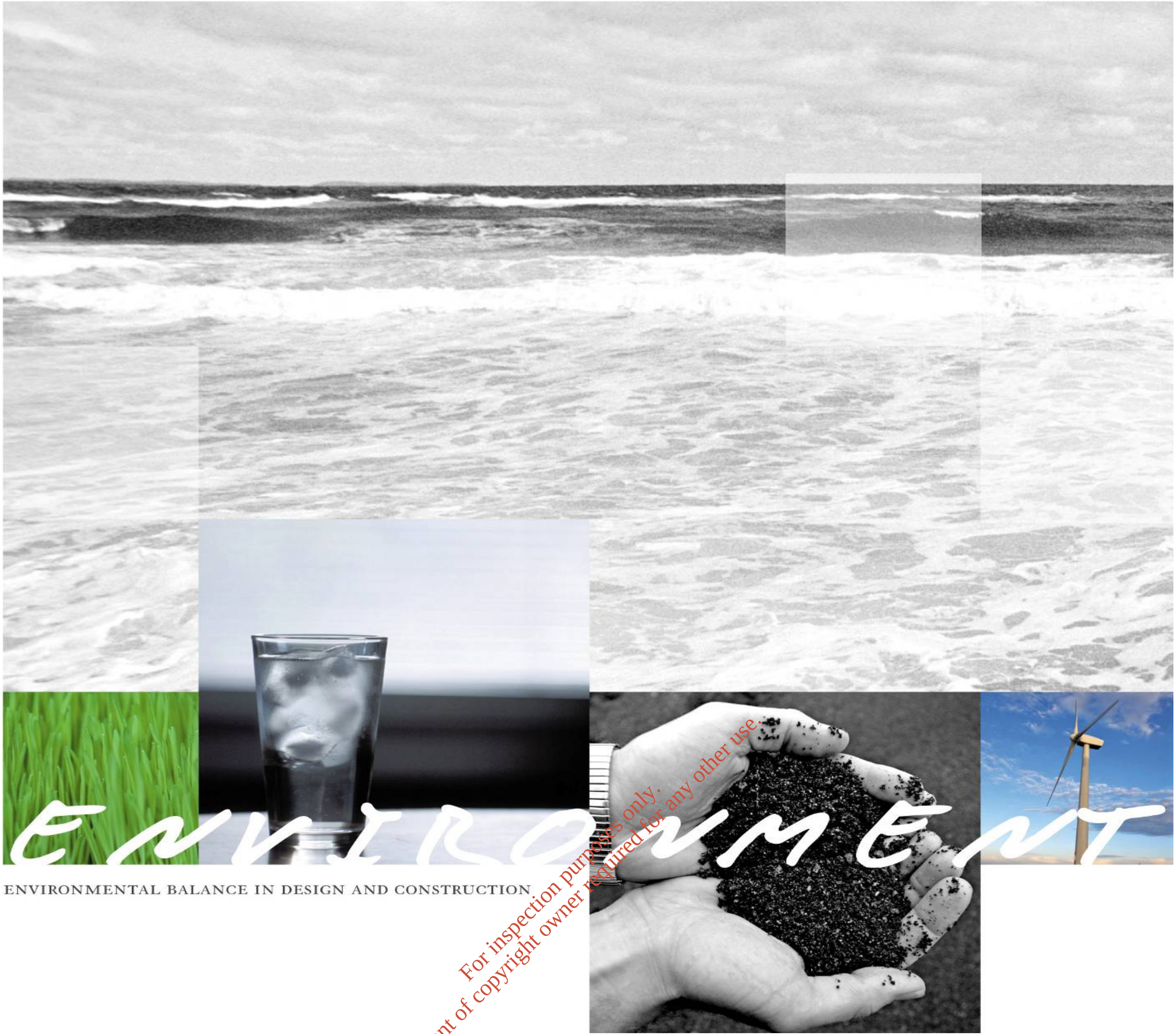

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TIER 3 RISK ASSESSMENT

BALLYMULVEY HISTORIC LANDFILL SITE, CO. LONGFORD

March 2020

AN LONGFORT CONNECTED
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30 YEARS

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TIER 3 RISK ASSESSMENT

BALLYMULVEY HISTORIC LANDFILL, CO. LONGFORD

User is Responsible for Checking the Revision Status of this Document

Rev. Nr.	Description of Changes	Prepared by:	Checked by:	Approved by:	Date:
0	Issue for Client Comment	EOC/CF/MG	JON	BG	14.06.2019
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Client: Longford County Council

Keywords: Site Investigation, environmental risk assessment, waste, leachate, soil samples

Abstract: This report represents the findings of a Tier 3 risk assessment carried out on Ballymulvey 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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EPA Export 06-10-2021:02:44:31

TABLE OF CONTENTS

Page

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LIST OF APPENDICES

EPA Export 06-10-2021:02:44:31

LIST OF TABLES

Page

LIST OF FIGURES

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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 Ballymulvey 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 in Ballymulvey, approximately 1.5km north-east of Ballymahon, Co. Longford and situated 250m from the junction with the N55 road to the north-west, Toome Cross Roads. It is understood that the site began operation as a landfill sometime in the mid-1960s and ceased sometime in the mid-1990s, following a High Court Order. Despite the lack of written records, it is understood that the site accepted municipal waste/domestic refuse, but no chemical/hazardous waste; although, asbestos containing material (ACM) was accepted and deposited in a discrete area of the landfill.

A Tier 1 study was conducted by AECOM and determined the site to be a high-risk classification (Class A). The primary risks identified relate to the risk of leachate runoff entering surface water and the risk of leachate migration to groundwater.

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

The results of the Tier 2 assessment and risk model indicate that the site is being maintained as 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 risk posed to the unnamed tributary stream of the River Inny from the migration of landfill leachate from the site.

The purpose of this Tier 3 assessment is to further examine and quantify those risks/impacts through quantitative risk modelling allowing for prediction of both the current and future impact on groundwater quality and the current and future extent landfill gas generation on site. This information will be used to inform the appropriate remedial and mitigation measures required to either eliminate or reduce environmental risks.

Results obtained from the LandSim model confirmed a potential risk to groundwater and potential migration of pollutants further downgradient of the site. As the site is currently capped and has undergone previous remediation works, LandSim was used to demonstrate the impact the installation landfill cap over the portion of the site currently underlain with waste material on the generation of leachate and the dispersion of pollutants within the aquifer.

The Tier 3 assessment concludes, that additional site remediation works are not required to further reduce the impact the site may have on underlying groundwater and beyond the site. The Tier 3 assessment concludes that groundwater impacts are relatively minor and likely to remain localised to the site. It is considered based on the ground conditions and remediation works undertaken to date that no major works are required. Additional groundwater monitoring wells are recommended both upgradient and downgradient of the site. These will be installed and monitored to further investigate groundwater conditions.

It is recommended that the surrounding boundary drains be cleared and maintained. Continued surface water monitoring immediately downstream of the site is recommended. Evidence suggests that leachate from the site is not a significant contributor to the elevated sulphate concentration observed at surface water monitoring location in 2018. Sulphate concentrations in the leachate in 2018 were significantly below the level in the surface water.

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1 TIER 3 QUANTITATIVE RISK ASSESSMENT

1.1 Background

Following the completion of a Tier 2 risk assessment and site investigation at former landfill at Ballymulvey, 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 and characterisation of the site and facilitated the production of a revised Conceptual Site Model (CSM).

As per EPA CoP for Environmental Risk Assessment for Unregulated Waste Disposal Sites, a Tier 3 assessment includes a 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. Having identified elevated concentrations of ammonia present in a groundwater downstream of the site as part of the Tier 2 site investigation it was determined that the generation and subsequent leaching of ammonia generated from the waste present may pose a risk to downstream receptors. Sulphates have historically been shown to be elevated at surface water monitoring locations on land drains in the immediate vicinity of the site. Concentrations have been shown to reduce on monitoring locations further downstream of the site.

