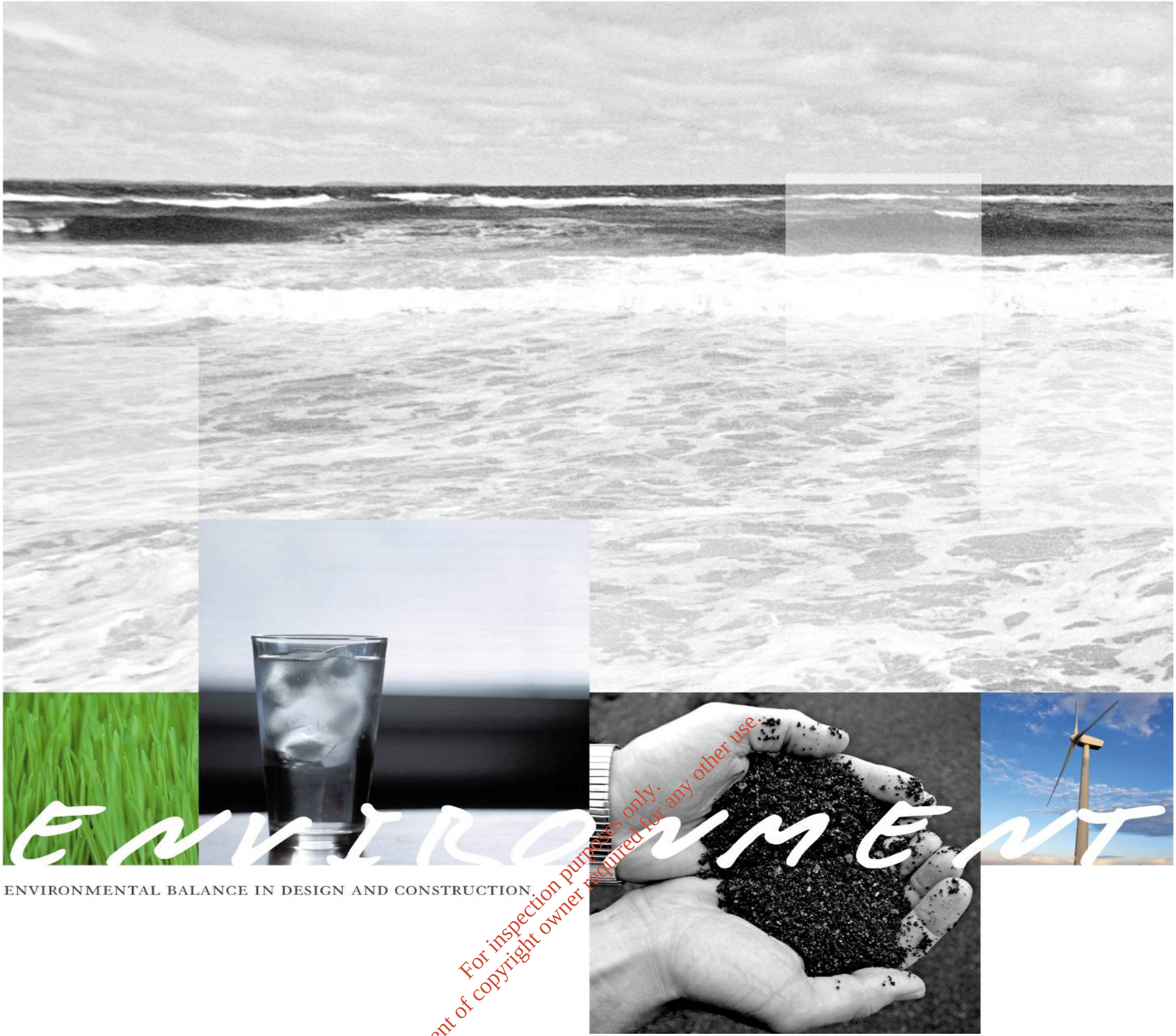

TIER 3 RISK ASSESSMENT

KILLYCRONAGHAN HISTORIC LANDFILL SITE, CO. MONAGHAN

DECEMBER 2019

FEHILY TIMONEY
30 YEARS

TIER 3 RISK ASSESSMENT

KILLYCRONAGHAN HISTORIC LANDFILL, CO. MONAGHAN

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Abstract: This report represents the findings of a Tier 3 risk assessment carried out on Killycronaghan Historic Landfill site, Co. Monaghan, and conducted in accordance with the EPA Code of Practice for unregulated landfill sites. The Tier 3 risk assessment was conducted following on from the findings on the previously conducted Tier 2 risk assessment.

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NON-TECHNICAL SUMMARY

Fehily Timoney & Company (FT) was appointed by Monaghan County Council (MCC) to complete a Tier 3 environmental risk assessment (ERA) on Killycronaghan Historic Landfill in accordance with the Environmental Protection Agency (EPA) Code of Practice (CoP) (2007): *Environmental Risk Assessment for Unregulated Waste Disposal Sites*.

The site is located approximately 8km North-East of Clones town circa 1km off the N54 national road, close to the village of Smithborough. It was previously reported by MCC that the landfill accepted waste throughout the 1970s and early 1980s, ceasing in 1984.

A Tier 1 study conducted by FT in June 2018 determined the site to be a high-risk classification (Class A). The primary risks identified relate to the risk of leachate runoff entering the Kilgormly river and the risk of landfill gas migration to nearby human receptors.

The Tier 2 study consisted of a desktop study, geophysical survey, intrusive site investigation works, environmental monitoring (soil, waste and groundwater sampling) and laboratory analysis. The results of these works updated the CSM (conceptual site model) and risk screening model.

The results of this Tier 2 assessment and risk model indicated the site remained to be classified as a **High-Risk Classification (Class A)**. The principal risks identified on the site are the risk posed to on-site and off-site receptors from migration of landfill and the risk to the groundwater aquifer from the migration of leachate from the waste body.

The purpose of this Tier 3 assessment was to further examine and quantify those risks/impacts through generation of quantitative models (LandSim, LandGEM) to predict the current and future impact of the site on both; groundwater and surface water quality and potential for landfill gas generation/migration at the site. Information obtained from these models was used to inform the appropriate remedial and mitigation measures required on site to either eliminate or reduce risks.

Results obtained from the LandSim model confirmed a risk to groundwater underlying the site and the likely migration of pollutants further downgradient of the site. LandSim was used to examine the impact the installation of a landfill cap over the interred waste may have on the generation of leachate and the dispersion of pollutants within the aquifer.

LandGEM was utilised to estimate the potential quantities of landfill gas being produced by the waste.

The Tier 3 assessment concludes, that to mitigate the impact of leachate generated on site would have on the underlying aquifer and receptors downgradient, that the site should be capped. The proposed landfill cap should be constructed in accordance with the EPA requirements for landfill site design. The cap will mitigate the contribution of rainfall infiltration towards leachate generation from the site.

It is recommended that the landfill cap should also include passive landfill gas controls. The most appropriate landfill gas control measures should be determined with reference to EPA Guidance: Management of Low Levels of Landfill Gas and EPA Landfill Manuals, Landfill Site Design. Passive ventilation will ensure the low levels of landfill gas being generated at the site or vented to atmosphere in a manner that limits the potential effects upon human receptors.

1 TIER 3 QUANTITATIVE RISK ASSESSMENT

1.1 Background

Following the completion of a site investigation and Tier 2 risk assessment at a former landfill at Killycronaghan, Co. Monaghan in 2018, it was concluded that a Tier 3 assessment should also be conducted. The findings of the Tier 2 assessment produced a firmer understanding of the characterisation of the site and facilitated the production of an updated Conceptual Site Model (CSM).

A Tier 3 assessment includes some form of quantitative risk assessment either as a Generic Quantitative Risk Assessment (GQRA) or as a Detailed Quantitative Risk Assessment (DQRA). This Tier 3 assessment report outlines the outcomes of a DQRA. Elevated concentrations of ammonia above the groundwater quality threshold values were detected in all groundwater monitoring wells (GW01 to GW03) along the site boundary, both upgradient and downgradient within the site area. Groundwater concentrations for ammoniacal nitrogen were highest at downgradient well GW03 indicating that leachate generated is having a deleterious effect on groundwater quality. Surface water monitoring was in the Kilgormley River which is located to the east and north of the site and the Magheramey River located to the north/north-west of the site. Elevated concentrations above the 2009 surface water regulation water quality threshold values were only observed for ammoniacal nitrogen at monitoring location SW-1 on the Magheramey River.

LandSim modelling software was utilised as part of this DQRA to examine, quantify and forecast the potential impact of leachate generation from the landfill on downstream receptors. The outcomes of this exercise aids in the determine of appropriate remedial measures, which is a vital aspect of the Tier 3 assessment.

The potential impact of gas generation was also considered as part of the Tier 3 assessment using LandGEM is a MS Excel operated model, developed by the US EPA, that estimates the quantity of landfill gases generated on site over a defined period. Again, as with LandSim this can be used to determine what, if any, remedial measures may be required to appropriately manage any emissions from the site and mitigate the potential risk to human or environmental health.

1.2 LandSim

LandSim was created by Golder Associates Ltd for the UK Environmental Agency to provide probabilistic quantitative risk assessments of specific landfill site performance in relation to groundwater protection. LandSim is a probabilistic model which uses the Monte Carlo simulation technique to select randomly from a pre-defined range of possible input values to create parameters for use in the model calculations.

Repeating the process many times gives a range of output values, the distribution of which reflects the uncertainty inherent in the input values and enables the likelihood of the estimated output levels being achieved to be ascertained.

1.3 DQRA Model Setup

LandSim setup involves several different stages and these are described hereunder. For many of the parameters and characteristics entered to the model, a degree of uncertainty is involved. This is modelled using a probability distribution function (PDF) i.e. the probability of the random numbers chosen by the model falling within a range of values. These PDFs have been determined based on the information available at the time of writing of this report and statistical analysis of this information. Advice and default data provided in the LandSim documentation and guidance provided by the National Groundwater and Contaminated Land Centre (UK) have also been used where appropriate.

1.3.1 Domain Area

The initial step involves the definition of the domain area. The domain area is the total area that will be modelled and contains the landfill phase and receptor.

The domain area is defined in terms of x and y. The x direction (left to right) is orientated in the direction of groundwater flow, and the y direction runs perpendicular to the direction of groundwater flow (i.e. the site is modelled with an alternative orientation to its actual orientation in terms of North, South, East and West).

Phase Definition

Within the domain, the landfill is broken into distinct areas or Phases. Based on available information and investigation into the history of the site, no defined phases of waste acceptance and filling of the area could be defined, either spatially or chronologically. Therefore, for the purposes of defining the estimated waste disposal footprint area within the model, the Killycronaghan site was defined as a single 'phase'.

Figure 1-1 shows the screen shot of the domain area for the Killycronaghan model. The model can only simulate groundwater flow from left to right, so the orientation of the site is adjusted accordingly.

For each domain, the time offset from the start of filling (i.e. the opening year of the facility) is also defined.

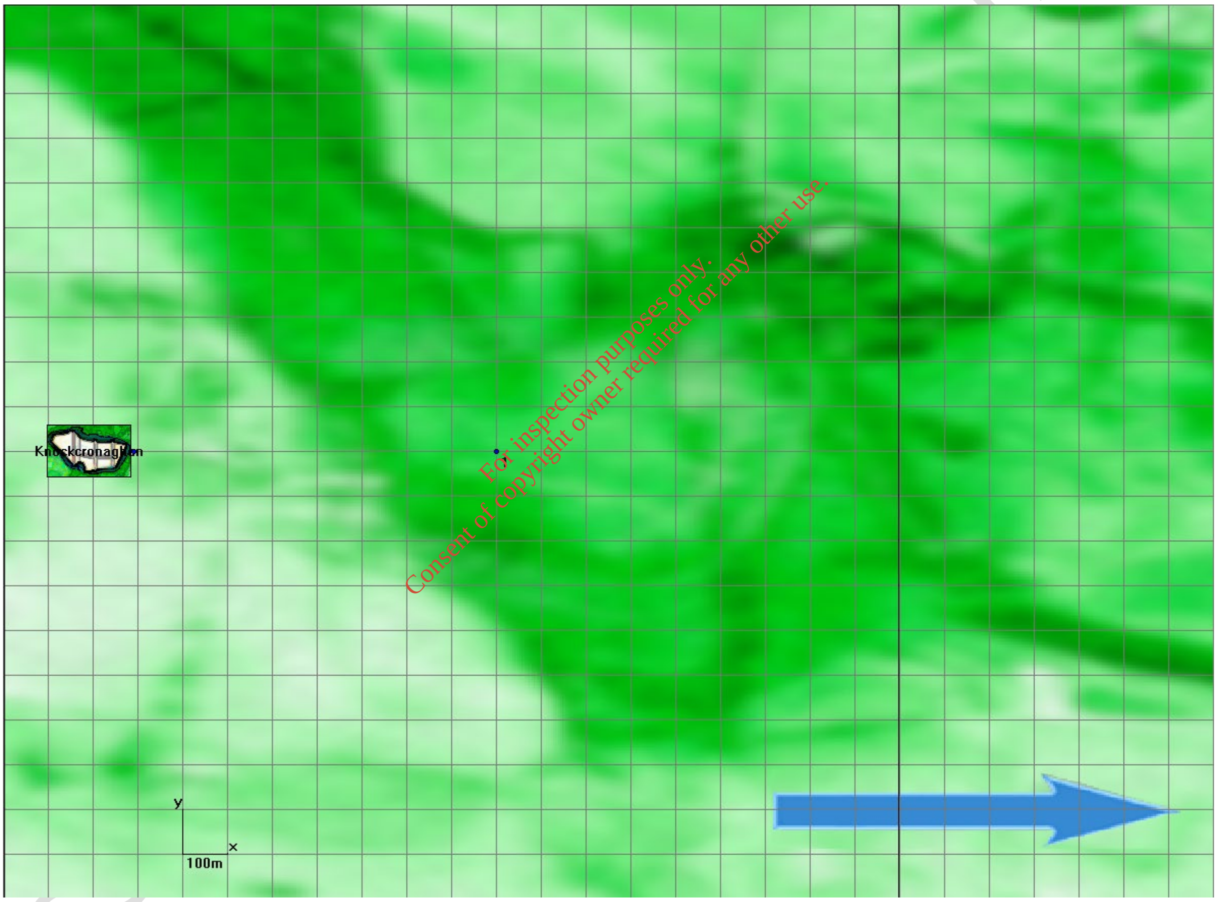


Figure 1-1: Domain Layout in LandSim

Aquifer Properties

Within the domain area, the aquifer properties (which will in general be common to all phases) are defined. LandSim automatically calculates the pathway length, which is dependent on the domain area and the geometry of the site, while the pathway width will vary for each phase, as it is the width of the phase across groundwater flow.

The remaining aquifer characteristics are aquifer thickness, vertical, longitudinal and transverse dispersivity, hydraulic conductivity, regional hydraulic grade, and pathway porosity.

The Tier 2 site investigations determined that the groundwater water table at the site likely transects the waste body.

LandSim assumes that all layers i.e. the landfill cells, unsaturated pathway, vertical pathway and aquifer pathway etc. are clearly separate layers with defined boundaries, each with their own characteristics.

Intrusive site investigation did not confirm the thickness of the bedrock aquifer. Based on the estimated waste thickness and publicly available information on the general characteristics of the bedrock aquifer provided by Geological Survey Ireland (GSI) an aquifer thickness of between 3m to 40m was applied in the model.

The vertical, longitudinal and transverse dispersivities were calculated using standard calculation methods:

- Longitudinal Dispersivity:
  $a_x = 0.1 * L$ (Pickens and Grisak, 1981)

- Transverse Dispersivity:
  $a_y = 0.1 * a_x \rightarrow a_x$ (Freeze & Cherry, 1979)
  or
  $a_y = 0.1 * a_x \rightarrow 0.33*a_x$ (Gelhar, 1992)

- As a rule of thumb, vertical dispersivity may range between $1*10^{-99}$ to 0.1 times the longitudinal dispersivity.

