-02	4.273E+00	1.685E-02

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APPENDIX 4

Remediation Plan Drawing
P1766-0102-0001

Legend

- Site Boundary
- Proposed Leachate Interceptor Trench
- Proposed Leachate Storeage/Pump Station
- Ground Water Extraction Wells
- Perimeter Gas Monitoring Well
- Continous Gas Monitoring Building

0m 5m 10m 15m 20m 25m 30m 35m 40m 45m 50m

Scale 1:500

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Rev.	Description	App By	Date
A	ISSUE FOR APPROVAL	CJC	10.03.20

PROJECT	SOUTH AND WEST KERRY LANDFILLS
CLIENT	KERRY COUNTY COUNCIL
SHEET	LISTOWEL HISTORIC LANDFILL PROPOSED REMEDIATION PLAN
Date	10.03.20
Project number	P1766
Scale (@ A1-)	1:500
Drawn by	SOC
Checked by	EA
Drawing Number	P1766-0102-0001
Rev	A

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31 March 2020

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