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 required, if any,, which is a vital aspect of the Tier 3 assessment.

1.2 LandSim

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

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

1.3 Model Setup - LandSim

LandSim setup involves several different stages; these are described below. For many of the parameters and characteristics entered into 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.

1.3.1 Domain Area

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

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

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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. Although there are two defined waste disposal areas 'bunds' as shown on site drawings to simplify the model the source/waste footprint area was defined as a single 'phase'. Additionally, there is no historical evidence with respect the rate

Figure 1.1 shows the screen shot of the domain area for the Ballymulvey 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.

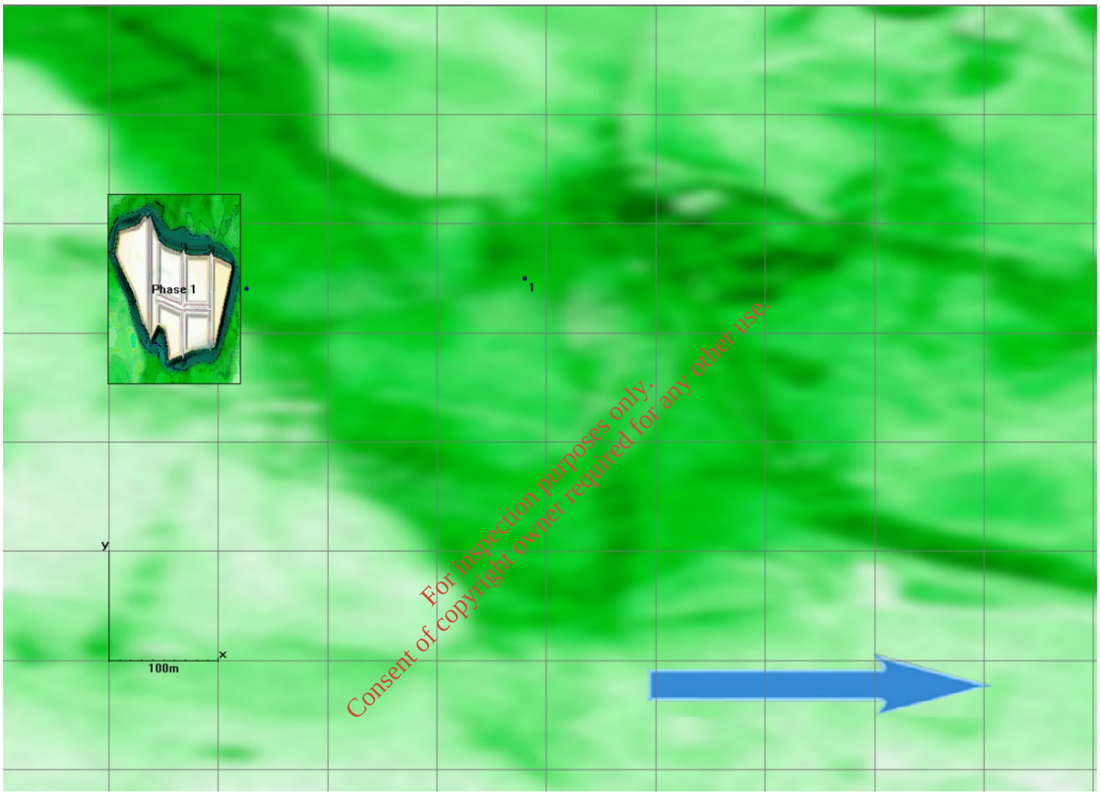

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Figure 1-1: Domain Layout in LandSim

Aquifer Properties

Within the domain area, the aquifer properties (which will in general be common to all phases) are also 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.

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.

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Site investigation did not confirm the thickness of the limestone bedrock aquifer however based on the depth of waste and available literature on the regional characteristics of the aquifer provided by GSI an aquifer thickness of between 8m and 12m, given 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 0.0091. This corresponds with observations and topographical surveying of the site. Site specific permeability data for the underlying limestone bedrock and aquifer was not available therefore it was necessary to assume a range of hydraulic conductivity values for the model.

The LandSim manual provides min/max hydraulic conductivity values for 'Limestone, dolomite' of $1x10^{-9}$ to $6x10^{-6}$ m/s.

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

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1.3.2 Phase Details

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

Each input must be defined at the time of entry. Appendix I 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 single and uniform distributions accordingly. GSI maps provide an effective rainfall rate of 541 mm/year for the area. This rate was applied to the open waste infiltration rate.

A reduced cap design infiltration rates of 5 - 20% of the effective rainfall rate was assumed in the model. The two waste mounds on site are currently capped with layers of topsoil, fly ash and sand with an approximate thickness of 1.6m.

In situ permeability testing yielded permeability rates of $3.98x10^{-6}$ to $1.3x10^{-5}$ m/s for the existing cap layer onsite which would have an impact on reducing infiltration of rainwater to the waste promoting run-off and evapotranspiration therefore limiting leachate generation rate.

The Tier 1 and Tier 2 assessments concluded that landfilling of waste took place from the 1960s to the mid-1990s.

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

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Cell Geometry

Based on review of site drawings included as part of the Tier 2 assessment and available evidence it has been assumed that the single phase comprises two cells of approximate equal size. This reflects the two main waste 'bunds' as shown on site drawings previously prepared by Malachi Cullen & Partners.

There are no boreholes or borehole logs available that describe the extent of the waste and the geology immediately underlying it. The final waste thickness applied to the model was estimated upon review of the Tier 2 assessment, conceptual site models developed, previously prepared site drawings and site sections provided with the Tier 1 assessment report. A uniform distribution, *Uniform (3,6)* metre thickness was applied in the model to reflect the variation in waste thickness likely to be present.

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 completed as part of the Tier II assessment coupled with the use of default values provided in LandSim.

Two leachate wells BH5 and BH6 were previously installed onsite and leachate sampling and monitoring has been conducted at the site with analysis results available from 2002 to 2014. Additional samples were taken as part of the Tier 2 site investigation conducted in 2018. Leachate analysis results were within the expected range of values and composition as provided in the 2003 EPA Landfill Manual.

Leachate indicator parameters were assessed against the European Union Environmental Objectives (Groundwater) (Amendment) Regulations 2016 (S.I. no. 366 of 2016) and the EPA's Interim Guideline Values (IGVs). It was predominantly municipal waste accepted onsite with some asbestos containing C&D waste and it is believed that filling operations took place between the 1960s and continued to the early/mid 1990s.

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Although it is generally considered that municipal waste generated during this period would be relatively low in food waste and organic material, the potential still exists for biodegradable, organic wastes to be present and this type of waste. The decomposition of this waste material can generate a leachate high in organic material and organic/biological breakdown products such as ammonia.

A review of groundwater and surface water monitoring and the outcome of the Tier 2 assessment was conducted to identify those contaminants or elements of concern to be considered in the model. Sampling and analysis of groundwater from onsite wells showed elevated concentrations above EPA IGV thresholds and threshold values as outlined in the 2016 Groundwater Regulations (S.I. No. 366 of 2016) for ammoniacal nitrogen, Arsenic and Phosphorous. It is noted that concentrations were elevated above threshold values in both the upgradient and downgradient wells and that historically upgradient wells (BH1 & BH2) have exceeded downgradient well BH3 for some parameters. Elevated concentrations in wells BH1, BH2, GW01 and GW02 may be due to their relative proximity to the waste material or underlying peat may also be a natural source of ammonia.