The site-specific findings on groundwater levels within investigative wells across the sites yielded a hydraulic gradient for the aquifer underlaying the site, of approximately 0.0051.

In-situ falling head and rising permeability tests were conducted to the determine permeability of the underlying subsoil and rock. Of the three boreholes tested (GW01, GW02 & GW03) only GW01 took account of the permeability of the underlying weathered bedrock. GW03 permeability testing was carried out within brown gravelly clay. Testing on GW01 yielded a permeability result of 1.58×10^{-6} m/s. This result is within the expected range when compared to hydraulic conductivity values provided in the LandSim manual for limestones and sandstones.

The pathway porosity was inputted based on standard published data for the lithologies present[1].

1.3.2 Phase Details

The next step was to define the characteristics of each phase. For each phase, the characteristics listed below are defined.

Each input must be defined at the time of entry. Appendix 1 contains the output from LandSim, which details the inputs for each of the parameters for each phase.

Infiltration

The cap design infiltration rate in each phase were entered as single values. The effective rainfall for area (606 mm/year) as determined by Geological Survey Ireland (GSI) spatial data was utilised for the infiltration rate to open waste. There is very minimal capping onsite, with only a shallow layer of topsoil present. Permeability of three samples from trial pits TP03, TP07 and TP09 was determined applying Hazen's relationship. This yielded permeabilities of 6.72×10^{-7} m/s, 4.16×10^{-8} and 1.72×10^{-4} m/s respectively. These are significantly above EPA Landfill Site Design Manual requirements for capping.

The GSI have applied a groundwater recharge co-efficient 85% for the area. A calculated recharge of 515 mm/yr. (85% of 606 mm/yr.) was applied as the current cap design infiltration rate.

The infiltration rate was adjusted for the remedial scenario model. This scenario assumes the installation of a more robust landfill cap achieving a reduced infiltration rate.

[1] Domenico, P.A. and Schwartz, F.W. (1990) Physical and Chemical Hydrogeology

The remedial scenarios modelled aims to represent a 'what if' scenario whereby an alternate landfill management and/or engineering design were applied to the site. A further reduction in infiltration (10% of the effective rainfall rate) was applied. The proposed remedial measures are discussed in greater detail in Section 3 below.

Cell Geometry

Based on site history and available evidence, it has been assumed that each phase comprises a single cell area. Site investigation is not suggestive of any clear designed cells or cell structures within the overall the waste deposition area. As a conservative measure it has been assumed that each cell covers approximately the same total area of the defined waste footprint i.e. is the same area of each of the corresponding phases.

The final waste thickness applied to the model was determined as part of the Tier 2 assessment, following site investigation. Trial pits located within the waste footprint area demonstrated that the waste extended up to 5m below ground level to the base of several trial pits. Geophysical surveying estimated that the average waste thickness was 5m. Surveys further indicated that below this is a layer of leachate contaminated sands and gravels. The thickness appeared to be quite uniform across the waste body, upon review of the geophysical survey cross-sections a triangular distribution, *Uniform (5,12,14)* metre thickness was applied in the model.

As no exact data on waste porosity is available, review of available literature yielded an estimated waste porosity included in the model as *Triangular (0.42,0.54,0.62).*

Density of waste assumed a range between 1.4 and 1.6 kg/l.

The waste field capacity used ranged between 0.2 and 0.4.

Leachate Inventory

Groundwater monitoring conducted as part of the Tier 2 assessment and site investigation yielded elevated concentrations of ammoniacal nitrogen and lead above the groundwater quality thresholds in downgradient well GW03. Only these elements were considered in the model. Ammoniacal nitrogen was also noted to be elevated above the groundwater quality threshold values in wells GW01 and GW02.

No historical monitoring of leachate characteristics and composition has been carried out. It is unknown what the characteristics of leachate generated at the site may have been while the site was operational and in the immediate years. It would be expected that concentrations of contaminants of concern such as ammonia would be significantly higher than concentrations determined in leachate or groundwater monitoring of wells presently. It was necessary to assume the initial source concentrations to apply in the model. For both ammoniacal nitrogen and lead the default concentrations available in LandSim were applied. These values included were derived based on data analysis and review presented in *'A review of the composition of leachate from waste in landfill sites'* (Robinson, 1995).

No groundwater wells upgradient of the site and waste footprint area are present therefore site-specific background concentrations could not be determined for the model. It is stated in the Tier 2 assessment report that the presence of peat underlying the site and waste could be a potential source elevated ammonia in groundwater.

An EPA study report titled '*Assessing and Developing Natural Background Levels for Chemical Parameters in Irish Groundwater*' (2017) was reviewed to aid in determining suitable background concentrations. That study yielded a 95th percentile concentration for lead in groundwater of 0.0029 mg/l. This was the chosen background concentration applied in the model.

With respect to ammoniacal nitrogen or ammonium only, a limited number of appropriate monitoring points and data sets were available for study. The generated background concentrations exceeded groundwater threshold values. As a conservative measure, the lower limit of 0.065 mg/l (65 ug/l) for ammonium as per the European Union Environmental Objectives (Groundwater) (Amendment) Regulations 2016 (S.I. No. 366 of 2016 was applied as a background concentration.

Final leachate concentrations and background concentrations applied in the model are shown in below Table 1.1:

Table 1-1: Leachate and Background Concentrations

Parameter	Concentration in Leachate [1] (mg/l)	Background Concentration (mg/l)
Ammonia	Triangular (4.37, 723, 3640)	Single (0.065)
Lead	Triangular (0.00957,0.13, 1.02)	Single (0.0029)

[†] A triangular distribution is defined by a minimum, most likely and maximum, based on statistical analysis.

Note 1: Leachate concentrations as per LandSim UK Default Leachate Inventory values

Drainage System (at the base of the cell)

For this calculation it was only necessary to specify the head of leachate at the base of the landfill. There is no constructed drainage system underlying the landfill nor is there any form of leachate head control. As an estimation the leachate head was specified as being the range of thicknesses of overburden or waste material from the underlying bedrock to ground surface, that is a thickness of between 5 to 14m.

Engineered Barrier

There is no known engineered barrier underlying the landfill therefore none was accounted for in the model.

1.3.3 Geosphere Details

The output from the engineered barrier systems module of the LandSim is a rate of leachate leakage through the base of each phase of the landfill. Along with the individual contaminant concentrations output from the source term, these rates are used as a starting point to examine the behaviour of the leachate within the geosphere.

The geosphere consists of three pathways - the unsaturated zone, the vertical pathway and the aquifer pathway, as shown in Figure 1-2 below. Each of these geosphere pathways is assumed homogeneous and isotropic.

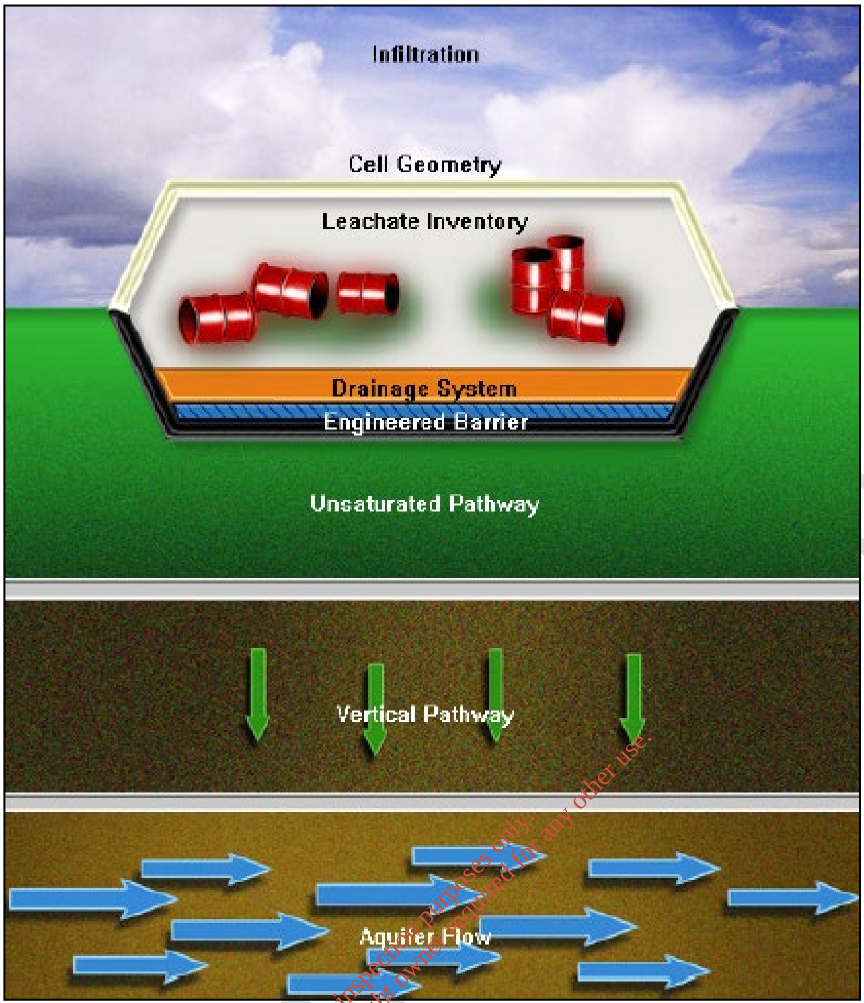


Figure 1-2: Geosphere Schematic

Unsaturated Pathway

It is known from site investigation that the groundwater transects the waste material. One limitation of LandSim is that it is not possible to reflect this exactly. LandSim assumed that each aspect or layer of the geosphere as shown above is separate. As means to reflect the saturated nature of the waste body itself and the assumed direct contact between waste material and underlying aquifer a minimal unsaturated pathway thickness was applied in the model.

Vertical Pathway

As per the comments regarding the unsaturated pathway aspect of the model, to mimic the direct contact much of the waste material is likely to have with the underlying aquifer no vertical pathway was modelled.

Aquifer

The aquifer details were input as described above.

1.3.4 Model Scenarios

LandSim is used as part of this Tier 3 assessment to aid in the determination of any engineering works or other remedial measures that may be required in to mitigate the identified risks to the environment associated with the historical landfill.

Two different model scenarios were developed to facilitate comparison between mitigated and unmitigated landfill conditions.

Scenario 1 - a 'base' model was developed to reflect current conditions of the site as closely and to predict the present and future risk to groundwater should no measures be implemented.

Scenario 2 - 'Remediation' scenario model was developed to predict the potential effects of the implementation of site remediation measures i.e. landfill cap would have on the generation and propagation of leachate from the landfill. As the site has been modelled as only one phase it is assumed that any hypothetical remedial measures are applied across the whole site. The installation of a landfill cap can be reflected through the adjustment of several model inputs, shown below:

- Cap design Infiltration (mm/yr.)
- PE Cap (yes/no)
- Infiltration to grassland (mm/yr.)
- Start of cap degradation (years from end of waste disposal)
- End of cap degradation (years from end of waste disposal)

Scenario2 – the remediation scenario modelled examined the impact of the installation of a lower permeability capping layer across the site. This was reflected in the model through the input of a reduced cap design infiltration rate. A single value of 60.6mm/year (10% of effective rainfall rate) cap design infiltration rate was applied.

A list of model inputs, generated by LandSim, for both scenarios are presented in Appendix 1 of this report.

1.4 Results - LandSim

1.4.1 Leachate Concentration

A full calculation run of 1,001 iterations was carried out on each model to examine the relative changes in model outputs or potential impacts between each model scenario.

Table 1-2: Source Concentration at Year 0, 50 and 500 (Base Model)

Parameter	Year	5%ile	50%ile	95%ile
Ammoniacal Nitrogen (mg/l)	0	193.96	459.87	927.75
	50	74.3399	160.538	343.624
	100	15.71	57.83	143.12
	500	$9.66x10^{-5}$	0.026	0.22
Lead (mg/l)	0	0.0836001	0.162063	0.270296
	50	0.0538935	0.102346	0.170095
	100	0.0365638	0.0665778	0.11871
	500	0.000289251	0.00283663	0.00668586

Table 1-3 presents species concentration values below which concentrations will remain for respective %-iles i.e. time intervals (95%, 50% and 5%).

For example, Ammoniacal Nitrogen will remain below:

- 927.75 mg/l for 95% of the time
- 459.87 mg/l for 50% of the time
- 193.96 mg/l for 5% of the time

LandSim results generated at the 50-year point is assumed to roughly represent present day conditions. It is noted that groundwater monitoring wells installed as part of the Tier 2 assessment site investigation are located outside what has been identified as the primary waste filling area (Zone A) and therefore it is likely that groundwater monitoring results would not be representative of leachate source characteristics.

1.4.2 Leachate Generation

The rate of leachate generation under the current condition scenario and remediation scenario were compared. The rate of leachate generation is directly dependent on the rainfall infiltration rate to the waste material. As stated above, the installation of an improved landfill cap is reflected in the model through the application of a reduced cap design infiltration rate.

Table 1-3: Leachate Generation Rates

Site Scenario	Time slice (years)	95%-ile (l/day)	50%-ile (l/day)	5%-ile (l/day)
Current	7	37,828	37,828	37,828
	50	32,147	32,147	32,147
	100	32,147	32,147	32,147
Remediation (Cap only)	7	37,828	37,828	37,828
	50	3,782	3,782	3,782
	100	3,782	3,782	3,782

At 7 years the site was still operational and waste material was still being deposited. As the site has been modelled as a single phase it is assumed that the entirety of the site area contains waste. To develop the model, it has been assumed that waste activities took place for 14 years. During this 14-year period the open waste infiltration rate is applied, after which it is assumed that the site is closed and has been capped. At this point the 'cap design infiltration rate' is applied. This corresponds with a c.15% reduction in leachate generation rate at the 50-year point as shown in Table 1.3. The remediation scenarios assume the installation of a more effective, lower permeability capping yielding a greater reduction in leachate generation (c.90%).

1.4.3 Monitor Well Concentrations

Another output from the LandSim model that was examined as part of this assessment was the concentration of each contaminant of concern at the perimeter of the waste body/phase as defined in the model. LandSim automatically places a monitor well at the downstream perimeter edge of each phase area included in the model. The 95%-ile and 50%-ile results were examined with the 95%-ile values representing an extreme worst-case scenario.

A summary of concentration results at the monitor well location for each of the selected parameters is provided in Table 1-4 over.

Table 1-4: Monitor Well Concentrations

		Base Scenario		Capping Scenario	
Parameter	Time slice	95%-ile (mg/l)	50%-ile (mg/l)	95%-ile (mg/l)	50%-ile (mg/l)
Ammoniacal N	7	2.33	0.065	0.065	0.065
	50	441.47	216.21	250.75	1.99
	100	338.29	158.54	656.49	185.22
	500	18.58	4.16	282.52	114.03
Lead	7	0.0029	0.0029	0.0029	0.0029
	50	0.0029	0.0029	0.0029	0.0029
	100	0.0029	0.0029	0.0029	0.0029
	500	0.0029	0.0029	0.0029	0.0029

1.4.4 Discussion of Results

Table 1-4 summarises the predicted source concentrations generated by LandSim under the base/current scenario. Direct monitoring of leachate quality as not historically been conducted, therefore it is not possible to compare predicted source concentrations, as determined by LandSim with real field results. Predicted source concentrations at the 50-year point (assumed to be present day) are above the range of concentrations observed in groundwater samples obtained and analysed in 2018.

