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NORTH KERRY LANDFILLS

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

Prepared for: Kerry County Council

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Abstract: This report presents the findings of a Tier 3 risk assessment carried out on Ardfert Historic Landfill site, Co. Kerry, and conducted in accordance with the EPA Code of Practice for unregulated landfill sites. The Tier 3 risk assessment was conducted following recommendations made in the Tier 2 risk assessment.

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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 Ardfert Historical landfill located at Ardfert, Co. Kerry. This Tier 3 makes reference to the:

- Tier 1 risk assessment findings and classifications (2019).
- 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.

1.2 Tier 1 Risk Classification

KCC previously prepared Tier 1 risk assessments for a site located immediately east and adjacent to the R551 road. FT following a site walkover concluded, through a visual inspection of the site and wider area, gathering of anecdotal evidence from a local landowner, that an adjacent area of land directly north of St. Brendan's Cathedral was the likely location of the historical landfill. FT subsequently prepared a Tier 1 report in 2019 for the correct site of the historical landfill. The risk scores generated from the 2019 Tier 1 risk assessment are presented in Table 1-1 below.

Table 1-1: Tier 1 SPR Linkages (2019)

SPR No.	Linkage	Normalised Score[2]	Justification[1]
Leachate migration through combined groundwater and surface water pathways			
SPR1	Leachate => surface water	27% (2019)	Groundwater vulnerability was identified as being extreme and site is underlain by a regionally important karstified aquifer however there were no direct surface water pathways from the site to sensitive surface water receptors
SPR2	Leachate => SWDTE	0% (2019)	Groundwater vulnerability was identified as being extreme and site is underlain by a regionally important karstified aquifer however there are no SWDTEs close to the site.
Leachate migration through groundwater pathway			
SPR3	Leachate => human presence	33% (2019)	Groundwater vulnerability was identified as being extreme and site is underlain by a regionally important karstified aquifer. Potential human receptors located between 50-250m from the site.
SPR4	Leachate => GWDTE	) 0% (2019)	No GWDTE areas located in proximity to the site.
SPR5	Leachate => Aquifer	50% (2019)	Groundwater vulnerability was identified as being extreme and site is underlain by a regionally important karstified aquifer.
SPR6	Leachate => Public Supply	36% (2019)	Groundwater vulnerability was identified as being extreme and site is underlain by a regionally important karstified aquifer and public water supply located between 100-300m from the site.
SPR7	Leachate => SWDTE	33% (2019)	Groundwater vulnerability was identified as being extreme and site is underlain by a regionally important karstified aquifer and there is a surface water receptor between 50-250m from the site.
Leachate migration through surface water pathway			
SPR8	Leachate => Surface Water	0% (2019)	There is no direct surface water connection from the site
SPR9	Leachate => SWDTE	0% (2019)	There is no direct surface water connection from the site
Landfill gas migration pathway (lateral & vertical)			
SPR10	Landfill Gas => Human Presence	30% (2019)	The underlying geology at the site is bedrock and human receptors located between 50-150m from the site.
SPR11	Landfill Gas => Human Presence	0% (2019)	There are no buildings located directly above the estimated waste footprint area

Note 1: justification refers to 2019 risk scoring

1.3 Tier 2 Site investigation

The Tier 2 assessment was conducted in accordance with the Environmental Protection Agency's (EPA) Code of Practice guidance document -Environmental Risk Assessment for Unregulated Waste Disposal Sites.

Ardfert site investigations included the following elements:

- Site walkover.
- 1 No. Geophysical survey (2D resistivity and seismic refraction profiling).
- 4 No. trial pit excavations.
- Installation and monitoring of 2 No. groundwater boreholes.
- Topographical survey.

The Tier 2 site investigations confirmed that the historic landfill:

- Typically contains mixed municipal/household waste deposited within a single infill area covering an area of 1,675 m^2. It is estimated that 5,025 m^3 of waste is present at the site. This estimate assumes an average thickness of waste and made ground of 3 m albeit that waste extends to depths of 4.2 m at some locations. Cap thickness in the 4 trial pits was greater than 1.0 m.
- Waste samples from the trial pits, when assessed against the inert waste acceptance criteria indicated that much of the waste material within the site can be classified as typically inert.
- Cap 0.9 m to 1.2 m deep.

1.4 Tier 2 Risk Classification and Tier 3 SPRs

The Tier 2 risk assessment concluded that the risk rating of the site was Moderate (Class B). The highest single risk rating for the site was calculated to be 50% for source-pathway-receptor (SPR) Linkage 5 which referred to leachate migration through groundwater pathway to underlying aquifer. The SPR linkages examined in the Tier 2 are presented in Table 1-2 and discussed in further detail:

Table 1-2: Tier 2 Selected SPR Linkages (2020)

SPR No.	Linkage	Normalised Score	Justification
Leachate migration through combined groundwater and surface water pathways			
SPR1	Leachate => surface water	33%	Groundwater vulnerability was identified as being extreme and site is underlain by a regionally important karstified aquifer and conservatively assuming there are direct surface water pathways from the site to sensitive surface water receptors. Surface water monitoring was conducted at upstream and downstream locations on the River Tyshe as part of the Tier 2 site investigation. Surface water monitoring did not demonstrate any deterioration in water quality between upstream and downstream monitoring locations therefore indicating that the landfill is not having a deleterious effect on the River Tyshe, as the nearest surface water receptor.
SPR2	Leachate => SWDTE	33%	Aquifer and bedrock present a groundwater pathway and conservatively assuming there are direct surface water pathways from the site to sensitive surface water receptors.
Leachate migration through groundwater pathway			
SPR3	Leachate => human presence	33%	One residential dwelling is located between 50 m and 250 m to the north-west of the site boundary. Not likely that this dwelling would be exposed to any subsurface leachate. House drinking water is supplied via mains water supply.
SPR4	Leachate => GWDTE	33%	The nearest groundwater source protection zone (SPZ) is located approximately 270 m north of the site at its closest point. Aquifer is shown to be regionally important and karstified providing a preferential pathway
SPR5	Leachate => Aquifer	**50%**	The Cloonagh formation is a Regionally Important Aquifer – Karstified (Diffuse) Bedrock (Rkd) and therefore direct contamination of this aquifer presents an innate risk from the site.
SPR6	Leachate => Public Supply	21%	The nearest groundwater protection zone (outer source protection area) is located approximately 270 m north of the site at its closest point. The inner source protection abstraction boreholes are approximately 500 m north of the site.
SPR7	Leachate => Surface Water	33%	The River Tyshe is located approximately 70m north of the site. Surface water monitoring did not indicate any deterioration in surface quality attributable to the presence of waste at the historical landfill.
Leachate migration through surface water pathway			
SPR8	Leachate => Surface Water	33%	Conservatively assumes there are direct surface water pathways from site to sensitive surface water receptors. EPA monitoring indicates that River Tyshe is of poor quality requiring further assessment of potential impact of site on surface water quality to be conducted.
SPR9	Leachate => SWDTE	33%	Conservatively assumes there are direct surface water pathways from site to sensitive surface water receptors.

SPR No.	Linkage	Normalised Score	Justification
			EPA monitoring indicates that River Tyshe is of poor quality requiring further assessment of potential impact of site on surface water quality to be conducted.
Landfill gas migration pathway (lateral & vertical)			
SPR10	Landfill Gas => Human Presence	17%	The intrusive site investigation identified the shallow bedrock as karstified bedrock outcrop. Ardfert Cathedral located within 50m south of the identified waste body. Landfill gas monitoring indicated presence of methane at concentrations above the threshold requiring further examination.
SPR11	Landfill Gas => Human Presence	10%	No buildings located directly above estimated waste footprint area. Ardfert Cathedral located within 50m south of the identified waste body. Landfill gas monitoring indicated presence of methane at concentrations above the threshold requiring further examination.

1.4.1 Leachate Migration Through Groundwater Pathway to Underlying Aquifer (SPR5)

A risk rating of 50% was calculated for the SPR5 linkage. This rating refers to the risk of leachate migrating to the underlying groundwater aquifer. The aquifer underlying the site was identified as being a regionally important and a karstified limestone aquifer. The karst characteristic of the aquifer was a contributing factor when calculating the risk the historical landfill site poses to groundwater contamination.

1.4.2 Leachate Migration Through Groundwater Pathway to Public Water Supply (SPR6)

A risk score of 36% was calculated for the SPR6 linkage which referred to leachate migration to public water supply.

The Ardfert Public Water Supply (PWS) Outer Source Protection zone is located approximately 270 m north of the site at its closest point. The PWS abstraction wells are located 0.5 km from the site. The source of this groundwater supply is identified as the underlying sand and gravel aquifer. The total zone of contribution / source protection area encompasses 1.5 km^2.

Although the defined zone of contribution does not encompass the historical landfill site, taking a precautionary approach it was determined that the site may still pose a potential risk to drinking water quality via karstified limestone pathways to the sand and gravel aquifer underlying the site in order to confirm the potential risk it is included in this Tier 3 DQRA.

1.4.3 Lateral and Vertical Migration of Landfill Gas (SPR10 And SPR11)

Scores of 17% and 10% were calculated for lateral and vertical landfill gas migration respectively. Tier 2 site investigation monitoring detected methane concentrations at the trigger value of 1% v/v for boundary monitoring wells. Methane concentrations were also shown to be marginally above this trigger value within the waste body, thus indicating that landfill gas migration from the site may still pose a slight risk.

1.4.4 Leachate Migration Through Surface Water Pathway to Surface Water Receptor and SWDTE (SPR8) (SPR9)

A risk score of 33% was calculated for SPR8 linkage which refers to leachate migration through surface water pathway to a surface water receptor. Although no leachate breakout was observed at the site the location of the River Tyshe being in relatively close proximity to and downgradient of the site presents a potential risk for potentially contaminated surface to migrate from the site to the river.

2. TIER 3 ASSESSMENT SCOPE OF WORKS

2.1 Tier 3 Overview

A Tier 3 assessment includes some form of quantitative risk 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:

- SPR 5 Leachate migration through groundwater pathway to underlying aquifer 50%.
- SPR 6 Leachate migration through groundwater pathway to public water supply 36%.
- SPR 8 Leachate migration to adjacent surface waters.
- SPR 9 Leachate migration to SWDTE.
- SPR10 and SPR11 Lateral and vertical migration of landfill 17% and 10%.

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

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

As part of the Tier 3 assessment, a further review of previous site investigations and environment risk assessments carried out as part of the Tier 2 assessment was conducted. As shown in Section 1 of this report both the Tier 1 and the Tier 2 investigations concluded that the site presented a **moderate risk** to the environment.

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

- 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.
- Groundwater contaminant dispersion modelling (EA Remedial Targets Worksheet) was undertaken to quantitatively assess the risks posed to the aquifer.
- 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 risks:

- Leachate migration through groundwater pathway to underlying aquifer (SPR5).
- Leachate migration through groundwater pathway to public water supply (SPR6).
- Leachate migration through surface water pathway to surface water receptor and SWDTE (SPR8) (SPR9)
- Lateral and vertical migration of landfill gas (SPR10 and SPR11).

The detailed quantitative risk assessments used information gathered as part of the Tier 2 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 representation and rating of the geological and hydrogeological characteristics of the site and environment are required to determine the primary source-pathway-receptor linkages and potential impacts/risks associated with the site.

Quaternary mapping identifies the quaternary sediments at the site as 'Karstified bedrock outcrop or subcrop (KaRck)' indicating that shallow rock and outcrops dominate locally.

The bedrock beneath to be founded the Cloonagh limestone formation comprising Dinantian '*Bedded bioclastic limestone*'. A bedrock outcrop is present within a portion of site, at the north-eastern corner. This outcrop extends further east beyond the site boundary. The presence of limestone was detected at shallow depths of 1.10 m and 4.5 m at boreholes BH01 and BH02 respectively during the site investigation. Limestone within this formation was observed to be karstified within the upper 5 m which typically provides a preferential pathway for groundwater flow.

An examination of the national bedrock aquifer mapping classifies the Cloonagh formation as a Regionally Important Aquifer – Karstified (Diffuse) Bedrock (Rkd), i.e., dominated by diffuse rather than conduit flow. The Ardfert gravel body is located approximately 340 m north of the site and encompasses an area of approximately 0.520 km^2.

The nearest groundwater protection zone (outer source protection zone) is located approximately 270 m north of the site at its closest point. This groundwater protection zone relates to the Ardfert Group Water Supply Scheme/Ardfert South Boreholes. The Ardfert sand and gravel body is the source of groundwater for this public supply. The total zone of contribution / source protection zone encompasses an area of approximately of 1.5 km^2.

Groundwater recharge is variable in the region. The annual recharge for the site as 670 mm/yr. The effective rainfall for the area is 788 mm/yr, returning a recharge coefficient of 85%.