The Tier 1 assessment of the site concluded that there was an apparent trend in decreasing concentrations in surface water features and sampling locations for select parameters the greater the distance from the site. This highlighted the potential pathway from the site to the to surface water receptors offsite via either groundwater/leachate or land drains located within the site. Water quality within the drainage located within and in the immediate vicinity has generally been shown to be of poor quality.

The following parameters were considered in the development of models applied in this assessment:

- Ammoniacal Nitrogen as N,
- Arsenic,
- Sulphate

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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 model for those relevant pollutants above. Of the selected parameters included in the model a reasonable quantity of leachate monitoring data was only available for ammonia, with BH5 and BH6 monitoring data dating from 2002 to 2014. Statistical analysis of the 2002 – 2014 and 2018 (Tier 2 assessment) data yielded the following results.

Table 1-1: Leachate Monitoring (2002 – 2018) Statistical Analysis

Ammonia	mg/l
Minimum	10.6
Maximum	3500
Mean	663.52
Standard Deviation	785.56
95%-ile	2080.75
50%-ile	333
99%-ile	3198.73
Geometric mean	311

Table 1-2: Groundwater Analysis Results for Sulphate (upgradient)

	26th Sept 2018		8th Oct 2018	
	GW01	GW02	GW01	GW02
Sulphate (mg/l)	27.1	23.1	6.83	10.1
Arsenic (mg/l)	0.00226	0.0184	0.00472	0.0523

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As stated previously leachate composition was found to be within expected ranges for each parameter when compared to values provided in the EPA Landfill Manual. It is noted that leachate composition will change over time and that leachate monitoring results obtained after filling had ceased may not be truly reflective of leachate composition originally.

Selected leachate and background concentrations are presented in Table 1-3 below. 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).

Table 1-3: Selected leachate and background concentrations

Parameter	Background levels (mg/l)	Concentration in Leachate [1] (mg/l)
Ammonia	Triangular (0.27,9.8,168)	Log Triangular (4.37,723,3640)
Sulphate	Uniform (6.83,27)	Log Triangular (1,100,800)
Arsenic	Uniform (0.0026,0.0523)	Log triangular (0.000673,0.00484,1.31)

† A 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 as per LandSim UK Default Leachate Inventory values

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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. The leachate head is specified as being the maximum possible level of leachate from the base of the landfill to the lowest surface ground level whereby surface breakout could occur. Review of the site section drawings and CSM provided as estimated leachate head of between 2.5 to 5m.

Engineered Barrier

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

1.3.3 Geosphere Details

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

The geosphere consists of three pathways - the unsaturated zone, the vertical pathway and the aquifer pathway, as shown in Figure 1.2 below. Each of these geosphere pathways is assumed homogeneous and isotropic.

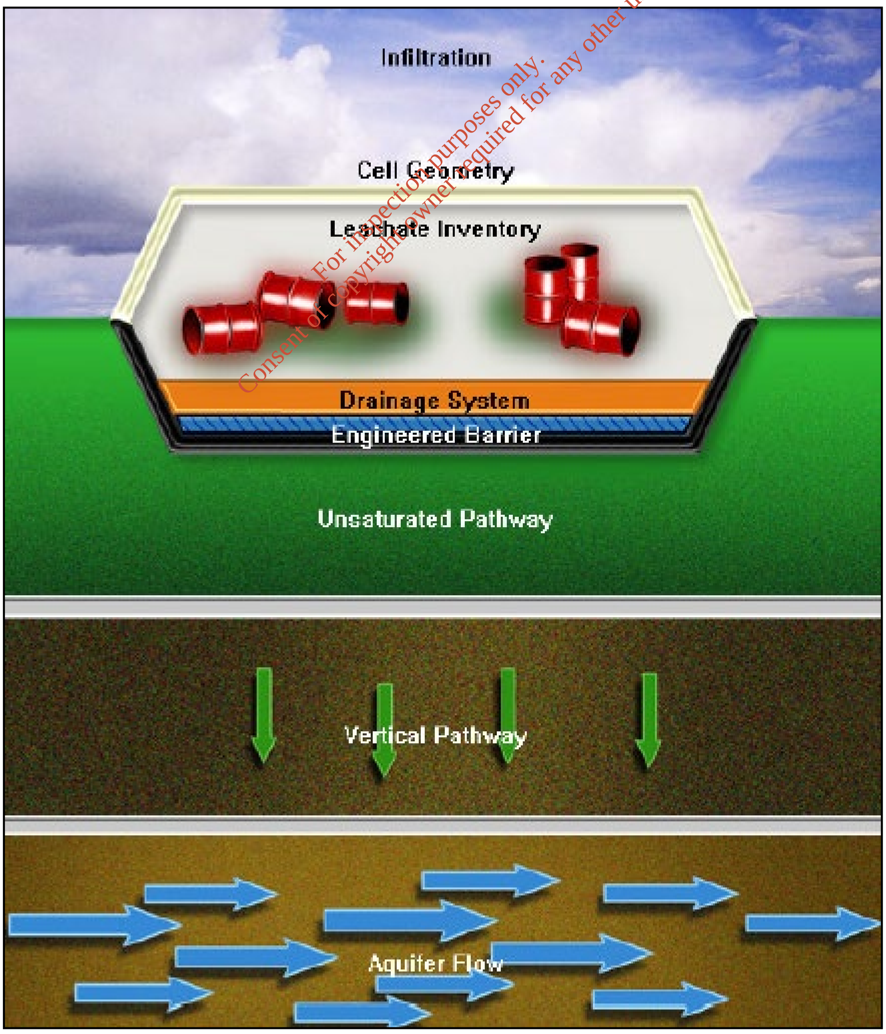

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Figure 1-2: Geosphere Schematic

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Unsaturated Pathway

Review of the Tier 2 site investigation information, CSM and site drawings yielded and estimated unsaturated pathway of between 0.5 to 1.5m. It is assumed that the waste material is underlain by a relatively shallow layer of either peat or glacial till before the groundwater table is encountered.

Vertical Pathway

Review of site investigation information particularly groundwater levels and borehole loads led to the assumption that prior to encountering limestone bedrock the site was underlain by a saturated layer of peat or glacial till across the site. The sections of the site underlain by a layer of peat or glacial till as indicated on the CSM.

A triangular distribution *Triangular (*3.5, 5.75,8.5) was applied.

Aquifer

The aquifer details were input as described above.

1.3.4 Model Scenarios

As mentioned above LandSim was utilised to aid in the determination of whether any engineering works or such remedial measures were required to mitigate the identified risks from the landfill and what measures may be appropriate.

The LandSim model was developed to, where possible reflect the current site conditions.

A list of model inputs generated by LandSim are presented in Appendix I of this report.

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1.4 Results - LandSim

1.4.1 Leachate Concentration

A full calculation run of 1,001 iterations was carried out on the model to examine the relative changes in model outputs or potential impacts between each model scenario. 1,001 iterations were selected in the model as this yields the full range of available percentiles.

Table 1-4: Source concentration at Year 0, 55 and 100

Parameter	Year	5%ile	50%ile	95%ile
Ammoniacal Nitrogen (mg/l)	0	176.65	461.64	905.87
	55	31.68	95.69	243.76
	100	22.81	74.284	194.11
	300	3.654	22.34	94.97
Arsenic (mg/l)	0	0.011	0.048	0.160
	55	0.010	0.039	0.117
	100	0.010	0.038	0.109
	300	0.01	0.031	0.087
Sulphate (mg/l)	0	36.15	88.90	177.18
	55	15.50	39.76	80.93
	100	13.41	34.02	70.74
	300	5.89	17.51	44.9

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Table 1.5 presents species concentration values below which concentrations will remain for respective %-iles i.e. time intervals (5%, 50% and 95%).