The results obtained from the LandSim model show that there is a likely ongoing risk to groundwater and thus surface water quality via hydrological linkages downstream of the site. The model predicts aquifer concentrations greater than those observed from groundwater samples therefore limiting the application of the model to accurately determine/predict downstream aquifer concentrations in the future. However, for demonstrating the potential efficacy of remedial measures on leachate generation and dispersion the model was deemed to be suitable.

As shown in Table 1-3, there is a significant reduction in leachate generation/leakage when a lower permeability capping material is assumed resulting in a lower infiltration rate to the underlying waste material. One limitation of LandSim in its application to quantitatively assessing the Killycronaghan site is that it is assumed that all leachate generated relates directly to the volume of rainfall. As stated above it is known from site investigation that the groundwater table transects the waste body and it would be expected that a significant of the waste volume is saturated with groundwater. As such it is likely that the movement of groundwater through the waste body has historically and currently a significant factor in the generation of leachate from the site. It is proposed that limiting that limiting leachate generation will have a knock-on effect on surface water quality through minimisation of potential groundwater contribution

Proposed remediation measures are discussed in Section 3 of this report.

Monitoring well concentrations as predicted by LandSim for ammonia are significantly higher than concentrations measured at perimeter groundwater monitoring wells GW01, GW02 and GW03. As stated above the monitor well automatically generated by LandSim for each defined phase is located directly downstream of the waste source, only c.5m away from the waste boundary, therefore differences between groundwater quality between this hypothetical monitoring well location and actual groundwater monitoring wells located further downstream would be expected.

Regarding predicted monitor well concentrations both model scenarios predict that lead concentrations remain at the background concentration at all various time slices. This is likely because of the relatively low source concentrations applied and to the potentially high soil-water partition co-efficient applied for lead, increasing retardation of lead within the underlying aquifer.

1.5 EA UK Remedial Targets Worksheet

In addition to LandSim, another modelling and prediction tool was utilised - The Hydrogeological Risk Assessment for Land Contamination – Remedial Targets Worksheet developed by the Environment Agency's Science Group. Generally, this model is utilised to develop remediation targets in soil or groundwater to ensure a desired downstream concentration at a point e.g. a well or receptor.

This assessment tool was utilised to predict the potential groundwater concentration for select parameters 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)

The limitation associated with this tool in comparison to LandSim is that it does not utilise Monte Carlo simulation /prediction and is reliant on the input of single values for each model parameter. Model inputs used were predominantly based on those utilised in the setup of the LandSim model where applicable.

Where ranges of values where applied in LandSim, for this tool median values were calculated and applied in the worksheet. It should be noted that the median value may not fully account for potentially significant variation in model inputs e.g. aquifer hydraulic conductivity.

The source concentrations used for the model where taken from LandSim outputs. Specifically, the 95%-ile monitor/perimeter well concentrations (i.e. worst-case scenario) predicted by LandSim were applied as the varying initial source concentrations.

The LandSim modelled well concentrations at 50 years, 100 years, 500 years and 1000 years for sodium, chloride and ammoniacal nitrogen were applied in this model. The dispersion of these contaminants at these starting concentrations over a specified the same period i.e. 50-year monitoring well concentration dispersion after 50 years, 100-year monitoring well concentration dispersion after 100 years etc. was examined using the EA worksheet.

This time step approach again is conservative as the model inputs assumed that the initial concentration modelled at 50 years remains static for 50 years when the source concentration is modelled as declining.

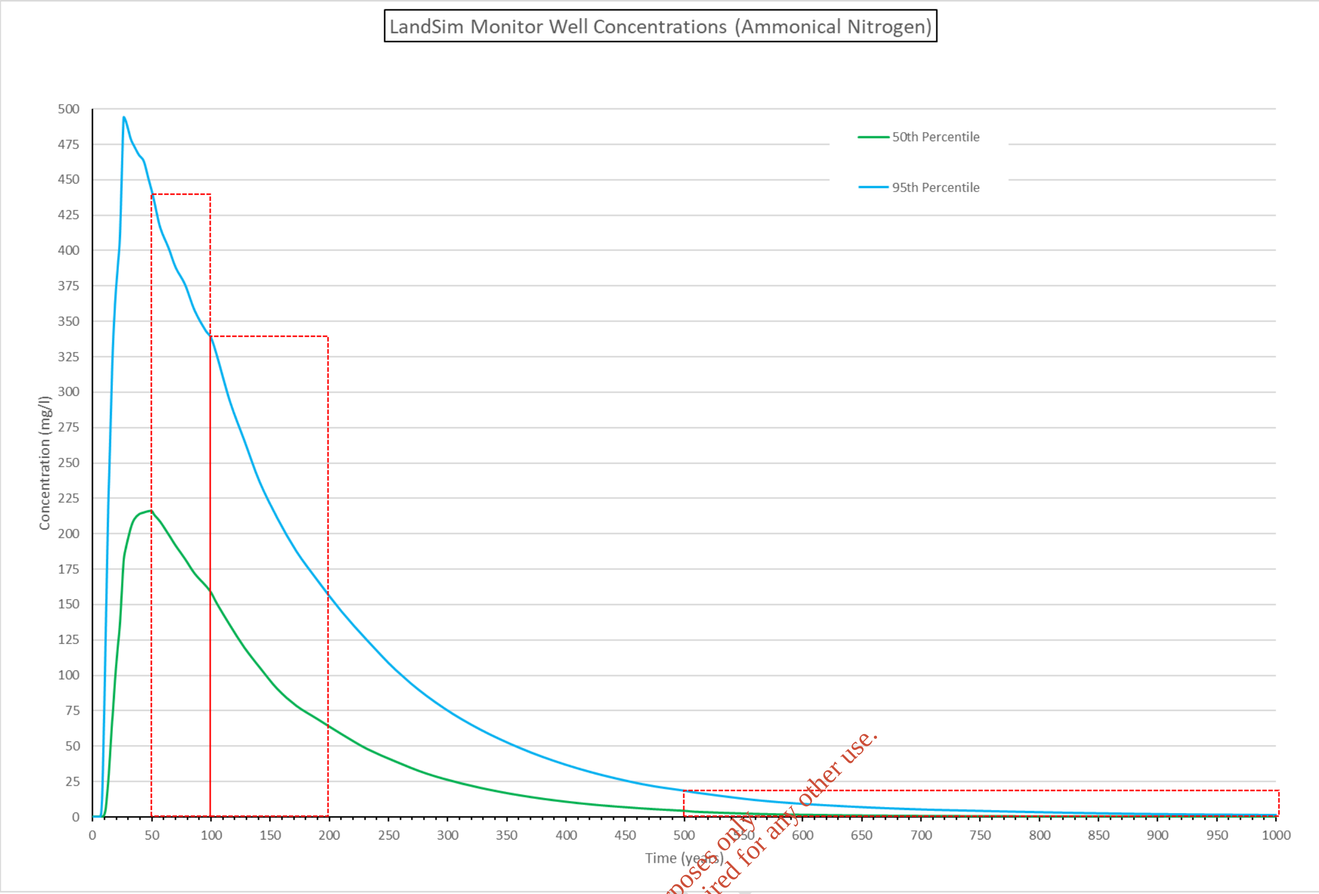


Figure 1-3: Monitor Well Concentrations (Ammoniacal Nitrogen) with Modelled Timesteps (red)

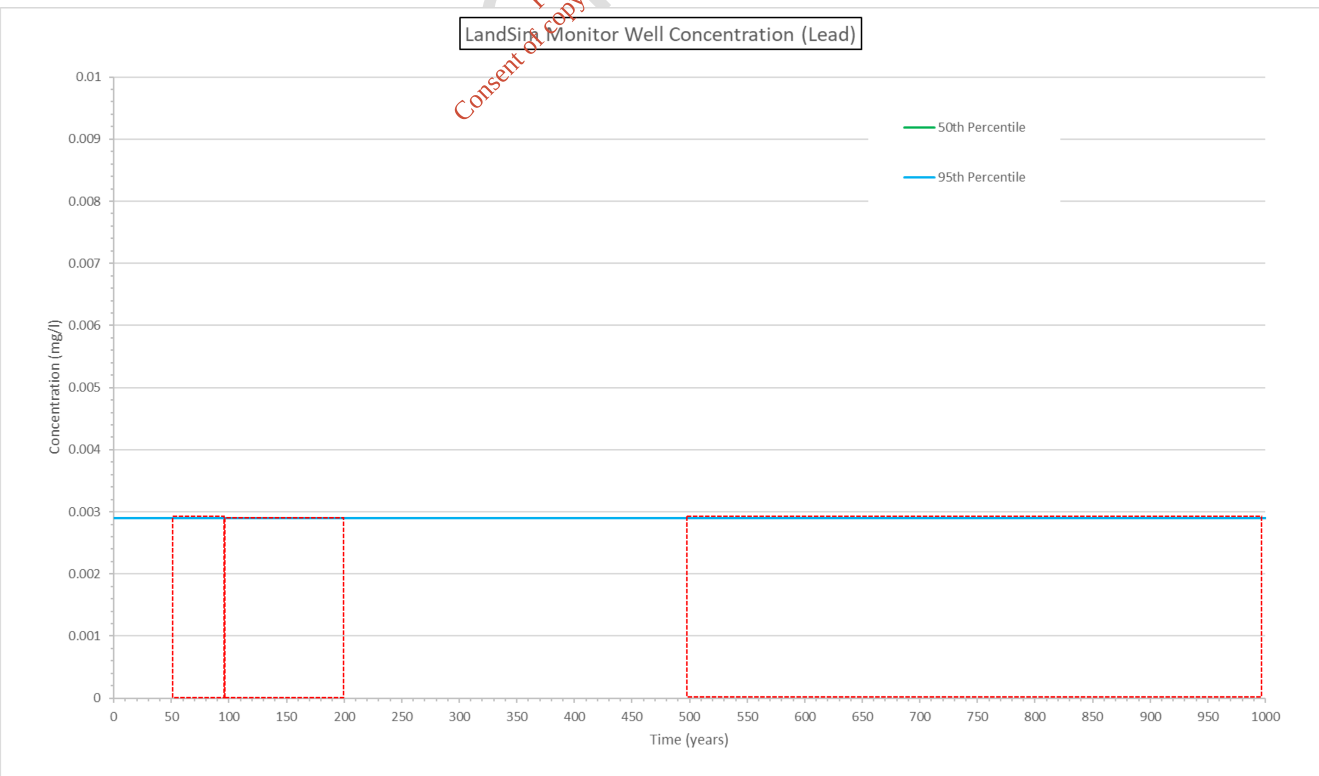


Figure 1-4: Monitor Well Concentrations (Lead) with Modelled Timesteps (red)

Table 1-5: 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 (LandSim) (mg/l)**	***Conc.at 10m (mg/l)***	***Conc. at 50m (mg/l)***	***Conc. at 100m (mg/l)***	***Conc. at 200m (mg/l)***
50	441.47	**441.47**	**12.75**	0	0
100	338.29	**338.29**	**43.15**	0	0
500	18.58	**18.58**	**9.70**	0.013	0
Lead (mg/l)			***Groundwater threshold Value (GTV) = 0.0075 mg/l***		
Years of Dispersion	**Initial Plume Concentration (LandSim) (mg/l)**	***Conc.at 10m (mg/l)***	***Conc. at 50m (mg/l)***	***Conc. at 100m (mg/l)***	***Conc. at 200m (mg/l)***
50	0.0029	0	0	0	0
100	0.0029	0	0	0	0
500	0.0029	5.17×10^{-6}	0	0	0

1.5.1 Discussion of Results

This model is used to predict downgradient concentrations of the identified pollutants (ammoniacal nitrogen, lead), 10, 50, 100 and 200m downstream of site after the stated number of years of influence (50, 100 and 500) at the defined permanent source concentration. Concentrations greater than groundwater threshold values are emboldened.

With respect to ammoniacal nitrogen exceedances of the groundwater threshold value, these are only observed within 50m of the site, indicating that contamination of groundwater with ammonia emanating from the site remains a local issue.

As discussed in Section 1.3.3. LandSIM predicted that lead concentrations would not exceed the selected lead background concentration at the monitor well. Unlike ammoniacal nitrogen there is no predicted decline in lead concentrations. Lead has a relatively high soil-water partition co-efficient (K_d). The K_d value applied in LandSim was 27 – 270000. A higher K_d means that the chemical is more adsorptive to soil and less readily dissolved in water. As a conservative approach in developing the Remedial Worksheet model for lead the minimum Kd value of 27 was applied. As shown in Table 1-5 above dispersion of lead beyond the site is limited. Of the three time periods modelled lead is only predicted to move up to 10m beyond the source after 500 years. This indicated the dispersion of lead emanating from the is likely to remain a local issue into the future.

1.6 Model Setup - 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 1-7 below.

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

The Tier 2 assessment identified lateral and vertical landfill gas migration as a high risk, (normalised risk scores of 42% and 70% respectively).

Monitoring for landfill gases emitted from onsite, perimeter groundwater monitoring wells was conducted on two occasions as part of the Tier 2 site investigation. All wells yielded trace quantities of methane on both monitoring rounds. No results were detected were above the thresholds. This is indicative that the site is no longer active or has only limited biological activity and the waste contained within is producing small quantities methane. The monitoring results from the two gas monitoring rounds are shown in Table 1-6.

Table 1-6: Groundwater Well Gas Monitoring Results September and October 2018

Date: 1-10-2018						
Sample Station	**CH_4 (% v/v)**	**CO_2 (% v/v)**	**O_2 (% v/v)**	**Atmospheric Pressure (mbar)**	**Staff Member**	**Weather**
GW01	0.1	0.2	21.6	1028	Daniel Hayden	Cloudy with light wind N-NE, 12°C - 14°C
GW02	0.2	0.7	21.1	1028		
GW03	0.2	0.1	23.8	1028		
Date: 9-10-2018						
Sample Station	**CH_4 (% v/v)**	**CO_2 (% v/v)**	**O_2 (% v/v)**	**Atmospheric Pressure (mbar)**	**Staff Member**	**Weather**
GW01	0.1	0.2	22.6	1005	Daniel Hayden	Cloudy with light wind N - NE, 14°C - 16°C
GW02	0.1	0.5	22.4	1005		
GW03	0.1	0.3	21.9	1005		

Table 1-7: LandGEM Model Primary Inputs and Variables

Landfill Characteristics	Input	Source
Landfill Open Year	1970	Exact timeframe of landfill operation is unknown. Site believed to be operational through the 1970s. Start of filling operations assumed.
Landfill Closure Year	1984	Anecdotal evidence suggests landfilling activities ceased c.1984.
Have Model Closure Calculate Closure Year	Yes	
Waste Design Capacity (megagrams/tonnes)	147784	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	
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 - 1984	10,556	Exact waste acceptance quantities per year are unknown. Worst case assumed waste design capacity was filled equally over 1970 to 1984 (14 year) period

1.7 Results – LandGEM

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

As an output, LandGEM produces a report on the model inputs and outputs. This report is included in Appendix 2 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 1-8. The model predicted that the site is currently generating 108.65 m^3/hr of methane across the entire site area. This will reduce to 65.9 m^3/hr by 2029.

Table 1-8: 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	393	238	314756	190909	0.045	0.027	**35.93**	**21.79**
Methane	105	64	157378	95455	0.012	0.007	17.97	10.90
Carbon dioxide	288	175	157378	95455	0.033	0.020	17.97	10.90
NMOC	5	3	1259	764	0.001	0.000	0.14	0.09

The approximate maximum waste deposition footprint was estimated to be approximately 2.28 Ha[Zone A + Zone C] (22,800 m^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 1-9.