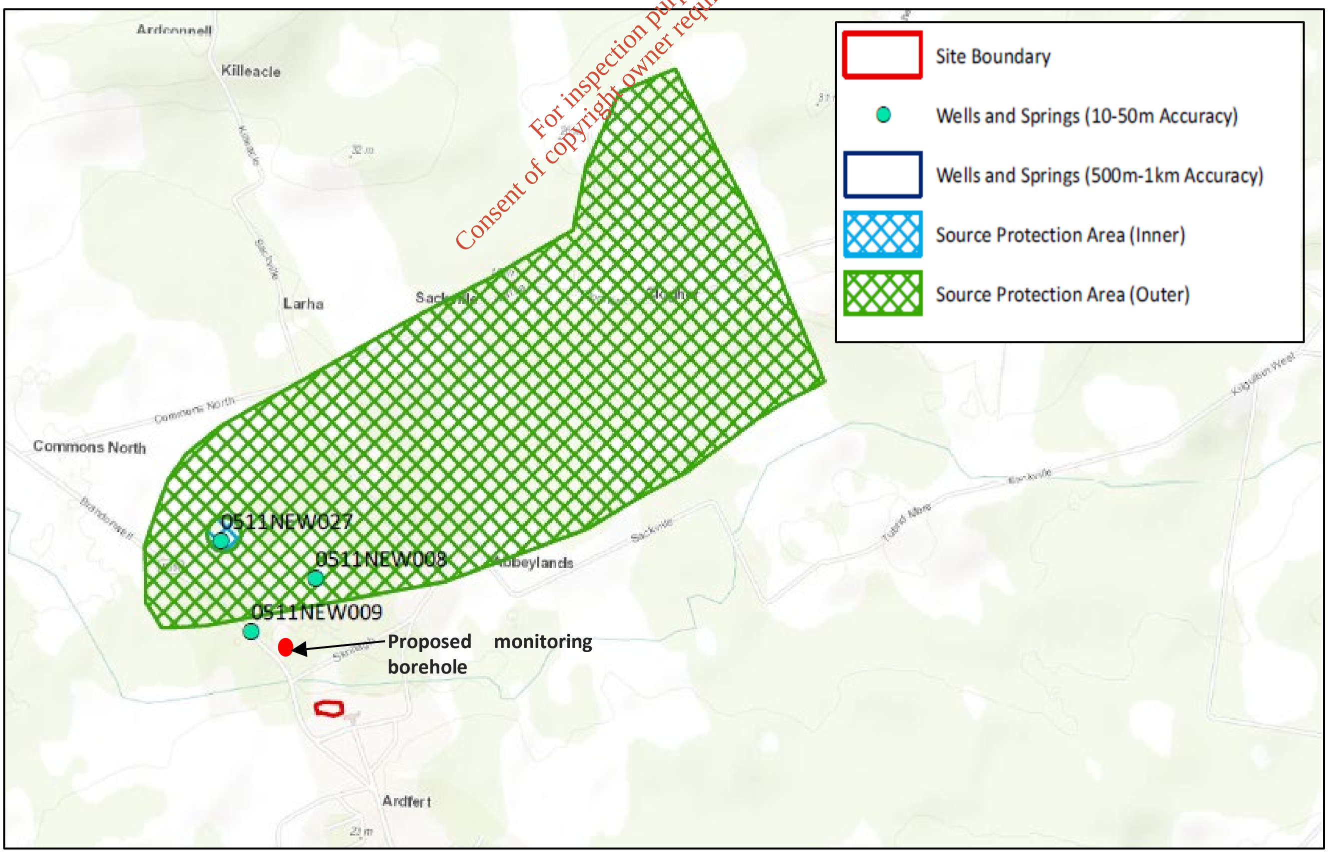
Mapping data set identifies rock / karts at or near the surface with extreme vulnerability to groundwater contamination (owing to rock out crops with a thin overburden cover). This facilitates a relatively easy pathway for rainfall and potential leachate to enter the underlying groundwater aquifer.

3.3 Ardfert Public Water Supply (PWS)

As stated in Section 1.4 there is potential for leachate arising from waste deposits in the Ardfert historical landfill site to negatively impact groundwater quality in the Ardfert PWS and sand-gravel aquifer, located c. 270 m north of the site. The EPA report Establishment of Groundwater Source Protection Zones, Ardfert Water Supply Scheme, Ardfert South Borehole (2012) states that the groundwater quality is 'generally good'. The report includes a review of historical groundwater monitoring data specifically examining key indicators of contamination namely; nitrate, chloride, molybdate reactive phosphorous, potassium, sodium, faecal coliforms, and trace metals.

Historical bacteriological exceedances were associated with older boreholes which had poorer well head protection. Elevated concentrations of chloride detected are likely due to the proximity of the groundwater supply to the coast (c. 3km) and low elevation.

Figure 3.1 is an extract from the Tier 2 report shows the location of GSI recorded wells and source protection areas in relation to the site.



Note: proposed monitoring borehole recommended as part of remedial action plan (see Section 5)

Figure 3-1: Location of Ardfert Source Protection Areas (Figure 2.5 Tier 2 Report)

3.3.1 Reference Data: Groundwater Source Protection Zones

The Tier 2 risk assessment report refers to a report entitled *Establishment of Groundwater Source Protection Zone-Ardfert Water Supply Scheme, Ardfert South Borehole (December 2012)* prepared on behalf of the EPA which characterises the Ardfert water supply. This report characterises the aquifer and establishes a groundwater source protection zone for the Ardfert water supply scheme. The report was produced by Tobin Consulting Engineers with inputs from Trinity College Dublin and Kerry County Council on behalf of the EPA.

The assessment and report were carried out as part of the EPA 'Establishment of Groundwater Source Protection Zones' project.

The full extents of this aquifer are not known however it is described as occurring in a low-lying north-east - south-west direction trough and is bounded by an elevated limestone bedrock catchment to the north, north-east and south. Recharge to the aquifer occurs from direct rainfall as well as from surrounding bedrock. The zone of contribution shown in Figure 3-1 above represents the most likely zone are to be 1.5 km^2 .

The bedrock geology at the source comprises the same Dinantian Pure Unbedded Limestones (Cloonagh Formation) underlying the Ardfert historical landfill site, with Dinantain Impure Limestones (Dirtoge Formation) to the north and south of the source. Field mapping conducted as part of the assessment shows that this limestone, where exposed, is karstified in the upper 5 m. Depth to bedrock at the source is stated to be approximately 18 - 18.5 m b.g.l. The depth to bedrock is suspected to vary however over short distances.

The overburden at the source area is described as comprising layers of sand and gravels separated by layers of till soil.

3.3.1.1 Public Water Supply

The Tobin report states that the public water supply currently comprises two abstraction boreholes, PW1 and PW2 which are located 0.7 km north-west of Ardfert village adjacent to the R551 regional road. Historic boreholes also exist but have since been abandoned, decommissioned and/or backfilled. It is stated that groundwater has been pumped at this location from at least 1966. The two active boreholes are pumped alternatively on a 24-hour basis to an adjacent treatment plant through approximately 9 km of drinking water supply pipework. The abstraction rate ranges between 1,200 to 1,920 m^3/day. Wells PW1 and PW2 are constructed to a depth of 18 m and 14 m respectively, with bedrock being encountered between 18-20 m below ground level and a static water level of approximately 1 m below ground level. Accordingly, the source aquifer is classified as having 'high' to 'extreme' vulnerability.

Pumping tests classify the boreholes as being 'excellent' yielding and equilibrium can be achieved between the current pumping rates and recharge of the aquifer. The permeability of the sand and gravel source ranges from 35 to 90 m/day with 50 m/day generally applied for estimating groundwater permeability.

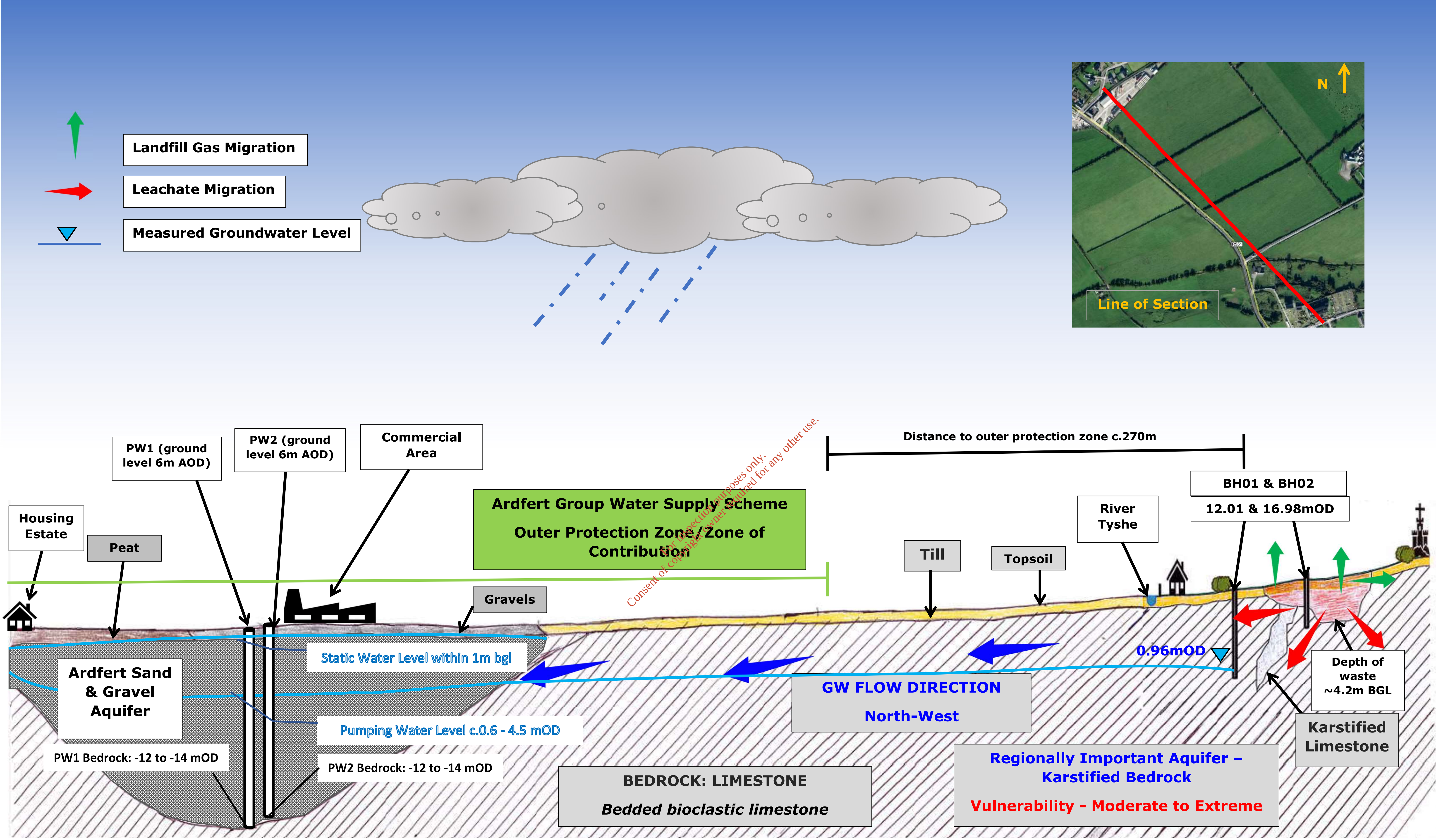
3.3.1.2 Hydrology

In terms of surface hydrology there are a number of streams, rivers and springs in the wider area. An unnamed stream flows in an east to west direction immediately adjacent to the supply source and is a tributary of the River Tyshe which is the main surface water feature in the area.

This stream flows adjacent to the supply source and is noted to be dry frequently, however it is understood that this stream is hydraulically linked to the groundwater and the stream level has been observed to be comparable to the static groundwater level. All streams and springs identified in this report are said to join the River Tyshe downstream of the source.

3.3.2 Conceptual Site Model (CSM)

A revised conceptual site model was prepared as part of this Tier 3 assessment. The revised CSM illustrates the identified potential groundwater pathway from the site to the Ardfert public water supply.



CROSS SECTION NORTH-WEST / SOUTH-EAST

FIGURE 3.2 ARDFERT HISTORIC LANDFILL

CONCEPTUAL SITE MODEL

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3.4 Historic Landfill: Contaminants of Concern

Environmental monitoring detected concentrations of ammoniacal nitrogen, chloride and potassium above the groundwater quality threshold values within groundwater monitoring well BH01 adjacent to the site boundary.

The Tier 2 site investigation identified that the following chemicals in BH01 samples exceed groundwater quality overall threshold values as per the S.I. No. 9 of 2010[1]:

- Ammoniacal Nitrogen as N.
- Chloride.
- Manganese.
- Potassium.
- Iron.

Ammoniacal nitrogen concentration (at 0.296 mg/l) was 1.7 times the groundwater quality threshold value (0.175 mg/l), chloride concentrations (at 73.2 mg/l) were 2.4 times the groundwater quality threshold value (30 mg/l), manganese concentrations were 2.4 times the groundwater quality threshold value (50 µg/l), potassium concentrations (at 14 mg/l) were 2.8 times the groundwater quality threshold value (5 mg/l) while iron concentrations (at 0.355 mg/l) were 1.8 times the groundwater quality threshold (0.2 mg/l).

Accordingly, groundwater quality and the public groundwater supply are at risk of becoming contaminated. Elevated groundwater concentrations of chloride could also be caused by naturally occurring saline water from the coast.

3.5 Impact of Leachate on Groundwater

3.5.1 Groundwater Source Protection Zone

The EPA 'Establishment of Groundwater Source Protection Zones - Ardfert Water Supply Scheme' report states:

- The southern extent of the zone of contribution for the Ardfert public supply is uncertain. Based on the current boundaries of the protection zone the historical landfill site is approximately 270 m to the outer source protection zone, at its closest point.
- Recharge to the sand and gravel aquifer not only comes from direct infiltration of rainfall over the area underlain by the sands and gravels but also from karstified surrounding bedrock.

Both the desktop study and site investigation conducted as part of the Tier 2 assessment confirm the presence of karstified bedrock beneath the historical landfill site.

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

The revised CSM illustrates the identified potential groundwater pathway from the site to the Ardfert sand and gravel aquifer and public water supply.

As the site is located within the same geological unit as the Ardfert sand and gravel aquifer, and comprises karstified bedrock, there may be a groundwater pathway to the Ardfert public water supply from the historical landfill site however the historical landfill is not identified or referenced as being a potential risk within the EPA Establishment of Groundwater Source Protection Zones, Ardfert Water Supply Scheme, Ardfert South Borehole 2012 report.

3.5.2 Potential Leachate Generation

It is important to estimate the potential quantity of leachate or contaminated groundwater produced at the site in order to quantify any potential impacts that leachate generation from the historical landfill, may have on the underlying groundwater aquifer and the Ardfert PWS. At Ardfert the groundwater level is below the waste body therefore, the generation and subsequent vertical migration of leachate is driven only by rainfall percolation inputs through the waste body.

The vertical infiltration of rainfall above the site to the underlying groundwater aquifer is determined by the groundwater recharge rate at the site.

The recharge rate at the site is estimated to be 670 mm/year with an effective rainfall rate of 788 mm/year resulting in a recharge co-efficient of 85%.

85% x 788 mm/year = 669.8 mm/year or 0.6698 m/year (available rainfall for recharge over the landfill area.

Aquifer Recharge Volume = Recharge x Area of Landfill.

