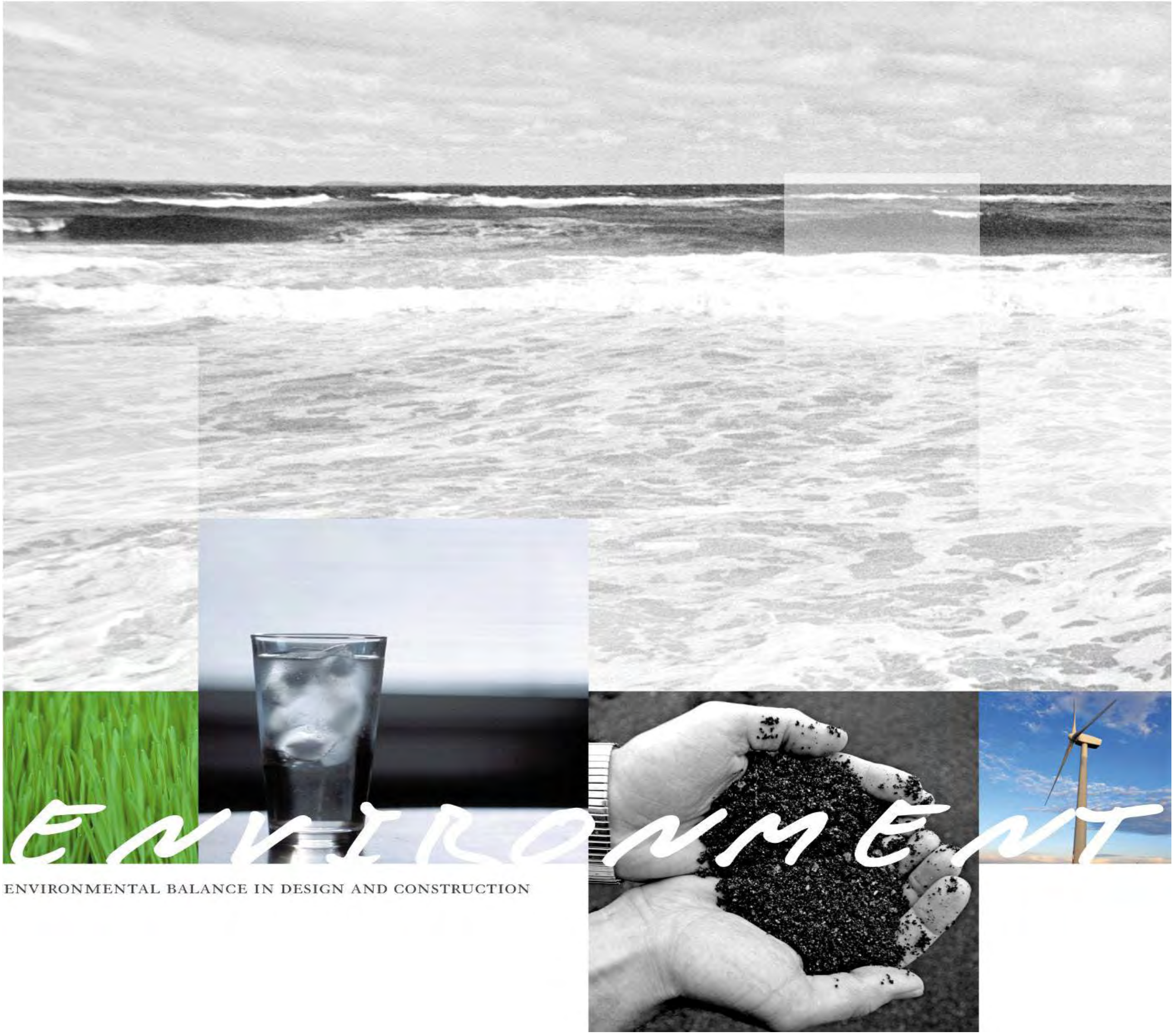

TIER 3 RISK ASSESSMENT

CARTRON BIG HISTORIC LANDFILL SITE, CO. LONGFORD

March 2020

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Longford County Council
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FEHILY TIMONEY
30 YEARS

TIER 3 RISK ASSESSMENT

CARTRON BIG HISTORIC LANDFILL, CO. LONGFORD

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Abstract: This report represents the findings of a Tier 3 risk assessment carried out on Cartron Big Historic Landfill site, Co. Longford, 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 Longford County Council (LCC) to complete a Tier 3 environmental risk assessment (ERA) on Cartron Big 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 within the Cartron Big townland approximately 3km east of Longford Town, at the intersection of the L1071 and L3538 tertiary roads. The site was operated under the ownership of Longford County Council (LCC) for the disposal of municipal and industrial waste. It was previously reported by LCC that the landfill accepted waste throughout the 1970s and 1980s, ceasing in 1989.

A Tier 1 study was conducted by AECOM and determined the site to be a high-risk classification (Class A). The primary risks identified related to the risk of leachate runoff entering a nearby stream and the risk of leachate runoff entering a public water supply..

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

The results of this Tier 2 assessment and risk model indicates that the site is a **High-Risk Classification (Class A)**. The principal risks identified on the site are the migration of leachate from the site to the groundwater aquifer and the associated risk posed to the Clooncoose Stream from the migration of landfill leachate from the waste material encountered at the site.

The purpose of this Tier 3 assessment was to further examine and quantify those risks/impacts through generation of computer models allowing a prediction of both the current and future impact on groundwater quality and the current and future extent landfill gas being generated by the waste present on site. This information was used to inform what appropriate remedial and mitigation measures should be implemented on site to either eliminate or reduce those risks.

Results obtained from the LandSim model confirmed the 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 material over the portion of the site currently underlain with waste material may have on the generation of leachate and the dispersion of pollutants within the aquifer. The adjacent Clooncoose Stream is hydraulically linked with groundwater migrating through the landfill and so any impact on groundwater is likely to have an impact on the stream.

The Hydrogeological Risk Assessment – Remedial Targets Worksheet developed by the Environment Agency UK was applied to examine how contaminants might disperse downstream of the site. This model suggested that potential adverse effects on groundwater quality would likely be localised within a relatively short distance downstream of the site.

LandGEM was utilised to estimate the quantity of landfill gas produced by the waste underlying the site.

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 a landfill cap layer should be constructed across the site. The proposed landfill cap will be constructed in accordance with the EPA recommendations/requirements for landfill site design. This will mitigate the contribution of rainfall infiltration towards leachate generation from the site. Modelling of downstream concentrations demonstrated that even at elevated concentrations, above those observed in downgradient monitoring wells it is expected that the impact on groundwater is limited to a relatively small area downstream of the site.

The landfill cap shall include a vertical cut off and leachate interception trench along the stream boundary of the site. The leachate interception trench shall be constructed to break the pathway linkage between the landfill waste and the boundary stream.

As means of monitoring the efficacy of the proposed remediation measures additional groundwater monitoring locations are recommended downstream of the site.

The landfill capping shall also include active or passive landfill gas controls. A final decision on landfill gas control measures will be made upon completion of a landfill gas pumping trial. The pumping trial shall be used to determine the quantity and quality of landfill gas actively produced at the site. 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.

1 TIER 3 QUANTITATIVE RISK ASSESSMENT

1.1 Background

Following the completion of a site investigation and Tier 2 risk assessment at former landfill at Cartron Big, Co. Longford by Fehily Timoney & Co in 2018 it was concluded that a Tier 3 assessment should also be conducted. The findings of that Tier 2 assessment produced a firmer understanding of the characterisation of the site and facilitated the production of a revised Conceptual Site Model (CSM).

A Tier 3 assessment includes some form of quantitative risk assessment either a Generic Quantitative Risk Assessment (GQRA) or a Detailed Quantitative Risk Assessment (DQRA). This Tier 3 assessment report outlines the outcomes of a DQRA. Elevated concentrations of ammonia were detected in downgradient groundwater monitoring well GW03 and were shown to be significantly above upgradient wells GW01 and GW02, indicating that the landfill and leachate generated is having a deleterious effect on groundwater quality. Surface water monitoring conducted on the Clooncoose Stream which runs immediately adjacent to the landfill in a north/north-westerly direction also has elevated ammonia concentrations at monitoring location SW04. The results of monitoring and site investigation shows possible surface water pathways from the site, possibly the onsite man-made drainage channels. It is also noted that owing to the topography of the site and high water table there is a direct groundwater to surface water linkage from the site to the Clooncoose Stream. Any impact on groundwater underlying the site is therefore highly likely to impact on nearby surface water features.

LandSim modelling software has been 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.

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.

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 DQRA Model Setup - LandSim

LandSim setup involves several different stages; these are described below. 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 & Contaminated Land Centre (UK) have also been used where appropriate.

1.2.1 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 Cartron Big site was defined as a single 'phase'.

Figure 1-1 shows the screen shot of the domain area for the Cartron Big 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.

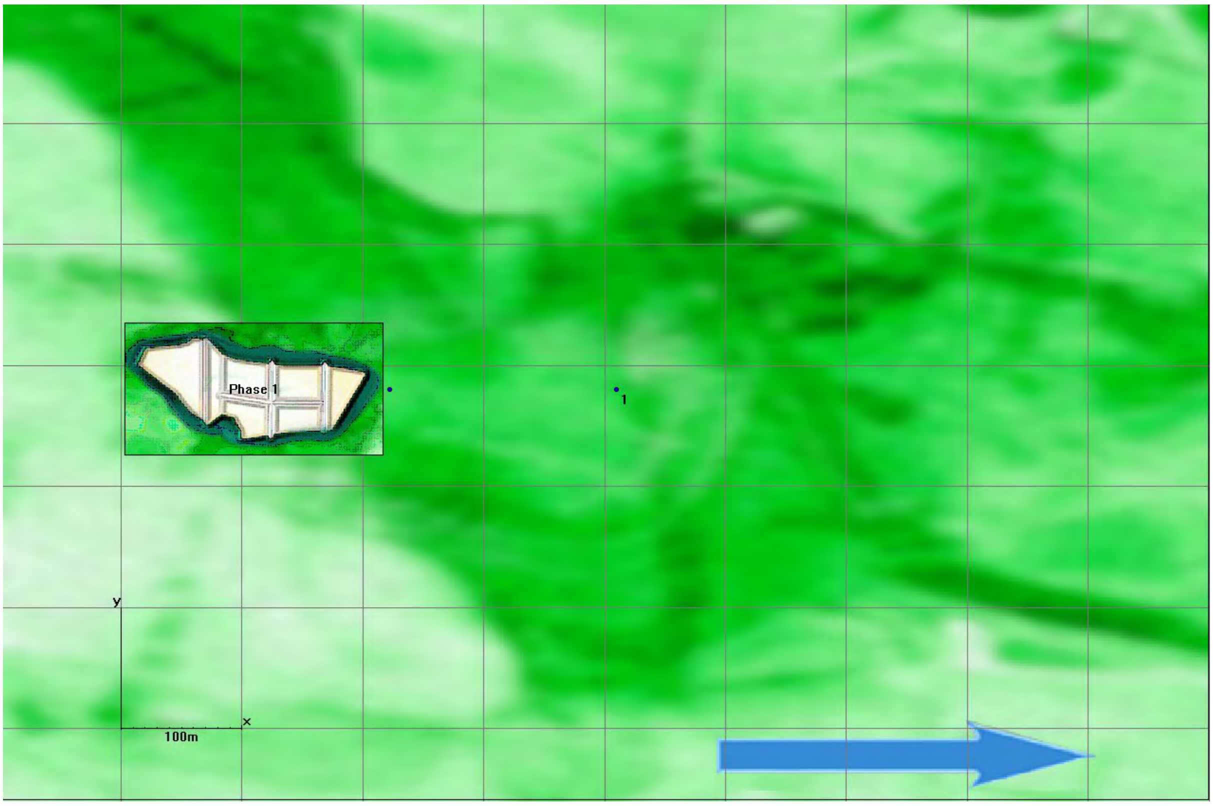


Figure 1-1: Domain Layout in LandSim

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 assessment site investigation determined that the groundwater water table transects the waste body and is confined at its base only by the competent limestone bedrock identified, underlying the site. It is understood that as a result the limestone bedrock may also be confining the spread of leachate generated onsite. Groundwater and leachate are potentially confined to moving downgradient along the surface of the limestone bedrock. It is this limestone stratum that has been applied in the LandSim model as the aquifer pathway.

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 limestone bedrock aquifer. Based on the estimated waste thickness and publicly available information on the general characteristics of the bedrock aquifer an aquifer thickness of between 7m and 10m was applied in the model. The variation in thickness was used to account for the variation in waste thickness across the site.

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 0.0186. This corresponds with observations and topographical surveying of the site. Falling head permeability tests were conducted to the determine permeability of the limestone bedrock.

These tests were conducted on three wells on site (GW01, GW02 & GW03) and yielded permeabilities of $6.98x10^{-8}$ m/s, $3.29x10^{-7}$ m/s and $9.33x10^{-8}$ m/s, respectively (mean = $1.64x10^{-7}$).

These results are within the expected range of hydraulic conductivity for the geology type identified onsite. The pathway porosity was inputted based on standard published data for the lithologies present[1].

1.2.2 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 infiltration to open waste, the design infiltration of the cap and the infiltration to open grassland in each phase were entered as normal distributions. Rainfall data from the Termonbarry metrological rain gauge (c.12km west of the subject site) was reviewed as part of this assessment. Based on monthly rainfall measurements from 1996 to Sept 2018, a total average annual rainfall of 994 mm/year was applied. The site is currently capped with layers of shale, bark and topsoil at varying thicknesses across the site. Soakaway tests were conducted on the capping material at locations throughout the site and yielded permeability (k-values) ranging from $1.10x10^{-5}$ to $6.53x10^{-5}$ m/s. As a conservative measure the maximum recharge capacity (mm/year) for the area, as determined by the Geological Survey Ireland (GSI) was applied to the cap infiltration rate. This was stated as being 200 mm/year.

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

The infiltration rate was adjusted for the remedial scenario model. This scenario assumes the installation of a more robust landfill cap layer achieving a reduced infiltration rate, following the cessation of filling activities. The remedial scenarios modelled aims to represent a 'what if' scenario whereby an alternate landfill management and/or engineering design were applied after site closure. The outcome of this model will aid in determining a suitable cap to apply and target infiltration rate to achieve. This 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. A triangular distribution, *Triangular (2,6,10)* metre thickness was applied in the model to reflect the variation in waste thickness likely to be present, particularly between the centre and boundaries of the waste footprint area.

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 1.2 and 1.6 kg/l.

The waste field capacity used ranged between 0.2 and 0.4.

Leachate Inventory

The leachate inventory was modelled based on a statistical analysis of monitoring results for a number of leachate parameters. Leachate indicator parameters were assessed against the European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. no. 9 of 2010) and the EPA's Interim Guideline Values (IGVs). The waste encountered onsite during the site investigation phase included animal waste i.e. bones, hair, hides most likely from local abattoirs. The decomposition of this waste material can generate a leachate high in organic breakdown products such as Ammonia.

Leachate was encountered during the intrusive site investigation conducted as part of the Tier 2 assessment and samples were taken via two leachate monitoring wells (LG01 and LG02) and analysed. A number of parameters were included in the model for Cartron Big leachate inventory as they were found to be present in the leachate in elevated concentrations above typical expected when compared to the ranges provided by the EPA Landfill Manual (2003). The inclusion of selected parameters is limited by the information required by the model and the availability of information to generate a complete model. Those parameters included in the model are as follows:

- Ammoniacal Nitrogen as N,
- Nickel,
- Chromium,
- Sodium,
- Chloride,

A review of monitoring data obtained for leachate and groundwater samples was conducted to inform suitable leachate concentrations and background concentrations to apply to the mode for those relevant pollutants above. A summary of that monitoring data is presented in Table 1-1 and Table 1-2 over.

Table 1-1: Leachate Analysis Results of Select Parameters

	26th Sept 2018		8th Oct 2018	
	LH01	LH02	LH01	LH02
Nickel (mg/l)	29.8	132	25.7	<2.4
Chromium (mg/l)	2.1	150	4.72	<6
Sodium (mg/l)	329	6690	256	76.21
Chloride (mg/l)	613	14500	453	24700
Ammonia (mg/l)	223	3080	203	5170
Iron (mg/l)	34.7	23.4	37.4	0.128

Table 1-2: Groundwater Analysis Results of Select parameters (upgradient)

	26th Sept 2018		8th Oct 2018	
	GW01	GW02	GW01	GW02
Nickel (mg/l)	16.8	3.31	11.3	2.9
Chromium (mg/l)	<1	<1	<1	<1
Sodium (mg/l)	18.8	11.2	13.9	8.24
Chloride (mg/l)	15.1	24	11.2	26.3
Ammonia (mg/l)	0.401	0.423	<0.2	<0.2
Iron (mg/l)	0.0277	<0.019	0.963	0.054

Background concentrations were also derived for the model. Statistical analysis of monitoring results from upgradient monitoring wells was conducted to determine an appropriate background concentration for ammonia. Selected leachate and background concentrations are presented in Table 1-3. The main aim of the modelling exercise is to examine the relative changes in outputs from the model under an existing conditions scenario versus a remediation scenario, therefore only contribution from the landfill itself was considered.