Table 1-9: 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	0.017	13.805	1.97E-06	1.58E-03
Methane	0.005	6.903	5.26E-07	7.88E-04
Carbon dioxide	0.013	6.903	1.44E-06	7.88E-04
NMOC	1.98E-04	0.055	2.26E-08	6.30E-06

1.7.1 Discussion of Results

The outcome of the LandGEM model predicts a low rate of landfill gas generation in the current year (35.93 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 1-8: LandGEM estimated that in the current year (2019) a relatively moderate quantity, of 35.93 m^3/hour of landfill gas across the whole site is generated and assuming 50% percent of that volume being methane (17.97 m^3). Landfill gas monitoring of groundwater wells conducted in 2018 yielded only trace amounts of methane present. It is noted however that these wells are located outside the primary waste deposition area (Zone A), along the perimeter of the subject site as such high quantities of landfill gas may not be expected. The LandGEm model suggests that at the estimated quantity of waste deposited at the site that methane production is still occurring in moderate quantities and will continue for a number of years.

Figure 1-3 below shows the estimated landfill gas generation rates per year during the assumed operational phase (c.1970 to 1984) and predicted generation rates from 1984 onwards following closure of the site. It is noted that the model assumes equal production rates for both methane and carbon dioxide and are represented by the pink trendline.

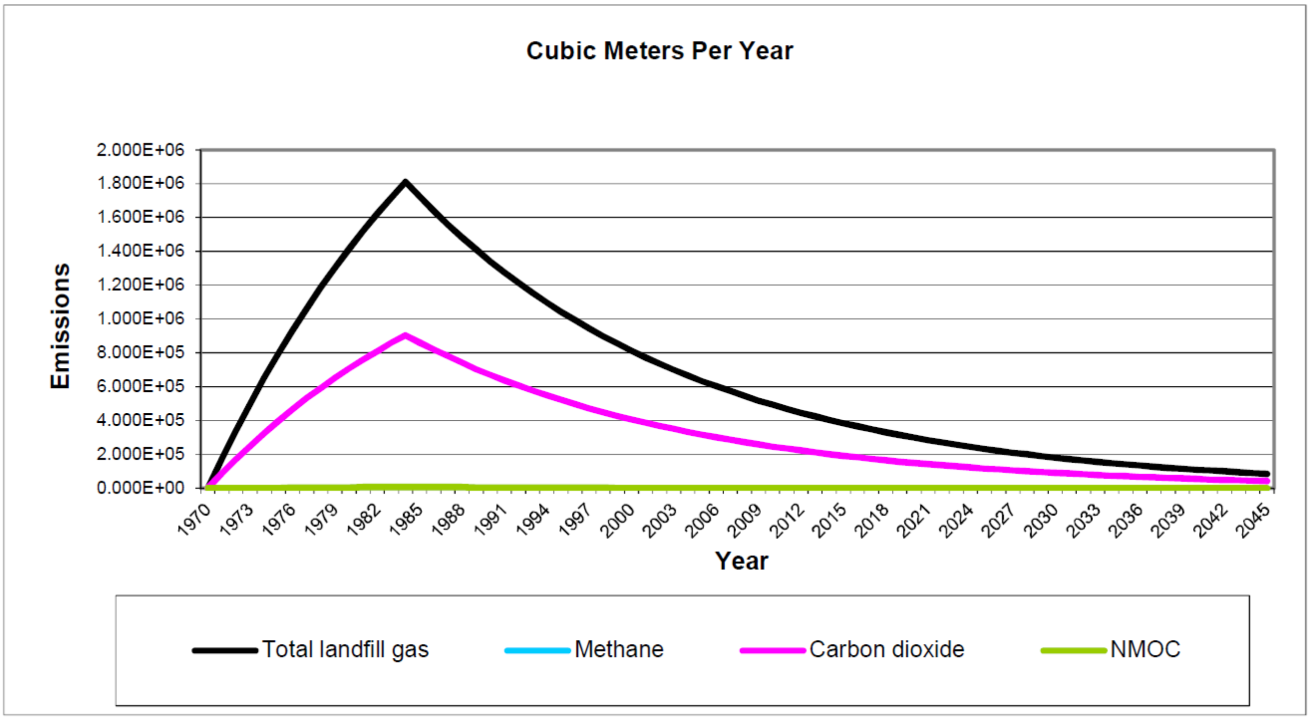


Figure 1-5: LandGEM Landfill Gas Volume Generation Rate

The complete summary report on model inputs and outputs/results generated by LandGEM is included in Appendix 2 of this report.

2 CONCLUSION AND RECCOMENDATIONS

The aim of this Tier 3 assessment was to examine (quantitatively) the potential impact of the historical landfill site on the receiving environment i.e. leachate generation/migration upon groundwater and surface water quality and potential vertical and lateral gas migration upon nearby receptors.

Two computer models were used in this Tier 3 assessment. LandSim was used to examine the potential impacts on aquifer/groundwater quality and subsequently on the receiving surface water body and to compare the magnitude of the impact where potential remediation measures are applied.

Two different modelling scenarios (Scenario 1 - current site conditions 'base' scenario and Scenario 2 - improved cap) were examined as part of this assessment. Scenario 1 - base model was prepared to represent the current site conditions with respect to existing site capping Scenario 2 included the adjustment of the cap design infiltration rate to represent the installation of an improved low permeability cap layer.

The installation of a lower permeability cap limiting the infiltration rate to the landfill yielded a significant predicted reduction in leachate generation and leakage from the base of the landfill. As discussed, in LandSim the rate of landfill leachate generation is directly related to the infiltration rate and is heavily dependent on the rainfall data applied in the model. It is likely that that the influx of groundwater through the subsoil upgradient of the waste body is a significant contributor to the volume of water present in the site.

The application of the EA UK Remedial Targets Worksheet to the figures generated from the LandSIM indicating that contamination of groundwater with ammonia emanating from the site is likely to remain a localised issue to the site due to the declining source concentration, nature of the underlying aquifer and dispersion of the pollutant. The same is true for other identified contaminants.

The output from LandGEM showed that landfill gas will continue to be generated for several years although in minimal quantities. It is recommended that landfill gas control measures should be installed at the site to 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.* Passive ventilation to atmosphere combined with landfill gas migration cut off trenches will be utilised to minimise the risks associated with low levels of landfill gas.

3 REMEDIAL ACTION PLAN

Based on the findings of the modelling exercises and quantitative risk assessment the following measures are proposed to mitigate the identified risks to groundwater and identified risk arising from gas generation at the landfill.

3.1 S-P-R Linkages

Following comprehensive desktop review, a site investigation and a Tier 2 assessment identified the primary source-pathway-receptors (S-P-R) linkages for the site to be leachate migration through surface water pathways and vertical and lateral migration of landfill gases. Proposed remedial measures for each of these linkages are discussed below. High risk scores (>70%) were also calculated for leachate migration through combined groundwater and surface water pathways

3.1.1 Leachate Migration through surface water pathway (SPR8)

The following remediation measures are proposed to mitigate the effect of the landfill on adjacent surface water features.

Landfill Capping

A fully engineered landfill cap is proposed for the site. The landfill cap shall be design in accordance with the EPA Landfill design manual for non-inert, non-hazardous landfills. The capping shall typically consist of the following or equivalent

- 200mm Topsoil Layer
- 800mm Sub Soil
- Sub-Surface Drainage Geocomposite
- 1mm LLDPE Barrier Layer
- Sub-Surface Landfill GAS Collection Geocomposite

The capping design shall be consistent with the future uses of the site for low intensity agricultural grazing purposes. The sub soil layer shall be therefore be adequately specified to ensure it is free draining to support grazing.

3.1.2 Vertical and Lateral Gas Generation (SPR10 & SPR11)

It is recommended that landfill gas control measures will be installed at the site. It is proposed that passive ventilation measures and vertical landfill gas interception trenches be used to mitigate the risk of landfill gas migration. The proposed measures are discussed in further detail below.

Passive Ventilation

The DQRA model indicates insufficient landfill gas volumes are present to warrant active abstraction and passive ventilation may be the most appropriate technique to mitigate landfill gas migration. It is proposed that capping will include a landfill gas drainage layer, the drainage layer will be directly connected to collection network and a series of vertical stand pipes venting to atmosphere at 2-3m above the final ground level.

The vertical stand pipes will provide a preferential pathway for LFG to escape to atmosphere mitigation risks associated with migration to offsite receptors.

Installed ventilation stand pipes will include a carbon filtration packs to "scrub" any odour and low concentrations of methane from the landfill gas prior to venting. Wind driven rotating cowls will also be used to induce a negative pressure within the stand pipe improving potential LFG flow.

3.1.3 Environmental Monitoring: Existing Locations

It is recommended that groundwater and surface water monitoring continue at all existing monitoring locations at the site specifically:

- Groundwater (Groundwater Quality and Landfill Gas Migration):
    - GW01
    - GW02
    - GW03
- Surface Water (Surface Water Quality):
    - SW1
    - SW2
    - SW3
    - SW4

Continued environmental monitoring should be undertaken on a quarterly basis up until the recommendations of the Certificate of Authorisation are known and remediation works are complete. Monitoring data should be available prior to detailed remediation design to confirm the findings of this report and for use post remediation as baseline data for comparative analysis.

3.1.4 Environmental Monitoring: Proposed New Locations

It is proposed that an additional groundwater monitoring points be installed up and down gradient of the site.

The following locations are recommended:

- GW04 –Baseline Upgradient (>25m<50m Upgradient of Waste Body)
- GW05 - Downgradient Receptor (>50m <100m Downgradient of Waste Body)
- GW06   Downgradient Receptor (>50m <100m Downgradient of Waste Body)

Future final locations should be agreed on site based on site conditions and access.

3.2 Remediation Design

The preliminary remediation design is presented in the following drawings:

- P1724-0105-0001
- P1724-0105-0002
- P1724-0505-0001
- P1724-0705-0001
- P1724-0905-0001
- P1724-0905-0002
- P1724-0905-0003

Drawings are included in Appendix 3 to this document.

3.2.1 Landfill Capping Works

The proposed capping works shall be subject to detailed design and agreement with existing site users and private landowner(s) and shall be cognisant of the future site use.

A standard 1m capping layer is recommended across the site in line with the EPA Landfill Design Manual Guidance for non-inert, non-hazardous landfills.

Details are shown in drawing: P1724-0905-0001

The proposed sub-surface drainage system will comprise a herring bone drainage network across the site. The network shall comprise sub-surface drains within the capping area connected with French drains external to the capping area.

Plan details are shown in drawing: P1724-0505-0001

The subsurface drainage shall be extended vertically as land drains to accommodate future agricultural uses. The network will outfall to one of three possible outfall locations. Inspection chambers will be located at all drain junctions for future maintenance and inspection.

3.2.2 Landfill Gas Management

Active landfill gas management may be required at the site dependent on the results of the recommended landfill gas pumping trials. It is recommended that dependant on the results of the trials an appropriate remediation design shall be adopted. Appropriate control measures shall be selected in accordance with the EPA Guidance document: *Management of Low Levels of Landfill Gas.*

3.3 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.

3.3.1 Landfill Capping

Table 3-1 over outlines the costs associated with capping the site. The proposed capping is as per the EPA Landfill Design manual recommendations as presented previously.

Table 3-1: Landfill Capping: Cost Estimates

Item	Quantity	Unit	Rate, €	Cost	Note
Allowance for Additional Site Investigation works	1	Rate	€25,000.00	€25,000.00	Allowance
Detailed Design and Supervision	1	Rate	€100,000.00	€100,000.00	Allowance
Land Rental Costs	1	Rate	€5,000.00	€5,000.00	Allowance
-	-	-	-		
General Site Clearance and Demolition Works	***2.2***	***ha***	-		
-	-	-	-		
General Site Clearance	2.2	ha	€20,000.00	€44,000.00	Allowance for Clearance of Existing Site
Excavation Works	22000	m²			Estimated area of Capping Area 15,200m²
-					
Excavation of Existing Cover/Capping for Reuse/Filling	2200	m³	€1.50	€3,300.00	Excavation of area to 100mm
Landfill Capping Works	22000				
Preparation of Excavated Surfaces	22000	m²	€0.75	€16,500.00	Approximate Area, Local Rates 2018
Supply and Installation of 50mm Protection Layer	22000	m²	€1.75	€38,500.00	Approximate Area, Local Rates 2018
Supply and Installation of Landfill Gas Collection Layer	22000	m²	€5.50	€121,000.00	Approximate Area, Local Rates 2018
Installation of 1mm LLDPE Cap	22000	m²	€6.50	€143,000.00	Approximate Area, Local Rates 2018
Installation of Surface Water Collection Layer	22000	m²	€5.50	€121,000.00	Approximate Area, Local Rates 2018
Importation of 800mm Subsoil Capping Layer	22000	m²	€8.50	€187,000.00	Approximate Area, Local Rates 2018
Importation of 200mm Topsoil Capping Layer	22000	m²	€3.00	€66,000.00	Approximate Area, Local Rates 2018

Item	Quantity	Unit	Rate, €	Cost	Note
Allowance Landfill Gas Migration Network Infrastructure	22000	m^2	€3.00	€66,000.00	Allowance
Allowance Sub surface Water Drainage Infrastructure	22000	m^2	€4.00	€88,000.00	Allowance
Independent CQA	1	Sum	€35,000.00	€35,000.00	Estimate Local Rates
Sub-Total 1				**€1,059,300.00**	
Add 10% Contractor Prelims	10.0%			€105,930.00	
Sub-Total 2				**€1,165,230.00**	
Add 10% Contingency	10.0%			€116,523.00	
Grand Total (excl VAT)				**€1,281,753.00**	

The estimated total remediation cost is **€1,281,753.0 (ex. VAT)** including the contingency as specified (10%).

Appendix 1

LandSim Model Inputs

Calculation Settings

Number of iterations: 1001

Results calculated using sampled PDFs

Full Calculation

Clay Liner:

Retarded values used for simulation

Biodegradation

Unsaturated Pathway:

Retarded values used for simulation

Biodegradation

Saturated Vertical Pathway:

No Vertical Pathway

Aquifer Pathway:

Retarded values used for simulation

Biodegradation

Timeslices at: 7, 50, 100, 500

Decline in Contaminant Concentration in Leachate

Ammoniacal_N	Non-Volatile
c (kg/l): 0.59	m (kg/l): 0
Lead	Non-Volatile
c (kg/l): 0.0171	m (kg/l): 0.0443
Phosphate	Non-Volatile
c (kg/l): 0	m (kg/l): 0

Contaminant Half-lives (years)

Unsaturated Pathway:

Ammoniacal_N	SINGLE(1e+009)
Lead	SINGLE(1e+009)
Phosphate	SINGLE(1e+009)

Aquifer Pathway:

Ammoniacal_N	SINGLE(1e+009)
Lead	SINGLE(1e+009)
Phosphate	SINGLE(1e+009)

Background Concentrations of Contaminants

Justification for Contaminant Properties

Applied LandSim UK default values, Kd values as per landsim manual, background concentrations basedo n EPA research and regulatory thresholds.

All units in milligrams per litre

Ammoniacal_N	SINGLE(0.065)
Lead	SINGLE(0.0029)

Phase: Knockcronaghan

Infiltration Information

Cap design infiltration (mm/year):	SINGLE(515)
Infiltration to waste (mm/year):	SINGLE(606)
End of filling (years from start of waste deposit):	14

Justification for Specified Infiltration

Open waste infiltration rate = GSI effective rainfall

Cap design rate assumed, based on application of 85% recharge coefficient

Duration of management control (years from the start of waste disposal): 2000

Cell dimensions

Cell width (m):	120
Cell length (m):	187.5
Cell top area (ha):	2.28
Cell base area (ha):	2.25
Number of cells:	1
Total base area (ha):	2.25
Total top area (ha):	2.28
Head of Leachate when surface water breakout occurs (m)	UNIFORM(5,7)
Waste porosity (fraction)	TRIANGULAR(0.42,0.54,0.62)
Final waste thickness (m):	TRIANGULAR(5,12,14)
Field capacity (fraction):	UNIFORM(0.2,0.4)
Waste dry density (kg/l)	UNIFORM(1.4,1.6)

Justification for Landfill Geometry

Cell dimensions assumed. Waste thickness based on site investigation. Porosity, field capacity and density assumed.