Aquifer Recharge Volume = 0.6698 m/year x 1,675 m^2.

Aquifer Recharge Volume over landfill area = ***1,122 m^3/year [3 m^3/day]****.*

The Ardfert Water Supply currently abstracts from two groundwater abstractions wells PW1 and PW2 which are pumped alternatively on a 24-hour basis. The abstraction yield ranges from 1,200 to 1,900 m^3/day.

Based on the calculations shown above, assuming all groundwater was contributing to the water supply source, the estimated volume of aquifer recharge over the landfill area would be contributing **0.16% - 0.26%** of the daily drinking water supply provided by the Ardfert water supply.

This determination shows the risk of landfill leachate negatively impacting the drinking water quality of the Ardfert Public Water Supply is low.

This determination is consistent with the review of historical groundwater monitoring and the conclusions drawn within the 2012 EPA report, which stated that the groundwater quality was 'generally good'.

3.5.3 Leachate Dispersion Modelling and Assessment

Although water quality monitoring of the water supply suggests that the historical landfill is not compromising water quality in the Ardfert source protection areas, the EPA CoP requires a conservative assessment of potential leachate impacts on groundwater quality.

To conduct this conservative assessment, the Hydrogeological Risk Assessment for Land Contamination - Remedial Targets Worksheet developed by the UK Environment Agency's Science Group was utilised.

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 downstream. 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 on the following (simplified) inputs:

- Source characteristics (i.e., leachate species concentration, retardation, half-life).
- Aquifer characteristics (permeability, porosity, hydraulic gradient).

As noted in Section 3.4 ammoniacal nitrogen, chloride, manganese, potassium and iron were shown to be present in groundwater at the site in concentrations above the relevant groundwater quality thresholds. The Tier 2 investigation noted that slightly elevated iron and elevated manganese concentrations at BH01 were typical of the local bedrock hydrochemistry and as such do not need further examination in the Tier 3 assessment.

The UK EA worksheet relies on the input of single values; therefore, it was necessary to make several assumptions using available site-specific data and typical values obtained from literature studies representing prevailing site conditions.

The input parameters used in this model are outlined in Table 3-1:

Table 3-1: UK EA Remedial Targets Worksheet Model Inputs

Input Parameter	Unit	Ammoniacal Nitrogen	Chloride	Potassium	Source
Target Concentration	*mg/l*	0.175	30	5	S.I No. 9 of 2016 and EPA IGV
Initial contaminant concentration in groundwater at plume core	*mg/l*	0.296	73.2	14	Maximum BH01 groundwater monitoring well concentration (2019)[1]
Half-life for degradation of contaminant in water	*days*	$1x10^9$			Assumed high value (no degradation)

Input Parameter	Unit	Ammoniacal Nitrogen	Chloride	Potassium	Source
Width of plume in aquifer at source (perpendicular to flow)	*m*	80			Approximate width of site/waste extent based on site investigation
Plume thickness at source	*m*	1			Assumed thickness, waste is deposited directly on limestone bedrock
Saturated aquifer thickness	*m*	9.5			Average aquifer thickness based on Ardfert PWS gravel thickness of 7-12m
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
Hydraulic gradient	*fraction*	0.001			Assumed - hydraulic gradient applied in EPA Ardfert PWS report
Hydraulic conductivity of aquifer	*m/d*	50			Assumed single conductivity based on permeability of Ardfert sand/gravel aquifer
Distance to compliance point	*m*	270			Distance from site to boundary of Ardfert PWS outer protection zone
Time Since Pollutant entered groundwater	*days*	50, 100, 500 and 1000 years [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

Note 1: Groundwater monitoring well BH01 is located slightly cross-gradient from estimated groundwater flow

3.5.4 Results - EA UK Remedial Targets Worksheet

This model was used to estimate the dispersion of ammoniacal nitrogen, chloride and potassium. The groundwater concentrations at a range of distances from the source at different time intervals are presented in Table 3-2.

The range of distances are automatically generated by the model based on the percentages of the compliance point distance (270 m) i.e., 13.5 m [5%], 54 m [20%], 108 m [40%] and 270 m [100%].

Table 3-2: 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 13.5m (mg/l)*	*Conc. at 54 m (mg/l)*	*Conc. at 108m (mg/l)*	*Conc. at 270 m (mg/l)*
25	0.296	0.0826	0.0423	0.0273	0.0114
50	0.296	0.0855	0.0426	0.0278	0.0137
100	0.296	0.0855	0.0426	0.0278	0.0137
500	0.296	0.0855	0.0426	0.0278	0.0137
1000	0.296	0.0855	0.0426	0.0278	0.0137
Chloride (mg/l)			*Groundwater threshold Value (GTV) = 30 mg/l*		
25	73.2	21.1	10.5	6.88	3.41
50	73.2	21.1	10.5	6.88	3.41
100	73.2	21.1	10.5	6.88	3.41
Years of Dispersion	Initial Plume Concentration (mg/l)	*Conc.at 13.5m (mg/l)*	*Conc. at 54 m (mg/l)*	*Conc. at 108m (mg/l)*	*Conc. at 270 m (mg/l)*
500	73.2	21.1	10.5	6.88	3.41
1000	73.2	21.1	10.5	6.88	3.41
Potassium (mg/l)			*Groundwater threshold Value (GTV) = 5 mg/l*		
25	14	4.04	4.04	4.04	4.04
50	14	4.04	2.02	1.32	0.652
100	14	4.04	2.02	1.32	0.652
500	14	4.04	2.02	1.32	0.652
1000	14	4.04	2.02	1.32	0.652

3.5.5 Discussion of Results

The model was used to predict downgradient concentrations of the identified pollutants (ammoniacal nitrogen, chloride and manganese) at 13.5 m, 54 m, 108 m and 270 m downstream of the site after the stated number of years of dispersion (25, 50, 100, 500 and 1000 years) at the defined permanent source concentrations.

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, no exceedances of the groundwater threshold were observed at any distance from the source or at any time interval. This indicates that leachate will not impact on the groundwater quality of the underlying aquifer at a local level, or the Ardfert Public Water Supply.

3.6 Impact of Leachate on Receiving Surface Waters

The assessment of the potential impact of leachate migration on the River Tyshe, downgradient and north of the site was shown to be a low.

If rainfall (deep) percolation inputs occur this may encourage leachate breakouts to enter the waterbody. Ammonia was shown to exceed the relevant groundwater quality thresholds at borehole BH01 (upgradient of the River Tyshe). Ammonia is a commonly occurring pollutant associated with landfills and/or agricultural practices.

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.

3.6.1 Assimilative Capacity Assessment

Table 3-3 shows the assimilative capacity of receiving waters in relation to Ammonia to be **0.023 kg/day**.

Table 3-3: Assimilative Capacity

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)	0.13	Assumed background concentration as per 2014 baseline concentration from EPA monitoring Station RS23T020400 on the River Tyshe
F95 = the 95%ile flow in the river (m^3/s)	0.027	Obtained from online EPA Hydrotool for river segment adjacent to site.
Assimilative Capacity kg/day	**0.023**	AC (kg/day) = (0.14 - 0.035) x 0.019 x 86.4

3.6.2 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:* *0.0035-5 l/s*
- *Concentration of ammonia in leachate:* *0.296 mg/l NH_4 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 leachate breakout flows (0.0035 - 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 0.296 mg/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 3-5.

3.6.3 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 3-4 was applied:

Table 3-4: 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);	0.027	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);	0.13	Assumed background concentration as per 2014 baseline concentration from EPA monitoring Station RS23T020400 on River Tyshe
f is the flow of the discharge (litre/sec);	0.035[1] to 5	Assumed discharge rate based on leachate generation estimate and notional leachate breakout rates

c is the maximum concentration of pollutant in the discharge (mg/l);	0.296	Maximum concentration of ammonia (NH_4) detected in BH01
T is the concentration of pollutant downstream of the discharge.	Varies based on flows of 0.0035 - 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

Note 1: leachate breakout flow of 0.0035 l/s assumed based on leachate generation estimation (See Section 3.5.1)

Table 3-5: 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 0.296 mg/l	% Impact Breakout has on of Assimilative Capacity (see Note 3)	Estimated Downstream Concentration ammoniacal nitrogen (mg/l)
0.035	3	0.001	4%	0.130
1	86	0.026	110%	0.136
2	173	0.051	219%	0.141
3	259	0.077	329%	0.147
4	346	0.102	439%	0.151
5	432	0.128	548%	0.156

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 0.023 kg/day ammonia (Table 3-3).

Table 3-5 results show that only leachate breakout flow rates between 0.0035 and 1 l/s (86 m^3/day) will be compliant with S.I. No. 77 of 2019 ('Good' status 95%-ile 0.140 mg/l).

At discharge rates of 0.0035 l/s (3 m^3/day) and 1 l/s (86 m^3/day) the discharges to surface waters will consume between 4 % and 110% of the assimilative capacity of the river, with respect to ammoniacal nitrogen. Assuming these flow rates the estimated downstream ammonia concentrations:

- Will not comply with "Good" status mean threshold value of 0.065 mg/l ammoniacal nitrogen. However, upstream monitoring of the River Tyshe shows that ammonia concentrations are already exceeding this limit.
- Will remain compliant with "Good" status 95%-ile threshold value of 0.140 mg/l with predicted concentrations of 0.130 and 0.136 mg/l ammoniacal nitrogen at assumed discharge flow rates of 0.0035 l/s and 1 l/s.

Tables 3-4 and 3-5 mass balance calculations predict that if leachate breakouts occurred containing concentrations of 0.296 mg/l NH_4 this discharge will cause downstream concentrations of ammonia 0.130 mg/l to 0.156 mg/l (increases of 0% to 20%) for flow rates between 0.0035 l/s and 5 l/s.

The leachate breakout estimate of 1 l/s from the site is considered to be very conservative given that the percolation inputs are estimated to be 0.035 l/s (3 m^3/day).

3.6.4 Discussion of Results

Overall, the assimilative capacity assessment to determine potential impacts of leachate breakouts on receiving surface waters shows that the:

- For a leachate breakout flow rate of <0.035 l/s and assuming that all potential leachate is discharged to the receiving water, here will be no change in ammonia concentration downstream of the site. Elevated ammonia concentration upstream of the site limits the available assimilative capacity in the river, however at a leachate breakout flow rate of 0.035 l/s the discharge would consume only 4% of the assimilative capacity.
- For a higher, albeit unlikely leachate breakout flow rate (1 l/s), the downstream surface water assimilative capacity will not be able to accommodate leachate breakouts containing up to 0.296 mg/l ammoniacal nitrogen. Under this flow rate, additional loading of ammonia to the river will potentially exacerbate the poor quality of the river with respect to nutrient concentrations.

There are no records of leachate breakout occurring on site and the estimate of surface rainwater infiltration of 0.035 l/s assumes in this assessment there will be no percolation inputs to groundwater as a worst-case scenario.

Given the small catchment area of the site and the existing soil cap thickness it is unlikely that breakout flow rates in excess of 0.035 l/s will occur. Accordingly, the risk of leachate contaminating the River Tyshe is low.

Accordingly, only minor remedial measures will be required to mitigate the low risk of leachate breakout contaminating receiving surface waters.

3.7 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 3-6.

The results of this model 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 gas emissions from onsite well (BH02) and perimeter groundwater monitoring well (BH01) was conducted in October 2019 as part of the Tier 2 site investigation. Both wells yielded trace quantities of methane at 1.2% and 1.0% respectively and carbon dioxide concentrations of 1.3% and 0.8% respectively.

In accordance with the EPA CoP the trigger level for methane outside the waste body is 1.0% v/v for 1.5% v/v for carbon dioxide.

Table 3-6: Well Gas Monitoring Results October 2019

Date: 23-10-2019						
Sample Station	CH_4	CO_2	O_2	Atmospheric Pressure	Staff Member	Weather
	(% v/v)	(% v/v)	(% v/v)	(mbar)		
BH01	**1.2**	1.3	21.8	1005	Emily Archer	Overcast, heavy rain, showers, 12°C
BH02	1.0	0.8	20.9			

The trigger levels indicate of continued biological breakdown of organic material. Whilst methane at these very low levels can be caused by roots and other organic debris, this analysis takes a conservative approach and assumes it derives from historic waste inputs.

Table 3-7: LandGEM Model Inputs

Landfill Characteristics	Input	Source
Landfill Open Year	1970	Exact timeframe of landfill operation is unknown. Assumed site to be operational through the 1970s. Start of filling operations assumed.
Landfill Closure Year	1980	Anecdotal evidence suggests landfilling activities ceased c.1980
Have Model Closure Calculate Closure Year	Yes	
Waste Design Capacity (megagrams/tonnes)	7,035	Mass based on estimated waste volume determined as part of Tier 2 assessment and site investigation.
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	

Landfill Characteristics	Input	Source
NMOC Concentration (ppmv as hexane)	CAA – 4,000	
Methane Content (% by volume)	CAA – 50% by volume	
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)		
1970 - 1980	704	Exact waste acceptance quantities per year are unknown. Worst case assumed waste design capacity was filled equally over 1970 to 1980 (10 year) period

3.7.1 Results - LandGEM

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

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 3-8. The model predicted that the site is currently generating 1.532 m^3/hr of methane across the entire site area. This will reduce to 0.929 m^3/hr by 2029.

Table 3-8: 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	17	10.168	13423	8142	0.002	0.001	1.532	0.929
Methane	4	2.716	6712	4071	0.001	0.000	0.766	0.465
Carbon dioxide	12	7.452	6712	4071	0.001	0.001	0.766	0.465
NMOC	0	0.117	54	33	0.000	0.000	0.006	0.004

The approximate maximum waste deposition footprint was estimated to be 1,675m^2. The estimated volume and mass of landfill gas generated and potentially released per m^2 of the total landfill area are presented in Table 3-9.