It is noted that although leachate concentrations were determined during the site investigation in 2018, these concentrations may not be representative of concentrations within the waste material originally, during the operational phase of the landfill and in the immediate years preceding its closure. LandSim software also provides default values within the model, that can be selected and 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). For comparison both sets of values for those parameters of interest and considered as part of the model setup process are included in Table 1-3.

It is noted that across both sets of values of the minimum and maximum concentrations vary. As a conservative approach, final concentrations applied are based on a combination of the values from both sources. Where leachate concentrations determined in the field exceed those provided by the LandSim these values have been input as the maximum concentrations. Final leachate concentrations applied in the model are shown in Table 1-4.

Table 1-3: Leachate and Background Concentrations

Parameter	Background levels (mg/l)	Concentration in Leachate [1] (mg/l)	Concentration in Leachate [2] (mg/l)
Nickel	Uniform (0.0029, 0.0168)	Uniform (2.4, 0.132)	Triangular (0.00883, 0.12, 2.21)
Chromium	Triangular (0.001,0.001,0.05)	Uniform (2.1, 0.150)	Triangular (0.00855, 0.0647, 1.75)
Sodium	Uniform (8.24, 18.8)	Uniform (76.21, 6690)	Triangular (13.8, 1760, 5410)
Chloride	Uniform (11.2, 26.3)	Uniform (453, 24700)	Triangular (36.6, 2270, 7760)
Ammonia	Uniform (0.02,0.423)	Uniform (203, 5170)	Triangular (4.37, 723, 3640)
Iron	Uniform (0.002, 0.963)	Uniform (0.128, 37.4)	Triangular (0.29, 9.93, 5530)

† A log uniform and uniform distribution is defined by a minimum and maximum, based on statistical analysis.

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

Note 1: Leachate Concentrations based on 2018 leachate analysis

Note 2: Leachate concentrations as per LandSim UK Default Leachate Inventory values

Table 1-4: Final Model Leachate Concentrations

Parameter	Concentration in Leachate (mg/l)
Nickel	Triangular (0.00883, 0.12, 2.21)
Chromium	Triangular (0.00855, 0.0647, 1.75)
Sodium	Triangular (13.8, 1760, 6690)
Chloride	Triangular (36.6, 2270, 24700)
Ammonia	Triangular (4.37, 723, 5170)
Iron	Triangular (0.29, 9.93, 5530)

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 limestone bedrock to ground surface, that is 2 to 10m. A Triangular (2,6,10 m) distribution was applied in model as, based on review of the geophysical surveys it was deemed that much of the site would be underlain by at least of 6m of either soil or waste material before encountering competent bedrock.

In the remediation scenario it was assumed that there was some form of drainage and leachate control limiting the leachate head. To examine the impact of having a reduced leachate head, the specified leachate head input within LandSim was reduced to 1m, i.e. the head of leachate was limited to rising to only 1m above the base of the landfill.

Engineered Barrier

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

1.2.3 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.

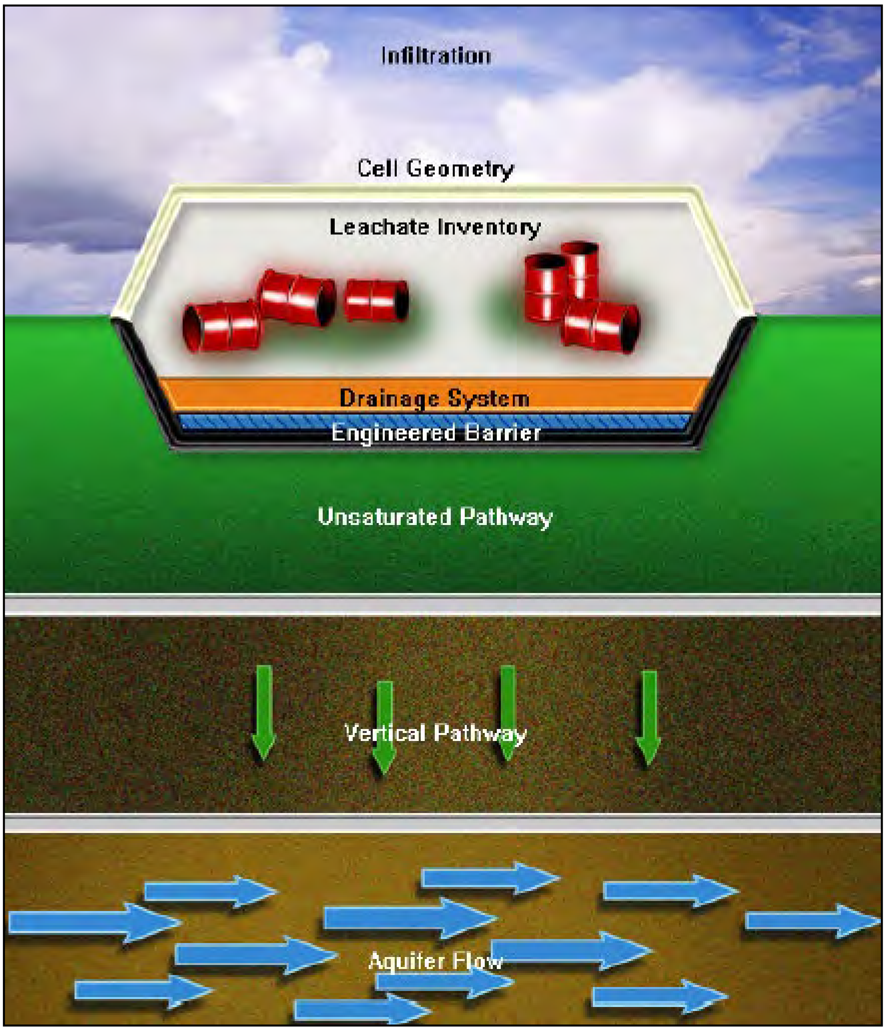


Figure 1-2: Geosphere Schematic

Unsaturated Pathway

It is known from site investigation that the groundwater table 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.

It is noted that the presence of the Clooncoose Stream immediately adjacent to the site is likely significant factor in the dispersion of contaminants from the waste material and site. The Clooncoose stream turns west c. 180m north/downgradient of the site and traverses the groundwater pathway and aquifer flow from the site. The conceptual site model and site investigation suggest that the Clooncoose stream in hydrologically linked to the groundwater underlying the site and elevated levels of ammonia detected in the Clooncoose stream downstream of the site indicate a potential impact.

It is likely that the Clooncoose stream is influencing the dispersion of contaminated groundwater directly downgradient of the site and it is likely a significant factor in the defining the pathway and overall movement of material and pollutants emanating from the site. This cannot be accounted for in LandSim as it specifically examines groundwater dispersion only.

1.2.4 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.

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

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.

Two 'Remediation' scenario models were developed to predict the potential effects of the implementation of site remediation measures e.g. landfill cap, drainage system, sumps etc. 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)

One remediation scenario model 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 triangular distribution, Triangular (10,20, 50) mm/year cap design infiltration rate was applied. A PE cap was assumed to be installed on site as part of the remediation scenario.

The second remediation scenario modelled remedial measures that would include the manipulation of the existing groundwater table and/or the control of leachate head within the existing waste body i.e. leachate control.

The second remediation scenario modelled included both the application of a reduced infiltration rate to the underlying waste i.e. an improved capping and some form of leachate control. Leachate control was reflected in the model through the input of a reduced specified leachate head of 1m.

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

1.3 Results - LandSim

1.3.1 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 1-5: Source Concentration at Year 0, 50 and 1000

Parameter	Year	95%ile	50%ile	5%ile	26th Sept 2018		8th Oct 2018	
					LH01	LH02	LH01	LH02
Nickel (mg/l)	0	1.12	0.79	0.49				
	50	0.35	0.19	0.06	0.0298	0.132	0.0257	0.0024
	1000	0.14	0.048	0.004				
Chromium (mg/l)	0	0.88	0.6	0.37				
	50	0.36	0.21	0.09	0.0021	0.15	0.0047	<0.018
	1000	0.18	0.077	0.012				
Sodium (mg/l)	0	3757	2832	1965				
	50	2163	1450	775	329	6690	256	76.21
	1000	1355	738	212				
Chloride (mg/l)	0	12855	8986	5725				
	50	2453	1139	202	613	14500	453	24700
	1000	701	138	2.97				
Ammoniacal Nitrogen (mg/l)	0	2699	1959	1289				
	50	756	404	109	223	3080	203	5170
	1000	299	75	4				
Iron (mg/l)	0	2700	1830	1073				
	50	0	0	0	34.7	23.4	37.4	0.128
	1000	0	0	0				

Table 1-5 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

- 2699 mg/l for 95% of the time
- 1959 mg/l for 50% of the time
- 1289 mg/l for 5% of the time

1.3.2 Leachate Generation

The rate of leachate generation under the current condition scenario and remediation scenarios 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 1-6: Leachate Generation Rates

Site Scenario	Time slice (years)	95%-ile (l/day)	50%-ile (l/day)	5%-ile (l/day)
Current	10	64362	64362	64362
	50	12950	12950	12950
	100	12950	12950	12950
Remediation (Cap only)	10	64362	64362	64362
	50	2661	1627	927
	100	2661	1627	927
Remediation (Cap and Leachate Control)	10	64362	64362	64362
	50	2788	1671	921
	100	2788	1671	921

At 10 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. It has been stated in the model that waste activities took place for 19 years. During this 19-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.80% reduction in leachate generation rate at the 50-year point as shown in Table 1-6 above. The remediation scenarios assume the installation of a more effective, lower permeability capping and a form of leachate head control, both yielding a greater reduction in leachate generation (c.95%).

1.3.3 Discussion of Results

Table 1-6 summarises the predicted source concentrations generated by LandSim under the base/current scenario. Predicted source concentrations at the 50-year point (assumed to be present day) are within the range of concentrations observed in groundwater samples obtained and analysed in 2018. It is noted that monitoring results were shown to vary considerably between the two leachate wells/sampling locations, particularly with respect to sodium, chloride and ammoniacal nitrogen. This is indicative of the likely heterogeneity of the waste and its composition throughout the site. Results for source concentrations at 1000 years are also included showing the predicted decline in source concentration over a greater time period. As discussed previously in the report, lateral infiltration of groundwater to the waste body is likely to be contributing to the removal and leaching of material from the landfill.

The results obtained from the LandSim model show that there is a likely ongoing risk to groundwater quality beneath and 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 1-6 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 Cartron Big 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 not possible to model this in LandSim therefore the capping of the site to reduce infiltration and subsequent leachate generation may only have a limited impact. It is likely that other measures would need to be incorporated to reduce ingress of groundwater to the waste material in conjunction with capping of the site. A third model was developed to examine for any significant changes in model outputs. This included the inclusion of a form of leachate head control.

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

1.4 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 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 did not identify lateral and vertical landfill gas migration as a high risk, (normalised risk scores of 21% and 25.2% respectively) as there are currently no occupied buildings located within the former landfill site therefore limiting the potential risks associated with any gas generation and emission from the site.

However, it is evident from gas monitoring as discussed in the Tier 2 assessment that landfill gases continue to be produced with significant methane concentrations. Groundwater wells located at the perimeter of the site both upgradient and downgradient of the estimated waste footprint area exceeded the trigger values for methane and carbon dioxide (1.0 - 1.5% v/v respectively) content across two monitoring rounds on the 25th of September and the 8th of October.

Table 1-7: Perimeter Well Monitoring Results September and October 2018

Sample Station	CH_4 (% v/v)	CO_2 (% v/v)	O_2 (% v/v)	Atmospheric Pressure (mbar)	Staff Member	Weather
Date: 25-9-2018						
GW01	1.8	4.2	15.5	1032	Daniel Hayden	Sunny with light wind S-SE, 14°C - 16°C
GW02	0.1	0.1	22.3	1032		
GW03	8.8	11.6	8.7	1032		
Date: 8-10-2018						
Sample Station	**CH_4 (% v/v)**	**CO_2 (% v/v)**	**O_2 (% v/v)**	**Atmospheric Pressure (mbar)**	**Staff Member**	**Weather**
GW01	1.0	1.1	20.7	1012	Daniel Hayden	Cloudy with light rain and wind NW-W, 13°C - 15°C
GW02	0.1	1.9	21.5	1012		
GW03	2.1	3.3	20.1	1012		

Monitoring of leachate wells located inside the waste body yielded methane contents of 30.4 to 49.5% and carbon dioxide content from 12.5 to 21.3%.

Table 1-8: Onsite Leachate Well Monitoring Results September and October 2018

Date: 25-9-2018						
Sample Station	CH_4 (% v/v)	CO_2 (% v/v)	O_2 (% v/v)	Atmospheric Pressure (mbar)	Staff Member	Weather
LG01	30.4	12.5	11.8	1032	Daniel Hayden	Sunny with light wind S-SE, 14°C - 16°C
LG02	49.5	21.3	1.7	1032		
Date: 8-10-2018						
Sample Station	**CH_4 (% v/v)**	**CO_2 (% v/v)**	**O_2 (% v/v)**	**Atmospheric Pressure (mbar)**	**Staff Member**	**Weather**
LG01	40.7	15.3	11.2	1012	Daniel Hayden	Cloudy with light rain and wind NW-W, 13°C - 15°C
LG02	49.0	17.0	5.5	1012		

Monitoring conducted indicates that the interred waste mass is still generating significant quantities of landfill gas with corresponding high methane concentrations and this landfill gas is migrating horizontal in the surrounding bedrock.

Table 1-9: LandGEM Model Primary Inputs and Variables

Landfill Characteristics	Input	Source
Landfill Open Year	1970	Estimated beginning of landfilling activities.
Landfill Closure Year	1989	Historical evidence suggests landfilling activities ceased c.1989.
Have Model Closure Calculate Closure Year	Yes	
Waste Design Capacity (megagrams/tonnes)	329,600	Estimated waste volume determined as part of Tier 2 assessment and site investigation applied multiplied by assumed conservative waste bulk density (1.4 – 1.6 kg/l).
Determining Model Parameters		
Methane Generation Rate, k (year^{-1})	CAA Conventional – 0.05	Default value
Potential Methane Generation Capacity, L_0 (m^3/Mg)	CAA Conventional – 1070	Default value. Higher capacity default value selected as encountered waste as likely high in organic material and expected generate higher quantities of methane. Field monitoring and observations.
NMOC Concentration (ppmv as hexane)	CAA – 4,000	Default value.
Methane Content (% by volume)	CAA – 50% by volume	Default value. Corresponds with methane content observed in landfill gas monitoring results.
Select Gases/pollutants		
Gas/Pollutant #1	Total Landfill Gas	Standard – No other specific gases of concern

Landfill Characteristics	Input	Source
Gas/Pollutant #2	Methane	
Gas/Pollutant #3	Carbon Dioxide	
Gas/Pollutant #4	NMOC	
Enter Waste Acceptance Rates (Mg/year)		
1970 - 1989	16,263	Exact waste acceptance quantities per year are unknown. Worst case assumed waste design capacity was filled equally over 1970 to 1989 (19 year) period

1.5 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 1-10 The model predicted that the site is currently generating 47.93 m^3/hr of methane. This will reduce to 29.07 m^3/hr by 2029.

Table 1-10: 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	1049	636	839700	509320	0.120	0.073	95.86	58.14
Methane	280	170	419900	254660	0.032	0.019	47.93	29.07
Carbon dioxide	769	466	419900	254660	0.088	0.053	47.93	29.07
NMOC	12	7	3359	2037	0.001	0.001	0.38	0.23

The approximate maximum waste deposition footprint was estimated to be approximately 2.35 Ha (23,500 m2). The estimated volume and mass of landfill gas generated and potentially released per m^2 of the total landfill area are presented in Table 1-11.

Table 1-11: 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	0.045	35.732	$5.10x10^{-6}$	0.0041
Methane	0.012	17.868	$1.36x10^{-6}$	0.0020
Carbon dioxide	0.033	17.868	$3.73x10^{-6}$	0.0020
NMOC	0.001	0.143	$5.85x10^{-8}$	$1.63x10^{-5}$

1.5.1 Discussion of Results

The outcome of the LandGEM model predicts a low rate of landfill gas generation in the current year (96m^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 1-10 LandGEM estimated that in the current year (2019) 95.86 m^3/hour of landfill gas across the whole site is generated and assuming 50% percent of that volume being methane. Landfill gas monitoring of leachate wells conducted in 2018 yielded methane contents of 30.4 to 49.5% therefore justifying this assumption.

Given that the waste encountered included significant quantities of highly putrescible wastes it is not unexpected for there to be a noticeable quantity of methane and landfill gas being generated.