Source concentrations of contaminants

All units in milligrams per litre

Declining source term

Ammoniacal_N	LOGTRIANGULAR(4.37,723,3640) *Data are spot measurements of Leachate Quality*
Lead	LOGTRIANGULAR(0.00957,0.13,1.02) *Data are spot measurements of Leachate Quality*
Phosphate	LOGTRIANGULAR(0.01,2.54,22.6) *Data are spot measurements of Leachate Quality*

Justification for Species Concentration in Leachate

LandSim UK default values. Background concentrations assumed based on regulatory values and EPA research.

Drainage Information

Fixed Head.

Head on EBS is given as (m): TRIANGULAR(5,12,14)

Justification for Specified Head

Based on total thicknesses of waste body

Barrier Information

There is no barrier

Justification for Engineered Barrier Type

n/a - no engineered barrier installed

Sandy Gravelly Clay Glacial Till pathway parameters

Modelled as unsaturated pathway

Pathway length (m):	SINGLE(1)
Flow Model:	porous medium
Pathway moisture content (fraction):	UNIFORM(0.3,0.5)
Pathway Density (kg/l):	UNIFORM(1.3,2.3)

Justification for Unsat Zone Geometry

Assumed narrow unsaturated zone and high moisture content due to evidence that goundwater transects waste body

Pathway hydraulic conductivity values (m/s):	UNIFORM(1e-011,7.65e-008)

Justification for Unsat Zone Hydraulics Properties

Estimated pathway length based on SI and geohphys. High moisture content assumed due to high groundwater level. Conductivity based on literature and permeability tests

Pathway longitudinal dispersivity (m):	UNIFORM(0.01,0.03)

Justification for Unsat Zone Dispersion Properties

10% of pathway length

Retardation parameters for Sandy Gravelly Clay Glacial Till pathway

Modelled as unsaturated pathway

Uncertainty in Kd (l/kg):

Ammoniacal_N	UNIFORM(0.5,2)
Lead	UNIFORM(27,27000)
Phosphate	SINGLE(0)

Justification for Kd Values by Species

Assumed values as per LandSim manual

Aquifer Pathway Dimensions for Phase

Pathway length (m):	UNIFORM(815,1005)
Pathway width (m):	SINGLE(120)

pathway parameters

No Vertical Pathway

Limestone/Mudstone - Sandstone bedrock pathway parameters

Modelled as aquifer pathway.

Mixing zone (m):	
Calculated. Aquifer Thickness:	UNIFORM(3,40)

Justification for Aquifer Geometry
Pathway width - width of source/phase area
Aquifer thickness based on GSI groundwater body characterisation
Vertical dispersivity =1% of pathway length

Pathway regional gradient (-):	SINGLE(0.005125)
Pathway hydraulic conductivity values (m/s):	UNIFORM(3e-010,6e-006)
Pathway porosity (fraction):	UNIFORM(0.05,0.3)

Justification for Aquifer Hydraulics Properties
Conductivity assued based on lithology and values provided in LandSim Manual

Pathway longitudinal dispersivity (m):	UNIFORM(81.5,100.5)
Pathway transverse dispersivity (m):	UNIFORM(24.45,30.15)

Justification for Aquifer Dispersion Details
3% of pathway length

Retardation parameters for Limestone/Mudstone - Sandstone bedrock pathway

Modelled as aquifer pathway.

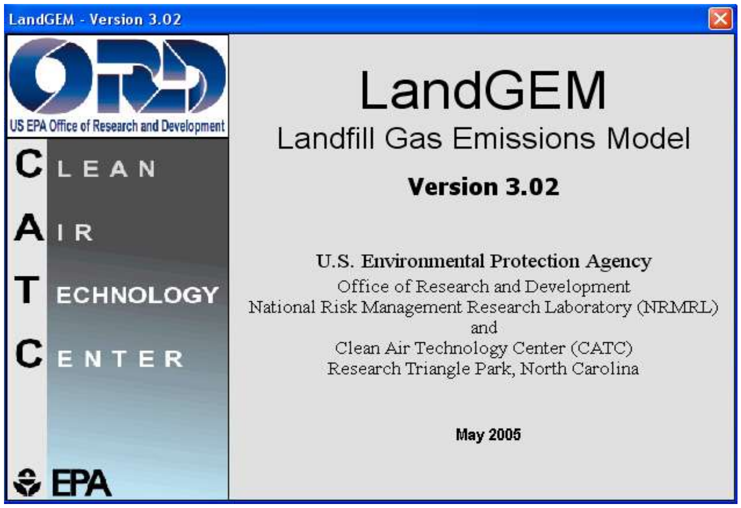
Uncertainty in Kd (l/kg):	
Ammoniacal_N	UNIFORM(0.5,2)
Lead	LOGUNIFORM(27,270000)
Phosphate	SINGLE(0)

Justification for Aquifer Kd Values by Species
Assumed. LandSim manual values

Pathway Density (kg/l):	UNIFORM(1.3,2.3)

Appendix 2

LandGEM Model Summary Report



Summary Report

Landfill Name or Identifier: Knockcronaghan Historical Landfill - Co.Monaghan

Date: Monday 13 May 2019

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)	**1983**	
Actual Closure Year (without limit)	***1983***	
Have Model Calculate Closure Year?	**Yes**	
Waste Design Capacity	**147,784**	*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	10,556	11,612	0	0
1971	10,556	11,612	10,556	11,612
1972	10,556	11,612	21,112	23,223
1973	10,556	11,612	31,668	34,835
1974	10,556	11,612	42,224	46,446
1975	10,556	11,612	52,780	58,058
1976	10,556	11,612	63,336	69,670
1977	10,556	11,612	73,892	81,281
1978	10,556	11,612	84,448	92,893
1979	10,556	11,612	95,004	104,504
1980	10,556	11,612	105,560	116,116
1981	10,556	11,612	116,116	127,728
1982	10,556	11,612	126,672	139,339
1983	10,556	11,612	137,228	150,951
1984	0	0	147,784	162,562
1985	0	0	147,784	162,562
1986	0	0	147,784	162,562
1987	0	0	147,784	162,562
1988	0	0	147,784	162,562
1989	0	0	147,784	162,562
1990	0	0	147,784	162,562
1991	0	0	147,784	162,562
1992	0	0	147,784	162,562
1993	0	0	147,784	162,562
1994	0	0	147,784	162,562
1995	0	0	147,784	162,562
1996	0	0	147,784	162,562
1997	0	0	147,784	162,562
1998	0	0	147,784	162,562
1999	0	0	147,784	162,562
2000	0	0	147,784	162,562
2001	0	0	147,784	162,562
2002	0	0	147,784	162,562
2003	0	0	147,784	162,562
2004	0	0	147,784	162,562
2005	0	0	147,784	162,562
2006	0	0	147,784	162,562
2007	0	0	147,784	162,562
2008	0	0	147,784	162,562
2009	0	0	147,784	162,562

WASTE ACCEPTANCE RATES (Continued)

Year	Waste Accepted		Waste-In-Place	
	(Mg/year)	*(short tons/year)*	*(Mg)*	*(short tons)*
2010	0	0	147,784	162,562
2011	0	0	147,784	162,562
2012	0	0	147,784	162,562
2013	0	0	147,784	162,562
2014	0	0	147,784	162,562
2015	0	0	147,784	162,562
2016	0	0	147,784	162,562
2017	0	0	147,784	162,562
2018	0	0	147,784	162,562
2019	0	0	147,784	162,562
2020	0	0	147,784	162,562
2021	0	0	147,784	162,562
2022	0	0	147,784	162,562
2023	0	0	147,784	162,562
2024	0	0	147,784	162,562
2025	0	0	147,784	162,562
2026	0	0	147,784	162,562
2027	0	0	147,784	162,562
2028	0	0	147,784	162,562
2029	0	0	147,784	162,562
2030	0	0	147,784	162,562
2031	0	0	147,784	162,562
2032	0	0	147,784	162,562
2033	0	0	147,784	162,562
2034	0	0	147,784	162,562
2035	0	0	147,784	162,562
2036	0	0	147,784	162,562
2037	0	0	147,784	162,562
2038	0	0	147,784	162,562
2039	0	0	147,784	162,562
2040	0	0	147,784	162,562
2041	0	0	147,784	162,562
2042	0	0	147,784	162,562
2043	0	0	147,784	162,562
2044	0	0	147,784	162,562
2045	0	0	147,784	162,562
2046	0	0	147,784	162,562
2047	0	0	147,784	162,562
2048	0	0	147,784	162,562
2049	0	0	147,784	162,562

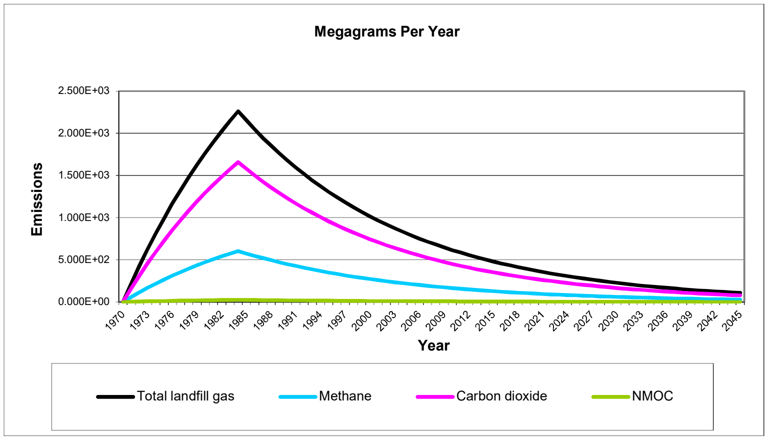
Pollutant Parameters

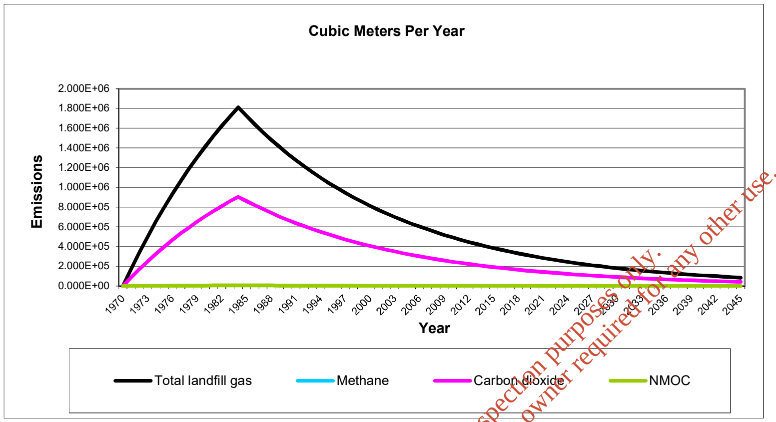
	Compound	Gas / Pollutant Default Parameters: Concentration (*ppmv*)	Molecular Weight	User-specified Pollutant Parameters: Concentration (*ppmv*)	Molecular Weight
Gases	Total landfill gas		0.00		
	Methane		16.04		
	Carbon dioxide		44.01		
	NMOC	4,000	86.18		
Pollutants	1,1,1-Trichloroethane (methyl chloroform)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

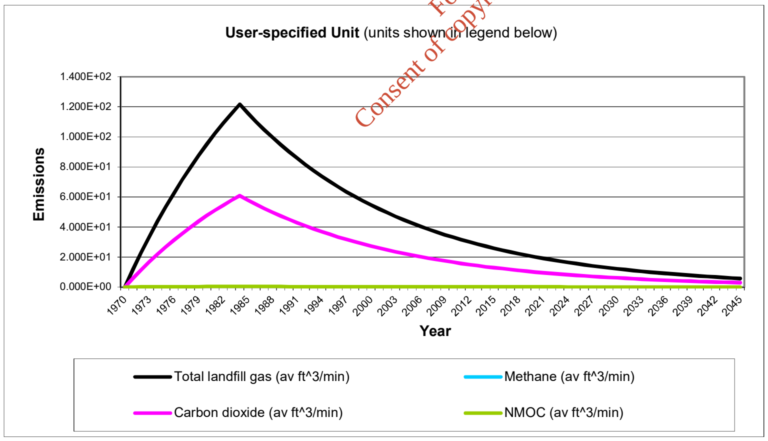
Pollutant Parameters (Continued)