Table 3-9: 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	0.010	4.861	8.014	4.861
Methane	0.003	2.430	4.007	2.430
Carbon dioxide	0.007	2.430	4.007	2.430
NMOC	0.000	0.019	0.032	0.019

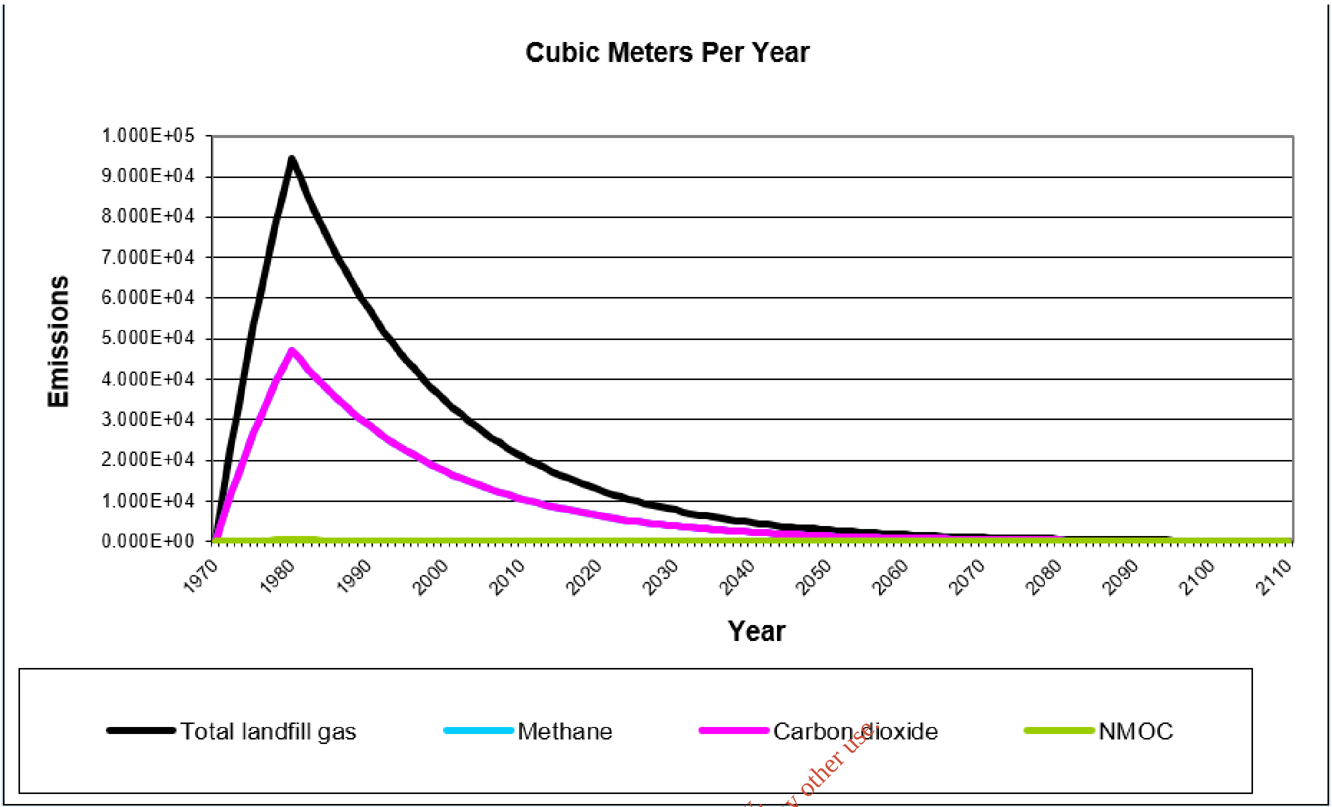
3.7.2 Discussion of Results

The outcome of the LandGEM model predicts a low rate of landfill gas generation in the 2019 (1.532 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 40-2,500+ 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 3-8, LandGEM estimated that in the current year (2019) a very small quantity of 1.532 m3/hour of landfill gas from the whole site is generated 50% percent of which is assumed to be methane (0.766 m3) and 50 % of which is carbon dioxide. Landfill gas monitoring of groundwater wells conducted in 2019 yielded only trace amounts of methane. The LandGEM model using estimated waste inputs, predicts that methane production is still occurring at low flow rates and that this will continue for a number of years.

Figure 3-3 below shows the estimated landfill gas generation rates per year during the assumed operational phase (c.1970 to 1980) and predicted generation rates from 1980 onwards following closure of the site. The model assumes equal production rates for both methane and carbon dioxide and are represented by the pink trendline.



Note 1: LandGEM assumes methane and carbon dioxide production volumes are equal and the magenta line shown represents both methane and carbon dioxide.

Figure 3-3: LandGEM Landfill Gas Volume Generation Rate

The complete summary report on model inputs and outputs/results generated by LandGEM is included in Appendix 3 of this report.

4. SUMMARY FINDINGS AND RECOMMENDATIONS

4.1 Summary Findings

The Tier 3 assessment:

- Reviewed the findings of the Tier 1 risk assessment (determined the site to be of Moderate Risk (Class B)).
- Reviewed the findings of the Tier 2 site investigation and risk assessment (determined the site to be of Moderate Risk (Class B)).
- Assessed and determined the overall risk the site may pose to the receiving environment.
- Determined appropriate measures to mitigate or eliminate risks to the environment.

Subsequent reviews in this Tier 3 assessment determined:

- The site to be a Moderate Risk (Class B), with the main risk being the direct connection between the waste body and the underlying groundwater aquifer and potential connection to a public water supply.
- The site presents moderate risks to ground water quality and due to the proximity of the Ardfert Public Water Supply, presents a low potential impact to human receptor. Monitoring of the drinking water supply does not show evidence of contamination however.
- The site presents a low risk of landfill gas migration to human receptors.
- The site presents a low risk of surface water contamination.

Intrusive investigations showed the cap thickness varied between 0.9 m and 1.2 m and results also suggested that waste comprised predominantly inert soils or MSW.

Three quantitative models were used in this Tier 3 assessment to further examine risks associated with groundwater, surface water and landfill gas.

4.1.1 Groundwater

The UK EA Remedial Targets Worksheet model (1) was used to examine the potential impacts on aquifer/groundwater quality and subsequently on the public water supply. This model demonstrated that leachate generated at the landfill site is not likely to have a negative impact on groundwater quality at the Ardfert Public Water Supply or groundwater downstream of the site and the risk of the deposited waste causing a deterioration in groundwater quality at the water supply aquifer is low to very low. Ammoniacal nitrogen, chloride and potassium downstream concentrations were estimated using this model and it was shown that for all parameters, groundwater concentrations were below groundwater quality thresholds (at 0.0138 mg/l, 3.41 mg/l and 0.652 mg/l respective) at the designated compliance point, in this case the edge of the outer groundwater protection zone.

The potential contribution of groundwater and leachate to the public water supply aquifer was also estimated. Calculations based on estimated groundwater recharge at the site and typical pumping rates at the public water supply it was calculated that groundwater, and potentially leachate could contribute 0.16% - 0.26% to public drinking water supply.

The classification of the underlying groundwater aquifer as regionally important also dictates that further protection of the aquifer from the site should be afforded. Whilst there is no evidence of leachate contamination within the source protection zones it is recommended that an additional monitoring borehole be placed approximately midway between the Ardfert Public water supply and the landfill to assess whether or not groundwater quality is influenced by leachate, see Section 5.2.4 below.

4.1.2 Surface Water

An assimilative capacity assessment and mass balance calculations indicated that if leachate breakouts occurred, albeit that there was no visible evidence of such, potential breakout of leachate and discharge to the River Tyshe. This may potentially impact on water quality by further exacerbating the poor quality of the river through additional nutrient loading. The receiving river is not likely to have sufficient assimilative capacity to accommodate a potential leachate emission at the site assuming a conservative leachate breakout flow rate of 1 l/s (a flow of 1l/s is highly unlikely and there is no evidence of leachate breakouts occurring). A mass balance calculation was carried out to predict the potential concentration of ammonia within the river downstream of the site, assuming discharge rates of 0.0035 l/s to 5l/s of leachate to the river. The calculation predicted the background concentration of 0.13 mg/l would increase from 0 mg/l to 0.026 mg/l at each discharge rate and predicted downstream concentrations ranged from 0.13 mg/l to 0.156 mg/l. Only at an assumed discharge flow rate of 0.0035 l/s and 1 l/s the predicted downstream concentration remains below the 95%-ile threshold value (0.140 mg/l).

The risk of surface water contamination from the waste body is considered to be extremely low given that there is no evidence of leachate breakouts, the cap typically exceeds 1.0 m in thickness and underlying waste is typically inert and as such will not be subject to significant settlement which might otherwise create preferential pathways.

4.1.3 Landfill Gas

The output from LandGEM model (2) showed that landfill gas will continue to be generated for several years although in minimal quantities. Although the risk from landfill gas is relatively low, the concentrations of gas detected during fielding monitoring and the indication that gas will continue to be produced, it is recommended that appropriate landfill gas management measures be maintained at the site to further minimise the risk of landfill gas migration.

Appropriate control measures shall be selected in accordance with the EPA Guidance document: *Management of Low Levels of Landfill Gas.* Appropriate measures are are discussed in Section 5. 1.2.

4.2 Recommendations

The existing site has an established grass cover, an effective cap that varies in thickness between 0.9 m and 1.2 m and a waste body that is predominantly inert and will not be subject to significant settlement.

The Tier 3 environmental risk assessment:

- Determined, because the site is in relative proximity to the Ardfert Water Supply and a developed area the need for:
    - Minor remedial capping works.
    - On-going environmental monitoring of groundwater, surface water and landfill gas.

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 grass cover, a cap that varies in thickness between 0.9 m and 1.2 m and contains waste that is predominantly inert and will not be subject to significant settlement. This cap is considered to be compliant with both the Landfill Directive and the Environmental Protection Agency (EPA) publication landfill manual - Landfill Site Design.

The Tier 3 environmental risk assessment:

- Determined the need for minor remedial and monitoring works.

5.1.2 Overview of Primary Risks

The primary environmental risks, were deemed to be:

- Leachate potentially contaminating ground and surface waters.
- Landfill gas impacting nearby receptors via lateral migration.

5.1.3 Environmental Objectives of the Proposed Remediation Plan

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

- Reduce the risk of rainfall inputs percolating into the waste body that might otherwise encourage vertical or lateral movements of leachate into receiving ground and surface waters.
- Encourage vertical passive venting of landfill gas as may be present and so reduce the risk of lateral gas migration from the waste body into adjacent lands.

The primary objectives of the proposed ongoing and improved environmental monitoring will be to provide additional environmental data to advise if the landfill is having any ongoing impacts on adjacent sensitive receptors.

5.1.4 Proposed Remediation Plan

The recommended approach to implement the primary objectives will be to improve the surface condition of the existing grassed cap by regrading, topsoiling and reseeding the cap to encourage:

- Surface water runoff, and
- Establishment of an improved soil structure and cover by seeding with Rhizobium inoculated grass seed and clover.

The proposed grass cover will:

- Facilitate passive venting of gas.
- Facilitate oxidation of low concentration methane emissions.
- Mitigate the risk of lateral gas migration.
- Provide an indicator of excessive methane emissions should they occur as evidenced by vegetation die-back.

The proposed grass cover will:

- Require regular mowing.
- Require fencing to mitigate the risk of poaching that might otherwise encourage water logging of the surface.

It is also recommended that:

- Landfill gas monitoring be carried out from borehole locations shown in Appendix 3 Drawing P1766-0100-0003
- Gas management risk assessments be carried out for future developments on or immediately adjacent to the site.

5.2 Remediation Plan

5.2.1 Proposed Remediation Works

The site is currently used as a general amenity area and proposed capping works shall be cognisant of continued amenity site use.

The proposed remediation cap design and aftercare will require:

- Scrub within the footprint and on the perimeter to be removed.
- Topsoil layer to be rotovated and supplemented if required to establish a 200 mm topsoil layer. Topsoil shall be compliant to BS3882:2015 or equal approved and graded to ensure no localised surface depressions are present.
- Top surface to be re-profiled to remove local depressions to facilitate improved surface runoff and rolled thereafter.
- Grass cover using permanent rhizobium inoculated pasture species rich clover grass mix.
- Regular maintenance requiring a minimum 3 mowings per annum.
- Fenced to prevent poaching by livestock.

The preliminary remediation design is presented in Appendix 4 in the following drawing:

- P1766-0100-0002

The proposed borehole monitoring locations are presented in Appendix 4 in the following drawing:

- P1766-0100-0003

Drawings are included in Appendix 3 to this document.

5.3 Environmental Monitoring

5.3.1 Monitoring Locations

Proposed monitoring locations are shown in Appendix 4 Drawing P1766-0100-0003.

It is recommended that groundwater monitoring be carried out at:

- Existing borehole locations BH02 and BH 0511NEW027 (as referenced by GSI)
- An additional groundwater monitoring well (BH03-Downgradient) be installed at a location (to be confirmed) to the north-west of the waste body. This well should be installed directly downgradient of the waste body between the Ardfert Landfill and the Ardfert Public Water supply.
- Surface water monitoring Locations SW1 and SW2 (as used in the Tier 2 investigation).

It is recommended that gas monitoring be carried out at:

- Existing borehole locations BH02 and BH 0511NEW027 (as referenced by GSI)

5.3.2 Proposed Groundwater and Surface Water Monitoring Regime

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 over 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[2] See Footnote	Frequency*	Surface Water	Groundwater
Level	Quarterly+	-	✓
Flow Rate		-	-
Temperature		✓	✓
Dissolved Oxygen		✓	-
pH		✓	✓
Electrical Conductivity[3]		✓	✓
Total suspended solids		✓	-
Total dissolved solids		-	✓
Ammonia (as N)		✓	✓
Total oxidized nitrogen (as N)		✓	✓
Total organic carbon		-	✓
Biochemical Oxygen Demand		✓	-
Chemical Oxygen Demand		✓	-

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

Groundwater samples shall be taken quarterly from groundwater monitoring boreholes BH02, BH 0511NEW027 (as referenced by the GSI) and proposed BH03.

Surface water samples shall be taken from SW1 and SW2 locations previously used in the Tier 2 assessment and shall be taken every 6 months.

The suite of tests required for groundwater and surface water monitoring shall be as per Table 5-1.

5.3.3 Proposed Gas Monitoring Regime

It is recommended that:

- Gas monitoring be carried out annually.
- Vertical gas monitoring wells be allowed to vent passively throughout the year.
- Prior to annual monitoring, well vents should be closed for a period of 24 hours to allow representative sampling.