The results of the LandGEM model are consistent with observations made on site, in that in 2019 methane is still being generated onsite, with peak landfill gas generation predicted to have occurred c.1989, when filling operations ceased with the generation rate decreasing since then.

Figure 1-3 below shows the estimated landfill gas generation rates per year during the operational phase (c.1970 to 1989) and predicted generation rates from 1989 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.

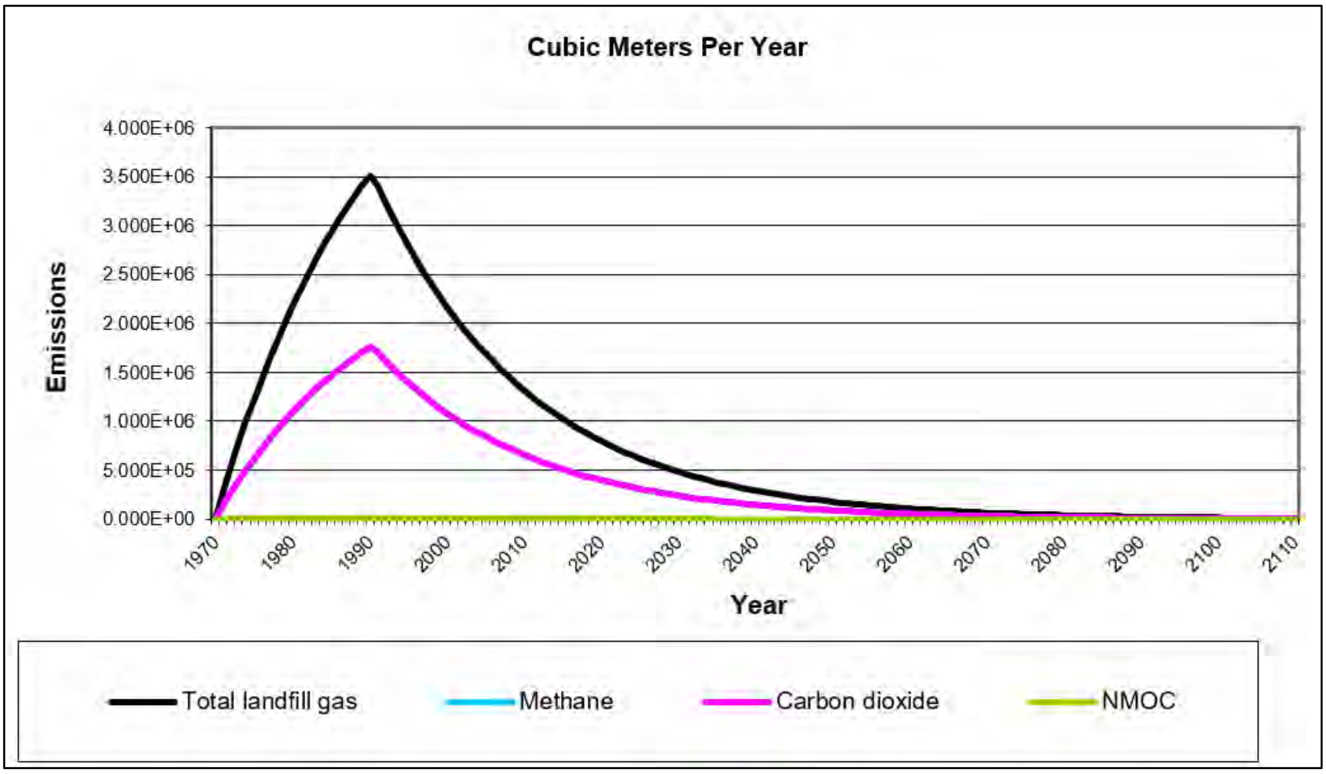


Figure 1-3: LandGEM Landfill Gas Volume Generation Rate

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

1.6 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 the 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 take 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. It is noted that the 95%-ile values applied are more than those observed from groundwater monitoring (GW3) conducted in 2018 and as such represent a highly conservative scenario.

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.

The predicted concentrations at the monitor/perimeter well generated by LandSim are presented graphically in Figure 1-4 to Figure 1-6 below. The outputs of the EA model are shown in Table 1-12.

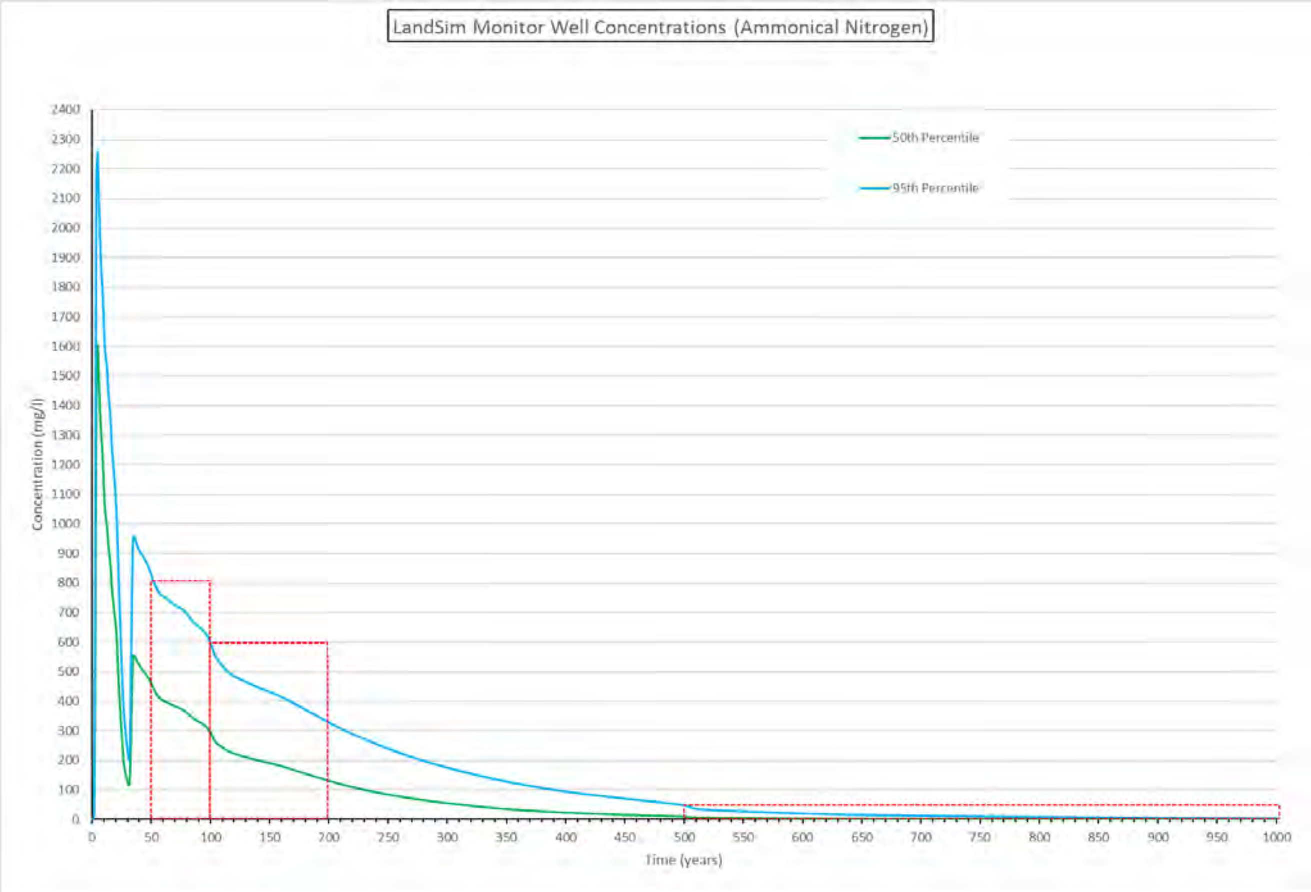


Figure 1-4: Monitor Well Concentrations (Ammoniacal Nitrogen) with Modelled Time Steps (red)

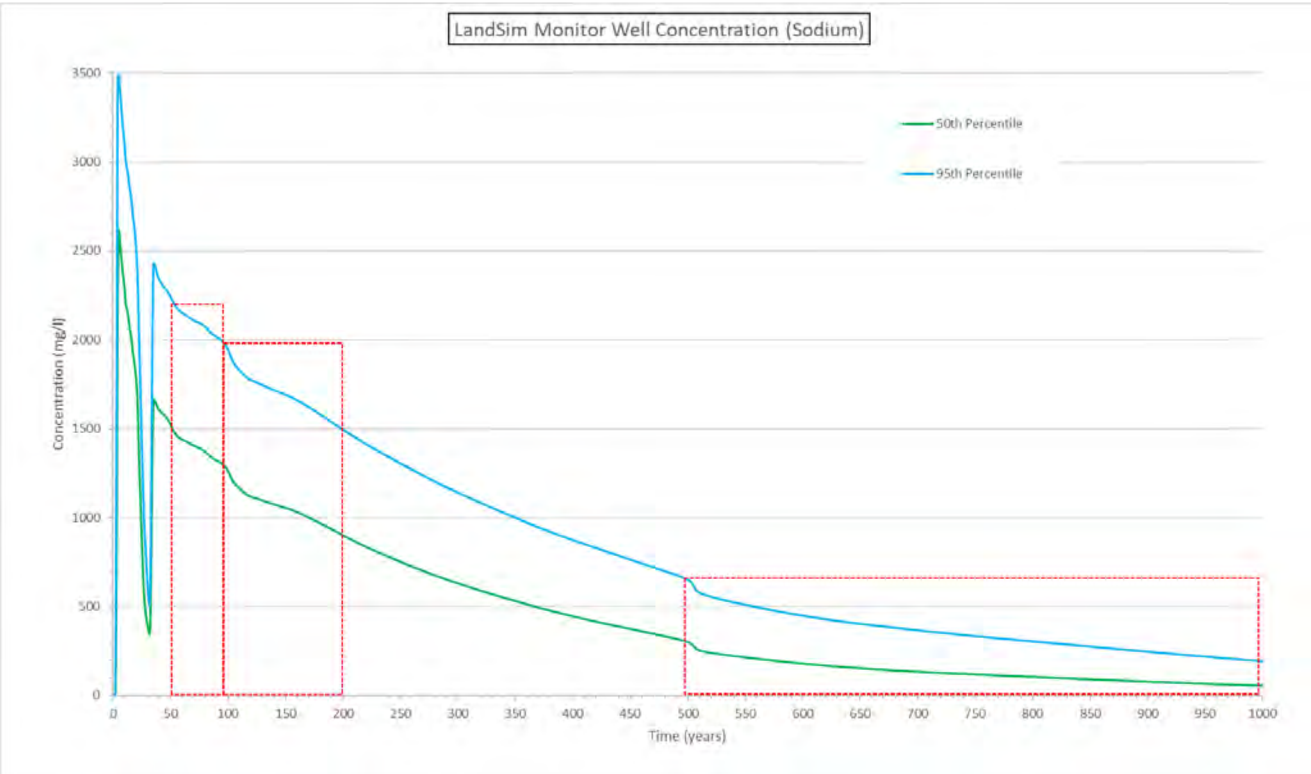


Figure 1-5: Monitor Well Concentrations (Sodium) with Modelled Time Steps (red)

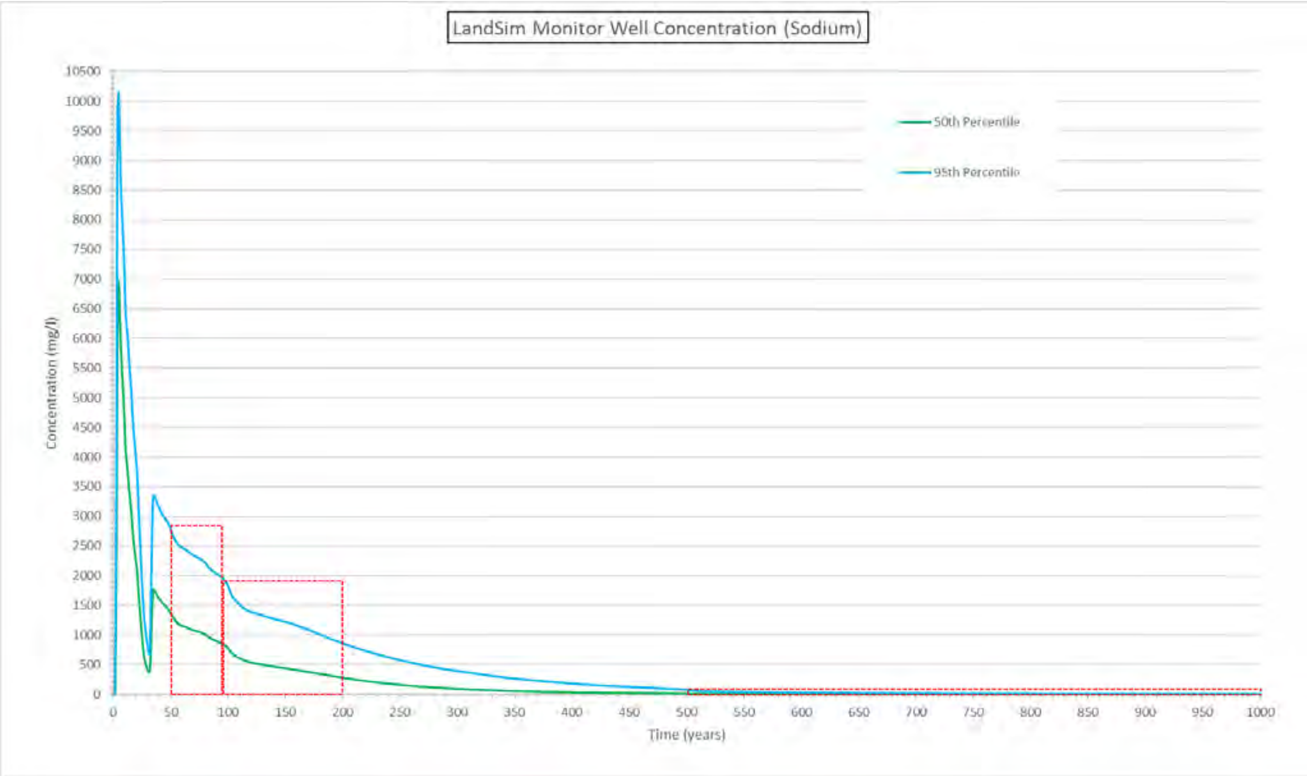


Figure 1-6: Monitor Well Concentrations (Chloride) with Modelled Time Steps (red)

Table 1-12: 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	832.29	**123.13**	0.00	0.00	0.00
100	600.71	**198.55**	3.00E-05	0.00	0.00
500	47.68	**35.28**	**1.37**	2.42E-04	0.00
1000	2.44	**2.05**	0.37	0.01	0.00
Sodium (mg/l)			***Groundwater threshold Value (GTV) = 150 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	2163	**1330.19**	**208.43**	2.91	0.00
100	1755	**1305.21**	**457.71**	61.09	0.03
500	368	**345.86**	**221.53**	**152.05**	63.54
1000	180	**171.66**	112.92	83.98	56.03

Chloride (mg/l)			*Groundwater threshold Value (GTV) = 187.5 mg/l*		
Year 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	2802	**1723.15**	**270.00**	3.77	0.00
100	1836	**1365.45**	**478.84**	63.91	0.03
500	75	70.49	45.15	30.99	12.95
1000	2	1.91	1.25	0.93	0.62

1.6.1 Discussion of Results

This model is used to predict downgradient concentrations of the identified pollutants (ammoniacal nitrogen, sodium and chloride), 10, 50, 100 and 200m downstream of site after the stated number of years of influence (50, 100,5000, 1000) 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. It is noted that elevated ammonia concentrations were also observed upstream of the site and may be representative of background concentrations within the wider area. Predicted downstream concentrations are within range of those observed upstream.

Exceedances of the groundwater threshold value for sodium are predicted to occur within 200m from the site but only after 500 years of dispersion have occurred. The greatest impact on groundwater is predicted to occur within relative proximity to the site.

The greatest impact on groundwater quality associated with chloride emissions from the site are likely to occur within the locality of the site as no exceedances in the GTV are predicted beyond 50m from the site.

It should be noted again that the results observed should be considered as conservative as they assumed constant source concentrations from within the landfill site where as declining sources are expected. The source concentration utilised are also taken from the 95-%ile (worst case scenario) outputs of the LandSim modelling exercise

It is concluded that the affect of the historical landfill upon groundwater are limited spatially and are likely only within the local extents. This is likely due to the highly impermeable nature of the local bedrock and shallow groundwater gradient.

2 CONCLUSION AND RECCOMENDATIONS

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

Three computer models were applied 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 (Clooncoose Stream) and to compare the magnitude of the impact where potential remediation measures are applied.

Three different modelling scenarios (current site conditions 'base' scenario, improved cap scenario and improved cap and leachate control scenario) were examined as part of this assessment. One base model was prepared to represent the current site conditions with respect to existing site capping and any current site management methods. Two remediation scenarios were developed. One scenario included the adjustment of the cap design infiltration rate to representing the installation of an improved, low permeability cap layer. This model also assumed the inclusion of a PE cap material. Another remediation included the management of the leachate head within the waste body as well an improved cap.