	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	2.191E+02	1.755E+05	1.179E+01	5.853E+01	8.774E+04	5.895E+00
1972	4.276E+02	3.424E+05	2.301E+01	1.142E+02	1.712E+05	1.150E+01
1973	6.259E+02	5.012E+05	3.367E+01	1.672E+02	2.506E+05	1.684E+01
1974	8.145E+02	6.522E+05	4.382E+01	2.176E+02	3.261E+05	2.191E+01
1975	9.939E+02	7.959E+05	5.348E+01	2.655E+02	3.979E+05	2.674E+01
1976	1.165E+03	9.325E+05	6.266E+01	3.111E+02	4.663E+05	3.133E+01
1977	1.327E+03	1.063E+06	7.139E+01	3.544E+02	5.313E+05	3.570E+01
1978	1.481E+03	1.186E+06	7.970E+01	3.957E+02	5.931E+05	3.985E+01
1979	1.628E+03	1.304E+06	8.760E+01	4.349E+02	6.519E+05	4.380E+01
1980	1.768E+03	1.416E+06	9.512E+01	4.722E+02	7.079E+05	4.756E+01
1981	1.901E+03	1.522E+06	1.023E+02	5.077E+02	7.611E+05	5.114E+01
1982	2.027E+03	1.623E+06	1.091E+02	5.415E+02	8.117E+05	5.454E+01
1983	2.148E+03	1.720E+06	1.155E+02	5.736E+02	8.598E+05	5.777E+01
1984	2.262E+03	1.811E+06	1.217E+02	6.042E+02	9.056E+05	6.085E+01
1985	2.152E+03	1.723E+06	1.158E+02	5.747E+02	8.615E+05	5.788E+01
1986	2.047E+03	1.639E+06	1.101E+02	5.467E+02	8.195E+05	5.506E+01
1987	1.947E+03	1.559E+06	1.047E+02	5.200E+02	7.795E+05	5.237E+01
1988	1.852E+03	1.483E+06	9.964E+01	4.947E+02	7.415E+05	4.982E+01
1989	1.762E+03	1.411E+06	9.478E+01	4.706E+02	7.053E+05	4.739E+01
1990	1.676E+03	1.342E+06	9.016E+01	4.476E+02	6.709E+05	4.508E+01
1991	1.594E+03	1.276E+06	8.576E+01	4.258E+02	6.382E+05	4.288E+01
1992	1.516E+03	1.214E+06	8.158E+01	4.050E+02	6.071E+05	4.079E+01
1993	1.442E+03	1.155E+06	7.760E+01	3.853E+02	5.775E+05	3.880E+01
1994	1.372E+03	1.099E+06	7.382E+01	3.665E+02	5.493E+05	3.691E+01
1995	1.305E+03	1.045E+06	7.022E+01	3.486E+02	5.225E+05	3.511E+01
1996	1.241E+03	9.941E+05	6.679E+01	3.316E+02	4.970E+05	3.340E+01
1997	1.181E+03	9.456E+05	6.353E+01	3.154E+02	4.728E+05	3.177E+01
1998	1.123E+03	8.995E+05	6.043E+01	3.000E+02	4.497E+05	3.022E+01
1999	1.068E+03	8.556E+05	5.749E+01	2.854E+02	4.278E+05	2.874E+01
2000	1.016E+03	8.139E+05	5.468E+01	2.715E+02	4.069E+05	2.734E+01
2001	9.668E+02	7.742E+05	5.202E+01	2.582E+02	3.871E+05	2.601E+01
2002	9.197E+02	7.364E+05	4.948E+01	2.457E+02	3.682E+05	2.474E+01
2003	8.748E+02	7.005E+05	4.707E+01	2.337E+02	3.503E+05	2.353E+01
2004	8.321E+02	6.663E+05	4.477E+01	2.223E+02	3.332E+05	2.239E+01
2005	7.916E+02	6.338E+05	4.259E+01	2.114E+02	3.169E+05	2.129E+01
2006	7.530E+02	6.029E+05	4.051E+01	2.011E+02	3.015E+05	2.026E+01
2007	7.162E+02	5.735E+05	3.853E+01	1.913E+02	2.868E+05	1.927E+01
2008	6.813E+02	5.456E+05	3.666E+01	1.820E+02	2.728E+05	1.833E+01
2009	6.481E+02	5.189E+05	3.487E+01	1.731E+02	2.595E+05	1.743E+01
2010	6.165E+02	4.936E+05	3.317E+01	1.647E+02	2.468E+05	1.658E+01
2011	5.864E+02	4.696E+05	3.155E+01	1.566E+02	2.348E+05	1.577E+01
2012	5.578E+02	4.467E+05	3.001E+01	1.490E+02	2.233E+05	1.501E+01
2013	5.306E+02	4.249E+05	2.855E+01	1.417E+02	2.124E+05	1.427E+01
2014	5.047E+02	4.042E+05	2.716E+01	1.348E+02	2.021E+05	1.358E+01
2015	4.801E+02	3.844E+05	2.583E+01	1.282E+02	1.922E+05	1.292E+01
2016	4.567E+02	3.657E+05	2.457E+01	1.220E+02	1.828E+05	1.229E+01
2017	4.344E+02	3.479E+05	2.337E+01	1.160E+02	1.739E+05	1.169E+01
2018	4.132E+02	3.309E+05	2.223E+01	1.104E+02	1.654E+05	1.112E+01
2019	3.931E+02	3.148E+05	2.115E+01	1.050E+02	1.574E+05	1.057E+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	3.739E+02	2.994E+05	2.012E+01	9.987E+01	1.497E+05	1.006E+01
2021	3.557E+02	2.848E+05	1.914E+01	9.500E+01	1.424E+05	9.568E+00
2022	3.383E+02	2.709E+05	1.820E+01	9.037E+01	1.355E+05	9.101E+00
2023	3.218E+02	2.577E+05	1.731E+01	8.596E+01	1.289E+05	8.657E+00
2024	3.061E+02	2.451E+05	1.647E+01	8.177E+01	1.226E+05	8.235E+00
2025	2.912E+02	2.332E+05	1.567E+01	7.778E+01	1.166E+05	7.834E+00
2026	2.770E+02	2.218E+05	1.490E+01	7.399E+01	1.109E+05	7.452E+00
2027	2.635E+02	2.110E+05	1.418E+01	7.038E+01	1.055E+05	7.088E+00
2028	2.506E+02	2.007E+05	1.348E+01	6.695E+01	1.003E+05	6.742E+00
2029	2.384E+02	1.909E+05	1.283E+01	6.368E+01	9.545E+04	6.414E+00
2030	2.268E+02	1.816E+05	1.220E+01	6.058E+01	9.080E+04	6.101E+00
2031	2.157E+02	1.727E+05	1.161E+01	5.762E+01	8.637E+04	5.803E+00
2032	2.052E+02	1.643E+05	1.104E+01	5.481E+01	8.216E+04	5.520E+00
2033	1.952E+02	1.563E+05	1.050E+01	5.214E+01	7.815E+04	5.251E+00
2034	1.857E+02	1.487E+05	9.990E+00	4.960E+01	7.434E+04	4.995E+00
2035	1.766E+02	1.414E+05	9.503E+00	4.718E+01	7.071E+04	4.751E+00
2036	1.680E+02	1.345E+05	9.039E+00	4.488E+01	6.727E+04	4.520E+00
2037	1.598E+02	1.280E+05	8.598E+00	4.269E+01	6.399E+04	4.299E+00
2038	1.520E+02	1.217E+05	8.179E+00	4.061E+01	6.086E+04	4.089E+00
2039	1.446E+02	1.158E+05	7.780E+00	3.863E+01	5.790E+04	3.890E+00
2040	1.376E+02	1.101E+05	7.401E+00	3.674E+01	5.507E+04	3.700E+00
2041	1.308E+02	1.048E+05	7.040E+00	3.495E+01	5.239E+04	3.520E+00
2042	1.245E+02	9.966E+04	6.696E+00	3.325E+01	4.983E+04	3.348E+00
2043	1.184E+02	9.480E+04	6.370E+00	3.162E+01	4.740E+04	3.185E+00
2044	1.126E+02	9.018E+04	6.059E+00	3.008E+01	4.509E+04	3.030E+00
2045	1.071E+02	8.578E+04	5.764E+00	2.861E+01	4.289E+04	2.882E+00
2046	1.019E+02	8.160E+04	5.483E+00	2.722E+01	4.080E+04	2.741E+00
2047	9.693E+01	7.762E+04	5.215E+00	2.589E+01	3.881E+04	2.608E+00
2048	9.220E+01	7.383E+04	4.961E+00	2.463E+01	3.692E+04	2.480E+00
2049	8.771E+01	7.023E+04	4.719E+00	2.343E+01	3.512E+04	2.359E+00
2050	8.343E+01	6.681E+04	4.489E+00	2.228E+01	3.340E+04	2.244E+00
2051	7.936E+01	6.355E+04	4.270E+00	2.120E+01	3.177E+04	2.135E+00
2052	7.549E+01	6.045E+04	4.062E+00	2.016E+01	3.022E+04	2.031E+00
2053	7.181E+01	5.750E+04	3.863E+00	1.918E+01	2.875E+04	1.932E+00
2054	6.831E+01	5.470E+04	3.675E+00	1.825E+01	2.735E+04	1.838E+00
2055	6.497E+01	5.203E+04	3.496E+00	1.736E+01	2.601E+04	1.748E+00
2056	6.181E+01	4.949E+04	3.325E+00	1.651E+01	2.475E+04	1.663E+00
2057	5.879E+01	4.708E+04	3.163E+00	1.570E+01	2.354E+04	1.582E+00
2058	5.592E+01	4.478E+04	3.009E+00	1.494E+01	2.239E+04	1.504E+00
2059	5.320E+01	4.260E+04	2.862E+00	1.421E+01	2.130E+04	1.431E+00
2060	5.060E+01	4.052E+04	2.723E+00	1.352E+01	2.026E+04	1.361E+00
2061	4.813E+01	3.854E+04	2.590E+00	1.286E+01	1.927E+04	1.295E+00
2062	4.579E+01	3.666E+04	2.463E+00	1.223E+01	1.833E+04	1.232E+00
2063	4.355E+01	3.488E+04	2.343E+00	1.163E+01	1.744E+04	1.172E+00
2064	4.143E+01	3.318E+04	2.229E+00	1.107E+01	1.659E+04	1.115E+00
2065	3.941E+01	3.156E+04	2.120E+00	1.053E+01	1.578E+04	1.060E+00
2066	3.749E+01	3.002E+04	2.017E+00	1.001E+01	1.501E+04	1.008E+00
2067	3.566E+01	2.855E+04	1.919E+00	9.525E+00	1.428E+04	9.593E-01
2068	3.392E+01	2.716E+04	1.825E+00	9.060E+00	1.358E+04	9.125E-01
2069	3.227E+01	2.584E+04	1.736E+00	8.618E+00	1.292E+04	8.680E-01
2070	3.069E+01	2.458E+04	1.651E+00	8.198E+00	1.229E+04	8.257E-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)*
2071	2.920E+01	2.338E+04	1.571E+00	7.798E+00	1.169E+04	7.854E-01
2072	2.777E+01	2.224E+04	1.494E+00	7.418E+00	1.112E+04	7.471E-01
2073	2.642E+01	2.115E+04	1.421E+00	7.056E+00	1.058E+04	7.106E-01
2074	2.513E+01	2.012E+04	1.352E+00	6.712E+00	1.006E+04	6.760E-01
2075	2.390E+01	1.914E+04	1.286E+00	6.385E+00	9.570E+03	6.430E-01
2076	2.274E+01	1.821E+04	1.223E+00	6.073E+00	9.103E+03	6.117E-01
2077	2.163E+01	1.732E+04	1.164E+00	5.777E+00	8.659E+03	5.818E-01
2078	2.057E+01	1.647E+04	1.107E+00	5.495E+00	8.237E+03	5.535E-01
2079	1.957E+01	1.567E+04	1.053E+00	5.227E+00	7.835E+03	5.265E-01
2080	1.862E+01	1.491E+04	1.002E+00	4.972E+00	7.453E+03	5.008E-01
2081	1.771E+01	1.418E+04	9.527E-01	4.730E+00	7.090E+03	4.764E-01
2082	1.684E+01	1.349E+04	9.063E-01	4.499E+00	6.744E+03	4.531E-01
2083	1.602E+01	1.283E+04	8.621E-01	4.280E+00	6.415E+03	4.310E-01
2084	1.524E+01	1.220E+04	8.200E-01	4.071E+00	6.102E+03	4.100E-01
2085	1.450E+01	1.161E+04	7.800E-01	3.873E+00	5.805E+03	3.900E-01
2086	1.379E+01	1.104E+04	7.420E-01	3.684E+00	5.522E+03	3.710E-01
2087	1.312E+01	1.050E+04	7.058E-01	3.504E+00	5.252E+03	3.529E-01
2088	1.248E+01	9.992E+03	6.714E-01	3.333E+00	4.996E+03	3.357E-01
2089	1.187E+01	9.505E+03	6.386E-01	3.171E+00	4.752E+03	3.193E-01
2090	1.129E+01	9.041E+03	6.075E-01	3.016E+00	4.521E+03	3.037E-01
2091	1.074E+01	8.600E+03	5.779E-01	2.869E+00	4.300E+03	2.889E-01
2092	1.022E+01	8.181E+03	5.497E-01	2.729E+00	4.090E+03	2.748E-01
2093	9.718E+00	7.782E+03	5.229E-01	2.596E+00	3.891E+03	2.614E-01
2094	9.244E+00	7.402E+03	4.974E-01	2.469E+00	3.701E+03	2.487E-01
2095	8.793E+00	7.041E+03	4.731E-01	2.349E+00	3.521E+03	2.366E-01
2096	8.365E+00	6.698E+03	4.500E-01	2.234E+00	3.349E+03	2.250E-01
2097	7.957E+00	6.371E+03	4.281E-01	2.125E+00	3.186E+03	2.140E-01
2098	7.569E+00	6.061E+03	4.072E-01	2.022E+00	3.030E+03	2.036E-01
2099	7.199E+00	5.765E+03	3.873E-01	1.923E+00	2.882E+03	1.937E-01
2100	6.848E+00	5.484E+03	3.685E-01	1.829E+00	2.742E+03	1.842E-01
2101	6.514E+00	5.216E+03	3.505E-01	1.740E+00	2.608E+03	1.752E-01
2102	6.197E+00	4.962E+03	3.334E-01	1.655E+00	2.481E+03	1.667E-01
2103	5.894E+00	4.720E+03	3.171E-01	1.574E+00	2.360E+03	1.586E-01
2104	5.607E+00	4.490E+03	3.017E-01	1.498E+00	2.245E+03	1.508E-01
2105	5.333E+00	4.271E+03	2.870E-01	1.425E+00	2.135E+03	1.435E-01
2106	5.073E+00	4.062E+03	2.730E-01	1.355E+00	2.031E+03	1.365E-01
2107	4.826E+00	3.864E+03	2.596E-01	1.289E+00	1.932E+03	1.298E-01
2108	4.591E+00	3.676E+03	2.470E-01	1.226E+00	1.838E+03	1.235E-01
2109	4.367E+00	3.497E+03	2.349E-01	1.166E+00	1.748E+03	1.175E-01
2110	4.154E+00	3.326E+03	2.235E-01	1.109E+00	1.663E+03	1.117E-01

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	1.606E+02	8.774E+04	5.895E+00	2.516E+00	7.019E+02	4.716E-02
1972	3.134E+02	1.712E+05	1.150E+01	4.909E+00	1.370E+03	9.202E-02
1973	4.587E+02	2.506E+05	1.684E+01	7.186E+00	2.005E+03	1.347E-01
1974	5.969E+02	3.261E+05	2.191E+01	9.351E+00	2.609E+03	1.753E-01
1975	7.284E+02	3.979E+05	2.674E+01	1.141E+01	3.184E+03	2.139E-01
1976	8.535E+02	4.663E+05	3.133E+01	1.337E+01	3.730E+03	2.506E-01
1977	9.725E+02	5.313E+05	3.570E+01	1.523E+01	4.250E+03	2.856E-01
1978	1.086E+03	5.931E+05	3.985E+01	1.701E+01	4.745E+03	3.188E-01
1979	1.193E+03	6.519E+05	4.380E+01	1.869E+01	5.215E+03	3.504E-01
1980	1.296E+03	7.079E+05	4.756E+01	2.030E+01	5.663E+03	3.805E-01
1981	1.393E+03	7.611E+05	5.114E+01	2.182E+01	6.089E+03	4.091E-01
1982	1.486E+03	8.117E+05	5.454E+01	2.328E+01	6.494E+03	4.363E-01
1983	1.574E+03	8.598E+05	5.777E+01	2.466E+01	6.879E+03	4.622E-01
1984	1.658E+03	9.056E+05	6.085E+01	2.597E+01	7.245E+03	4.868E-01
1985	1.577E+03	8.615E+05	5.788E+01	2.470E+01	6.892E+03	4.631E-01
1986	1.500E+03	8.195E+05	5.506E+01	2.350E+01	6.556E+03	4.405E-01
1987	1.427E+03	7.795E+05	5.237E+01	2.235E+01	6.236E+03	4.190E-01
1988	1.357E+03	7.415E+05	4.982E+01	2.126E+01	5.932E+03	3.986E-01
1989	1.291E+03	7.053E+05	4.739E+01	2.023E+01	5.643E+03	3.791E-01
1990	1.228E+03	6.709E+05	4.508E+01	1.924E+01	5.367E+03	3.606E-01
1991	1.168E+03	6.382E+05	4.288E+01	1.830E+01	5.106E+03	3.430E-01
1992	1.111E+03	6.071E+05	4.079E+01	1.741E+01	4.857E+03	3.263E-01
1993	1.057E+03	5.775E+05	3.880E+01	1.656E+01	4.620E+03	3.104E-01
1994	1.005E+03	5.493E+05	3.691E+01	1.575E+01	4.394E+03	2.953E-01
1995	9.565E+02	5.225E+05	3.511E+01	1.498E+01	4.180E+03	2.809E-01
1996	9.098E+02	4.970E+05	3.340E+01	1.425E+01	3.976E+03	2.672E-01
1997	8.654E+02	4.728E+05	3.177E+01	1.356E+01	3.782E+03	2.541E-01
1998	8.232E+02	4.497E+05	3.022E+01	1.290E+01	3.598E+03	2.417E-01
1999	7.831E+02	4.278E+05	2.874E+01	1.227E+01	3.422E+03	2.299E-01
2000	7.449E+02	4.069E+05	2.734E+01	1.167E+01	3.255E+03	2.187E-01
2001	7.086E+02	3.871E+05	2.601E+01	1.110E+01	3.097E+03	2.081E-01
2002	6.740E+02	3.682E+05	2.474E+01	1.056E+01	2.946E+03	1.979E-01
2003	6.411E+02	3.503E+05	2.353E+01	1.004E+01	2.802E+03	1.883E-01
2004	6.099E+02	3.332E+05	2.239E+01	9.554E+00	2.665E+03	1.791E-01
2005	5.801E+02	3.169E+05	2.129E+01	9.088E+00	2.535E+03	1.704E-01
2006	5.518E+02	3.015E+05	2.026E+01	8.645E+00	2.412E+03	1.620E-01
2007	5.249E+02	2.868E+05	1.927E+01	8.223E+00	2.294E+03	1.541E-01
2008	4.993E+02	2.728E+05	1.833E+01	7.822E+00	2.182E+03	1.466E-01
2009	4.750E+02	2.595E+05	1.743E+01	7.441E+00	2.076E+03	1.395E-01
2010	4.518E+02	2.468E+05	1.658E+01	7.078E+00	1.975E+03	1.327E-01
2011	4.298E+02	2.348E+05	1.577E+01	6.733E+00	1.878E+03	1.262E-01
2012	4.088E+02	2.233E+05	1.501E+01	6.404E+00	1.787E+03	1.200E-01
2013	3.889E+02	2.124E+05	1.427E+01	6.092E+00	1.700E+03	1.142E-01
2014	3.699E+02	2.021E+05	1.358E+01	5.795E+00	1.617E+03	1.086E-01
2015	3.519E+02	1.922E+05	1.292E+01	5.512E+00	1.538E+03	1.033E-01
2016	3.347E+02	1.828E+05	1.229E+01	5.243E+00	1.463E+03	9.828E-02
2017	3.184E+02	1.739E+05	1.169E+01	4.988E+00	1.391E+03	9.349E-02
2018	3.029E+02	1.654E+05	1.112E+01	4.744E+00	1.324E+03	8.893E-02
2019	2.881E+02	1.574E+05	1.057E+01	4.513E+00	1.259E+03	8.459E-02