For example, in Ammoniacal Nitrogen will remain below

- 905.87mg/l for 95% of the time i.e worst-case scenario
- 461.64mg/l for 50% of the time i.e. most likely scenario
- 176.65 mg/l for 5% of the time i.e. best-case scenario

1.4.2 Leachate Generation

The rate of leachate generation under the current condition model scenario was examined. The rate of leachate generation is directly dependent on the rainfall infiltration rate to the waste material. The installation of a landfill cap is reflected in the model through the application of a reduced infiltration rate.

Table 1-5: Leachate Generation Rates

Site Scenario	Time slice (years)	95%-ile (l/day)	50%-ile (l/day)	5%-ile (l/day)
Current	15	31846	31856	1200
	55	6043	3544	1200
	100	6043	3544	1200

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At 15 years the site is still operational and waste material is 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 30 years. During this 30-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.81% reduction in leachate generation rate (95%-ile) at the 55-year point as shown in Table 1.6 above.

1.4.3 Downstream Concentrations

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

As stated previously in the report it was estimated that the site accepted waste material from the 1960s to the mid-1990s, as such a 30-year filling period was specified in the model. Time slices of 15, 55, and 100 years were selected in the model with the 55-year point approximately representing the present time.

A summary of concentration results at the monitor well location for each of the selected parameters is provided in Table 1.6 below. It is noted that groundwater wells BH3 & GW03 are not located directly downstream of the waste footprint area, groundwater flow path and would be located further from the waste/source than the monitoring well generated by LandSim. It should be noted that monitor well concentrations predicted by LandSim are not regarded as being reflective but are only being indicative of current and future concentrations that may be observed on site.

It is noted that for both sulphate and arsenic, downstream monitoring data is limited with two monitoring rounds for each parameter at wells BH3/GW03 completed in 2018 as part of the Tier 2 assessment.

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Table 1-6: Monitor Well Concentrations

Parameter	Time slice	95%-ile (mg/l)	50%-ile (mg/l)	BH3/GW03 Monitoring Results (mg/l)	Groundwater Threshold Value² (mg/l)
Ammoniacal N[1]	15	132.491	52.842	Min: 0.38 Max: 60 Average: 14.51	0.065 – 0.175
	55	211.619	72.0309		
	100	1374.39	199.301		
	300	1602.35	358.548		
Arsenic	15	0.049	0.028	0.02 *(26/9/2018)* 0.0134 *(8/10/2018)*	0.0075
	55	0.049	0.028		
	100	0.049	0.028		
	300	0.049	0.028		
Sulphate	15	97.67	27.43	9 (29/5/2002) <3 (11/9/2002) 22.6 *(26/9/2018)* 3.9 *(8/10/2018)*	187.5
	55	126.98	65.05		
	100	866.22	140.49		
	300	87.86	43.63		

Note 1: Ammoniacal nitrogen/ammonia monitoring values shown are derived from historical monitoring (2002-2014) and two rounds of monitoring completed in 2018

Note 2: Groundwater quality threshold values as per *European Union Environmental Objectives (Groundwater) (Amendment) Regulations 2016, S.I. No. 366 of 2016*

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1.4.4 Discussion of Results

Source Concentrations

Source concentrations generated by LandSim were compared against leachate monitoring results obtained as part of the Tier 2 assessment and site investigation as a means of checking the model. Except for sulphates, source concentrations generated by LandSim at the 55-year point (assumed to be present day) generally correspond with those observed in groundwater samples obtained in 2018 as part of the Tier 2 assessment site investigation.

LandSim source sulphate concentrations were shown to be significantly above those observed in leachate samples analysed in 2018, sulphate concentrations in samples obtained on the 9th of October, 26th of September 2019 being reported as <1mg/l and <2 mg/l respectively. Historical monitoring data for leachate sulphate concentrations is highly limited, with only four results available for BH5 and BH6 from the 29th May and 11 September 2002. Only one result for groundwater at well BH6, in 2002 was shown to be significantly above the groundwater threshold value for sulphates.

Table 1-7: Groundwater/Leachate Sulphates Monitoring Results

	Sulphates (mg//l)		Groundwater Threshold Value² (mg/l)
	BH5	*BH6*	
29/5/2002	76	**424**	187.5
11/9/2002	<3	75	
26/9/2018	<2	<2	
8/10/2018	<1	<1	

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Leachate monitoring suggests that leachate may not be a significant contributor to elevated sulphate concentrations at nearby surface water features in the future. Both the LandSim predicted monitor well concentrations and the actual groundwater monitoring well results remain below the groundwater threshold value and below the concentrations detected in surface water monitoring conducted in 2018.

Perimeter Well Concentrations

The results obtained from the LandSim model show that there is potential for there to be a potential ongoing risk to groundwater quality downstream of the site. As stated the LandSim model was modified to attempt to reflect those observed concentrations at BH3/GW03 downstream of the waste footprint area. The 95%-ile values represent a worst-case result while 50%-ile are regarded as being more representative of expected values. LandSim produced 50%-ile concentrations at the waste perimeter within an order of magnitude of average concentrations observed in downstream groundwater monitoring rounds. It is noted that BH3 and GW03 are located slightly further downstream from the waste footprint area and so it would be expected to vary from that which may be observed directly at the perimeter of the waste body.

As shown in Table 1.6 above concentrations at the perimeter monitor well are shown to increase from 15 years to 55 years. This increasing concentration at the perimeter of the site may be illustrating the relatively slow movement of a leachate plume which exists under the site. Ammoniacal nitrogen is predicted to consistently remain above the groundwater threshold value. Monitor well concentrations of arsenic are shown to be consistent at each of the modelled time slices. It is likely that this may be due to the relatively high background concentrations applied in the model. As shown in Table 1.3 the background concentrations applied for arsenic are relatively high ranging from slightly below the groundwater threshold value and an order of magnitude above that threshold. As discussed previously, background concentrations were based on review of monitoring results for upgradient groundwater monitoring wells. The proximity of these wells to the waste body may mean that the groundwater quality may be influenced by the presence of leachate, giving rise to elevated concentrations of arsenic in groundwater.

To further assess the potential impact of the dispersion of ammoniacal nitrogen on groundwater quality downstream of the site another model was applied in this Tier 3 assessment. The use and outcome of this model is discussed in further detail in Section 1.5 below.

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1.5 EA UK Remedial Targets Worksheet

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

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

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The LandSim modelled well concentrations at 55 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 1.3.