The Remedial Targets Worksheet developed by Environment Agency UK was utilised to estimate the potential impact on groundwater quality downstream of the site. This exercise indicated that the potential impact on groundwater quality is most likely limited to be within a relatively close proximity to the site (c.100m) downstream.

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 limestone bedrock immediately upgradient of the waste body is a significant contributor to the volume of water present in the site.

There are currently eight passive landfill gas vents located across the site. These vents haven't been equipped with sampling taps therefore no historical monitoring data is available with respect to gas production or contents. Monitoring of two new leachate wells installed onsite as part of the Tier 2 site investigation phase and located within the waste footprint area yielded methane contents of between 30.4 to 49.5%. Monitoring of groundwater wells along the perimeters of the site also showed positive results for methane, some of which exceed GAC trigger values.

The vents currently installed onsite are not equipped with any form of gas treatment e.g. carbon filtration or biological, bio-oxidation material to treat gases. As per the EPA Landfill Manual on Landfill Site Design, utilisation or flaring of methane is the preferred method for landfill gas management, where quantities of gas and methane are suitable. Passive venting should only be applied where there are insufficient quantities of methane and oxygen present or methane has diminished. The output from LandGEM showed that landfill gas will continue to be generated for several years.

It is recommended that the feasibility of the application of utilisation or flaring technologies for landfill gas management at the site be assessed. This can be done through the implementation of a programme of pumping trials on wells to determine the quantity and characteristics of landfill gas. Any form of utilisation or flaring technology will require relatively consistent supply of gas and methane to operate effectively. No specific recommendations on landfill gas treatment can be made without investigating the likely yields from the site and assessing potentially suitable technologies.

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.

3.1.1 Leachate Migration through surface water pathway (SPR8)

Both environmental monitoring and observation made onsite demonstrate that site is hydrologically linked to the Clooncoose stream both immediately adjacent to the site and downgradient. The aquifer and groundwater underlying the landfill is also hydraulically connected with the stream.

It is expected that during the operational phase of the site that the Clooncoose Stream was a primary receptor of any leachate or contaminated runoff from the waste deposited in the former quarry, particularly along the section of stream which follows the eastern/north-eastern boundary of the site. Evidence of potential leachate seepage is also currently still evident at the site

The following remediation measures are proposed to mitigate the effect of the landfill on the neighbouring Clooncoose stream.

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

- 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 agricultural grazing purposes. The sub soil layer shall therefore be adequately specified to ensure it is free draining to support grazing.

Leachate Interception Trench – North East Boundary

The landfill cap shall also include vertical cut off and leachate interception trench along the stream boundary of the site (North East Boundary).

The leachate interception trench shall be constructed to break the pathway linkage between the landfill waste and the boundary stream. The leachate interception trench shall be drained to a controlled collection sump located in the North East corner of the site where the Clooncoose streams exits the site.

The leachate sump will be set to a control level 0.25m below (or greater) that of the stream bed level at the point it exits the site ensuring no hydraulic connectivity between the site and the stream.

A vertical cut-off constructed using LLPDE liner shall also be constructed to further limit the potential for leachate to enter the stream flow. The barrier will provide an impermeable pathway between the source (waste body) and stream receptor. The barrier shall also ensure that leachate pumping from the interceptor trench does not inadvertently affect the base flow of the stream.

Leachate Interception Trench – Northern Boundary

The landfill cap shall also include leachate interception trench along the down gradient boundary of the site (Northern Boundary).

The leachate interception trench shall be constructed to intercept the pathway linkage between the landfill waste and don gradient groundwater. The leachate interception trench shall be drained to a controlled collection sump located in the North East corner of the site where the Clooncoose streams exits the site.

The interception trench shall be constructed to the maximum achievable depth of excavation achievable (estimated 3-4.0m) and backfilled with rounded non-calcareous drainage stone.

The collected leachate will be removed from site to an authorised Wastewater Treatment Plant.

3.1.2 Vertical and Lateral Gas Generation (SPR10 & SPR11)

There are currently eight landfill gas vents installed across the site, seven of which the locations are known. These gas vents provide a preferential pathway for landfill gas to escape the site in a semi-controlled fashion.

It is recommended that landfill gas control measures shall be installed at the site. Suitable control measures should be selected following landfill gas pumping trials at the site. It is proposed that Landfill gas pumping trials be designed and conducted at the site to accurately quantify the nature and quality of landfill gas being produce at the site.

Landfill gas pumping trials should be designed and undertaken by an appropriately qualified person, the results of which should also be supported with a suitably calibrated landfill gas generation model.

It is recommended that dependant on the results of these 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.*

Potential options are discussed in brief detail below.

Active Gas Abstraction to LFG Flare

Active landfill gas abstraction to a flare would involve the installation of a network of landfill ages well across the site. The wells would be drilled into the waste body to 80-90% of the total waste depth and be connected via a network of gas collection pipework to the landfill gas flare.

The landfill gas flare would treat all abstracted landfill gas by oxidation (burning), it is assumed based on the age of the landfill that a Low Calorific landfill gas flare may utilised.

Active Gas Abstraction to Bio Oxidation

Active landfill gas abstraction to a bio-oxidation may be utilised if landfill gas with methane concentrations in the range of 0-15% are expected at the site following completion of pumping trials. This would also involve the installation of a network of landfill ages well across the site. The wells would drilled into the waste body to 80-90% of the total waste depth and be connected via a network of gas collection pipework to the bio oxidation unit.

The proposed bio-oxidation unit would treat abstracted landfill gas by bio-oxidation. Bio oxidation is the conversion of methane to carbon dioxide by bacteria typically grown or cultured within an organic (wood chip, mussels shells) or proprietary inorganic media.

Passive Ventilation

If pumping trial indicate insufficient landfill gas volumes are present to warrant active abstraction, passive ventilation may be utilised. Typically, landfill gas well will be installed within the waste body and directly connected to a series of vertical stand pipes venting to atmosphere at 2-3m above the final ground level. Alternatively stand pipes may be connected contiguously with the installed landfill gas migration layer in the absence of drilled wells.

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

Installed ventilation stand pipes may include a carbon filtration packs to “scrub” odour and methane from the landfill gas prior to venting. Rotating cowls may also be used to induce a negative pressure within the stand pipe improving the 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)
  - GW1
  - GW2
  - GW3

- Surface Water (Surface Water Quality)
  - SW1
  - SW2
  - SW3
  - SW4

- Leachate (Leachate Quality and Landfill Gas)
  - LH1
  - LH2

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 additional groundwater monitoring points be installed up and down gradient of the site.

The following locations are recommended

- GW0 Upgradient of Site 25-50m Upgradient of Waste Body
- GW4 Down Gradient 25-50m Down Gradient of Waste Body
- GW5 Down Gradient 75-100m Down Gradient of Waste Body

GW0 is recommended as a new monitoring location to establish an upgradient groundwater baseline remote from the waste body.

GW4 and 5 are proposed as new monitoring locations as act as a future check on the migration or establishment of a localised leachate plume remote from the site.

Future installed leachate/ landfill gas management infrastructure should be incorporated within any future environmental monitoring schedule.

3.2 Remediation Design

The preliminary remediation design is presented in the following drawings:

- P1444-0100-0001
- P1444-0500-0001
- P1444-0900-0001
- P1444-0900-0002
- P1444-0900-0003

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 land leaser(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: P1444-0900-0001

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: P1444-0500-0001

The subsurface drainage shall be extended vertically as land drains to accommodate future agricultural uses. The network will connect via a collection drain outfall at the downstream end of the site to the Clooncoose stream. Inspection chambers will be located at all drain junctions for future maintenance and inspection.

A leachate interception trench shall run along the North Eastern stream boundary and Northern boundary of the site.

The interception trench shall be excavated vertically within the existing waste body to the required depth. The target depth of the trench will vary depending on location and gradients but will typically extend from 2.5-4.0 m below existing ground level.

Plan details are shown in drawing: P1444-0500-0002

Section details for the proposed leachate interception trench along the stream boundary are shown in drawing P1444-0900-0001

Section details for the proposed leachate interception trench along the northern site boundary are shown in drawing P1444-0900-0003

It is proposed that the existing yard area be utilized for the construction of any required supporting site infrastructure principally the leachate collection tank and potential landfill gas management system e.g. flaring infrastructure. The yard area shall be cleared, levelled and appropriately finished e.g. reinforced concrete hard standing to allow for access.

The yard area and site shall be appropriately fenced and secured.

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, licence compliance and environmental liabilities are not considered.

3.3.1 Landfill Capping

Table 3-1 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
Design					
-					
Allowance for Additional Site Investigation works	1	Rate	€25,000.00	€25,000.00	Allowance
General Site Clearance and Demolition Works	***2.36***	***ha***			
General Site Clearance	2.36	ha	€5,000.00	€11,800.00	Allowance for Clearance of Existing Site
Excavation Works	23600	m^2			Estimated area of Capping Area 23600m^2
Excavation of Existing Cover/Capping for Reuse/Filling	2360	m^3	€1.50	€3,540.00	Excavation of area to 100mm

Item	Quantity	Unit	Rate, €	Cost	Note
Landfill Capping Works	23600 m^2				
Preparation of Excavated Surfaces	23600	m^2	€0.50	€11,800.00	Approximate Area, Local Rates 2018
Supply and Installation of 50mm Protection Layer	23600	m^2	€1.50	€35,400.00	Approximate Area, Local Rates 2018
Supply and Installation of Landfill Gas Collection Layer	23600	m^2	€3.50	€82,600.00	Approximate Area, Local Rates 2018
Installation of 1mm LLDPE Cap	23600	m^2	€5.00	€118,000.00	Approximate Area, Local Rates 2018
Installation of Surface Water Collection Layer	23600	m^2	€3.50	€82,600.00	Approximate Area, Local Rates 2018
Importation of 800mm Subsoil Capping Layer	23600	m^2	€5.50	€129,800.00	Approximate Area, Local Rates 2018
Importation of 200mm Topsoil Capping Layer	23600	m^2	€2.50	€59,000.00	Approximate Area, Local Rates 2018
Allowance Landfill Gas Migration Network Infrastructure	23600	m^2	€1.50	€35,400.00	Allowance
Allowance Sub surface Water Drainage Infrastructure	23600	m^2	€1.50	€35,400.00	Allowance
Independent CQA	1	Sum	€25,000.00	€25,000.00	Estimate Local Rates
Leachate Interception Trench	300				Leachate Trench - 300m
Excavation of Existing Waste Materials	525	m^3	€4.00	€2,100.00	Assumed design, Local Rates 2018
Disposal of Waste Offsite	840.0	tonnes	€50.00	€42,000.00	Assumed design, Local Rates 2018
Lining of Interception Trench	1050.0	m^2	€15.00	€15,750.00	Assumed design, Estimated Rate
Backfill with 16-23mm Rounded Washed Drainage Stone	525.0	m^3	€15.00	€7,875.00	Assumed design, Estimated Rate
225mm Slotted SDR 17 Drainage Pipe	300	m	€40.00	€12,000.00	Assumed design, Local Rates 2018
Leachate Collection Sump	1	Sum	€4,000.00	€4,000.00	Allowance
Intermediate Inspection Chambers	6	No.	€1,500.00	€9,000.00	Allowance
Mechanical and Electrical	1	Sum	€15,000.00	€15,000.00	Allowance

Item	Quantity	Unit	Rate, €	Cost	Note
Landfill Gas Pumping Trial					
Mobilisation	1	Sum	€3,500.00	€3,500.00	Local Rates 2018
Landfill Gas Well Ex. M&E, inc. piping and backfill	6	No.	€1,850.00	€11,100.00	Assumed design depth 6-8m and spacing, Local Rates 2018
Landfill Gas Well Heads	6	No.	€500.00	€3,000.00	Local Rates 20198
Supporting Infrastructure	1	Sum	€10,000.00	€10,000.00	Allowance
Design, Supervision and Interpretation	1	Sum	€15,000.00	€15,000.00	Allowance
Leachate Management Infrastructure					
Leachate Storage Tank	1	Sum	€75,000.00	€75,000.00	Estimate
Leachate Handling Yard	1500	m^2	€60.00	€90,000.00	Estimate
Landfill Gas Management Infrastructure					
Supporting Infrastructure	1	Sum	€25,000.00	€25,000.00	Estimate
Sub-Total 1				**€995,665.00**	
Add 10% Contractor Prelims	10.0%			€99,566.50	
Sub-Total 2				**€1,095,231.50**	
Add 7.5% Contingency	7.5%			€82,142.36	
Grand Total (excl VAT)				**€1,177,373.86**	

Notes:

- This preliminary cost estimate does not purport to guess potential tender submissions in current and future market conditions.
- FTC has used approximations of rates for similar works items where possible and has used engineering judgement to estimate rates & sums where similar rates are not available
- Management of Hazardous Materials has not been allowed for.
- Pricing is based primarily on concept design provided for the site, no detailed designs have been completed
- This cost estimate assumes that materials to be imported are available from local sources
- This cost estimate excludes VAT

- This cost estimate excludes in/deflation
- This estimate includes for a level of contingency as indicated
- Costs are largely based on previously tendered rates for similar work or cited reference sources, Prices may have changed in the intervening period.

The estimated total remediation cost is **€1,177,373.86 (ex. VAT)** including the contingency as specified (7.5%).

3.3.2 Landfill Gas Management

Table 3-2 outlines the costs associated installing permanent landfill gas abstraction infrastructure at the site. Costs are included should active gas abstraction be recommended post the completion of the recommended landfill gas pumping trials.

The proposed landfill gas costs are developed based on a typical landfill gas well spacing grid of 25mx 25m and a total well depth of 6-8m. Costs associated with the installation of a permanent landfill gas flare have also been estimated.

Table 3-2: Active Landfill Gas Abstraction Infrastructure: Cost Estimates

Item	Quantity	Unit	Rate, €	Cost	Note
Design					
Allowance for Infrastructure Design and Management	1	Rate	€15,000.00	€15,000.00	Allowance
-	-	-	-		
Landfill Gas/Leachate Well Installation	23600	625			Assumed Remediation Area 23600m^{2}, assumed 25x 25m grid spacing, 1 No. Well/625m2
Mobilisation	1	Sum	€3,500.00	€3,500.00	Local Rates 2018
Landfill Gas Well Ex. M&E, inc. piping and backfill	38	No.	€1,850.00	€69,856.00	Assumed design depth 6-8m and spacing, Local Rates 2018
Landfill Gas Well Heads	38	No.	€500.00	€18,880.00	Local Rates 20198
Landfill Gas Infrastructure	1	Sum	€20,000.00	€20,000.00	Allowance
Landfill Gas Management Infrastructure					
Low Calorific Landfill Gas Flare	1	Sum	€125,000.00	€125,000.00	Estimate
Supporting Infrastructure	1	Sum	€25,000.00	€25,000.00	Estimate

Item	Quantity	Unit	Rate, €	Cost	Note
Sub-Total 1				**€277,236.00**	
Add 10% Contractor Prelims	10.0%			€27,723.60	
Sub-Total 2				**€304,959.60**	
Add 10% Contingency	10.0%			€30,495.96	
Grand Total (excl VAT)				**€335,455.56**	

Notes:

- This preliminary cost estimate does not purport to guess potential tender submissions in current and future market conditions.
- FTC has used approximations of rates for similar works items where possible and has used engineering judgement to estimate rates & sums where similar rates are not available
- Management of Hazardous Materials has not been allowed for.
- Pricing is based primarily on concept design provided for the site, no detailed designs have been completed
- This cost estimate assumes that materials to be imported are available from local sources
- This cost estimate excludes VAT
- This cost estimate excludes in/deflation
- This estimate includes for a level of contingency as indicated
- Costs are largely based on previously tendered rates for similar work or cited reference sources, Prices may have changed in the intervening period.