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

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

Gas sampling should be carried out using a calibrated gas analyser for the following parameters:

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

Gas wells on or immediately adjacent to historic waste body should terminate at least 3.0 m above adjacent ground surfaces and be capped to prevent rainfall ingress and insertion of ignition sources (cigarettes or other).

Elsewhere monitoring boreholes can be terminated within 500 mm of ground level to mitigate visual impact.

5.4 Remediation Cost Estimates

The following section 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 outlines the costs associated with capping the site:

Table 5-2: Landfill Capping: Cost Estimates

Description	Quantity	Unit	Unit Rate	Capital cost excluding VAT
Design and supervision	1	Item	40,000	40,000
General site clearance	0.1675	ha	20,000	3,350
Excavation for reuse	168	m^3	1.5	2,512
Preparation of excavated surfaces	0.1675	ha	0.75	1,256
Importation of 200 mm topsoil	1,675	m^2	3	5,025
Seeding	1,675	m^2	2	3,350
Surface water drainage infrastructure	1,675	m^2	4	6,700
Fencing	164	m	100	16,370
Independent CQA	1	Item	5,000	5,000
Wells	2	no	4,000	8,000
Contractor prelims 10%	1	Item	9,156	9,156
7.5% contingency	1	Item	7,554	7,554
Total				**€108,273**

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.
- Prices may change subject to prevailing market conditions.

FEHILY TIMONEY

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APPENDIX 1

Environmental Agency (UK) Remedial Targets Worksheet

R&D Publication 20 Remedial Targets Worksheet, Release 3.2

Level 3 - Groundwater

See Note

Input Parameters (using pull down menu)

	Variable	Value	Unit	Source
Contaminant		Ammoniacal Nitrogen		from Level 1
Target Concentration	C_T	1.75E-01	mg/l	from Level 1

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

Domenico - Time Variant — 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

				Source of parameter value
Initial contaminant concentration in groundwater at plume core	C_0	2.96E-01	mg/l	*Maximum BH01 groundwater monitoring well concentration 2019*
Half life for degradation of contaminant in water	$t_{1/2}$	1.00E+09	days	*Assumed high value (no degradation)*
Calculated decay rate	λ	6.93E-10	$days^{-1}$	
Width of plume in aquifer at source (perpendicular to flow)	Sz	8.00E+01	m	*Approximate width of site/waste extent based on site investigation*
Plume thickness at source	Sy	1.00E+00	m	*Assumed thickness - waste is placed directly on limestone bedrock*
Saturated aquifer thickness	da	9.50E+00	m	*Average thickness based on Ardfert PWS*
Bulk density of aquifer materials	ρ	1.55E+00	g/cm^3	*Assumed limestone bulk density*
Effective porosity of aquifer	n	2.75E-01	fraction	*median of assumed assumed porosity applied in LandSim (0.05-0.5)*
Hydraulic gradient	i	1.00E-03	fraction	*Assumed - hydraulic gradient applied in EPA Ardfert Protection zone report*
Hydraulic conductivity of aquifer	K	5.00E+01	m/d	*Assumed single conductivity based on ran*
Distance to compliance point	x	2.70E+02	m	*Hypothetical compliance point at 270m. Di*
Distance (lateral) to compliance point perpendicular to flow direction	z	[redacted]	m	
Distance (depth) to compliance point perpendicular to flow direction	y		m	
Time since pollutant entered groundwater	t	1.83E+06	days	*time variant options only*

Parameters values determined from options

Partition coefficient	Kd	1.25E+00	l/kg	*see options*
Longitudinal dispersivity	ax	2.70E+01	m	*see options*
Transverse dispersivity	az	2.70E+00	m	*see options*
Vertical dispersivity	ay	2.70E-01	m	*see options*

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	1.25E+00	l/kg
Entry for non-polar organic chemicals (option)			
Fraction of organic carbon in aquifer	foc	[redacted]	fraction
Organic carbon partition coefficient	Koc		l/kg
Entry for ionic organic chemicals (option)			
Sorption coefficient for related species	$K_{oc.n}$	[redacted]	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	1.25E+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**	0.00E+00	2.70E+01	7.09E+00	m
Transverse dispersivity	**az**	0.00E+00	2.70E+00	7.09E-01	m
Vertical dispersivity	**ay**	0.00E+00	2.70E-01	7.09E-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

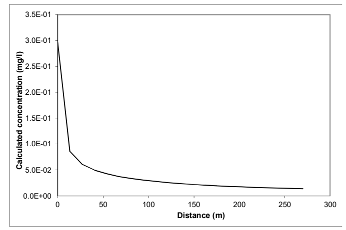
Calculated Parameters

	Variable		
Groundwater flow velocity	v	1.82E-01	m/d
Retardation factor	Rf	8.05E+00	fraction
Decay rate used	λ	6.93E-10	d^{-1}
Rate of contaminant flow due to retardation	u	2.26E-02	m/d
Contaminant concentration at distance x, assuming one-way vertical dispersion	C_{ED}	1.38E-02	mg/l
Attenuation factor (one way vertical dispersion, CO/CED)	**AF**	**2.15E+01**	

Remedial Targets

Remedial Target		**3.76E+00**	**mg/l**	For comparison with measured groundwater concentration.
Domenico - Time Variant				
Distance to compliance point		**270**	**m**	
Concentration of contaminant at compliance point	C_{ED}/C_0	**1.38E-02**	**mg/l**	Domenico - Time Variant
after		**1.8E+06**	**days**	

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.



Calculated concentrations for distance-concentration graph

Domenico - Time Variant
From calculation sheet

Distance	Concentration
	mg/l
0	3.0E-01
13.5	8.55E-02
27.0	6.11E-02
40.5	4.98E-02
54.0	4.27E-02
67.5	3.75E-02
81.0	3.36E-02
94.5	3.04E-02
108.0	2.78E-02
121.5	2.56E-02
135.0	2.38E-02
148.5	2.22E-02
162.0	2.08E-02
175.5	1.95E-02
189.0	1.84E-02
202.5	1.74E-02
216.0	1.66E-02
229.5	1.58E-02
243.0	1.50E-02
256.5	1.44E-02
270.0	1.38E-02

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:	Ardfert
Completed by:	EOC
Date:	########
Version:	1.01

FEHILY TIMONEY

CONSULTANTS IN ENGINEERING, ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX 2

LandGem Model Summary Report

Summary Report

Landfill Name or Identifier: Ardfert Historical Landfill - Co.Kerry

Date: Thursday 30 January 2020

Description/Comments:

About LandGEM:

First-Order Decomposition Rate Equation:

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

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	**1970**	
Landfill Closure Year (with 80-year limit)	**1979**	
Actual Closure Year (without limit)	***1979***	
Have Model Calculate Closure Year?	**Yes**	
Waste Design Capacity	**7,035**	*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)*
1970	704	774	0	0
1971	704	774	704	774
1972	704	774	1,407	1,548
1973	704	774	2,111	2,322
1974	704	774	2,814	3,095
1975	704	774	3,518	3,869
1976	704	774	4,221	4,643
1977	704	774	4,925	5,417
1978	704	774	5,628	6,191
1979	704	774	6,332	6,965
1980	0	0	7,035	7,739
1981	0	0	7,035	7,739
1982	0	0	7,035	7,739
1983	0	0	7,035	7,739
1984	0	0	7,035	7,739
1985	0	0	7,035	7,739
1986	0	0	7,035	7,739
1987	0	0	7,035	7,739
1988	0	0	7,035	7,739
1989	0	0	7,035	7,739
1990	0	0	7,035	7,739
1991	0	0	7,035	7,739
1992	0	0	7,035	7,739
1993	0	0	7,035	7,739
1994	0	0	7,035	7,739
1995	0	0	7,035	7,739
1996	0	0	7,035	7,739
1997	0	0	7,035	7,739
1998	0	0	7,035	7,739
1999	0	0	7,035	7,739
2000	0	0	7,035	7,739
2001	0	0	7,035	7,739
2002	0	0	7,035	7,739
2003	0	0	7,035	7,739
2004	0	0	7,035	7,739
2005	0	0	7,035	7,739
2006	0	0	7,035	7,739
2007	0	0	7,035	7,739
2008	0	0	7,035	7,739
2009	0	0	7,035	7,739

WASTE ACCEPTANCE RATES (Continued)

Year	Waste Accepted		Waste-In-Place	
	(Mg/year)	(short tons/year)	(Mg)	(short tons)
2010	0	0	7,035	7,739
2011	0	0	7,035	7,739
2012	0	0	7,035	7,739
2013	0	0	7,035	7,739
2014	0	0	7,035	7,739
2015	0	0	7,035	7,739
2016	0	0	7,035	7,739
2017	0	0	7,035	7,739
2018	0	0	7,035	7,739
2019	0	0	7,035	7,739
2020	0	0	7,035	7,739
2021	0	0	7,035	7,739
2022	0	0	7,035	7,739
2023	0	0	7,035	7,739
2024	0	0	7,035	7,739
2025	0	0	7,035	7,739
2026	0	0	7,035	7,739
2027	0	0	7,035	7,739
2028	0	0	7,035	7,739
2029	0	0	7,035	7,739
2030	0	0	7,035	7,739
2031	0	0	7,035	7,739
2032	0	0	7,035	7,739
2033	0	0	7,035	7,739
2034	0	0	7,035	7,739
2035	0	0	7,035	7,739
2036	0	0	7,035	7,739
2037	0	0	7,035	7,739
2038	0	0	7,035	7,739
2039	0	0	7,035	7,739
2040	0	0	7,035	7,739
2041	0	0	7,035	7,739
2042	0	0	7,035	7,739
2043	0	0	7,035	7,739
2044	0	0	7,035	7,739
2045	0	0	7,035	7,739
2046	0	0	7,035	7,739
2047	0	0	7,035	7,739
2048	0	0	7,035	7,739
2049	0	0	7,035	7,739

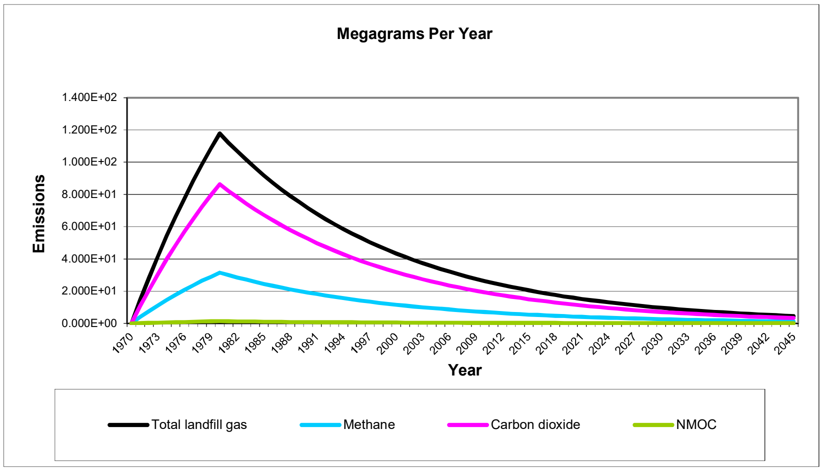
Pollutant Parameters

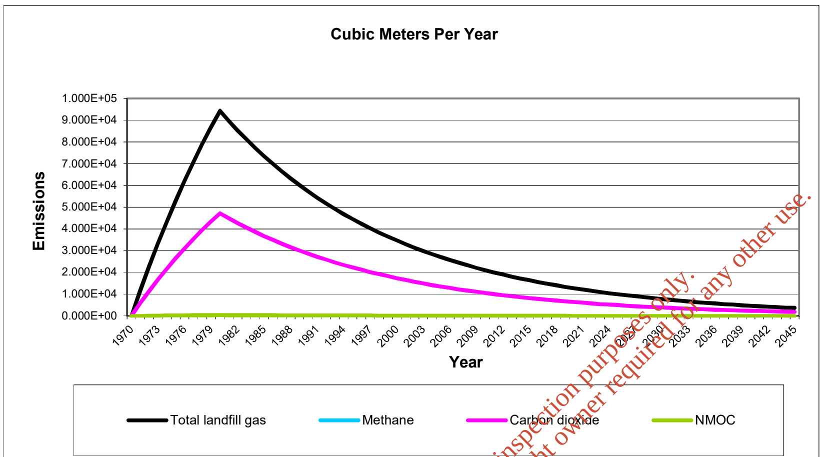
	Compound	Gas / Pollutant Default Parameters: Concentration (*ppmv*)	Molecular Weight	User-specified Pollutant Parameters: Concentration (*ppmv*)	Molecular Weight
Gases	Total landfill gas		0.00		
	Methane		16.04		
	Carbon dioxide		44.01		
	NMOC	4,000	86.18		
Pollutants	1,1,1-Trichloroethane (methyl chloroform) - 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		

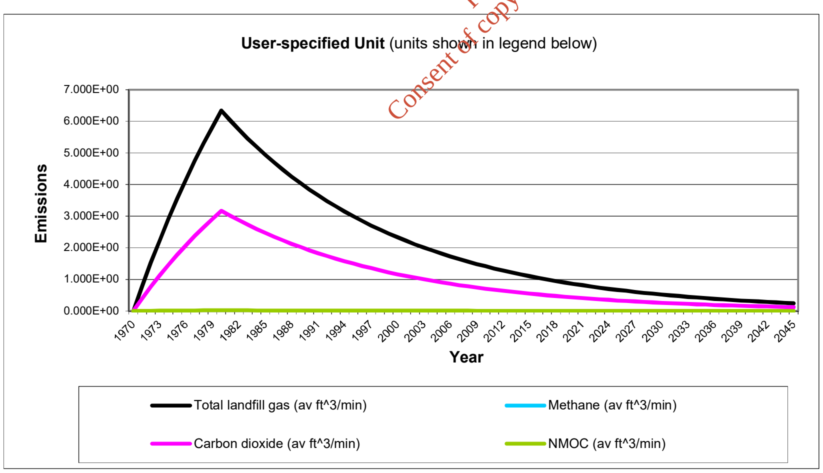
Pollutant Parameters (Continued)