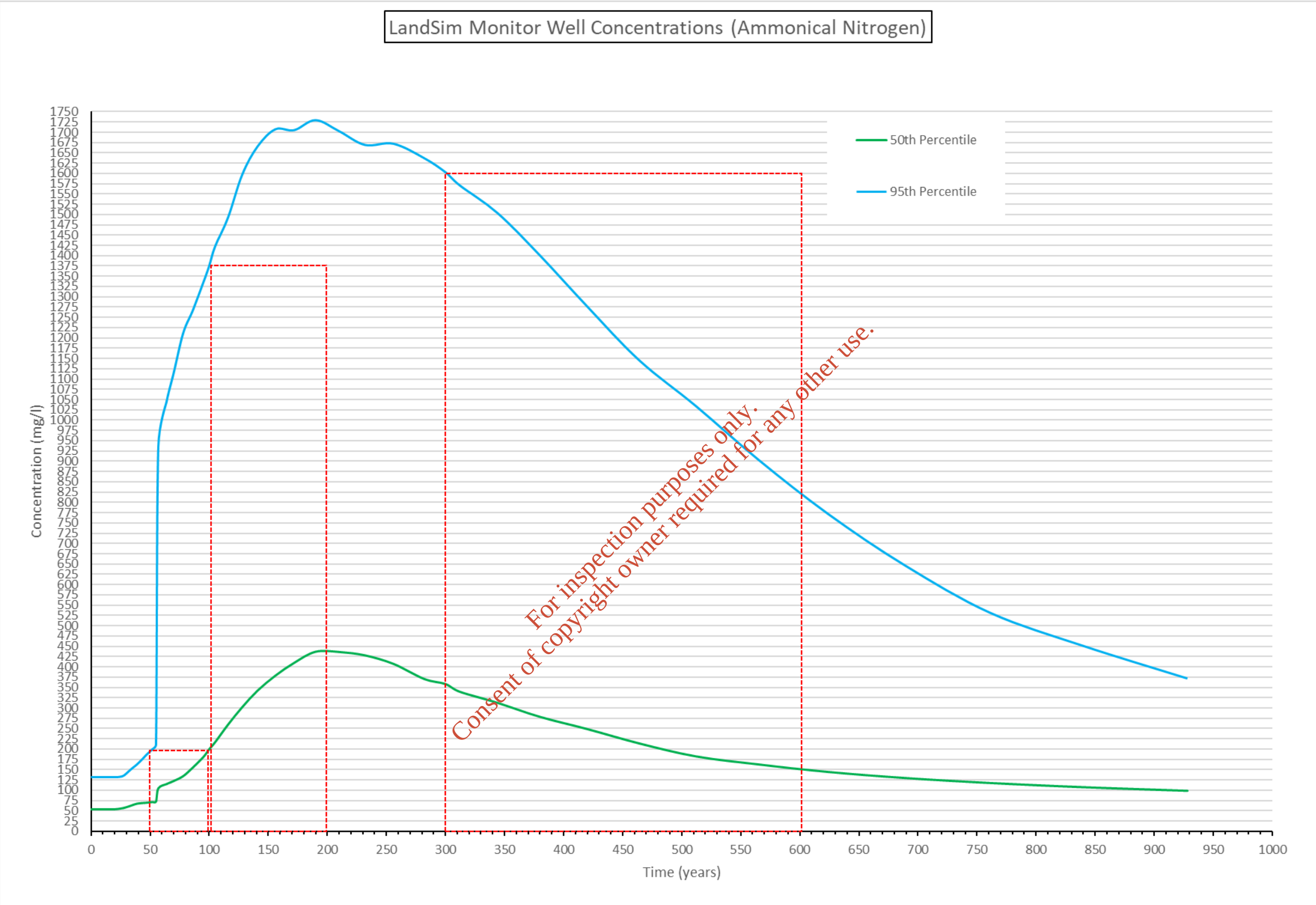

Figure 1-3: Monitor Well Concentrations (Ammoniacal Nitrogen) with Modelled Time Steps (red)

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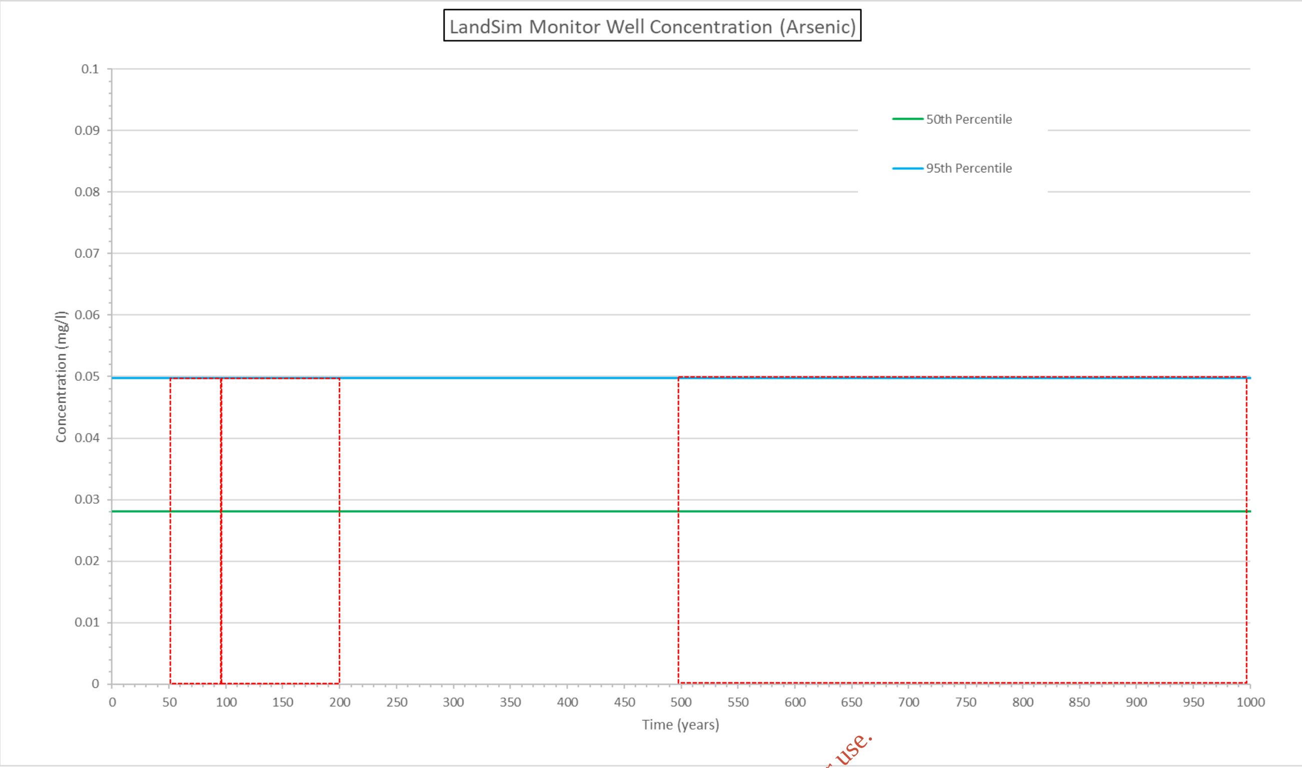

Figure 1-4: Monitor Well Concentrations (Arsenic) with Modelled Time Steps (red)

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Table 1-8: 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)***
55	211.6	**7.29**	0	0	0
100	1374.4	**137.45**	0	0	0
300	1602.35	**459.76**	0.066	0	0
Arsenic (mg/l)			***Groundwater threshold Value (GTV) = 0.0075 mg/l***		
Years of Dispersion	**Initial Plume Concentration (LandSim) (mg/l)**	***Conc.at 10m (mg/l)***	***Conc. at 50m (mg/l)***	***Conc. at 100m (mg/l)***	***Conc. at 200m (mg/l)***
55	0.049	**0.007**	0	0	0
100	0.049	**0.012**	$1.49x10^{-07}$	0	0
300	0.049	**0.02**	0.0004	$8.45x10^{-09}$	0

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1.5.1 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, 300) 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.

As with ammoniacal nitrogen the modelling of arsenic dispersion using the UK EA model also indicates that the dispersion of arsenic from the site and subsequent impact on groundwater quality is a local issue. Exceedances of the groundwater threshold value are only observed at the 10m distance point. The dispersion of arsenic from the is not likely to have a significant impact on any sensitive receptors downstream of 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 effect 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.

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1.6 ACM Management

1.6.1 Source

As stated in the Tier 2 report that a quantity of asbestos containing material (ACM) was deposited in a discrete area of the landfill. It is understood that this material originated from Lanesborough Power Station located c.20km north-west of the site and that this material was deposited between the 22nd and 27th of July 1987. The location of this material labelled 'Area of Special Precautions' is shown in Figure 1.3 below.

Recorded evidence suggests that the location of the ACM materials is highly accurate as it was defined in contemporaneous notes taken by LCC personnel involved in the deposition process with sketches and measurements from known boundary points.