The estimated installation costs associated with permanent active landfill gas management infrastructure is **€335,455.56 (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:

Unretarded values used for simulation

Biodegradation

Unsaturated Pathway:

Unretarded values used for simulation

Biodegradation

Saturated Vertical Pathway:

No Vertical Pathway

Aquifer Pathway:

Unretarded values used for simulation

Biodegradation

Timeslices at: 10, 50, 100, 500

Decline in Contaminant Concentration in Leachate

Ammoniacal_N	Non-Volatile
c (kg/l): 0.59	m (kg/l): 0
Chloride	Non-Volatile
c (kg/l): 0.2919	m (kg/l): 0.0298
Chromium	Non-Volatile
c (kg/l): 0.045	m (kg/l): 0.0514
Iron	Non-Volatile
c (kg/l): 0.1246	m (kg/l): 2.9837
Nickel	Non-Volatile
c (kg/l): -0.1479	m (kg/l): 0.0987
Sodium	Non-Volatile
c (kg/l): 0.242	m (kg/l): 0

Contaminant Half-lives (years)

Clay Liner:	
Ammoniacal_N	SINGLE(1e+009)
Chloride	SINGLE(1e+009)
Chromium	SINGLE(1e+009)
Iron	SINGLE(1e+009)
Nickel	SINGLE(1e+009)
Sodium	SINGLE(1e+009)
Unsaturated Pathway:	
Ammoniacal_N	SINGLE(1e+009)
Chloride	SINGLE(1e+009)
Chromium	SINGLE(1e+009)
Iron	SINGLE(1e+009)
Nickel	SINGLE(1e+009)
Sodium	SINGLE(1e+009)
Aquifer Pathway:	
Ammoniacal_N	SINGLE(1e+009)
Chloride	SINGLE(1e+009)
Chromium	SINGLE(1e+009)
Iron	SINGLE(1e+009)
Nickel	SINGLE(1e+009)
Sodium	SINGLE(1e+009)

Background Concentrations of Contaminants

Justification for Contaminant Properties

Field data and default values

All units in milligrams per litre

Phase: Phase 1

Infiltration Information

Cap design infiltration (mm/year):	SINGLE(200)
Infiltration to waste (mm/year):	SINGLE(994)
End of filling (years from start of waste deposit):	19

Justification for Specified Infiltration

Infiltration to open waste based on average monthly rainfall at Tarmonbarry rain gauge. Cap design infiltration is maximum recharge capacity specified by GSI for the area.

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

Cell dimensions

Cell width (m):	110
Cell length (m):	214.545
Cell top area (ha):	2.365
Cell base area (ha):	2.36
Number of cells:	1
Total base area (ha):	2.36
Total top area (ha):	2.365
Head of Leachate when surface water breakout occurs (m)	TRIANGULAR(2,6,10)
Waste porosity (fraction)	TRIANGULAR(0.42,0.54,0.62)
Final waste thickness (m):	TRIANGULAR(2,6,10)
Field capacity (fraction):	UNIFORM(0.2,0.4)
Waste dry density (kg/l)	UNIFORM(1.4,1.6)

Justification for Landfill Geometry

Simplified layout based on map, drawings and estimated waste footprint. Waste properties assumed

Source concentrations of contaminants

All units in milligrams per litre

Declining source term

Ammoniacal_N	TRIANGULAR(4.37,723,5170) *Data are spot measurements of Leachate Quality*
Chloride	TRIANGULAR(36.6,2270,24700) *Data are spot measurements of Leachate Quality*
Chromium	TRIANGULAR(0.00855,0.0647,1.75) *Data are spot measurements of Leachate Quality*
Iron	TRIANGULAR(0.29,9.93,5530) *Data are spot measurements of Leachate Quality*
Nickel	TRIANGULAR(0.00883,0.12,2.21) *Data are spot measurements of Leachate Quality*
Sodium	TRIANGULAR(13.8,1760,6690) *Data are spot measurements of Leachate Quality*

Justification for Species Concentration in Leachate

Based on combination of leachate sample analysis LG01 and LGO2 and LandSim values.

Drainage Information

Fixed Head.

Head on EBS is given as (m): TRIANGULAR(2,6,10)

Justification for Specified Head

No drainage sysem in place. Head on EBS assumed to be thickness of waste body

Barrier Information

There is no barrier

Justification for Engineered Barrier Type

No engineered barrier in place.

Waste body pathway parameters

Modelled as unsaturated pathway

Pathway length (m):	SINGLE(0.0001)
Flow Model:	porous medium
Pathway moisture content (fraction):	NORMAL(0.4,0.15)
Pathway Density (kg/l):	UNDEFINED

Justification for Unsat Zone Geometry

Minimum pathway length based on observations that groundwater table transects waste body.

Pathway hydraulic conductivity values (m/s):	LOGUNIFORM(1e-005,0.001)

Justification for Unsat Zone Hydraulics Properties

Based on field soakaway measurements

Pathway longitudinal dispersivity (m):	SINGLE(1e-005)

Justification for Unsat Zone Dispersion Properties

10% of pathway length

Retardation parameters for Waste body pathway

Modelled as unsaturated pathway

No retardation values used in this simulation.

Check 'Unretarded Contaminant Transport' setting under simulation preferences.

Aquifer Pathway Dimensions for Phase

Pathway length (m):	UNIFORM(192.5,407.5)
Pathway width (m):	SINGLE(110)

pathway parameters

No Vertical Pathway

pathway parameters

Modelled as aquifer pathway.

Mixing zone (m):	
Calculated. Aquifer Thickness:	UNIFORM(7,10)

Justification for Aquifer Geometry

Estimated porosity based on literature

Pathway regional gradient (-):	SINGLE(0.01554)
Pathway hydraulic conductivity values (m/s):	LOGUNIFORM(9.33e-008,3.29e-007)
Pathway porosity (fraction):	LOGUNIFORM(0.02,0.2)

Justification for Aquifer Hydraulics Properties

Regional Gradient: based on difference in water table head between GW02 & GW03 divided by approximate distance between two points.

Pathway longitudinal dispersivity (m):	UNIFORM(19.25,40.75)
Pathway transverse dispersivity (m):	UNIFORM(5.775,12.225)

Justification for Aquifer Dispersion Details

Longitudinal Dispersivity = 10% of pathwya length

Lateral Dispersivity = 3% of pathway length

Relative Vertical Dispersivity = 1% of pathway length

Retardation parameters for pathway

Modelled as aquifer pathway.

No retardation values used in this simulation.

Check 'Unretarded Contaminant Transport' setting under simulation preferences.

Appendix 2

LandGEM Model Summary Report

Summary Report

Landfill Name or Identifier: Cartron Big Landfill - Co.Longford

Date: Tuesday 12 February 2019

Description/Comments:

About LandGEM:

First-Order Decomposition Rate Equation:

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

Where,

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

i = 1-year time increment

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

j = 0.1-year time increment

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

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

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

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

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

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

Input Review

LANDFILL CHARACTERISTICS

Landfill Open Year	**1970**	
Landfill Closure Year (with 80-year limit)	**1990**	
Actual Closure Year (without limit)	***1990***	
Have Model Calculate Closure Year?	**Yes**	
Waste Design Capacity	**329,600**	*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	16,263	17,889	0	0
1971	16,263	17,889	16,263	17,889
1972	16,263	17,889	32,526	35,779
1973	16,263	17,889	48,789	53,668
1974	16,263	17,889	65,052	71,557
1975	16,263	17,889	81,315	89,447
1976	16,263	17,889	97,578	107,336
1977	16,263	17,889	113,841	125,225
1978	16,263	17,889	130,104	143,114
1979	16,263	17,889	146,367	161,004
1980	16,263	17,889	162,630	178,893
1981	16,263	17,889	178,893	196,782
1982	16,263	17,889	195,156	214,672
1983	16,263	17,889	211,419	232,561
1984	16,263	17,889	227,682	250,450
1985	16,263	17,889	243,945	268,340
1986	16,263	17,889	260,208	286,229
1987	16,263	17,889	276,471	304,118
1988	16,263	17,889	292,734	322,007
1989	16,263	17,889	308,997	339,897
1990	4,340	4,774	325,260	357,786
1991	0	0	329,600	362,560
1992	0	0	329,600	362,560
1993	0	0	329,600	362,560
1994	0	0	329,600	362,560
1995	0	0	329,600	362,560
1996	0	0	329,600	362,560
1997	0	0	329,600	362,560
1998	0	0	329,600	362,560
1999	0	0	329,600	362,560
2000	0	0	329,600	362,560
2001	0	0	329,600	362,560
2002	0	0	329,600	362,560
2003	0	0	329,600	362,560
2004	0	0	329,600	362,560
2005	0	0	329,600	362,560
2006	0	0	329,600	362,560
2007	0	0	329,600	362,560
2008	0	0	329,600	362,560
2009	0	0	329,600	362,560

WASTE ACCEPTANCE RATES (Continued)

Year	Waste Accepted		Waste-In-Place	
	(Mg/year)	(short tons/year)	(Mg)	(short tons)
2010	0	0	329,600	362,560
2011	0	0	329,600	362,560
2012	0	0	329,600	362,560
2013	0	0	329,600	362,560
2014	0	0	329,600	362,560
2015	0	0	329,600	362,560
2016	0	0	329,600	362,560
2017	0	0	329,600	362,560
2018	0	0	329,600	362,560
2019	0	0	329,600	362,560
2020	0	0	329,600	362,560
2021	0	0	329,600	362,560
2022	0	0	329,600	362,560
2023	0	0	329,600	362,560
2024	0	0	329,600	362,560
2025	0	0	329,600	362,560
2026	0	0	329,600	362,560
2027	0	0	329,600	362,560
2028	0	0	329,600	362,560
2029	0	0	329,600	362,560
2030	0	0	329,600	362,560
2031	0	0	329,600	362,560
2032	0	0	329,600	362,560
2033	0	0	329,600	362,560
2034	0	0	329,600	362,560
2035	0	0	329,600	362,560
2036	0	0	329,600	362,560
2037	0	0	329,600	362,560
2038	0	0	329,600	362,560
2039	0	0	329,600	362,560
2040	0	0	329,600	362,560
2041	0	0	329,600	362,560
2042	0	0	329,600	362,560
2043	0	0	329,600	362,560
2044	0	0	329,600	362,560
2045	0	0	329,600	362,560
2046	0	0	329,600	362,560
2047	0	0	329,600	362,560
2048	0	0	329,600	362,560
2049	0	0	329,600	362,560

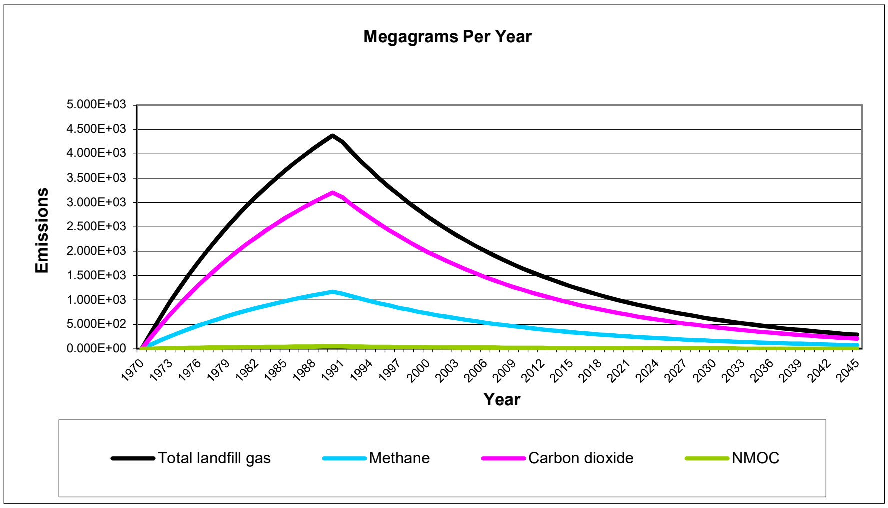
Pollutant Parameters

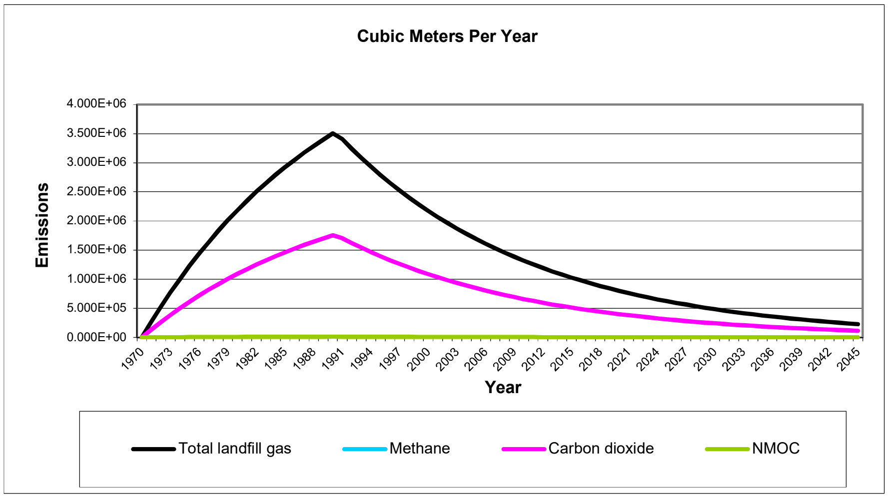
	Compound	Gas / Pollutant Default Parameters: Concentration (*ppmv*)	Molecular Weight	User-specified Pollutant Parameters: Concentration (*ppmv*)	Molecular Weight
Gases	Total landfill gas		0.00		
	Methane		16.04		
	Carbon dioxide		44.01		
	NMOC	4,000	86.18		
Pollutants	1,1,1-Trichloroethane (methyl chloroform)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

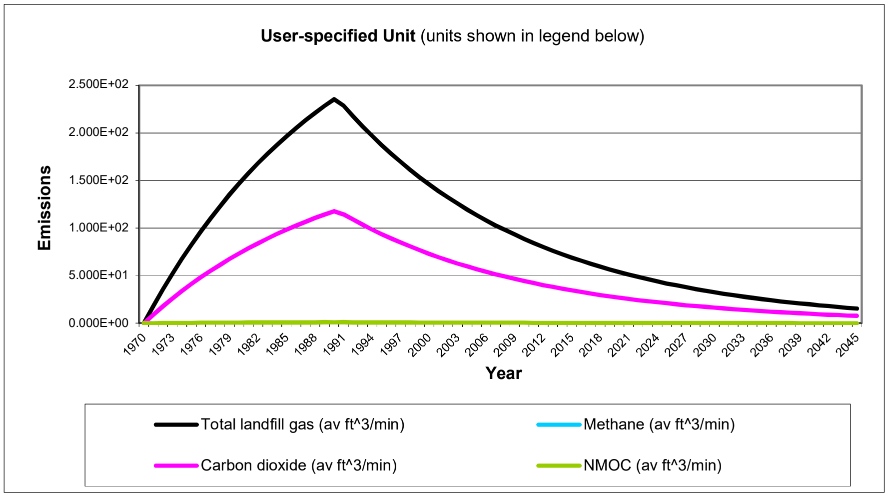
Pollutant Parameters (Continued)