	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
Year
Total landfill gas
Methane
Carbon dioxide
NMOC


Cubic Meters Per Year
Emissions
Year
Total landfill gas
Methane
Carbon dioxide
NMOC


User-specified Unit (units shown in legend below)
Emissions
Year
Total landfill gas (av ft^3/min)
Methane (av ft^3/min)
Carbon dioxide (av ft^3/min)
NMOC (av ft^3/min)

Results

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
1970	0	0	0	0	0	0
1971	1.460E+01	1.169E+04	7.858E-01	3.901E+00	5.847E+03	3.929E-01
1972	2.850E+01	2.282E+04	1.533E+00	7.612E+00	1.141E+04	7.666E-01
1973	4.171E+01	3.340E+04	2.244E+00	1.114E+01	1.670E+04	1.122E+00
1974	5.428E+01	4.347E+04	2.920E+00	1.450E+01	2.173E+04	1.460E+00
1975	6.624E+01	5.304E+04	3.564E+00	1.769E+01	2.652E+04	1.782E+00
1976	7.761E+01	6.215E+04	4.176E+00	2.073E+01	3.107E+04	2.088E+00
1977	8.843E+01	7.081E+04	4.758E+00	2.362E+01	3.541E+04	2.379E+00
1978	9.872E+01	7.905E+04	5.312E+00	2.637E+01	3.953E+04	2.656E+00
1979	1.085E+02	8.689E+04	5.838E+00	2.899E+01	4.345E+04	2.919E+00
1980	1.178E+02	9.435E+04	6.339E+00	3.147E+01	4.717E+04	3.170E+00
1981	1.121E+02	8.975E+04	6.030E+00	2.994E+01	4.487E+04	3.015E+00
1982	1.066E+02	8.537E+04	5.736E+00	2.848E+01	4.269E+04	2.868E+00
1983	1.014E+02	8.121E+04	5.456E+00	2.709E+01	4.060E+04	2.728E+00
1984	9.647E+01	7.725E+04	5.190E+00	2.577E+01	3.862E+04	2.595E+00
1985	9.176E+01	7.348E+04	4.937E+00	2.451E+01	3.674E+04	2.469E+00
1986	8.729E+01	6.990E+04	4.696E+00	2.332E+01	3.495E+04	2.348E+00
1987	8.303E+01	6.649E+04	4.467E+00	2.218E+01	3.324E+04	2.234E+00
1988	7.898E+01	6.324E+04	4.249E+00	2.110E+01	3.162E+04	2.125E+00
1989	7.513E+01	6.016E+04	4.042E+00	2.007E+01	3.008E+04	2.021E+00
1990	7.146E+01	5.723E+04	3.845E+00	1.909E+01	2.861E+04	1.922E+00
1991	6.798E+01	5.443E+04	3.657E+00	1.816E+01	2.722E+04	1.829E+00
1992	6.466E+01	5.178E+04	3.479E+00	1.727E+01	2.589E+04	1.740E+00
1993	6.151E+01	4.925E+04	3.309E+00	1.643E+01	2.463E+04	1.655E+00
1994	5.851E+01	4.685E+04	3.148E+00	1.563E+01	2.343E+04	1.574E+00
1995	5.566E+01	4.457E+04	2.994E+00	1.487E+01	2.228E+04	1.497E+00
1996	5.294E+01	4.239E+04	2.848E+00	1.414E+01	2.120E+04	1.424E+00
1997	5.036E+01	4.033E+04	2.710E+00	1.345E+01	2.016E+04	1.355E+00
1998	4.790E+01	3.836E+04	2.577E+00	1.280E+01	1.918E+04	1.289E+00
1999	4.557E+01	3.649E+04	2.452E+00	1.217E+01	1.824E+04	1.226E+00
2000	4.335E+01	3.471E+04	2.332E+00	1.158E+01	1.735E+04	1.166E+00
2001	4.123E+01	3.302E+04	2.218E+00	1.101E+01	1.651E+04	1.109E+00
2002	3.922E+01	3.141E+04	2.110E+00	1.048E+01	1.570E+04	1.055E+00
2003	3.731E+01	2.987E+04	2.007E+00	9.965E+00	1.494E+04	1.004E+00
2004	3.549E+01	2.842E+04	1.909E+00	9.479E+00	1.421E+04	9.547E-01
2005	3.376E+01	2.703E+04	1.816E+00	9.017E+00	1.352E+04	9.081E-01
2006	3.211E+01	2.571E+04	1.728E+00	8.577E+00	1.286E+04	8.638E-01
2007	3.055E+01	2.446E+04	1.643E+00	8.159E+00	1.223E+04	8.217E-01
2008	2.906E+01	2.327E+04	1.563E+00	7.761E+00	1.163E+04	7.816E-01
2009	2.764E+01	2.213E+04	1.487E+00	7.383E+00	1.107E+04	7.435E-01
2010	2.629E+01	2.105E+04	1.414E+00	7.022E+00	1.053E+04	7.072E-01
2011	2.501E+01	2.003E+04	1.346E+00	6.680E+00	1.001E+04	6.728E-01
2012	2.379E+01	1.905E+04	1.280E+00	6.354E+00	9.524E+03	6.399E-01
2013	2.263E+01	1.812E+04	1.217E+00	6.044E+00	9.060E+03	6.087E-01
2014	2.152E+01	1.724E+04	1.158E+00	5.750E+00	8.618E+03	5.790E-01
2015	2.048E+01	1.640E+04	1.102E+00	5.469E+00	8.198E+03	5.508E-01
2016	1.948E+01	1.560E+04	1.048E+00	5.202E+00	7.798E+03	5.239E-01
2017	1.853E+01	1.484E+04	9.968E-01	4.949E+00	7.418E+03	4.984E-01
2018	1.762E+01	1.411E+04	9.482E-01	4.707E+00	7.056E+03	4.741E-01
2019	1.676E+01	1.342E+04	9.019E-01	4.478E+00	6.712E+03	4.510E-01

Results (Continued)

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2020	1.595E+01	1.277E+04	8.579E-01	4.259E+00	6.384E+03	4.290E-01
2021	1.517E+01	1.215E+04	8.161E-01	4.052E+00	6.073E+03	4.080E-01
2022	1.443E+01	1.155E+04	7.763E-01	3.854E+00	5.777E+03	3.881E-01
2023	1.372E+01	1.099E+04	7.384E-01	3.666E+00	5.495E+03	3.692E-01
2024	1.306E+01	1.045E+04	7.024E-01	3.487E+00	5.227E+03	3.512E-01
2025	1.242E+01	9.944E+03	6.682E-01	3.317E+00	4.972E+03	3.341E-01
2026	1.181E+01	9.459E+03	6.356E-01	3.155E+00	4.730E+03	3.178E-01
2027	1.124E+01	8.998E+03	6.046E-01	3.002E+00	4.499E+03	3.023E-01
2028	1.069E+01	8.559E+03	5.751E-01	2.855E+00	4.280E+03	2.875E-01
2029	1.017E+01	8.142E+03	5.470E-01	2.716E+00	4.071E+03	2.735E-01
2030	9.672E+00	7.745E+03	5.204E-01	2.583E+00	3.872E+03	2.602E-01
2031	9.200E+00	7.367E+03	4.950E-01	2.457E+00	3.683E+03	2.475E-01
2032	8.751E+00	7.008E+03	4.708E-01	2.338E+00	3.504E+03	2.354E-01
2033	8.325E+00	6.666E+03	4.479E-01	2.224E+00	3.333E+03	2.239E-01
2034	7.919E+00	6.341E+03	4.260E-01	2.115E+00	3.170E+03	2.130E-01
2035	7.532E+00	6.032E+03	4.053E-01	2.012E+00	3.016E+03	2.026E-01
2036	7.165E+00	5.737E+03	3.855E-01	1.914E+00	2.869E+03	1.927E-01
2037	6.816E+00	5.458E+03	3.667E-01	1.821E+00	2.729E+03	1.833E-01
2038	6.483E+00	5.191E+03	3.488E-01	1.732E+00	2.596E+03	1.744E-01
2039	6.167E+00	4.938E+03	3.318E-01	1.647E+00	2.469E+03	1.659E-01
2040	5.866E+00	4.697E+03	3.156E-01	1.567E+00	2.349E+03	1.578E-01
2041	5.580E+00	4.468E+03	3.002E-01	1.491E+00	2.234E+03	1.501E-01
2042	5.308E+00	4.250E+03	2.856E-01	1.418E+00	2.125E+03	1.428E-01
2043	5.049E+00	4.043E+03	2.717E-01	1.349E+00	2.022E+03	1.358E-01
2044	4.803E+00	3.846E+03	2.584E-01	1.283E+00	1.923E+03	1.292E-01
2045	4.569E+00	3.658E+03	2.458E-01	1.220E+00	1.829E+03	1.229E-01
2046	4.346E+00	3.480E+03	2.338E-01	1.161E+00	1.740E+03	1.169E-01
2047	4.134E+00	3.310E+03	2.224E-01	1.104E+00	1.655E+03	1.112E-01
2048	3.932E+00	3.149E+03	2.116E-01	1.050E+00	1.574E+03	1.058E-01
2049	3.740E+00	2.995E+03	2.012E-01	9.991E-01	1.498E+03	1.006E-01
2050	3.558E+00	2.849E+03	1.914E-01	9.504E-01	1.425E+03	9.572E-02
2051	3.385E+00	2.710E+03	1.821E-01	9.040E-01	1.355E+03	9.105E-02
2052	3.219E+00	2.578E+03	1.732E-01	8.599E-01	1.289E+03	8.661E-02
2053	3.062E+00	2.452E+03	1.648E-01	8.180E-01	1.226E+03	8.238E-02
2054	2.913E+00	2.333E+03	1.567E-01	7.781E-01	1.166E+03	7.837E-02
2055	2.771E+00	2.219E+03	1.491E-01	7.402E-01	1.109E+03	7.454E-02
2056	2.636E+00	2.111E+03	1.418E-01	7.041E-01	1.055E+03	7.091E-02
2057	2.507E+00	2.008E+03	1.349E-01	6.697E-01	1.004E+03	6.745E-02
2058	2.385E+00	1.910E+03	1.283E-01	6.371E-01	9.549E+02	6.416E-02
2059	2.269E+00	1.817E+03	1.221E-01	6.060E-01	9.083E+02	6.103E-02
2060	2.158E+00	1.728E+03	1.161E-01	5.764E-01	8.640E+02	5.805E-02
2061	2.053E+00	1.644E+03	1.104E-01	5.483E-01	8.219E+02	5.522E-02
2062	1.953E+00	1.564E+03	1.051E-01	5.216E-01	7.818E+02	5.253E-02
2063	1.857E+00	1.487E+03	9.994E-02	4.961E-01	7.437E+02	4.997E-02
2064	1.767E+00	1.415E+03	9.506E-02	4.719E-01	7.074E+02	4.753E-02
2065	1.681E+00	1.346E+03	9.043E-02	4.489E-01	6.729E+02	4.521E-02
2066	1.599E+00	1.280E+03	8.602E-02	4.270E-01	6.401E+02	4.301E-02
2067	1.521E+00	1.218E+03	8.182E-02	4.062E-01	6.089E+02	4.091E-02
2068	1.447E+00	1.158E+03	7.783E-02	3.864E-01	5.792E+02	3.892E-02
2069	1.376E+00	1.102E+03	7.403E-02	3.676E-01	5.509E+02	3.702E-02
2070	1.309E+00	1.048E+03	7.042E-02	3.496E-01	5.241E+02	3.521E-02

Results (Continued)

Year	Total landfill gas			Methane		
	(Mg/year)	(m^3/year)	(av ft^3/min)	(Mg/year)	(m^3/year)	(av ft^3/min)
2071	1.245E+00	9.970E+02	6.699E-02	3.326E-01	4.985E+02	3.349E-02
2072	1.184E+00	9.484E+02	6.372E-02	3.164E-01	4.742E+02	3.186E-02
2073	1.127E+00	9.021E+02	6.061E-02	3.009E-01	4.511E+02	3.031E-02
2074	1.072E+00	8.581E+02	5.766E-02	2.863E-01	4.291E+02	2.883E-02
2075	1.019E+00	8.163E+02	5.485E-02	2.723E-01	4.081E+02	2.742E-02
2076	9.697E-01	7.765E+02	5.217E-02	2.590E-01	3.882E+02	2.609E-02
2077	9.224E-01	7.386E+02	4.963E-02	2.464E-01	3.693E+02	2.481E-02
2078	8.774E-01	7.026E+02	4.721E-02	2.344E-01	3.513E+02	2.360E-02
2079	8.346E-01	6.683E+02	4.490E-02	2.229E-01	3.342E+02	2.245E-02
2080	7.939E-01	6.357E+02	4.271E-02	2.121E-01	3.179E+02	2.136E-02
2081	7.552E-01	6.047E+02	4.063E-02	2.017E-01	3.024E+02	2.032E-02
2082	7.184E-01	5.752E+02	3.865E-02	1.919E-01	2.876E+02	1.932E-02
2083	6.833E-01	5.472E+02	3.676E-02	1.825E-01	2.736E+02	1.838E-02
2084	6.500E-01	5.205E+02	3.497E-02	1.736E-01	2.602E+02	1.749E-02
2085	6.183E-01	4.951E+02	3.327E-02	1.652E-01	2.476E+02	1.663E-02
2086	5.881E-01	4.710E+02	3.164E-02	1.571E-01	2.355E+02	1.582E-02
2087	5.595E-01	4.480E+02	3.010E-02	1.494E-01	2.240E+02	1.505E-02
2088	5.322E-01	4.261E+02	2.863E-02	1.421E-01	2.131E+02	1.432E-02
2089	5.062E-01	4.054E+02	2.724E-02	1.352E-01	2.027E+02	1.362E-02
2090	4.815E-01	3.856E+02	2.591E-02	1.286E-01	1.928E+02	1.295E-02
2091	4.580E-01	3.668E+02	2.464E-02	1.223E-01	1.834E+02	1.232E-02
2092	4.357E-01	3.489E+02	2.344E-02	1.164E-01	1.744E+02	1.172E-02
2093	4.145E-01	3.319E+02	2.230E-02	1.107E-01	1.659E+02	1.115E-02
2094	3.942E-01	3.157E+02	2.121E-02	1.053E-01	1.578E+02	1.061E-02
2095	3.750E-01	3.003E+02	2.018E-02	1.002E-01	1.501E+02	1.009E-02
2096	3.567E-01	2.856E+02	1.919E-02	9.528E-02	1.428E+02	9.596E-03
2097	3.393E-01	2.717E+02	1.826E-02	9.064E-02	1.359E+02	9.128E-03
2098	3.228E-01	2.585E+02	1.737E-02	8.622E-02	1.292E+02	8.683E-03
2099	3.070E-01	2.459E+02	1.652E-02	8.201E-02	1.229E+02	8.260E-03
2100	2.921E-01	2.339E+02	1.571E-02	7.801E-02	1.169E+02	7.857E-03
2101	2.778E-01	2.225E+02	1.495E-02	7.421E-02	1.112E+02	7.474E-03
2102	2.643E-01	2.116E+02	1.422E-02	7.059E-02	1.058E+02	7.109E-03
2103	2.514E-01	2.013E+02	1.352E-02	6.715E-02	1.006E+02	6.762E-03
2104	2.391E-01	1.915E+02	1.287E-02	6.387E-02	9.574E+01	6.433E-03
2105	2.275E-01	1.821E+02	1.224E-02	6.076E-02	9.107E+01	6.119E-03
2106	2.164E-01	1.733E+02	1.164E-02	5.779E-02	8.663E+01	5.820E-03
2107	2.058E-01	1.648E+02	1.107E-02	5.497E-02	8.240E+01	5.537E-03
2108	1.958E-01	1.568E+02	1.053E-02	5.229E-02	7.838E+01	5.267E-03
2109	1.862E-01	1.491E+02	1.002E-02	4.974E-02	7.456E+01	5.010E-03
2110	1.771E-01	1.418E+02	9.531E-03	4.732E-02	7.092E+01	4.765E-03