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	2.740E+02	1.497E+05	1.006E+01	4.293E+00	1.198E+03	8.047E-02
2021	2.607E+02	1.424E+05	9.568E+00	4.083E+00	1.139E+03	7.654E-02
2022	2.480E+02	1.355E+05	9.101E+00	3.884E+00	1.084E+03	7.281E-02
2023	2.359E+02	1.289E+05	8.657E+00	3.695E+00	1.031E+03	6.926E-02
2024	2.244E+02	1.226E+05	8.235E+00	3.515E+00	9.805E+02	6.588E-02
2025	2.134E+02	1.166E+05	7.834E+00	3.343E+00	9.327E+02	6.267E-02
2026	2.030E+02	1.109E+05	7.452E+00	3.180E+00	8.872E+02	5.961E-02
2027	1.931E+02	1.055E+05	7.088E+00	3.025E+00	8.439E+02	5.670E-02
2028	1.837E+02	1.003E+05	6.742E+00	2.878E+00	8.028E+02	5.394E-02
2029	1.747E+02	9.545E+04	6.414E+00	2.737E+00	7.636E+02	5.131E-02
2030	1.662E+02	9.080E+04	6.101E+00	2.604E+00	7.264E+02	4.881E-02
2031	1.581E+02	8.637E+04	5.803E+00	2.477E+00	6.910E+02	4.643E-02
2032	1.504E+02	8.216E+04	5.520E+00	2.356E+00	6.573E+02	4.416E-02
2033	1.431E+02	7.815E+04	5.251E+00	2.241E+00	6.252E+02	4.201E-02
2034	1.361E+02	7.434E+04	4.995E+00	2.132E+00	5.947E+02	3.996E-02
2035	1.294E+02	7.071E+04	4.751E+00	2.028E+00	5.657E+02	3.801E-02
2036	1.231E+02	6.727E+04	4.520E+00	1.929E+00	5.381E+02	3.616E-02
2037	1.171E+02	6.399E+04	4.299E+00	1.835E+00	5.119E+02	3.439E-02
2038	1.114E+02	6.086E+04	4.089E+00	1.745E+00	4.869E+02	3.272E-02
2039	1.060E+02	5.790E+04	3.890E+00	1.660E+00	4.632E+02	3.112E-02
2040	1.008E+02	5.507E+04	3.700E+00	1.579E+00	4.406E+02	2.960E-02
2041	9.589E+01	5.239E+04	3.520E+00	1.502E+00	4.191E+02	2.816E-02
2042	9.122E+01	4.983E+04	3.348E+00	1.429E+00	3.987E+02	2.679E-02
2043	8.677E+01	4.740E+04	3.185E+00	1.359E+00	3.792E+02	2.548E-02
2044	8.254E+01	4.509E+04	3.030E+00	1.293E+00	3.607E+02	2.424E-02
2045	7.851E+01	4.289E+04	2.882E+00	1.230E+00	3.431E+02	2.305E-02
2046	7.468E+01	4.080E+04	2.741E+00	1.170E+00	3.264E+02	2.193E-02
2047	7.104E+01	3.881E+04	2.608E+00	1.113E+00	3.105E+02	2.086E-02
2048	6.758E+01	3.692E+04	2.480E+00	1.059E+00	2.953E+02	1.984E-02
2049	6.428E+01	3.512E+04	2.359E+00	1.007E+00	2.809E+02	1.888E-02
2050	6.114E+01	3.340E+04	2.244E+00	9.579E-01	2.672E+02	1.795E-02
2051	5.816E+01	3.177E+04	2.135E+00	9.111E-01	2.542E+02	1.708E-02
2052	5.533E+01	3.022E+04	2.031E+00	8.667E-01	2.418E+02	1.625E-02
2053	5.263E+01	2.875E+04	1.932E+00	8.244E-01	2.300E+02	1.545E-02
2054	5.006E+01	2.735E+04	1.838E+00	7.842E-01	2.188E+02	1.470E-02
2055	4.762E+01	2.601E+04	1.748E+00	7.460E-01	2.081E+02	1.398E-02
2056	4.530E+01	2.475E+04	1.663E+00	7.096E-01	1.980E+02	1.330E-02
2057	4.309E+01	2.354E+04	1.582E+00	6.750E-01	1.883E+02	1.265E-02
2058	4.099E+01	2.239E+04	1.504E+00	6.421E-01	1.791E+02	1.204E-02
2059	3.899E+01	2.130E+04	1.431E+00	6.108E-01	1.704E+02	1.145E-02
2060	3.709E+01	2.026E+04	1.361E+00	5.810E-01	1.621E+02	1.089E-02
2061	3.528E+01	1.927E+04	1.295E+00	5.526E-01	1.542E+02	1.036E-02
2062	3.356E+01	1.833E+04	1.232E+00	5.257E-01	1.467E+02	9.854E-03
2063	3.192E+01	1.744E+04	1.172E+00	5.000E-01	1.395E+02	9.373E-03
2064	3.036E+01	1.659E+04	1.115E+00	4.757E-01	1.327E+02	8.916E-03
2065	2.888E+01	1.578E+04	1.060E+00	4.525E-01	1.262E+02	8.481E-03
2066	2.747E+01	1.501E+04	1.008E+00	4.304E-01	1.201E+02	8.068E-03
2067	2.613E+01	1.428E+04	9.593E-01	4.094E-01	1.142E+02	7.674E-03
2068	2.486E+01	1.358E+04	9.125E-01	3.894E-01	1.086E+02	7.300E-03
2069	2.365E+01	1.292E+04	8.680E-01	3.704E-01	1.033E+02	6.944E-03
2070	2.249E+01	1.229E+04	8.257E-01	3.524E-01	9.831E+01	6.605E-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)
2071	2.140E+01	1.169E+04	7.854E-01	3.352E-01	9.351E+01	6.283E-03
2072	2.035E+01	1.112E+04	7.471E-01	3.188E-01	8.895E+01	5.977E-03
2073	1.936E+01	1.058E+04	7.106E-01	3.033E-01	8.461E+01	5.685E-03
2074	1.842E+01	1.006E+04	6.760E-01	2.885E-01	8.049E+01	5.408E-03
2075	1.752E+01	9.570E+03	6.430E-01	2.744E-01	7.656E+01	5.144E-03
2076	1.666E+01	9.103E+03	6.117E-01	2.610E-01	7.283E+01	4.893E-03
2077	1.585E+01	8.659E+03	5.818E-01	2.483E-01	6.928E+01	4.655E-03
2078	1.508E+01	8.237E+03	5.535E-01	2.362E-01	6.590E+01	4.428E-03
2079	1.434E+01	7.835E+03	5.265E-01	2.247E-01	6.268E+01	4.212E-03
2080	1.364E+01	7.453E+03	5.008E-01	2.137E-01	5.963E+01	4.006E-03
2081	1.298E+01	7.090E+03	4.764E-01	2.033E-01	5.672E+01	3.811E-03
2082	1.234E+01	6.744E+03	4.531E-01	1.934E-01	5.395E+01	3.625E-03
2083	1.174E+01	6.415E+03	4.310E-01	1.840E-01	5.132E+01	3.448E-03
2084	1.117E+01	6.102E+03	4.100E-01	1.750E-01	4.882E+01	3.280E-03
2085	1.063E+01	5.805E+03	3.900E-01	1.665E-01	4.644E+01	3.120E-03
2086	1.011E+01	5.522E+03	3.710E-01	1.583E-01	4.417E+01	2.968E-03
2087	9.614E+00	5.252E+03	3.529E-01	1.506E-01	4.202E+01	2.823E-03
2088	9.145E+00	4.996E+03	3.357E-01	1.433E-01	3.997E+01	2.685E-03
2089	8.699E+00	4.752E+03	3.193E-01	1.363E-01	3.802E+01	2.555E-03
2090	8.275E+00	4.521E+03	3.037E-01	1.296E-01	3.617E+01	2.430E-03
2091	7.871E+00	4.300E+03	2.889E-01	1.233E-01	3.440E+01	2.311E-03
2092	7.488E+00	4.090E+03	2.748E-01	1.173E-01	3.272E+01	2.199E-03
2093	7.122E+00	3.891E+03	2.614E-01	1.116E-01	3.113E+01	2.091E-03
2094	6.775E+00	3.701E+03	2.487E-01	1.061E-01	2.961E+01	1.989E-03
2095	6.445E+00	3.521E+03	2.366E-01	1.010E-01	2.817E+01	1.892E-03
2096	6.130E+00	3.349E+03	2.250E-01	9.603E-02	2.679E+01	1.800E-03
2097	5.831E+00	3.186E+03	2.140E-01	9.135E-02	2.549E+01	1.712E-03
2098	5.547E+00	3.030E+03	2.036E-01	8.690E-02	2.424E+01	1.629E-03
2099	5.276E+00	2.882E+03	1.937E-01	8.266E-02	2.306E+01	1.549E-03
2100	5.019E+00	2.742E+03	1.842E-01	7.863E-02	2.194E+01	1.474E-03
2101	4.774E+00	2.608E+03	1.752E-01	7.479E-02	2.087E+01	1.402E-03
2102	4.541E+00	2.481E+03	1.667E-01	7.114E-02	1.985E+01	1.334E-03
2103	4.320E+00	2.360E+03	1.586E-01	6.767E-02	1.888E+01	1.269E-03
2104	4.109E+00	2.245E+03	1.508E-01	6.437E-02	1.796E+01	1.207E-03
2105	3.909E+00	2.135E+03	1.435E-01	6.123E-02	1.708E+01	1.148E-03
2106	3.718E+00	2.031E+03	1.365E-01	5.825E-02	1.625E+01	1.092E-03
2107	3.537E+00	1.932E+03	1.298E-01	5.541E-02	1.546E+01	1.039E-03
2108	3.364E+00	1.838E+03	1.235E-01	5.270E-02	1.470E+01	9.879E-04
2109	3.200E+00	1.748E+03	1.175E-01	5.013E-02	1.399E+01	9.398E-04
2110	3.044E+00	1.663E+03	1.117E-01	4.769E-02	1.330E+01	8.939E-04

Appendix 3

Remediation Plan Drawings

Legend
- Site Boundary
- Approximate Area For Capped 24,681m² To Be Confirmed By Additional S.I.

0m 10m 20m 30m 40m 50m 60m 70m 80m 90m 100m
Scale 1:1000

If Applicable : Ordnance Survey Ireland Licence No. EN 0001219 © Ordnance Survey Ireland and Government of Ireland

Rev.	Description	App By	Date
A	ISSUE FOR DISCUSSION	BG	10.05.19

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CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT
ERA OF HISTORIC LANDFILLS AT KILLYCARD AND KILLYCRONAGHAN

SHEET
SITE LOCATION MAP: KILLYCRONAGHAN

CLIENT
MONAGHAN COUNTY COUNCIL

Date	10.05.19	Project number	P1724	Scale (@ A1-)	1:1000
Drawn by	SOC	Drawing Number	P1724-0105-0001	Rev	A
Checked by	JON				

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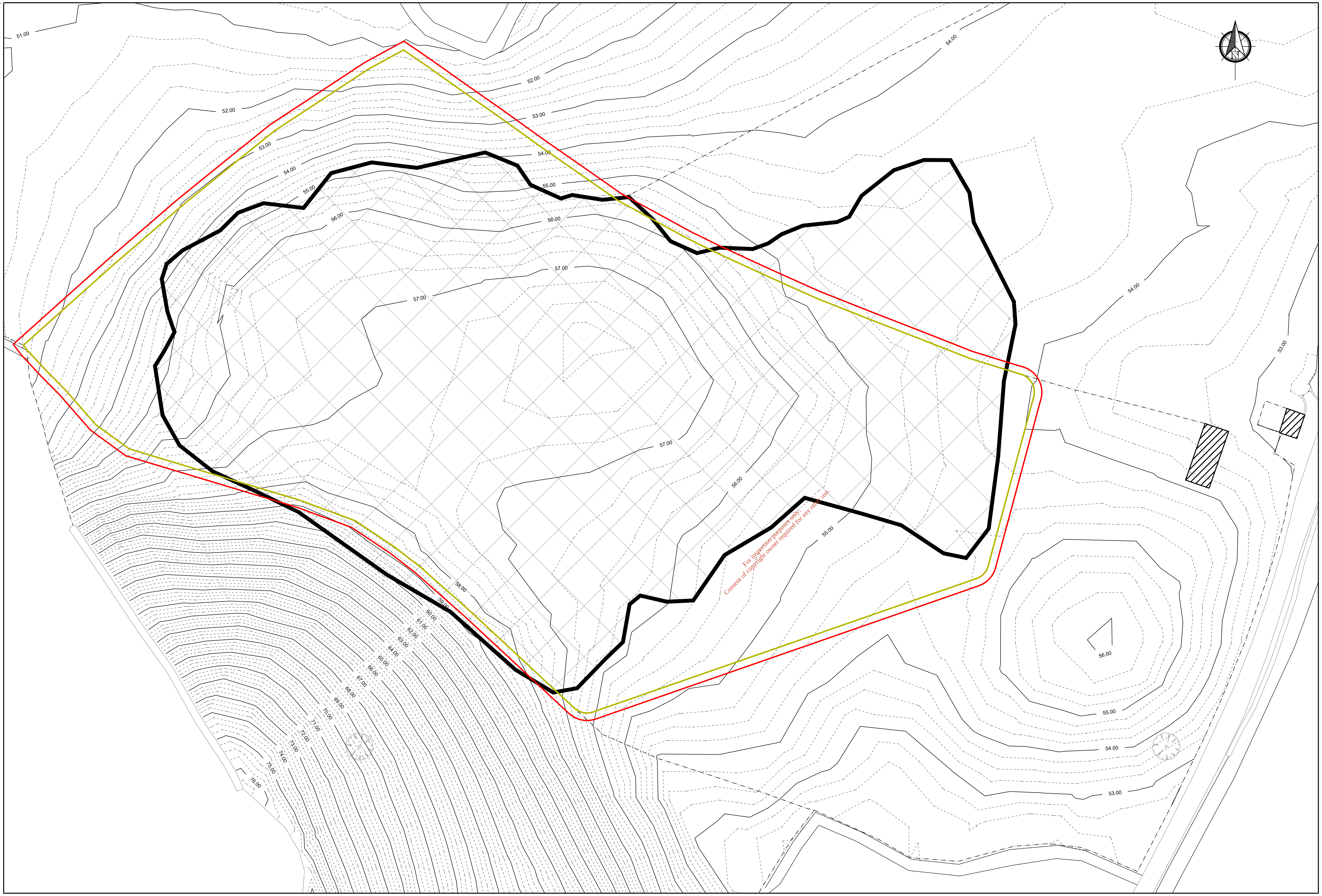
05 December 2019