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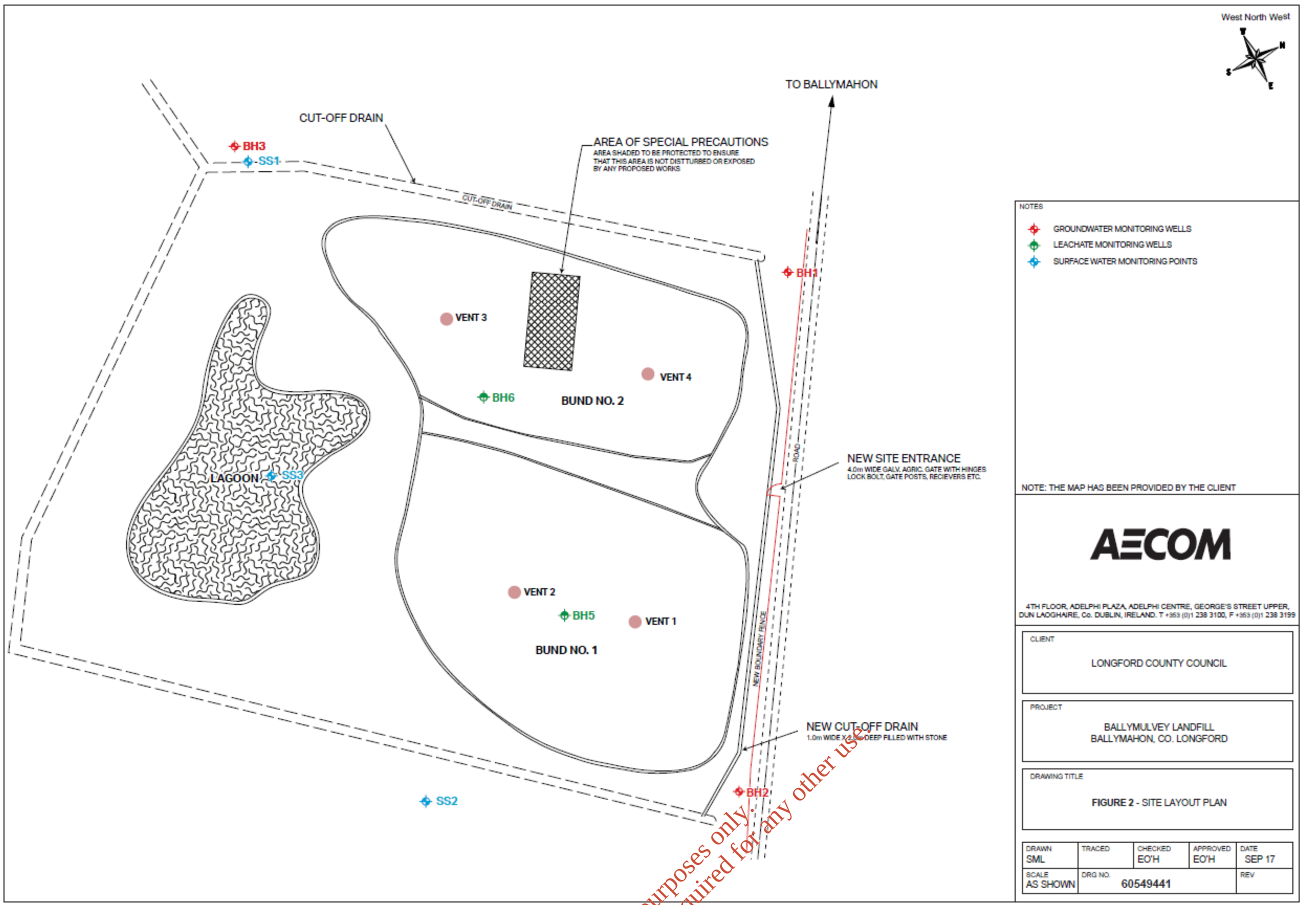

Figure 1-5: Extracted Tier 1 Site Layout Plan

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1.6.2 Disposal

The ACM was double bagged and marked with warnings indicating the presence of asbestos. The ACM was deposited within an excavated area measuring c.19m in length and 4m in width. Evidence suggests that c.1.8m thickness of double bagged ACM was buried (c.137m^3 on site). This waste is covered with 0.6 to 1.0 m of sand with an additional 1.2m of waste. The final cover above the ACM including capping material is estimated to be between 3 to 3.7m in thickness.

1.6.3 ACM General Risks

As part of this Tier 3 assessment an examination as to the potential risks associated with the presence of ACM on site was conducted. In reviewing this aspect of the site remediation and management reference is made to the EPAs Technical Guidance on '*The Landfilling of Asbestos Waste'* issued in December 2006 and the HSA '*Asbestos-containing Materials (ACMs) in Workplaces – Practical Guidelines on ACM Management and Abatement'*

It is not known specifically what type of asbestos is present or in what form and the relative quantity of asbestos contained within the materials deposited. There are three main types of asbestos commonly encountered, chrysolite (white asbestos), amosite (brown asbestos) and crocidolite (blue asbestos). Asbestos is a naturally occurring mineral but has historically been extracted for various applications particularly in construction and industry. This is due to its desirable combination of characteristics. It is quite resistant to abrasion, inert to acid and alkaline solutions and remains stable at high temperatures. Although it is not known exactly what form the ACM waste takes, asbestos is most commonly encountered bound in materials such as thermal lagging, sprayed insulation, insulation panels and cement bonded asbestos for roofing and gutters, all of which can contain variable proportions of asbestos mineral.

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As stated above asbestos is most commonly encountered bound as a component to a specific solid material and asbestos fibres are not freely dispersed unless disturbed. Asbestos in itself is not considered to pose a risk to the environment e.g. to groundwater or surface water quality. Asbestos fibres themselves are not volatile and do not dissolve or breakdown in water or the environment to form other environmentally harmful chemicals or materials.

Asbestos is a Category 1 carcinogen and can cause a range of different diseases e.g. asbestosis, asbestos related lung cancer and mesothelioma. The risk of an individual developing an asbestos related disease following exposure depends on several factors; asbestos type, age of first exposure, quantity of fibres inhaled and duration/frequency of exposure and if the person exposed smokes.

Risk of exposure and impacts asbestos exposure are usually examined and considered an occupational environment e.g. on a construction or demolition site. The primary risks associated with asbestos is its potential impact on human health, specifically to those who may encounter it, particularly with airborne fibres which can be inhaled. As such, where asbestos or ACM could be regarded to impact on the environment is with respect to air quality, but only in so far that air provides a pathway and exposure route to humans and in terms of its potential risk on human health.

Asbestos, if undisturbed should not pose an environmental risk.

1.6.4 ACM – Site Specific Risk Assessment

With respect to the Ballymulvey site it is considered that, considering the manner in which the ACM has been contained and disposed of on site, the current conditions the type and level of activity on the site the presence of asbestos within the site does not pose a significant environmental risk. Anecdotal evidence indicates that the ACM is contained in bags and was not loosely deposited within the site. This significantly limits the potential risk of release and subsequent transport of any asbestos fibres via groundwater. Additionally, asbestos by its physical nature is not mobile in soil. Should the bags in which the ACM is contained break down or are damaged any possible dispersion would be highly localised, and transport to any downstream sensitive receptors is not likely.

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The primary risks associated with asbestos are exposure of people to free asbestos fibres released to air and subsequently inhaling fibres. Attempting to excavate, disturb and remove the material in its current state would pose an unnecessary risk, particularly to those carrying out the removal. Although it would be assured that fully, and appropriately qualified contractors would be conducting the remediation works and that all necessary precautions would be applied to prevent exposure of individuals to asbestos fibres or for asbestos to be disturbed such that asbestos is not dispersed beyond the site it introduces an unnecessary risk associated with the site.