Results (Continued)

Year	Carbon dioxide			NMOC		
	(Mg/year)	(m^3/year)	(av ft^3/min)	(Mg/year)	(m^3/year)	(av ft^3/min)
1970	0	0	0	0	0	0
1971	1.070E+01	5.847E+03	3.929E-01	1.677E-01	4.678E+01	3.143E-03
1972	2.088E+01	1.141E+04	7.666E-01	3.272E-01	9.128E+01	6.133E-03
1973	3.057E+01	1.670E+04	1.122E+00	4.789E-01	1.336E+02	8.977E-03
1974	3.978E+01	2.173E+04	1.460E+00	6.232E-01	1.739E+02	1.168E-02
1975	4.855E+01	2.652E+04	1.782E+00	7.605E-01	2.122E+02	1.426E-02
1976	5.688E+01	3.107E+04	2.088E+00	8.911E-01	2.486E+02	1.670E-02
1977	6.481E+01	3.541E+04	2.379E+00	1.015E+00	2.832E+02	1.903E-02
1978	7.235E+01	3.953E+04	2.656E+00	1.133E+00	3.162E+02	2.125E-02
1979	7.953E+01	4.345E+04	2.919E+00	1.246E+00	3.476E+02	2.335E-02
1980	8.635E+01	4.717E+04	3.170E+00	1.353E+00	3.774E+02	2.536E-02
1981	8.214E+01	4.487E+04	3.015E+00	1.287E+00	3.590E+02	2.412E-02
1982	7.814E+01	4.269E+04	2.868E+00	1.224E+00	3.415E+02	2.294E-02
1983	7.432E+01	4.060E+04	2.728E+00	1.164E+00	3.248E+02	2.183E-02
1984	7.070E+01	3.862E+04	2.595E+00	1.108E+00	3.090E+02	2.076E-02
1985	6.725E+01	3.674E+04	2.469E+00	1.054E+00	2.939E+02	1.975E-02
1986	6.397E+01	3.495E+04	2.348E+00	1.002E+00	2.796E+02	1.879E-02
1987	6.085E+01	3.324E+04	2.234E+00	9.533E-01	2.659E+02	1.787E-02
1988	5.788E+01	3.162E+04	2.125E+00	9.068E-01	2.530E+02	1.700E-02
1989	5.506E+01	3.008E+04	2.021E+00	8.626E-01	2.406E+02	1.617E-02
1990	5.238E+01	2.861E+04	1.922E+00	8.205E-01	2.289E+02	1.538E-02
1991	4.982E+01	2.722E+04	1.829E+00	7.805E-01	2.177E+02	1.463E-02
1992	4.739E+01	2.589E+04	1.740E+00	7.424E-01	2.071E+02	1.392E-02
1993	4.508E+01	2.463E+04	1.655E+00	7.062E-01	1.970E+02	1.324E-02
1994	4.288E+01	2.343E+04	1.574E+00	6.718E-01	1.874E+02	1.259E-02
1995	4.079E+01	2.228E+04	1.497E+00	6.390E-01	1.783E+02	1.198E-02
1996	3.880E+01	2.120E+04	1.424E+00	6.078E-01	1.696E+02	1.139E-02
1997	3.691E+01	2.016E+04	1.355E+00	5.782E-01	1.613E+02	1.084E-02
1998	3.511E+01	1.918E+04	1.289E+00	5.500E-01	1.534E+02	1.031E-02
1999	3.340E+01	1.824E+04	1.226E+00	5.232E-01	1.460E+02	9.807E-03
2000	3.177E+01	1.735E+04	1.166E+00	4.977E-01	1.388E+02	9.328E-03
2001	3.022E+01	1.651E+04	1.109E+00	4.734E-01	1.321E+02	8.873E-03
2002	2.874E+01	1.570E+04	1.055E+00	4.503E-01	1.256E+02	8.441E-03
2003	2.734E+01	1.494E+04	1.004E+00	4.283E-01	1.195E+02	8.029E-03
2004	2.601E+01	1.421E+04	9.547E-01	4.074E-01	1.137E+02	7.637E-03
2005	2.474E+01	1.352E+04	9.081E-01	3.876E-01	1.081E+02	7.265E-03
2006	2.353E+01	1.286E+04	8.638E-01	3.687E-01	1.029E+02	6.911E-03
2007	2.239E+01	1.223E+04	8.217E-01	3.507E-01	9.784E+01	6.574E-03
2008	2.129E+01	1.163E+04	7.816E-01	3.336E-01	9.307E+01	6.253E-03
2009	2.026E+01	1.107E+04	7.435E-01	3.173E-01	8.853E+01	5.948E-03
2010	1.927E+01	1.053E+04	7.072E-01	3.018E-01	8.421E+01	5.658E-03
2011	1.833E+01	1.001E+04	6.728E-01	2.871E-01	8.010E+01	5.382E-03
2012	1.743E+01	9.524E+03	6.399E-01	2.731E-01	7.620E+01	5.120E-03
2013	1.658E+01	9.060E+03	6.087E-01	2.598E-01	7.248E+01	4.870E-03
2014	1.578E+01	8.618E+03	5.790E-01	2.471E-01	6.894E+01	4.632E-03
2015	1.501E+01	8.198E+03	5.508E-01	2.351E-01	6.558E+01	4.406E-03
2016	1.427E+01	7.798E+03	5.239E-01	2.236E-01	6.238E+01	4.192E-03
2017	1.358E+01	7.418E+03	4.984E-01	2.127E-01	5.934E+01	3.987E-03
2018	1.292E+01	7.056E+03	4.741E-01	2.023E-01	5.645E+01	3.793E-03
2019	1.229E+01	6.712E+03	4.510E-01	1.925E-01	5.369E+01	3.608E-03

Results (Continued)

Year	Carbon dioxide			NMOC		
	(Mg/year)	(m^3/year)	(av ft^3/min)	(Mg/year)	(m^3/year)	(av ft^3/min)
2020	1.169E+01	6.384E+03	4.290E-01	1.831E-01	5.108E+01	3.432E-03
2021	1.112E+01	6.073E+03	4.080E-01	1.741E-01	4.858E+01	3.264E-03
2022	1.057E+01	5.777E+03	3.881E-01	1.657E-01	4.621E+01	3.105E-03
2023	1.006E+01	5.495E+03	3.692E-01	1.576E-01	4.396E+01	2.954E-03
2024	9.568E+00	5.227E+03	3.512E-01	1.499E-01	4.182E+01	2.810E-03
2025	9.102E+00	4.972E+03	3.341E-01	1.426E-01	3.978E+01	2.673E-03
2026	8.658E+00	4.730E+03	3.178E-01	1.356E-01	3.784E+01	2.542E-03
2027	8.235E+00	4.499E+03	3.023E-01	1.290E-01	3.599E+01	2.418E-03
2028	7.834E+00	4.280E+03	2.875E-01	1.227E-01	3.424E+01	2.300E-03
2029	7.452E+00	4.071E+03	2.735E-01	1.167E-01	3.257E+01	2.188E-03
2030	7.088E+00	3.872E+03	2.602E-01	1.110E-01	3.098E+01	2.081E-03
2031	6.743E+00	3.683E+03	2.475E-01	1.056E-01	2.947E+01	1.980E-03
2032	6.414E+00	3.504E+03	2.354E-01	1.005E-01	2.803E+01	1.883E-03
2033	6.101E+00	3.333E+03	2.239E-01	9.557E-02	2.666E+01	1.792E-03
2034	5.803E+00	3.170E+03	2.130E-01	9.091E-02	2.536E+01	1.704E-03
2035	5.520E+00	3.016E+03	2.026E-01	8.648E-02	2.413E+01	1.621E-03
2036	5.251E+00	2.869E+03	1.927E-01	8.226E-02	2.295E+01	1.542E-03
2037	4.995E+00	2.729E+03	1.833E-01	7.825E-02	2.183E+01	1.467E-03
2038	4.751E+00	2.596E+03	1.744E-01	7.443E-02	2.077E+01	1.395E-03
2039	4.520E+00	2.469E+03	1.659E-01	7.080E-02	1.975E+01	1.327E-03
2040	4.299E+00	2.349E+03	1.578E-01	6.735E-02	1.879E+01	1.262E-03
2041	4.090E+00	2.234E+03	1.501E-01	6.407E-02	1.787E+01	1.201E-03
2042	3.890E+00	2.125E+03	1.428E-01	6.094E-02	1.700E+01	1.142E-03
2043	3.700E+00	2.022E+03	1.358E-01	5.797E-02	1.617E+01	1.087E-03
2044	3.520E+00	1.923E+03	1.292E-01	5.514E-02	1.538E+01	1.034E-03
2045	3.348E+00	1.829E+03	1.229E-01	5.245E-02	1.463E+01	9.832E-04
2046	3.185E+00	1.740E+03	1.169E-01	4.989E-02	1.392E+01	9.353E-04
2047	3.030E+00	1.655E+03	1.112E-01	4.746E-02	1.324E+01	8.896E-04
2048	2.882E+00	1.574E+03	1.058E-01	4.515E-02	1.259E+01	8.463E-04
2049	2.741E+00	1.498E+03	1.006E-01	4.294E-02	1.198E+01	8.050E-04
2050	2.608E+00	1.425E+03	9.572E-02	4.085E-02	1.140E+01	7.657E-04
2051	2.480E+00	1.355E+03	9.105E-02	3.886E-02	1.084E+01	7.284E-04
2052	2.359E+00	1.289E+03	8.661E-02	3.696E-02	1.031E+01	6.929E-04
2053	2.244E+00	1.226E+03	8.238E-02	3.516E-02	9.809E+00	6.591E-04
2054	2.135E+00	1.166E+03	7.837E-02	3.345E-02	9.331E+00	6.269E-04
2055	2.031E+00	1.109E+03	7.454E-02	3.181E-02	8.876E+00	5.963E-04
2056	1.932E+00	1.055E+03	7.091E-02	3.026E-02	8.443E+00	5.673E-04
2057	1.838E+00	1.004E+03	6.745E-02	2.879E-02	8.031E+00	5.396E-04
2058	1.748E+00	9.549E+02	6.416E-02	2.738E-02	7.639E+00	5.133E-04
2059	1.663E+00	9.083E+02	6.103E-02	2.605E-02	7.267E+00	4.882E-04
2060	1.582E+00	8.640E+02	5.805E-02	2.478E-02	6.912E+00	4.644E-04
2061	1.504E+00	8.219E+02	5.522E-02	2.357E-02	6.575E+00	4.418E-04
2062	1.431E+00	7.818E+02	5.253E-02	2.242E-02	6.254E+00	4.202E-04
2063	1.361E+00	7.437E+02	4.997E-02	2.133E-02	5.949E+00	3.997E-04
2064	1.295E+00	7.074E+02	4.753E-02	2.029E-02	5.659E+00	3.802E-04
2065	1.232E+00	6.729E+02	4.521E-02	1.930E-02	5.383E+00	3.617E-04
2066	1.172E+00	6.401E+02	4.301E-02	1.836E-02	5.121E+00	3.441E-04
2067	1.115E+00	6.089E+02	4.091E-02	1.746E-02	4.871E+00	3.273E-04
2068	1.060E+00	5.792E+02	3.892E-02	1.661E-02	4.633E+00	3.113E-04
2069	1.008E+00	5.509E+02	3.702E-02	1.580E-02	4.407E+00	2.961E-04
2070	9.593E-01	5.241E+02	3.521E-02	1.503E-02	4.193E+00	2.817E-04

Results (Continued)