	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	3.376E+02	2.703E+05	1.816E+01	9.018E+01	1.352E+05	9.082E+00
1972	6.588E+02	5.275E+05	3.544E+01	1.760E+02	2.638E+05	1.772E+01
1973	9.643E+02	7.721E+05	5.188E+01	2.576E+02	3.861E+05	2.594E+01
1974	1.255E+03	1.005E+06	6.751E+01	3.352E+02	5.024E+05	3.376E+01
1975	1.531E+03	1.226E+06	8.239E+01	4.090E+02	6.131E+05	4.119E+01
1976	1.794E+03	1.437E+06	9.653E+01	4.792E+02	7.184E+05	4.827E+01
1977	2.044E+03	1.637E+06	1.100E+02	5.461E+02	8.185E+05	5.499E+01
1978	2.282E+03	1.828E+06	1.228E+02	6.096E+02	9.138E+05	6.139E+01
1979	2.509E+03	2.009E+06	1.350E+02	6.701E+02	1.004E+06	6.748E+01
1980	2.724E+03	2.181E+06	1.465E+02	7.276E+02	1.091E+06	7.327E+01
1981	2.929E+03	2.345E+06	1.576E+02	7.823E+02	1.173E+06	7.878E+01
1982	3.123E+03	2.501E+06	1.680E+02	8.343E+02	1.251E+06	8.402E+01
1983	3.309E+03	2.649E+06	1.780E+02	8.838E+02	1.325E+06	8.901E+01
1984	3.485E+03	2.791E+06	1.875E+02	9.309E+02	1.395E+06	9.375E+01
1985	3.653E+03	2.925E+06	1.965E+02	9.756E+02	1.462E+06	9.826E+01
1986	3.812E+03	3.053E+06	2.051E+02	1.018E+03	1.526E+06	1.025E+02
1987	3.964E+03	3.174E+06	2.133E+02	1.059E+03	1.587E+06	1.066E+02
1988	4.108E+03	3.290E+06	2.210E+02	1.097E+03	1.645E+06	1.105E+02
1989	4.245E+03	3.399E+06	2.284E+02	1.134E+03	1.700E+06	1.142E+02
1990	4.376E+03	3.504E+06	2.354E+02	1.169E+03	1.752E+06	1.177E+02
1991	4.253E+03	3.405E+06	2.288E+02	1.136E+03	1.703E+06	1.144E+02
1992	4.045E+03	3.239E+06	2.176E+02	1.081E+03	1.620E+06	1.088E+02
1993	3.848E+03	3.081E+06	2.070E+02	1.028E+03	1.541E+06	1.035E+02
1994	3.660E+03	2.931E+06	1.969E+02	9.777E+02	1.465E+06	9.846E+01
1995	3.482E+03	2.788E+06	1.873E+02	9.300E+02	1.394E+06	9.366E+01
1996	3.312E+03	2.652E+06	1.782E+02	8.846E+02	1.326E+06	8.909E+01
1997	3.150E+03	2.523E+06	1.695E+02	8.415E+02	1.261E+06	8.475E+01
1998	2.997E+03	2.400E+06	1.612E+02	8.005E+02	1.200E+06	8.062E+01
1999	2.851E+03	2.283E+06	1.534E+02	7.614E+02	1.141E+06	7.668E+01
2000	2.712E+03	2.171E+06	1.459E+02	7.243E+02	1.086E+06	7.294E+01
2001	2.579E+03	2.065E+06	1.388E+02	6.890E+02	1.033E+06	6.939E+01
2002	2.454E+03	1.965E+06	1.320E+02	6.554E+02	9.823E+05	6.600E+01
2003	2.334E+03	1.869E+06	1.256E+02	6.234E+02	9.344E+05	6.278E+01
2004	2.220E+03	1.778E+06	1.194E+02	5.930E+02	8.889E+05	5.972E+01
2005	2.112E+03	1.691E+06	1.136E+02	5.641E+02	8.455E+05	5.681E+01
2006	2.009E+03	1.609E+06	1.081E+02	5.366E+02	8.043E+05	5.404E+01
2007	1.911E+03	1.530E+06	1.028E+02	5.104E+02	7.650E+05	5.140E+01
2008	1.818E+03	1.455E+06	9.779E+01	4.855E+02	7.277E+05	4.890E+01
2009	1.729E+03	1.384E+06	9.302E+01	4.618E+02	6.922E+05	4.651E+01
2010	1.645E+03	1.317E+06	8.849E+01	4.393E+02	6.585E+05	4.424E+01
2011	1.564E+03	1.253E+06	8.417E+01	4.179E+02	6.264E+05	4.209E+01
2012	1.488E+03	1.192E+06	8.007E+01	3.975E+02	5.958E+05	4.003E+01
2013	1.416E+03	1.134E+06	7.616E+01	3.781E+02	5.668E+05	3.808E+01
2014	1.347E+03	1.078E+06	7.245E+01	3.597E+02	5.391E+05	3.622E+01
2015	1.281E+03	1.026E+06	6.891E+01	3.421E+02	5.128E+05	3.446E+01
2016	1.218E+03	9.756E+05	6.555E+01	3.254E+02	4.878E+05	3.278E+01
2017	1.159E+03	9.280E+05	6.235E+01	3.096E+02	4.640E+05	3.118E+01
2018	1.102E+03	8.828E+05	5.931E+01	2.945E+02	4.414E+05	2.966E+01
2019	1.049E+03	8.397E+05	5.642E+01	2.801E+02	4.199E+05	2.821E+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	9.975E+02	7.988E+05	5.367E+01	2.664E+02	3.994E+05	2.683E+01
2021	9.489E+02	7.598E+05	5.105E+01	2.535E+02	3.799E+05	2.553E+01
2022	9.026E+02	7.228E+05	4.856E+01	2.411E+02	3.614E+05	2.428E+01
2023	8.586E+02	6.875E+05	4.619E+01	2.293E+02	3.438E+05	2.310E+01
2024	8.167E+02	6.540E+05	4.394E+01	2.182E+02	3.270E+05	2.197E+01
2025	7.769E+02	6.221E+05	4.180E+01	2.075E+02	3.110E+05	2.090E+01
2026	7.390E+02	5.917E+05	3.976E+01	1.974E+02	2.959E+05	1.988E+01
2027	7.029E+02	5.629E+05	3.782E+01	1.878E+02	2.814E+05	1.891E+01
2028	6.687E+02	5.354E+05	3.598E+01	1.786E+02	2.677E+05	1.799E+01
2029	6.361E+02	5.093E+05	3.422E+01	1.699E+02	2.547E+05	1.711E+01
2030	6.050E+02	4.845E+05	3.255E+01	1.616E+02	2.422E+05	1.628E+01
2031	5.755E+02	4.609E+05	3.096E+01	1.537E+02	2.304E+05	1.548E+01
2032	5.475E+02	4.384E+05	2.945E+01	1.462E+02	2.192E+05	1.473E+01
2033	5.208E+02	4.170E+05	2.802E+01	1.391E+02	2.085E+05	1.401E+01
2034	4.954E+02	3.967E+05	2.665E+01	1.323E+02	1.983E+05	1.333E+01
2035	4.712E+02	3.773E+05	2.535E+01	1.259E+02	1.887E+05	1.268E+01
2036	4.482E+02	3.589E+05	2.412E+01	1.197E+02	1.795E+05	1.206E+01
2037	4.264E+02	3.414E+05	2.294E+01	1.139E+02	1.707E+05	1.147E+01
2038	4.056E+02	3.248E+05	2.182E+01	1.083E+02	1.624E+05	1.091E+01
2039	3.858E+02	3.089E+05	2.076E+01	1.030E+02	1.545E+05	1.038E+01
2040	3.670E+02	2.939E+05	1.974E+01	9.802E+01	1.469E+05	9.872E+00
2041	3.491E+02	2.795E+05	1.878E+01	9.324E+01	1.398E+05	9.390E+00
2042	3.320E+02	2.659E+05	1.787E+01	8.869E+01	1.329E+05	8.933E+00
2043	3.159E+02	2.529E+05	1.699E+01	8.437E+01	1.265E+05	8.497E+00
2044	3.004E+02	2.406E+05	1.616E+01	8.025E+01	1.203E+05	8.082E+00
2045	2.858E+02	2.289E+05	1.538E+01	7.634E+01	1.144E+05	7.688E+00
2046	2.719E+02	2.177E+05	1.463E+01	7.262E+01	1.088E+05	7.313E+00
2047	2.586E+02	2.071E+05	1.391E+01	6.907E+01	1.035E+05	6.957E+00
2048	2.460E+02	1.970E+05	1.323E+01	6.571E+01	9.849E+04	6.617E+00
2049	2.340E+02	1.874E+05	1.259E+01	6.250E+01	9.368E+04	6.295E+00
2050	2.226E+02	1.782E+05	1.198E+01	5.945E+01	8.912E+04	5.988E+00
2051	2.117E+02	1.695E+05	1.139E+01	5.655E+01	8.477E+04	5.696E+00
2052	2.014E+02	1.613E+05	1.084E+01	5.380E+01	8.063E+04	5.418E+00
2053	1.916E+02	1.534E+05	1.031E+01	5.117E+01	7.670E+04	5.154E+00
2054	1.822E+02	1.459E+05	9.805E+00	4.868E+01	7.296E+04	4.902E+00
2055	1.733E+02	1.388E+05	9.326E+00	4.630E+01	6.940E+04	4.663E+00
2056	1.649E+02	1.320E+05	8.871E+00	4.404E+01	6.602E+04	4.436E+00
2057	1.568E+02	1.256E+05	8.439E+00	4.190E+01	6.280E+04	4.219E+00
2058	1.492E+02	1.195E+05	8.027E+00	3.985E+01	5.974E+04	4.014E+00
2059	1.419E+02	1.136E+05	7.636E+00	3.791E+01	5.682E+04	3.818E+00
2060	1.350E+02	1.081E+05	7.263E+00	3.606E+01	5.405E+04	3.632E+00
2061	1.284E+02	1.028E+05	6.909E+00	3.430E+01	5.141E+04	3.455E+00
2062	1.222E+02	9.781E+04	6.572E+00	3.263E+01	4.891E+04	3.286E+00
2063	1.162E+02	9.304E+04	6.252E+00	3.104E+01	4.652E+04	3.126E+00
2064	1.105E+02	8.851E+04	5.947E+00	2.952E+01	4.425E+04	2.973E+00
2065	1.051E+02	8.419E+04	5.657E+00	2.808E+01	4.210E+04	2.828E+00
2066	1.000E+02	8.008E+04	5.381E+00	2.671E+01	4.004E+04	2.690E+00
2067	9.513E+01	7.618E+04	5.118E+00	2.541E+01	3.809E+04	2.559E+00
2068	9.049E+01	7.246E+04	4.869E+00	2.417E+01	3.623E+04	2.434E+00
2069	8.608E+01	6.893E+04	4.631E+00	2.299E+01	3.446E+04	2.316E+00
2070	8.188E+01	6.557E+04	4.405E+00	2.187E+01	3.278E+04	2.203E+00