There is little to no human activity on site therefore the risk of any adverse impact associated with the asbestos material is highly unlikely both in terms of potential exposure and disturbance of the site.

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2 CONCLUSION AND RECCOMENDATIONS

The aim of this Tier 3 assessment was to examine (quantitatively) the potential impact the former landfill site and waste contained within could have on those primary identified risks associated with the site i.e. leachate generation and ground water quality.

Two 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 and to compare the magnitude of the impact where potential remediation measures are applied.

The installation of a lower permeability cap and reduced infiltration rate to the landfill yielded a significant 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. The use of the UK EA Remedial Targets Worksheet model demonstrated that the dispersion of ammonia and arsenic, being the primary contaminants of concern, from the site is likely to only impact on groundwater at a local level and therefore not present a significant risk to downstream receptors.

Regarding the presence of buried ACM onsite it is considered that given the current conditions of the site, the method by which the material was disposed and the level of activity on the site the ACM poses little to no environmental risk, therefore no further action is recommended.

Recommended landfill and site management measures are outlined Section 3 below.

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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 surface water. Landfill gas generation was not considered to be a significant issue with the site, based on the outcome of recent landfill gas monitoring and the characteristics of the site with respect to potential receptors.

3.1 S-P-R Linkages

The Tier 2 assessment identified the principal risks associated with the site are the migration of leachate from the site to the groundwater aquifer and the risk posed to the unnamed tributary stream of the River Inny from the migration of landfill leachate from waste material encountered on site.

3.1.1 Leachate Migration through surface water pathway

Most recent surface water monitoring conducted in 2018 suggested that elevated concentrations of sulphates are present in the nearby land drains downstream of the site, however based on recent leachate monitoring results, leachate may not be the source of the elevated concentration observed and it is not likely to be a cause of elevated concentrations at this location in the future.

Surface water Monitoring

It is recommended that quarterly monitoring at all surface water monitoring locations upstream and downstream of the site be conducted where feasible. It is noted, based on monitoring conducted in September and October 2018 that it was not possible to obtain samples at a number of monitoring locations. Safe and suitable access to monitoring locations should be established and maintained at the site where possible.

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3.1.2 Leachate migration to groundwater aquifer

The additional assessment as discussed in this report outlined that any impact on the underlying groundwater aquifer is most likely to be occurring within the general locality of the site and would not be expected to cause any adverse impact to any sensitive receptors further downstream of the site, e.g. the River Inny. The site has previously undergone remediation works with the installation of a landfill cap comprising approximately 0.2m of topsoil, 0.9m of fly ash and 0.5m of sand significantly limiting the rate of leachate generation and subsequent plume propagation and dispersion downstream of the site.

Additional Monitoring

Based on the outcome of the most recent groundwater monitoring in 2018 which determined that groundwater analysed both upgradient and downgradient of the site contained elevated concentrations of ammonia, it is recommended the additional groundwater monitoring wells/locations be established.

The following locations are recommended:

GW04 – Upgradient of the site c. 25-50m upgradient of the waste body
GW05 – Downgradient of the site c.25-50m downgradient of the waste body
GW06 – Downgradient of the site c.75-100m downgradient of the waste body

GW04 is recommended as a new monitoring location to establish an upgradient groundwater baseline remote from the waste body

GW05 & 06 are proposed as new monitoring locations to confirm affects remain localised to the site

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To facilitate routine monitoring as proposed it must be ensured that safe and suitable access to each monitoring location is established and maintained for the duration that monitoring is ongoing.

Site Maintenance

It is recommended that the general condition of the site be improved and continually maintained i.e.

- clearance of excessive vegetation growth within boundary ditches by mowing or grazing is suitable.
- dredging/maintenance of all existing drainage channels.
- marking (by appropriate signage) and protection of existing open monitoring points.
- provision of safe access paths/sties to existing and proposed environmental monitoring locations
- general improvements to existing fencing and access

3.2 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 works.

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

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Item	Quantity	Unit	Rate, €	Cost	Note
-	-	-	-		
Site Investigation Location	-	-	-		
-	-	-	-		
Allowance for Additional Site Investigation Location	3	Sum	€3,000.00	€9,000.00	Allowance
-	-	-	-		
General Site Clearance and Demolition Works	***2.36***	***ha***	-		
-	-	-	-		
General Site Clearance including drainage works	2.36	ha	€7,500.00	€17,700.00	Allowance for Clearance of Existing Site and drainage ditched
Site Upgrade Works					
-					
Fencing and Access	1	Sum	€5,000.00	€5,000.00	Allowance
Signage and Upgrade Works	1	Sum	€2,500.00	€2,500.00	Allowance
-					
Sub-Total 1				**€34,200.00**	
Add 10% Contractor Prelims	10.0%			€3,420.00	

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Item	Quantity	Unit	Rate, €	Cost	Note
Sub-Total 2				**€37,620.00**	
Add 7.5% Contingency	7.5%			€2,821.50	
Grand Total (excl VAT)				**€40,441.50**	

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 **€40,441.50 (ex. VAT)** including the contingency as specified (7.5%).

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Appendix 1

LANDSIM MODEL INPUTS

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Calculation Settings

Number of iterations: 1001

Results calculated using sampled PDFs

Full Calculation

Clay Liner:

Retarded values used for simulation

Biodegradation

Unsaturated Pathway:

Retarded values used for simulation

Biodegradation

Saturated Vertical Pathway:

Retarded values used for simulation

Biodegradation

Aquifer Pathway:

Retarded values used for simulation

Biodegradation

Timeslices at: 15, 55, 100, 300

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Decline in Contaminant Concentration in Leachate

Ammoniacal_N Non-Volatile
c (kg/l): 0.59 m (kg/l): 0

Arsenic Non-Volatile
c (kg/l): -0.0862 m (kg/l): 0.0415

Sulphate Non-Volatile
c (kg/l): 0.1209 m (kg/l): 0.0166

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Contaminant Half-lives (years)

Unsaturated Pathway:

Ammoniacal_N	SINGLE(1e+009)
Arsenic	SINGLE(1e+009)
Sulphate	SINGLE(1e+009)

Saturated Vertical Pathway:

Ammoniacal_N	SINGLE(1e+009)
Arsenic	SINGLE(1e+009)
Sulphate	SINGLE(1e+009)

Aquifer Pathway:

Ammoniacal_N	SINGLE(1e+009)
Arsenic	SINGLE(1e+009)
Sulphate	SINGLE(1e+009)

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Background Concentrations of Contaminants

Justification for Contaminant Properties

Properties based on combination of LandSim provided data and site specific information.

All units in milligrams per litre

Ammoniacal_N	TRIANGULAR(0.27,9.8,168)
Arsenic	UNIFORM(0.0026,0.0523)
Sulphate	UNIFORM(6.83,27)

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Phase: Phase 1

Infiltration Information

Cap design infiltration (mm/year):	UNIFORM(28,108)
Infiltration to waste (mm/year):	SINGLE(541)
End of filling (years from start of waste deposit):	30

Justification for Specified Infiltration

Open Waste infiltration rate based on average annual rainfall at Athlone OPW met station from 1965 to 1995.
Cap design rate based on 5%,10% & 20% of average annual rainfall at Athlone OPW station from 1996 to 2017 (931 mm/yr) [CHANGED] [CHANGED] [CHANGED] [CHANGED]

Duration of management control (years from the start of waste disposal): 20000

Cell dimensions

Cell width (m):	87.5
Cell length (m):	122
Cell top area (ha):	1.07505
Cell base area (ha):	1.0675
Number of cells:	2
Total base area (ha):	2.135
Total top area (ha):	2.15011
Head of Leachate when surface water breakout occurs (m)	UNIFORM(2.5,5)
Waste porosity (fraction)	TRIANGULAR(0.42,0.54,0.62)
Final waste thickness (m):	UNIFORM(3,6)
Field capacity (fraction):	UNIFORM(0.2,0.4)
Waste dry density (kg/l)	UNIFORM(1.4,1.6)

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Justification for Landfill Geometry

Inferred based on site drawings

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Source concentrations of contaminants

All units in milligrams per litre

Declining source term

Ammoniacal_N	LOGTRIANGULAR(4.37,723,3640) *Data are spot measurements of Leachate Quality*
Arsenic	LOGTRIANGULAR(0.000673,0.00484,1.31) *Data are spot measurements of Leachate Quality*
Sulphate	LOGTRIANGULAR(1,100,800) *Data are spot measurements of Leachate Quality*

Justification for Species Concentration in Leachate

Based on LandSim UK Default Values and adjustment in order to match observed downstream concentrations.