Year	Carbon dioxide			NMOC		
	(Mg/year)	(m^3/year)	(av ft^3/min)	(Mg/year)	(m^3/year)	(av ft^3/min)
2071	9.125E-01	4.985E+02	3.349E-02	1.429E-02	3.988E+00	2.680E-04
2072	8.680E-01	4.742E+02	3.186E-02	1.360E-02	3.794E+00	2.549E-04
2073	8.257E-01	4.511E+02	3.031E-02	1.293E-02	3.609E+00	2.425E-04
2074	7.854E-01	4.291E+02	2.883E-02	1.230E-02	3.433E+00	2.306E-04
2075	7.471E-01	4.081E+02	2.742E-02	1.170E-02	3.265E+00	2.194E-04
2076	7.107E-01	3.882E+02	2.609E-02	1.113E-02	3.106E+00	2.087E-04
2077	6.760E-01	3.693E+02	2.481E-02	1.059E-02	2.954E+00	1.985E-04
2078	6.430E-01	3.513E+02	2.360E-02	1.007E-02	2.810E+00	1.888E-04
2079	6.117E-01	3.342E+02	2.245E-02	9.582E-03	2.673E+00	1.796E-04
2080	5.818E-01	3.179E+02	2.136E-02	9.115E-03	2.543E+00	1.709E-04
2081	5.535E-01	3.024E+02	2.032E-02	8.670E-03	2.419E+00	1.625E-04
2082	5.265E-01	2.876E+02	1.932E-02	8.247E-03	2.301E+00	1.546E-04
2083	5.008E-01	2.736E+02	1.838E-02	7.845E-03	2.189E+00	1.471E-04
2084	4.764E-01	2.602E+02	1.749E-02	7.463E-03	2.082E+00	1.399E-04
2085	4.531E-01	2.476E+02	1.663E-02	7.099E-03	1.980E+00	1.331E-04
2086	4.310E-01	2.355E+02	1.582E-02	6.752E-03	1.884E+00	1.266E-04
2087	4.100E-01	2.240E+02	1.505E-02	6.423E-03	1.792E+00	1.204E-04
2088	3.900E-01	2.131E+02	1.432E-02	6.110E-03	1.705E+00	1.145E-04
2089	3.710E-01	2.027E+02	1.362E-02	5.812E-03	1.621E+00	1.089E-04
2090	3.529E-01	1.928E+02	1.295E-02	5.528E-03	1.542E+00	1.036E-04
2091	3.357E-01	1.834E+02	1.232E-02	5.259E-03	1.467E+00	9.858E-05
2092	3.193E-01	1.744E+02	1.172E-02	5.002E-03	1.396E+00	9.377E-05
2093	3.037E-01	1.659E+02	1.115E-02	4.758E-03	1.328E+00	8.919E-05
2094	2.889E-01	1.578E+02	1.061E-02	4.526E-03	1.263E+00	8.484E-05
2095	2.748E-01	1.501E+02	1.009E-02	4.306E-03	1.201E+00	8.071E-05
2096	2.614E-01	1.428E+02	9.596E-03	4.096E-03	1.143E+00	7.677E-05
2097	2.487E-01	1.359E+02	9.128E-03	3.896E-03	1.087E+00	7.303E-05
2098	2.366E-01	1.292E+02	8.683E-03	3.706E-03	1.034E+00	6.946E-05
2099	2.250E-01	1.229E+02	8.260E-03	3.525E-03	9.834E-01	6.608E-05
2100	2.140E-01	1.169E+02	7.857E-03	3.353E-03	9.355E-01	6.285E-05
2101	2.036E-01	1.112E+02	7.474E-03	3.190E-03	8.899E-01	5.979E-05
2102	1.937E-01	1.058E+02	7.109E-03	3.034E-03	8.465E-01	5.687E-05
2103	1.842E-01	1.006E+02	6.762E-03	2.886E-03	8.052E-01	5.410E-05
2104	1.752E-01	9.574E+01	6.433E-03	2.745E-03	7.659E-01	5.146E-05
2105	1.667E-01	9.107E+01	6.119E-03	2.611E-03	7.285E-01	4.895E-05
2106	1.586E-01	8.663E+01	5.820E-03	2.484E-03	6.930E-01	4.656E-05
2107	1.508E-01	8.240E+01	5.537E-03	2.363E-03	6.592E-01	4.429E-05
2108	1.435E-01	7.838E+01	5.267E-03	2.248E-03	6.271E-01	4.213E-05
2109	1.365E-01	7.456E+01	5.010E-03	2.138E-03	5.965E-01	4.008E-05
2110	1.298E-01	7.092E+01	4.765E-03	2.034E-03	5.674E-01	3.812E-05

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APPENDIX 3

Assimilative Capacity Assessment

Ardfert

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)	0.13
F95 = the 95%ile flow in the river (m^3/s)	0.027

Note: (60x60x24)/1000 = 86.4

AC kg/d	=	**(Cmax**	-	**Cbak)**	x	**F95**	x	**86.4**
	=	0.14	-	0.13	x	0.027	x	86.4
	=		0.01		x	0.027	x	86.4
AC kg/d	=	**0.023 kg/day**						

Emission Concentration (mg/l)	0.296		
	Flow (m3/day)	**Daily Mass Emission (kg/day)**	**%-age of AC**
	86.4	0.026	110%
	172.8	0.051	219%
	259.2	0.077	329%
	345.6	0.102	439%
	432	0.128	548%

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 =	0.027	m^3/sec
C =	0.13	mg/l
f =	86.4	m^3/day
	0.0000035	m^3/sec
c =	0.296	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 = (F x C + f x c) / (F + f)

1 (0.027 x 0.13 + 0.000 x 0.296) / (0.027 + 0.000)

2 (0.00351 + 0.000) / 0.0270

3 0.004 / 0.027

4 **T = 0.130 mg/l**

EQS (mg/l)	
0.14	*Good' Status 95%-ile EQS*
0.065	*Good' Status mean EQS*

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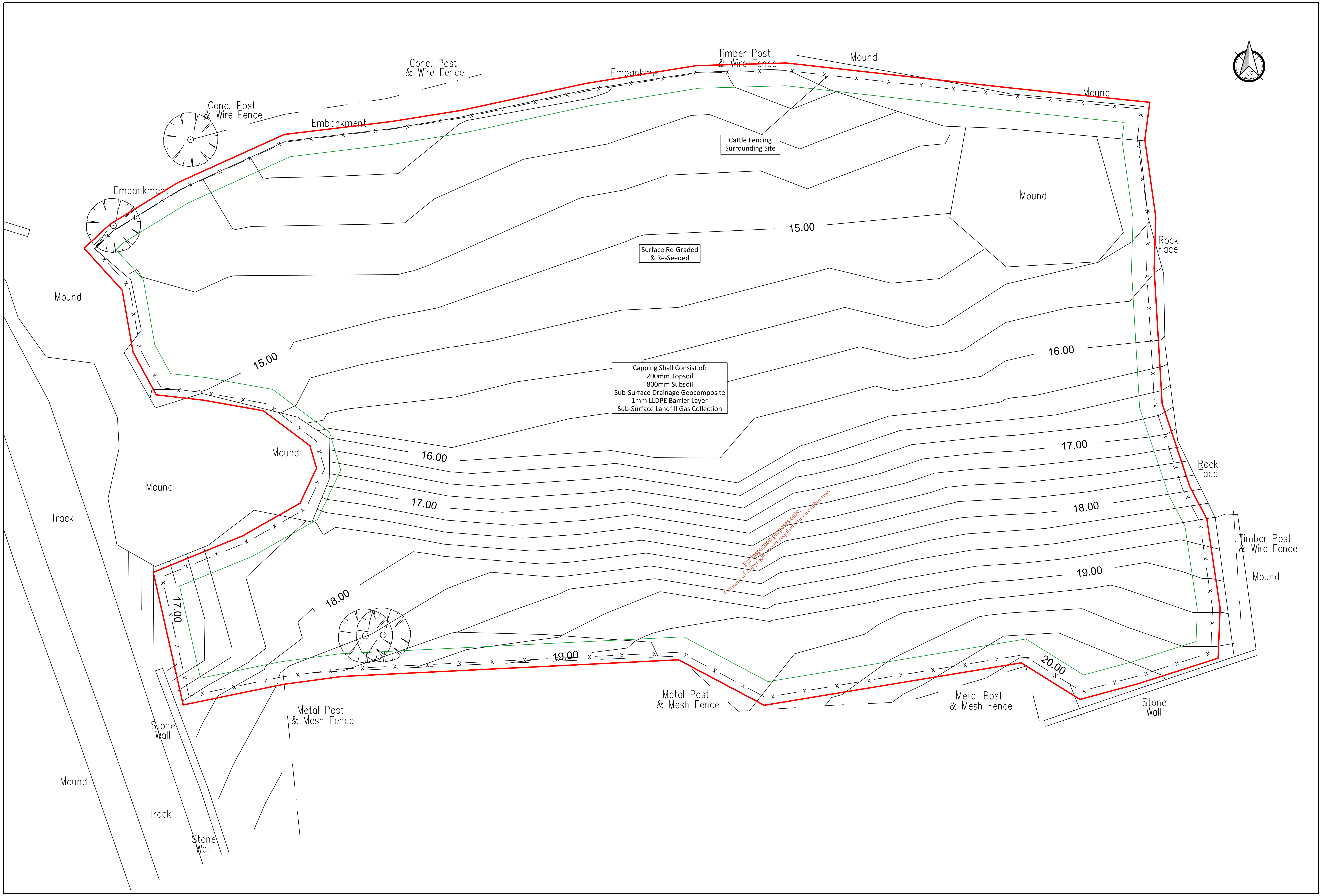
APPENDIX 4

Remediation Plan Drawings



Legend

- Site Boundary
- Cattle Fence
- Capping Area

0m 1.25m 2.50m 3.75m 5.00m 6.25m 7.50m 8.75m 10.00m 11.25m 12.50m

Scale 1:125

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Rev.	Description	App By	Date
A	ISSUE FOR COMMENT	CJC	21.02.20

PROJECT

TIER2/3 ASSESSMENT FOR FOUR NORTH KERRY LANDFILLS

CLIENT

KERRY COUNTY COUNCIL

SHEET

SITE CAPPING MAP

Date: 21.02.20	Project number: P1766	Scale (@ A1-) 1:125	
Drawn by: SOC	Drawing Number: P1766-0100-0002		Rev: A
Checked by: EA			

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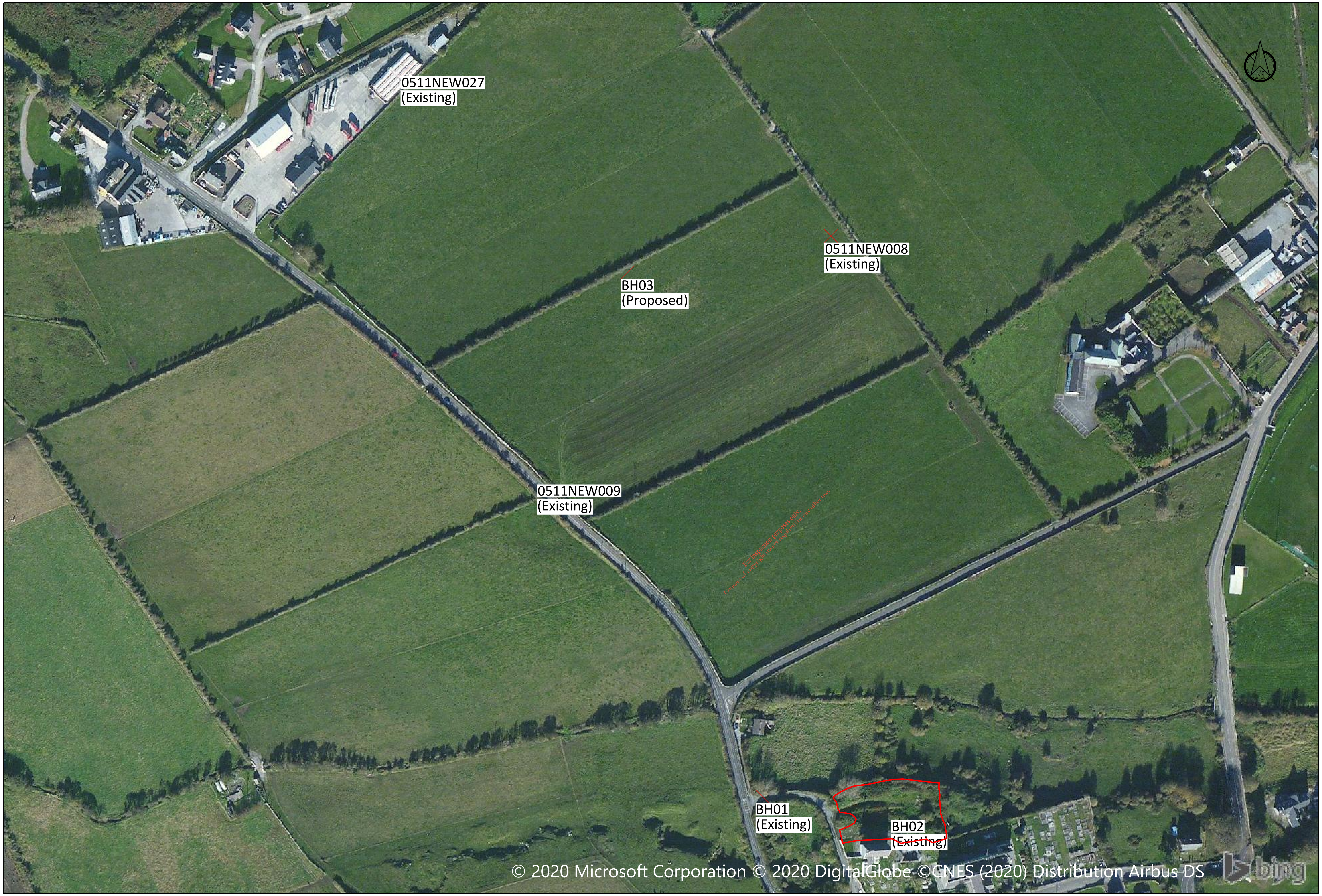
21 February 2020



Legend

Site Boundary

XXXXX Borehole Locations

0m 12.50m 25.00m 37.50m 50.00m 62.50m 75.00m 87.50m 100.00m 112.50m 125.00m

Scale 1:1250

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Rev.	Description	App By	Date
A	ISSUE FOR COMMENT	CJC	21.02.20

PROJECT

TIER2/3 ASSESSMENT FOR FOUR NORTH KERRY LANDFILLS

CLIENT

KERRY COUNTY COUNCIL

SHEET

BOREHOLE LOCATION MAP

Date 21.02.20	Project number P1766	Scale (@ A1-) 1:1250	
Drawn by SOC	Drawing Number P1766-0100-0003		Rev A
Checked by EA			

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21 February 2020

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