Legend

- Site Boundary
- Approximate Area For Capped 24,681m² To Be Confirmed By Additional S.I.
- Interpolated Waste Boundary Geophysics. Note: Area To The North West Removed Based On Site Observation To Be Confirmed By Intrusive Site Investigations

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

Scale 1:500

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CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT

ERA OF HISTORIC LANDFILLS AT KILLYCARD AND KILLYCRONAGHAN

SHEET

KILLYCRONAGHAN WASTE BOUNDARY PLAN

CLIENT

MONAGHAN COUNTY COUNCIL

Date 10.05.19	Project number P1724	Scale (@ A1-) 1:500	
Drawn by SOC	Drawing Number		Rev
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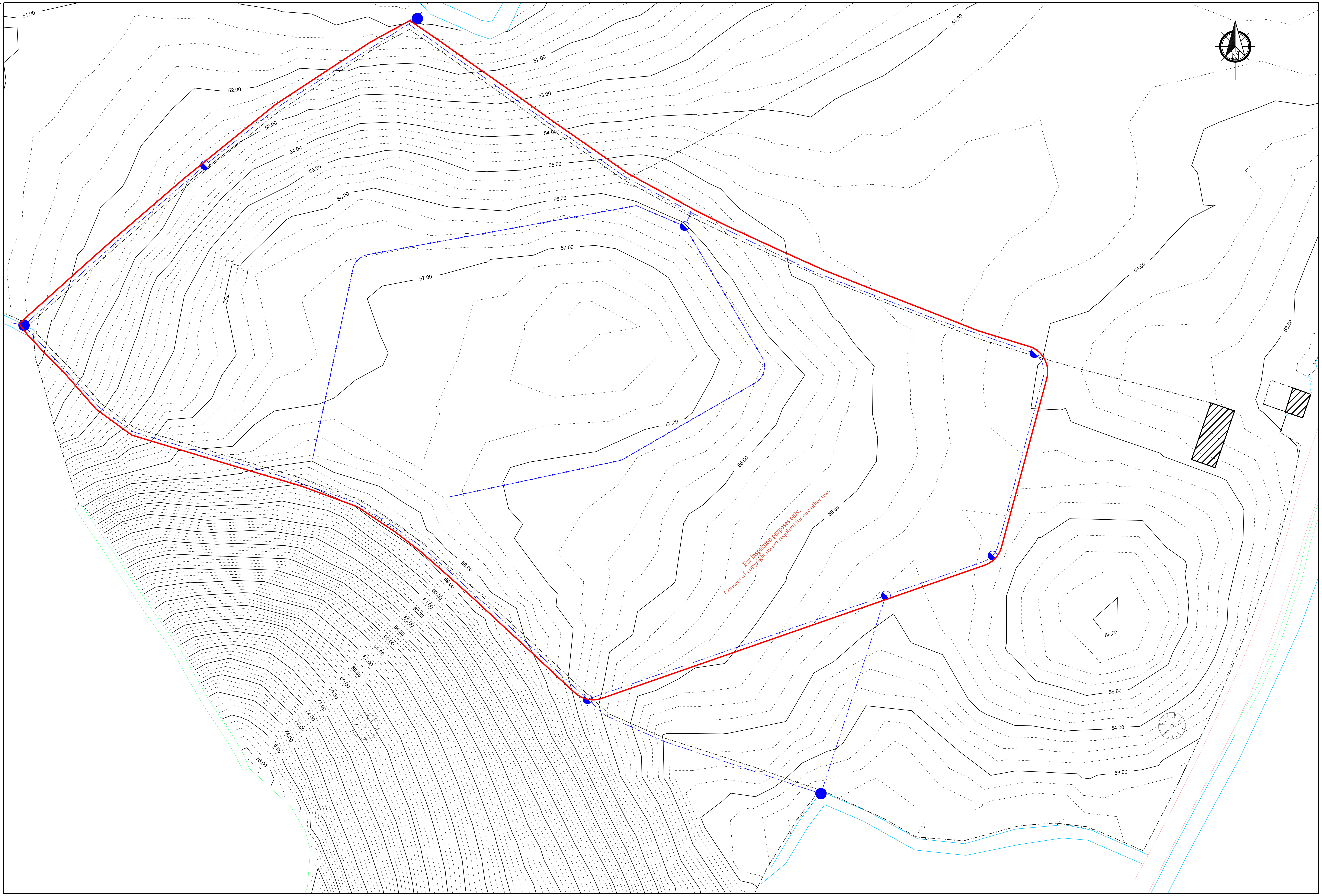
05 December 2019



Legend

- Site Boundary
- Sub Surface Contour Drain
- Combined Sub Surface/French Drain
- Intermediate Inspection Chamber
- Outfall Chamber
- Access Point/Setting Point

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

Scale 1:500

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CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT

ERA OF HISTORIC LANDFILLS AT KILLYCARD AND KILLYCRONAGHAN

SHEET

KILLYCRONAGHAN SUB-SURFACE AND SURFACE DRAINAGE PLAN

CLIENT

MONAGHAN COUNTY COUNCIL

Date	Project number	Scale (@ A1-)
13.05.19	P1724	1:500

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SOC	P1724-0505-0001	A
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05 December 2019

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

Scale 1:500

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CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT

ERA OF HISTORIC LANDFILLS AT KILLYCARD AND KILLYCRONAGHAN

SHEET

KILLYCRONAGHAN LANDFILL GAS MANAGEMENT PLAN

CLIENT

MONAGHAN COUNTY COUNCIL

Date 13.05.19	Project number P1724	Scale (@ A1-) 1:500	
Drawn by SOC	Drawing Number P1724-0705-0001		Rev A
Checked by JON			

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05 December 2019

TYPICAL DETAIL VERTICAL CUT OFF AND FRENCH DRAIN

Scale 1:10

0m 0.1m 0.2m 0.3m 0.4m 0.5m 0.6m 0.7m 0.8m 0.9m 1m

Scale 1:10

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CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT
ERA OF HISTORIC LANDFILLS AT KILLYCARD AND KILLYCRONAGHAN

SHEET
KILLYCRONAGHAN DETAILS SHEET 1 OF 3

CLIENT
MONAGHAN COUNTY COUNCIL

Date 13.05.19 | Project number P1724 | Scale (@ A1-) 1:10
Drawn by SOC | Drawing Number **P1724-0905-0001** | Rev **A**
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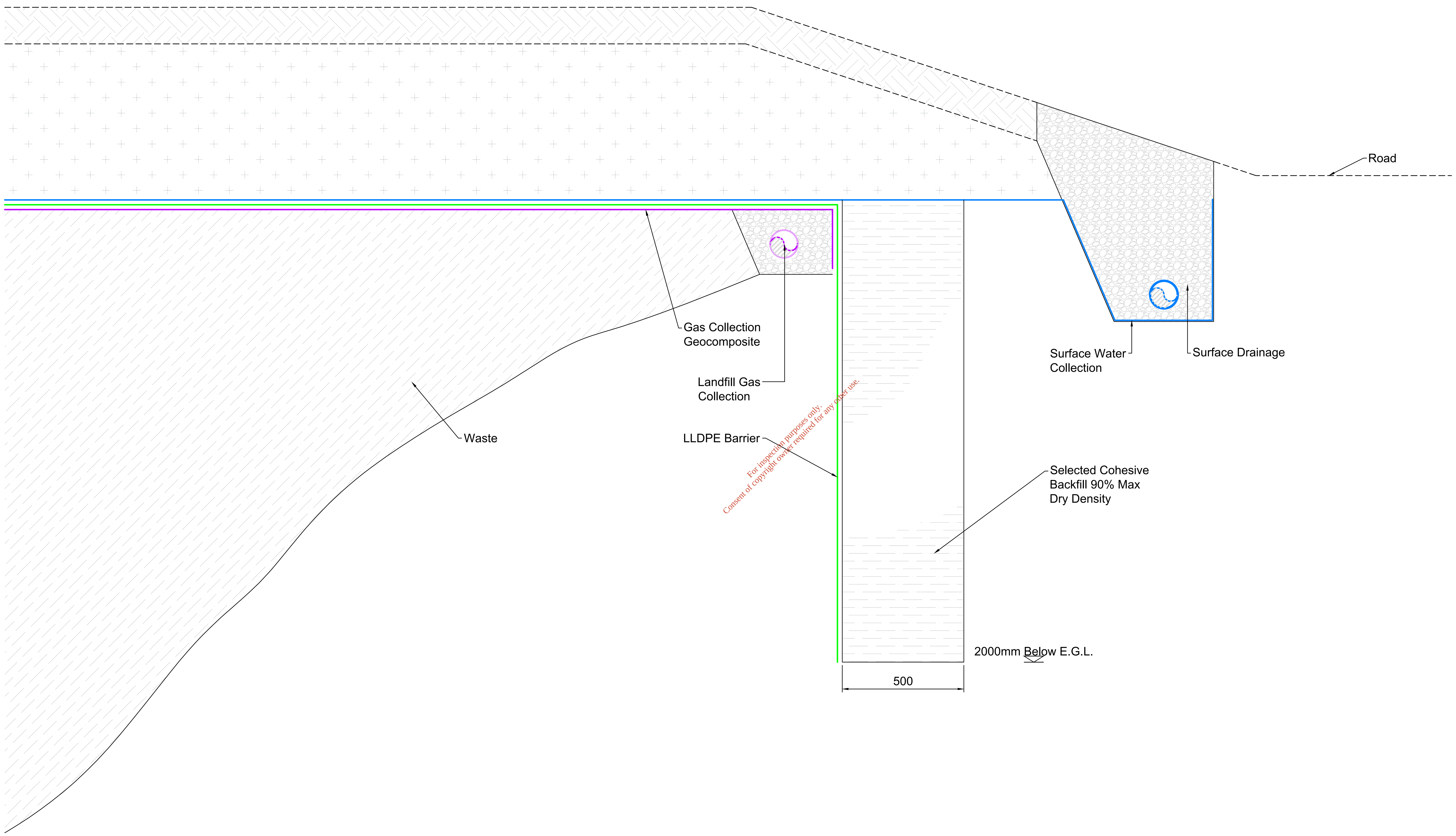

TYPICAL DETAIL VERTICAL CUT OFF AND FRENCH DRAIN TO BOUNDARY

Scale 1:10

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0m 0.1m 0.2m 0.3m 0.4m 0.5m 0.6m 0.7m 0.8m 0.9m 1m
Scale 1:10

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CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT
ERA OF HISTORIC LANDFILLS AT KILLYCARD AND KILLYCRONAGHAN

SHEET
KILLYCRONAGHAN DETAILS SHEET 2 OF 3

CLIENT
MONAGHAN COUNTY COUNCIL

Date 14.05.19
Project number P1724
Scale (@ A1-) 1:10
Drawn by SOC
Drawing Number P1724-0905-0002
Rev A
Checked by JON

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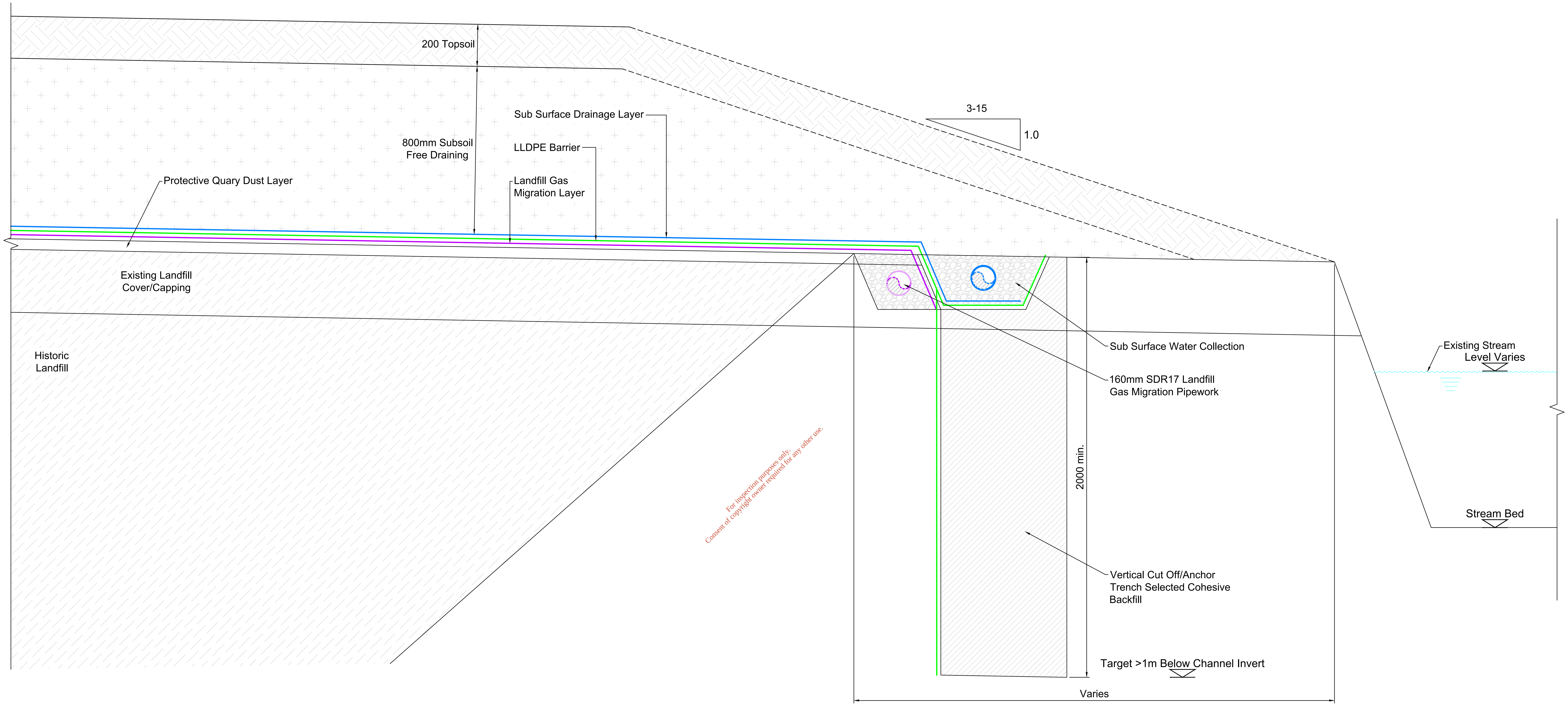
05 December 2019



TYPICAL DETAIL VERTICAL CUT OFF TO OPEN CHANNEL DRAIN

Scale 1:10

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0m 0.1m 0.2m 0.3m 0.4m 0.5m 0.6m 0.7m 0.8m 0.9m 1m

Scale 1:10

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CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT

ERA OF HISTORIC LANDFILLS AT KILLYCARD AND KILLYCRONAGHAN

SHEET

KILLYCRONAGHAN DETAIL SHEET 3 OF 3

CLIENT

MONAGHAN COUNTY COUNCIL

Date	Project number	Scale (@ A1-)
14.05.19	P1724	1:10

Drawn by	Drawing Number	Rev
SOC	P1724-0905-0003	A

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