Drainage Information

Fixed Head.

Head on EBS is given as (m): UNIFORM(2.5,5)

Justification for Specified Head

Assumed based on approximate minmum thickness from base of waste body to ground surface level.

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Barrier Information

There is no barrier

Justification for Engineered Barrier Type

No engineered barrier in place

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Combination of peat and glacial till across the site pathway parameters

Modelled as unsaturated pathway

Pathway length (m):	UNIFORM(0.5,1.5)
Flow Model:	porous medium
Pathway moisture content (fraction):	NORMAL(0.4,0.15)
Pathway Density (kg/l):	UNIFORM(0.8,1)

Justification for Unsat Zone Geometry

Inferred based on site investigation, CSM and sit drawings/sections

Pathway hydraulic conductivity values (m/s):	LOGUNIFORM(1e-010,1e-006)

Justification for Unsat Zone Hydraulics Properties

Assumed based on literature values for propeerties for peats and glacial tills

Pathway longitudinal dispersivity (m):	UNIFORM(0.05,0.15)

Justification for Unsat Zone Dispersion Properties

Estimated as 10% of pathway length

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Retardation parameters for Combination of peat and glacial till across the site pathway

Modelled as unsaturated pathway

Uncertainty in Kd (l/kg):

Ammoniacal_N	UNIFORM(0.5,2)
Arsenic	UNIFORM(25,250)
Sulphate	SINGLE(0)

Justification for Kd Values by Species

Assumed based on values provided in LandSim manual

Aquifer Pathway Dimensions for Phase

Pathway length (m):	UNIFORM(259,381)
Pathway width (m):	SINGLE(175)

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Peat pathway parameters

Modelled as vertical pathway.	
Pathway length (m):	TRIANGULAR(3,5.75,8.5)
Pathway porosity (fraction):	TRIANGULAR(0.2,0.6,0.8)

Justification for Vertical Path Geometry
Estimated based on site investigation, CSM and site drawings/sections.

Pathway dispersivity (m):	TRIANGULAR(0.3,0.575,0.85)

Justification for Vertical Path Dispersion Details
Longitudinal Dispersivity 10% of pathway length

Retardation parameters for Peat pathway
Modelled as vertical pathway.

Uncertainty in Kd (l/kg):	
Ammoniacal_N	UNIFORM(0.5,2)
Retardation parameters for Peat pathway	
Arsenic	UNIFORM(25,250)
Retardation parameters for Peat pathway	
Sulphate	SINGLE(0)
Retardation parameters for Peat pathway	

Justification for Vertical Path Kd Values by Species
Assumed based on data provided in LandSim manual

Pathway Density (kg/l):	TRIANGULAR(0.8,1,2)

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pathway parameters

Modelled as aquifer pathway.

Mixing zone (m):

Calculated. Aquifer Thickness: UNIFORM(8,12)

Justification for Aquifer Geometry

Estimated based on concepual site model, site drawings, site investigation details and GSI information on groundwater body characteristics.

Pathway regional gradient (-):	SINGLE(0.0091)
Pathway hydraulic conductivity values (m/s):	LOGUNIFORM(1e-009,6e-006)
Pathway porosity (fraction):	UNIFORM(0.02,0.2)

Justification for Aquifer Hydraulics Properties

Assumed based on hydraulic properties provided in LandSim manual

Pathway longitudinal dispersivity (m):	UNIFORM(25.9,38.1)
Pathway transverse dispersivity (m):	UNIFORM(7.77,11.43)

Justification for Aquifer Dispersion Details

Estimated based on 10%, 3% and 1% of pathway length.

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Retardation parameters for pathway

Modelled as aquifer pathway.

Uncertainty in Kd (l/kg):

Ammoniacal_N	UNIFORM(0.5,2)
Arsenic	UNIFORM(25,250)
Sulphate	SINGLE(0)

Justification for Aquifer Kd Values by Species

Assumed based on data provided in LandSim manual

Pathway Density (kg/l): UNIFORM(1.3,2)

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Appendix 2

ENVIRONMENT AGENCY REMEDIAL TARGETS WORKSHEET-GROUNDWATER CALCULATION SAMPLE

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R&D Publication 20 Remedial Targets Worksheet, Release 3.2

Level 3 - Groundwater

See Note

Input Parameters (using pull down menu)

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

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

Domenico - Time Variant — Equations in HRA publication

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

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

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

	Variable	Value	Unit	Source of parameter value
Initial contaminant concentration in groundwater at plume core	C_0	2.12E+02	mg/l	
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	1.75E+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	*Assumed bulk density of limestone bedrock(median v*
Effective porosity of aquifer	n	1.10E-01	fraction	*Assumed maximum porosity of limestone bedrock*
Hydraulic gradient	i	9.10E-03	fraction	*Calculated from groundwater levels between upgradient and downgradient wells on site*
Hydraulic conductivity of aquifer	K	8.00E-03	m/d	
Distance to compliance point	x	2.00E+02	m	*Hypothetical compliance point at 800m*
Distance (lateral) to compliance point perpendicular to flow direction	z		m	
Distance (depth) to compliance point perpendicular to flow direction	y		m	
Time since pollutant entered groundwater	t	2.01E+04	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

	Variable	Value	Unit
Groundwater flow velocity	v	6.62E-04	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	3.35E-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, C0/CED)	**AF**	**breakthrough at compliance point**	

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

Remedial Targets

Remedial Target		**No impact**	**mg/l**	For comparison with measured groundwater concentration.
Domenico - Time Variant				
Distance to compliance point		**200**	**m**	
Concentration of contaminant at compliance point	C_{ED}/C_0	**0.00E+00**	**mg/l**	Domenico - Time Variant
after		**2.0E+04**	**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.

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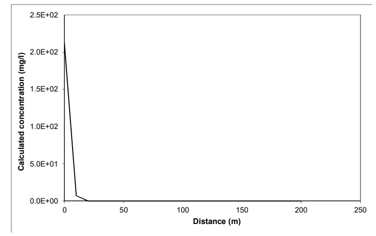

Calculated concentrations for distance-concentration graph

Domenico - Time Variant
From calculation sheet

Distance	**Concentration**
	mg/l
0	**2.1E+02**
10.0	**7.29E+00**
20.0	**1.74E-02**
30.0	**1.25E-06**
40.0	**0.00E+00**
50.0	**0.00E+00**
60.0	**0.00E+00**
70.0	**0.00E+00**
80.0	**0.00E+00**
90.0	**0.00E+00**
100.0	**0.00E+00**
110.0	**0.00E+00**
120.0	**0.00E+00**
130.0	**0.00E+00**
140.0	**0.00E+00**
150.0	**0.00E+00**
160.0	**0.00E+00**
170.0	**0.00E+00**
180.0	**0.00E+00**
190.0	**0.00E+00**
200.0	**0.00E+00**

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:	Ballymulvey Historical Landfill
Completed by:	EOC
Date:	########
Version:	1.01

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