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	7.789E+01	6.237E+04	4.191E+00	2.080E+01	3.118E+04	2.095E+00
2072	7.409E+01	5.933E+04	3.986E+00	1.979E+01	2.966E+04	1.993E+00
2073	7.048E+01	5.643E+04	3.792E+00	1.883E+01	2.822E+04	1.896E+00
2074	6.704E+01	5.368E+04	3.607E+00	1.791E+01	2.684E+04	1.803E+00
2075	6.377E+01	5.106E+04	3.431E+00	1.703E+01	2.553E+04	1.715E+00
2076	6.066E+01	4.857E+04	3.264E+00	1.620E+01	2.429E+04	1.632E+00
2077	5.770E+01	4.620E+04	3.104E+00	1.541E+01	2.310E+04	1.552E+00
2078	5.489E+01	4.395E+04	2.953E+00	1.466E+01	2.198E+04	1.477E+00
2079	5.221E+01	4.181E+04	2.809E+00	1.395E+01	2.090E+04	1.405E+00
2080	4.966E+01	3.977E+04	2.672E+00	1.327E+01	1.988E+04	1.336E+00
2081	4.724E+01	3.783E+04	2.542E+00	1.262E+01	1.891E+04	1.271E+00
2082	4.494E+01	3.598E+04	2.418E+00	1.200E+01	1.799E+04	1.209E+00
2083	4.275E+01	3.423E+04	2.300E+00	1.142E+01	1.711E+04	1.150E+00
2084	4.066E+01	3.256E+04	2.188E+00	1.086E+01	1.628E+04	1.094E+00
2085	3.868E+01	3.097E+04	2.081E+00	1.033E+01	1.549E+04	1.040E+00
2086	3.679E+01	2.946E+04	1.979E+00	9.828E+00	1.473E+04	9.897E-01
2087	3.500E+01	2.802E+04	1.883E+00	9.348E+00	1.401E+04	9.415E-01
2088	3.329E+01	2.666E+04	1.791E+00	8.892E+00	1.333E+04	8.956E-01
2089	3.167E+01	2.536E+04	1.704E+00	8.459E+00	1.268E+04	8.519E-01
2090	3.012E+01	2.412E+04	1.621E+00	8.046E+00	1.206E+04	8.103E-01
2091	2.865E+01	2.294E+04	1.542E+00	7.654E+00	1.147E+04	7.708E-01
2092	2.726E+01	2.183E+04	1.466E+00	7.280E+00	1.091E+04	7.332E-01
2093	2.593E+01	2.076E+04	1.395E+00	6.925E+00	1.038E+04	6.975E-01
2094	2.466E+01	1.975E+04	1.327E+00	6.588E+00	9.874E+03	6.634E-01
2095	2.346E+01	1.879E+04	1.262E+00	6.266E+00	9.393E+03	6.311E-01
2096	2.232E+01	1.787E+04	1.201E+00	5.961E+00	8.935E+03	6.003E-01
2097	2.123E+01	1.700E+04	1.142E+00	5.670E+00	8.499E+03	5.710E-01
2098	2.019E+01	1.617E+04	1.086E+00	5.393E+00	8.084E+03	5.432E-01
2099	1.921E+01	1.538E+04	1.033E+00	5.130E+00	7.690E+03	5.167E-01
2100	1.827E+01	1.463E+04	9.830E-01	4.880E+00	7.315E+03	4.915E-01
2101	1.738E+01	1.392E+04	9.350E-01	4.642E+00	6.958E+03	4.675E-01
2102	1.653E+01	1.324E+04	8.894E-01	4.416E+00	6.619E+03	4.447E-01
2103	1.573E+01	1.259E+04	8.461E-01	4.200E+00	6.296E+03	4.230E-01
2104	1.496E+01	1.198E+04	8.048E-01	3.996E+00	5.989E+03	4.024E-01
2105	1.423E+01	1.139E+04	7.656E-01	3.801E+00	5.697E+03	3.828E-01
2106	1.353E+01	1.084E+04	7.282E-01	3.615E+00	5.419E+03	3.641E-01
2107	1.287E+01	1.031E+04	6.927E-01	3.439E+00	5.155E+03	3.464E-01
2108	1.225E+01	9.807E+03	6.589E-01	3.271E+00	4.903E+03	3.295E-01
2109	1.165E+01	9.329E+03	6.268E-01	3.112E+00	4.664E+03	3.134E-01
2110	1.108E+01	8.874E+03	5.962E-01	2.960E+00	4.437E+03	2.981E-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	2.474E+02	1.352E+05	9.082E+00	3.876E+00	1.081E+03	7.266E-02
1972	4.828E+02	2.638E+05	1.772E+01	7.563E+00	2.110E+03	1.418E-01
1973	7.067E+02	3.861E+05	2.594E+01	1.107E+01	3.089E+03	2.075E-01
1974	9.197E+02	5.024E+05	3.376E+01	1.441E+01	4.019E+03	2.701E-01
1975	1.122E+03	6.131E+05	4.119E+01	1.758E+01	4.905E+03	3.295E-01
1976	1.315E+03	7.184E+05	4.827E+01	2.060E+01	5.747E+03	3.861E-01
1977	1.498E+03	8.185E+05	5.499E+01	2.347E+01	6.548E+03	4.400E-01
1978	1.673E+03	9.138E+05	6.139E+01	2.620E+01	7.310E+03	4.912E-01
1979	1.838E+03	1.004E+06	6.748E+01	2.880E+01	8.035E+03	5.399E-01
1980	1.996E+03	1.091E+06	7.327E+01	3.127E+01	8.724E+03	5.862E-01
1981	2.146E+03	1.173E+06	7.878E+01	3.362E+01	9.380E+03	6.303E-01
1982	2.289E+03	1.251E+06	8.402E+01	3.586E+01	1.000E+04	6.722E-01
1983	2.425E+03	1.325E+06	8.901E+01	3.799E+01	1.060E+04	7.121E-01
1984	2.554E+03	1.395E+06	9.375E+01	4.001E+01	1.116E+04	7.500E-01
1985	2.677E+03	1.462E+06	9.826E+01	4.194E+01	1.170E+04	7.861E-01
1986	2.794E+03	1.526E+06	1.025E+02	4.377E+01	1.221E+04	8.204E-01
1987	2.905E+03	1.587E+06	1.066E+02	4.551E+01	1.270E+04	8.530E-01
1988	3.011E+03	1.645E+06	1.105E+02	4.716E+01	1.316E+04	8.841E-01
1989	3.111E+03	1.700E+06	1.142E+02	4.874E+01	1.360E+04	9.136E-01
1990	3.207E+03	1.752E+06	1.177E+02	5.024E+01	1.402E+04	9.417E-01
1991	3.117E+03	1.703E+06	1.144E+02	4.882E+01	1.362E+04	9.152E-01
1992	2.965E+03	1.620E+06	1.088E+02	4.644E+01	1.296E+04	8.706E-01
1993	2.820E+03	1.541E+06	1.035E+02	4.418E+01	1.232E+04	8.281E-01
1994	2.683E+03	1.465E+06	9.846E+01	4.202E+01	1.172E+04	7.877E-01
1995	2.552E+03	1.394E+06	9.366E+01	3.997E+01	1.115E+04	7.493E-01
1996	2.427E+03	1.326E+06	8.909E+01	3.802E+01	1.061E+04	7.128E-01
1997	2.309E+03	1.261E+06	8.475E+01	3.617E+01	1.009E+04	6.780E-01
1998	2.196E+03	1.200E+06	8.062E+01	3.441E+01	9.599E+03	6.449E-01
1999	2.089E+03	1.141E+06	7.668E+01	3.273E+01	9.130E+03	6.135E-01
2000	1.987E+03	1.086E+06	7.294E+01	3.113E+01	8.685E+03	5.836E-01
2001	1.890E+03	1.033E+06	6.939E+01	2.961E+01	8.262E+03	5.551E-01
2002	1.798E+03	9.823E+05	6.600E+01	2.817E+01	7.859E+03	5.280E-01
2003	1.710E+03	9.344E+05	6.278E+01	2.680E+01	7.475E+03	5.023E-01
2004	1.627E+03	8.889E+05	5.972E+01	2.549E+01	7.111E+03	4.778E-01
2005	1.548E+03	8.455E+05	5.681E+01	2.425E+01	6.764E+03	4.545E-01
2006	1.472E+03	8.043E+05	5.404E+01	2.306E+01	6.434E+03	4.323E-01
2007	1.400E+03	7.650E+05	5.140E+01	2.194E+01	6.120E+03	4.112E-01
2008	1.332E+03	7.277E+05	4.890E+01	2.087E+01	5.822E+03	3.912E-01
2009	1.267E+03	6.922E+05	4.651E+01	1.985E+01	5.538E+03	3.721E-01
2010	1.205E+03	6.585E+05	4.424E+01	1.888E+01	5.268E+03	3.539E-01
2011	1.147E+03	6.264E+05	4.209E+01	1.796E+01	5.011E+03	3.367E-01
2012	1.091E+03	5.958E+05	4.003E+01	1.709E+01	4.767E+03	3.203E-01
2013	1.037E+03	5.668E+05	3.808E+01	1.625E+01	4.534E+03	3.046E-01
2014	9.868E+02	5.391E+05	3.622E+01	1.546E+01	4.313E+03	2.898E-01
2015	9.387E+02	5.128E+05	3.446E+01	1.471E+01	4.103E+03	2.757E-01
2016	8.929E+02	4.878E+05	3.278E+01	1.399E+01	3.902E+03	2.622E-01
2017	8.494E+02	4.640E+05	3.118E+01	1.331E+01	3.712E+03	2.494E-01
2018	8.080E+02	4.414E+05	2.966E+01	1.266E+01	3.531E+03	2.373E-01
2019	7.686E+02	4.199E+05	2.821E+01	1.204E+01	3.359E+03	2.257E-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)
2020	7.311E+02	3.994E+05	2.683E+01	1.145E+01	3.195E+03	2.147E-01
2021	6.954E+02	3.799E+05	2.553E+01	1.089E+01	3.039E+03	2.042E-01
2022	6.615E+02	3.614E+05	2.428E+01	1.036E+01	2.891E+03	1.942E-01
2023	6.292E+02	3.438E+05	2.310E+01	9.857E+00	2.750E+03	1.848E-01
2024	5.986E+02	3.270E+05	2.197E+01	9.377E+00	2.616E+03	1.758E-01
2025	5.694E+02	3.110E+05	2.090E+01	8.919E+00	2.488E+03	1.672E-01
2026	5.416E+02	2.959E+05	1.988E+01	8.484E+00	2.367E+03	1.590E-01
2027	5.152E+02	2.814E+05	1.891E+01	8.071E+00	2.252E+03	1.513E-01
2028	4.901E+02	2.677E+05	1.799E+01	7.677E+00	2.142E+03	1.439E-01
2029	4.662E+02	2.547E+05	1.711E+01	7.303E+00	2.037E+03	1.369E-01
2030	4.434E+02	2.422E+05	1.628E+01	6.946E+00	1.938E+03	1.302E-01
2031	4.218E+02	2.304E+05	1.548E+01	6.608E+00	1.843E+03	1.239E-01
2032	4.012E+02	2.192E+05	1.473E+01	6.285E+00	1.754E+03	1.178E-01
2033	3.817E+02	2.085E+05	1.401E+01	5.979E+00	1.668E+03	1.121E-01
2034	3.630E+02	1.983E+05	1.333E+01	5.687E+00	1.587E+03	1.066E-01
2035	3.453E+02	1.887E+05	1.268E+01	5.410E+00	1.509E+03	1.014E-01
2036	3.285E+02	1.795E+05	1.206E+01	5.146E+00	1.436E+03	9.646E-02
2037	3.125E+02	1.707E+05	1.147E+01	4.895E+00	1.366E+03	9.176E-02
2038	2.972E+02	1.624E+05	1.091E+01	4.656E+00	1.299E+03	8.728E-02
2039	2.827E+02	1.545E+05	1.038E+01	4.429E+00	1.236E+03	8.302E-02
2040	2.689E+02	1.469E+05	9.872E+00	4.213E+00	1.175E+03	7.898E-02
2041	2.558E+02	1.398E+05	9.390E+00	4.008E+00	1.118E+03	7.512E-02
2042	2.434E+02	1.329E+05	8.933E+00	3.812E+00	1.064E+03	7.146E-02
2043	2.315E+02	1.265E+05	8.497E+00	3.626E+00	1.012E+03	6.797E-02
2044	2.202E+02	1.203E+05	8.082E+00	3.449E+00	9.623E+02	6.466E-02
2045	2.095E+02	1.144E+05	7.688E+00	3.281E+00	9.154E+02	6.151E-02
2046	1.992E+02	1.088E+05	7.313E+00	3.121E+00	8.708E+02	5.851E-02
2047	1.895E+02	1.035E+05	6.957E+00	2.969E+00	8.283E+02	5.565E-02
2048	1.803E+02	9.849E+04	6.617E+00	2.824E+00	7.879E+02	5.294E-02
2049	1.715E+02	9.368E+04	6.295E+00	2.686E+00	7.495E+02	5.036E-02
2050	1.631E+02	8.912E+04	5.988E+00	2.555E+00	7.129E+02	4.790E-02
2051	1.552E+02	8.477E+04	5.696E+00	2.431E+00	6.782E+02	4.556E-02
2052	1.476E+02	8.063E+04	5.418E+00	2.312E+00	6.451E+02	4.334E-02
2053	1.404E+02	7.670E+04	5.154E+00	2.199E+00	6.136E+02	4.123E-02
2054	1.336E+02	7.296E+04	4.902E+00	2.092E+00	5.837E+02	3.922E-02
2055	1.270E+02	6.940E+04	4.663E+00	1.990E+00	5.552E+02	3.731E-02
2056	1.208E+02	6.602E+04	4.436E+00	1.893E+00	5.281E+02	3.549E-02
2057	1.150E+02	6.280E+04	4.219E+00	1.801E+00	5.024E+02	3.376E-02
2058	1.093E+02	5.974E+04	4.014E+00	1.713E+00	4.779E+02	3.211E-02
2059	1.040E+02	5.682E+04	3.818E+00	1.629E+00	4.546E+02	3.054E-02
2060	9.894E+01	5.405E+04	3.632E+00	1.550E+00	4.324E+02	2.905E-02
2061	9.412E+01	5.141E+04	3.455E+00	1.474E+00	4.113E+02	2.764E-02
2062	8.952E+01	4.891E+04	3.286E+00	1.402E+00	3.913E+02	2.629E-02
2063	8.516E+01	4.652E+04	3.126E+00	1.334E+00	3.722E+02	2.501E-02
2064	8.101E+01	4.425E+04	2.973E+00	1.269E+00	3.540E+02	2.379E-02
2065	7.705E+01	4.210E+04	2.828E+00	1.207E+00	3.368E+02	2.263E-02
2066	7.330E+01	4.004E+04	2.690E+00	1.148E+00	3.203E+02	2.152E-02
2067	6.972E+01	3.809E+04	2.559E+00	1.092E+00	3.047E+02	2.047E-02
2068	6.632E+01	3.623E+04	2.434E+00	1.039E+00	2.899E+02	1.948E-02
2069	6.309E+01	3.446E+04	2.316E+00	9.883E-01	2.757E+02	1.853E-02
2070	6.001E+01	3.278E+04	2.203E+00	9.401E-01	2.623E+02	1.762E-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)
2071	5.708E+01	3.118E+04	2.095E+00	8.942E-01	2.495E+02	1.676E-02
2072	5.430E+01	2.966E+04	1.993E+00	8.506E-01	2.373E+02	1.594E-02
2073	5.165E+01	2.822E+04	1.896E+00	8.091E-01	2.257E+02	1.517E-02
2074	4.913E+01	2.684E+04	1.803E+00	7.697E-01	2.147E+02	1.443E-02
2075	4.674E+01	2.553E+04	1.715E+00	7.321E-01	2.043E+02	1.372E-02
2076	4.446E+01	2.429E+04	1.632E+00	6.964E-01	1.943E+02	1.305E-02
2077	4.229E+01	2.310E+04	1.552E+00	6.625E-01	1.848E+02	1.242E-02
2078	4.023E+01	2.198E+04	1.477E+00	6.302E-01	1.758E+02	1.181E-02
2079	3.826E+01	2.090E+04	1.405E+00	5.994E-01	1.672E+02	1.124E-02
2080	3.640E+01	1.988E+04	1.336E+00	5.702E-01	1.591E+02	1.069E-02
2081	3.462E+01	1.891E+04	1.271E+00	5.424E-01	1.513E+02	1.017E-02
2082	3.293E+01	1.799E+04	1.209E+00	5.159E-01	1.439E+02	9.671E-03
2083	3.133E+01	1.711E+04	1.150E+00	4.908E-01	1.369E+02	9.199E-03
2084	2.980E+01	1.628E+04	1.094E+00	4.668E-01	1.302E+02	8.751E-03
2085	2.835E+01	1.549E+04	1.040E+00	4.441E-01	1.239E+02	8.324E-03
2086	2.696E+01	1.473E+04	9.897E-01	4.224E-01	1.178E+02	7.918E-03
2087	2.565E+01	1.401E+04	9.415E-01	4.018E-01	1.121E+02	7.532E-03
2088	2.440E+01	1.333E+04	8.956E-01	3.822E-01	1.066E+02	7.164E-03
2089	2.321E+01	1.268E+04	8.519E-01	3.636E-01	1.014E+02	6.815E-03
2090	2.208E+01	1.206E+04	8.103E-01	3.458E-01	9.648E+01	6.483E-03
2091	2.100E+01	1.147E+04	7.708E-01	3.290E-01	9.178E+01	6.167E-03
2092	1.998E+01	1.091E+04	7.332E-01	3.129E-01	8.730E+01	5.866E-03
2093	1.900E+01	1.038E+04	6.975E-01	2.977E-01	8.304E+01	5.580E-03
2094	1.807E+01	9.874E+03	6.634E-01	2.832E-01	7.899E+01	5.308E-03
2095	1.719E+01	9.393E+03	6.311E-01	2.693E-01	7.514E+01	5.049E-03
2096	1.635E+01	8.935E+03	6.003E-01	2.562E-01	7.148E+01	4.803E-03
2097	1.556E+01	8.499E+03	5.710E-01	2.437E-01	6.799E+01	4.568E-03
2098	1.480E+01	8.084E+03	5.432E-01	2.318E-01	6.467E+01	4.345E-03
2099	1.408E+01	7.690E+03	5.167E-01	2.205E-01	6.152E+01	4.134E-03
2100	1.339E+01	7.315E+03	4.915E-01	2.098E-01	5.852E+01	3.932E-03
2101	1.274E+01	6.958E+03	4.675E-01	1.995E-01	5.567E+01	3.740E-03
2102	1.212E+01	6.619E+03	4.447E-01	1.898E-01	5.295E+01	3.558E-03
2103	1.152E+01	6.296E+03	4.230E-01	1.805E-01	5.037E+01	3.384E-03
2104	1.096E+01	5.989E+03	4.024E-01	1.717E-01	4.791E+01	3.219E-03
2105	1.043E+01	5.697E+03	3.828E-01	1.634E-01	4.558E+01	3.062E-03
2106	9.920E+00	5.419E+03	3.641E-01	1.554E-01	4.335E+01	2.913E-03
2107	9.436E+00	5.155E+03	3.464E-01	1.478E-01	4.124E+01	2.771E-03
2108	8.976E+00	4.903E+03	3.295E-01	1.406E-01	3.923E+01	2.636E-03
2109	8.538E+00	4.664E+03	3.134E-01	1.338E-01	3.731E+01	2.507E-03
2110	8.122E+00	4.437E+03	2.981E-01	1.272E-01	3.549E+01	2.385E-03

Appendix 3

Remediation Plan Drawings

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

Scale 1:1000

Rev.	Description	App By	Date
A	ISSUE FOR DISCUSSION	CJC	22.02.19

CONSULTANTS IN ENGINEERING & ENVIRONMENTAL SCIENCES

FEHILY TIMONEY & COMPANY

Core House, Pouladuff Rd, Cork, Ireland.

J5 Plaza, North Park Business Park, North Road, Dublin 11, Ireland

T:+353-21-4964133, F:+353-21-4964464 T:+353-1-6583500, F:+353-1-6583501 W: www.fehilytimoney.ie, E: info@ftco.ie

CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT

LONGFORD LANDFILL REMEDIATION

SHEET

CARTON BIG: WASTE BOUNDARY PLAN

CLIENT

LONGFORD CO CO

Date 22.02.19	Project number P1444	Scale (@ A3-) 1:1000	
Drawn by SOC	Drawing Number P1444-0100-0001		Rev A
Checked by JON			

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Monday 4 March 2019

Legend

- Carton Big: Anticipated Waste Boundary (23576.155m²)
- Surface & Sub Surface Drain Only
- Sub Surface Drain Only
- Inspection Chamber

Scale 1:1000 (0m 5m 10m 15m 20m 25m 30m 35m 40m 45m 50m)

Rev.	Description	App By	Date
A	ISSUE FOR DISCUSSION	CJC	22.02.19

FEHILY TIMONEY & COMPANY
CONSULTANTS IN ENGINEERING & ENVIRONMENTAL SCIENCES
Core House, Pouladuff Rd, Cork, Ireland.
J5 Plaza, North Park Business Park, North Road, Dublin 11, Ireland
T:+353-21-4964133, F:+353-21-4964464 T:+353-1-6583500, F:+353-1-6583501 W: www.fehilytimoney.ie, E: info@ftco.ie

CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT: LONGFORD LANDFILL REMEDIATION

SHEET: HERRING BONE SUB SURFACE & SURFACE DRAINAGE: PLAN

CLIENT: LONGFORD CO CO

Date: 22.02.19	Project number: P1444	Scale (@ A3-) 1:1000	
Drawn by: SOC	Drawing Number: P1444-0500-0001		Rev: A
Checked by: JON			

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Monday 4 March 2019

Legend

- Carton Big: Anticipated Waste Boundary (23576.155m²)
- Inspection Chamber
- Leachate Interceptor Trench
- Leachate Collection Sump
- Leachate Rising Main
- Leachate Collection Tank
- Leachate Collection & Handling Yard

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

Scale 1:1000

Rev.	Description	App By	Date
A	ISSUE FOR DISCUSSION	CJC	22.02.19
B	ISSUE FOR DISCUSSION	BF	15.08.22

CONSULTANTS IN ENGINEERING & ENVIRONMENTAL SCIENCES

FEHILY TIMONEY & COMPANY

Core House, Pouladuff Rd, Cork, Ireland.

J5 Plaza, North Park Business Park, North Road, Dublin 11, Ireland

T:+353-21-4964133, F:+353-21-4964464 T:+353-1-6583500, F:+353-1-6583501 W: www.fehilytimoney.ie, E: info@ftco.ie

CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT

LONGFORD LANDFILL REMEDIATION

SHEET

LEACHATE INTERCEPTION TRENCH: PLAN

CLIENT

LONGFORD CO CO

Date 22.02.19	Project number P1444	Scale (@ A3-) 1:1000	
Drawn by SOC	Drawing Number P1444-0500-0002		Rev B
Checked by JON			

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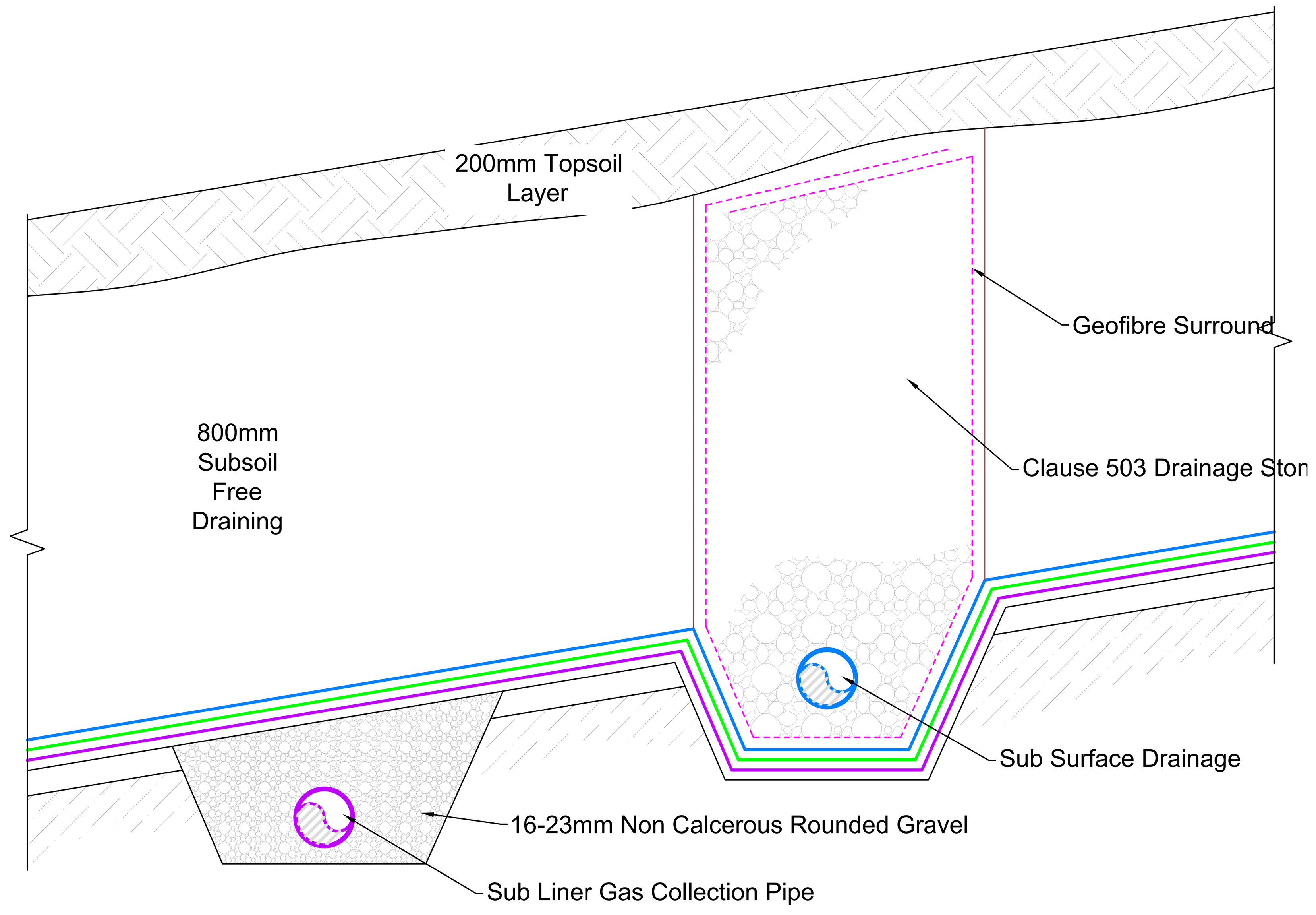
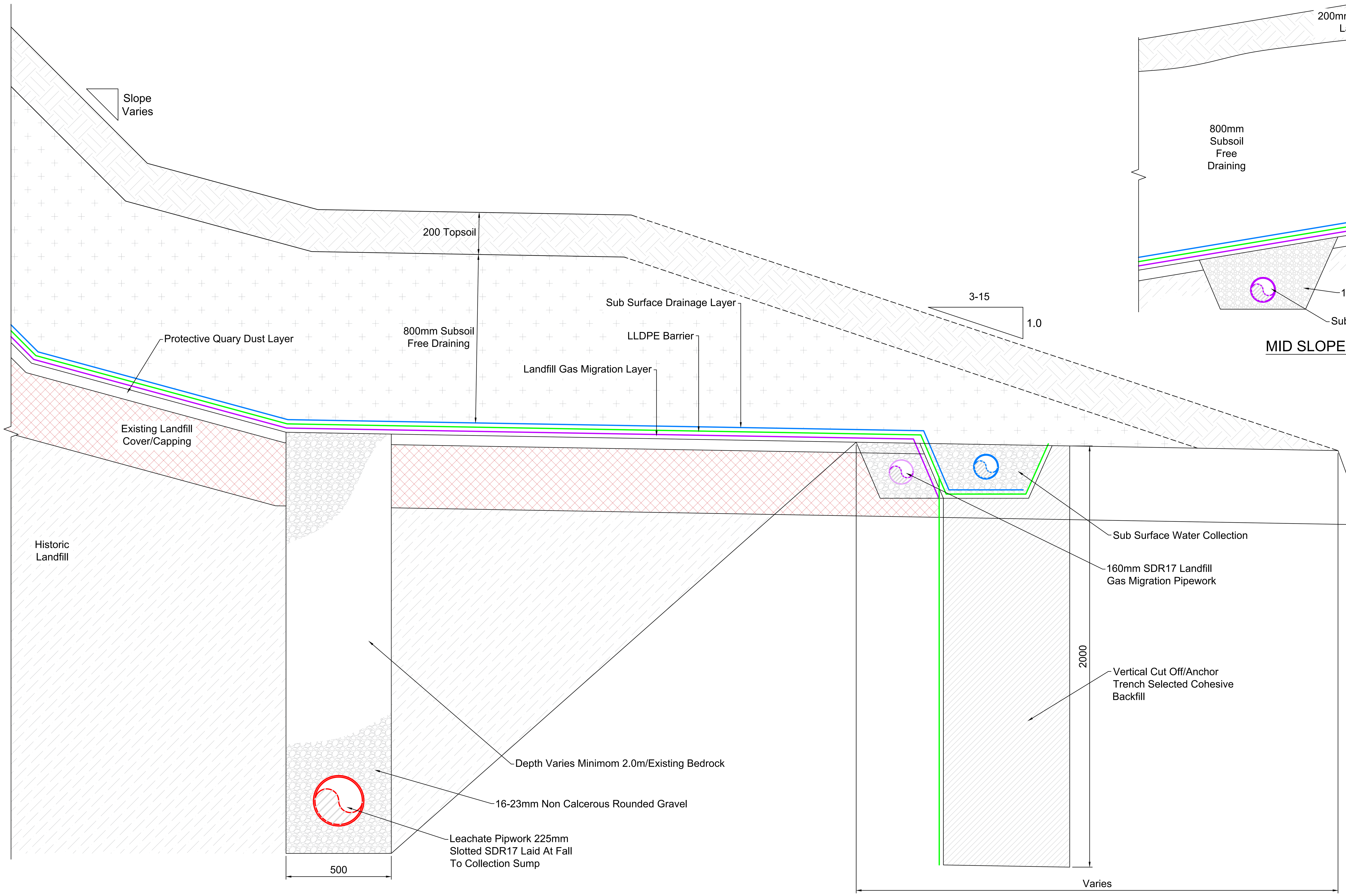
16 August 2022



MID SLOPE SUB SURFACE DRAINAGE

Scale 1:10



DETAIL A-A: LANDFILLI ANOCHOR TRENCH & LEACHATE INTERCEPTION 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

Rev.	Description	App By	Date
A	ISSUE FOR DISCUSSION	CJC	25.02.19

FEHILY TIMONEY & COMPANY
CONSULTANTS IN ENGINEERING & ENVIRONMENTAL SCIENCES
Core House, Pouladuff Rd, Cork, Ireland.
J5 Plaza, North Park Business Park, North Road, Dublin 11, Ireland
T:+353-21-4964133, F:+353-21-4964464 T:+353-1-6583500, F:+353-1-6583501 W: www.fehilytimoney.ie, E: info@ftco.ie

CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT
LONGFORD LANDFILL REMEDIATION

SHEET
DETAILS SHEET 1 OF 3

CLIENT
LONGFORD CO CO

Date	Project number	Scale (@ A1-)
25.02.19	P1444	1:10

Drawn by	SOC
Checked by	JON

Drawing Number: P1444-0900-0001
Rev: A

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Monday 4 March 2019

DETAIL B-B: ANCHOR TRENCH & FRENCH DRAIN

Scale 1:10

Scale 1:10

Rev.	Description	App By	Date
A	ISSUE FOR DISCUSSION	CJC	25.02.19

CONSULTANTS IN ENGINEERING & ENVIRONMENTAL SCIENCES

FEHILY TIMONEY & COMPANY

Core House, Pouladuff Rd, Cork, Ireland.

J5 Plaza, North Park Business Park, North Road, Dublin 11, Ireland

T:+353-21-4964133, F:+353-21-4964464 T:+353-1-6583500, F:+353-1-6583501 W: www.fehilytimoney.ie, E: info@ftco.ie

CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT: LONGFORD LANDFILL REMEDIATION

CLIENT: LONGFORD CO CO

SHEET: DETAILS SHEET 2 OF 3

Date: 25.02.19
Project number: P1444
Scale (@ A1-): 1:10
Drawn by: SOC
Checked by: JON
Drawing Number: P1444-0900-0002
Rev: A

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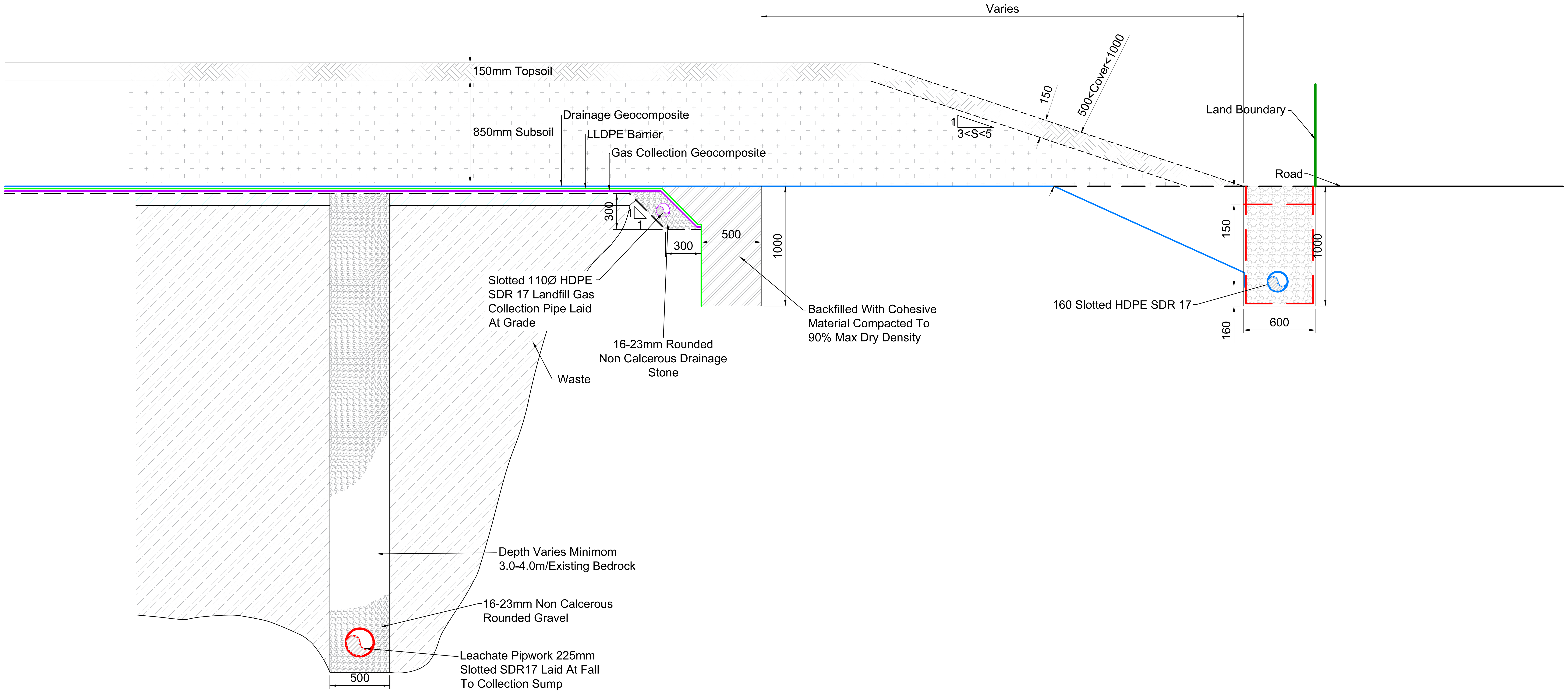
Monday 4 March 2019



DETAIL C-C: ANCHOR TRENCH & SURFACE/SUB SURFACE DRAINAGE

Scale 1:20

Scale 1:20

Rev.	Description	App By	Date
A	ISSUE FOR DISCUSSION	CJC	04.03.19

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CONSULTANTS IN ENGINEERING & ENVIRONMENTAL SCIENCES

Core House, Pouladuff Rd, Cork, Ireland.

J5 Plaza, North Park Business Park, North Road, Dublin 11, Ireland

T:+353-21-4964133, F:+353-21-4964464 T:+353-1-6583500, F:+353-1-6583501 W: www.fehilytimoney.ie, E: info@ftco.ie

CODE	STATUS	SUITABILITY DESCRIPTION	PURPOSE OF ISSUE

PROJECT

LONGFORD LANDFILL REMEDIATION

SHEET

DETAILS SHEET 3 OF 3

CLIENT

LONGFORD CO CO

Date 04.03.19	Project number P1444	Scale (@ A1-) 1:20	
Drawn by SOC	Drawing Number P1444-0900-0003		Rev A
Checked by JON			

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Monday 4 March 2019

Appendix 4

Environment Agency Remedial Targets Worksheet-Groundwater Calculation Sample

R&D Publication 20 Remedial Targets Worksheet, Release 3.2

Level 3 - Groundwater

See Note

Input Parameters (using pull down menu)

Parameter	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)

Ogata Banks — **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**

Parameter	Variable	Value	Unit	Source of parameter value
Initial contaminant concentration in groundwater at plume core	C_0	2.44E+00	mg/l	*Based on maximum predicted monitor well concentrations (LandSim)*
Half life for degradation of contaminant in water	$t_{1/2}$	1.00E+09	days	*Assumed no degradation*
Calculated decay rate	λ	6.93E-10	$days^{-1}$	
Width of plume in aquifer at source (perpendicular to flow)	Sz	1.10E+02	m	*Approximate width of site/waste extent*
Plume thickness at source	Sy	4.00E+00	m	*Half of minimum assumed aquifer thickness (8m)*
Saturated aquifer thickness	da	1.20E+01	m	*Assumed maximum aquifer thickness*
Bulk density of aquifer materials	ρ	1.65E+00	g/cm^3	*Median between assumed bulkd density applied in La*
Effective porosity of aquifer	n	1.10E-01	fraction	*median of assumed assumed porosity applied in LandSim (0.02-0.2)*
Hydraulic gradient	i	1.55E-02	fraction	*Calculated from groundwater levels between upgradient and downgradient wells on site*
Hydraulic conductivity of aquifer	K	8.00E-03	m/d	*Assumed single conductivity based on ran*
Distance to compliance point	x	2.00E+02	m	*Hypothetical compliance point at 200m*
Distance (lateral) to compliance point perpendicular to flow direction	z	0.00E+00	m	
Distance (depth) to compliance point perpendicular to flow direction	y	0.00E+00	m	
Time since pollutant entered groundwater	t	3.65E+05	days	*time variant options only*
Parameters values determined from options				
Partition coefficient	Kd	1.25E+00	l/kg	*see options*
Longitudinal dispersivity	ax	2.00E+01	m	*see options*
Transverse dispersivity	az	2.00E+00	m	*see options*
Vertical dispersivity	ay	2.00E-01	m	*see options*

Calculated Parameters

Parameter	Variable	Value	Unit
Groundwater flow velocity	v	1.13E-03	m/d
Retardation factor	Rf	1.98E+01	fraction
Decay rate used	λ	6.93E-10	d^{-1}
Rate of contaminant flow due to retardation	u	5.72E-05	m/d
Contaminant concentration at distance x, assuming one-way vertical dispersion	C_{ED}	0.00E+00	mg/l
Attenuation factor (one way vertical dispersion, CO/CED)	**AF**	breakthrough at compliance point	

Remedial Targets

Remedial Target	No impact	mg/l	For comparison with measured groundwater concentration.
Ogata Banks			

Distance to compliance point		**200**	**m**	
Concentration of contaminant at compliance point	C_{ED}/C_0	**0.00E+00**	**mg/l**	Ogata Banks
after		**3.7E+05**	**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.

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		fraction
Organic carbon partition coefficient	Koc		l/kg
Entry for ionic organic chemicals (option)			
Sorption coefficient for related species	$K_{oc.n}$		l/kg
Sorption coefficient for ionised species	$K_{oc.i}$		l/kg
pH value	pH		
acid dissociation constant	pKa		
Fraction of organic carbon in aquifer	foc		fraction
Soil water partition coefficient	Kd	1.25E+00	l/kg

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

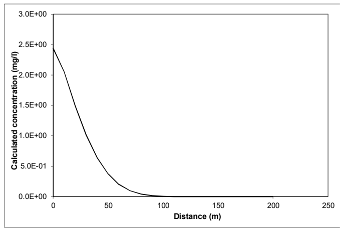
Dispersivities 10%, 1%, 0.1% of pathway length

		Enter value	Calc value	Xu & Eckstein	m
Longitudinal dispersivity	**ax**	0.00E+00	2.00E+01	6.21E+00	m
Transverse dispersivity	**az**	0.00E+00	2.00E+00	6.21E-01	m
Vertical dispersivity	**ay**	0.00E+00	2.00E-01	6.21E-02	

Note values of dispersivity must be > 0

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

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



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

Note

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

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

The measured groundwater concentration should be compared
with the Level 3 remedial target to determine the need for further action.
Note if contaminant is not subject to first order degradation, then set half life as 9.0E+99.

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

Site being assessed:	Cartron Big
Completed by:	EOC
Date:	########
Version:	1.01

Calculated concentrations for distance-concentration graph

Ogata Banks
From calculation sheet

Distance	Concentration
	mg/l
0	2.4E+00
10.0	2.05E+00
20.0	1.49E+00
30.0	1.01E+00
40.0	6.40E-01
50.0	3.73E-01
60.0	1.99E-01
70.0	9.68E-02
80.0	4.26E-02
90.0	1.69E-02
100.0	6.01E-03
110.0	1.92E-03
120.0	5.50E-04
130.0	1.41E-04
140.0	3.23E-05
150.0	3.72E-06
160.0	6.74E-07
170.0	1.09E-07
180.0	1.57E-08
190.0	0.00E+00
200.0	0.00E+00