HYDROGEOLOGICAL RISK ASSESSMENT

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Tables have been used whenever possible and included within the text to which they relate, to summarise large volumes of information/data into a manageable format and include the following;

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1.0 INTRODUCTION

1.1 Report Context

Enviroarm Limited were instructed by H Evason & Co, the owners and operators of Dorrington Quarry Landfill to undertake the Environmental Permit Application and associated risk assessments for the proposed new development at the site since obtaining planning permission to excavate the original part of the site which will be processed in the inert recycling area and to then engineer the new and old bits of the landfill with inert waste in line with the Environmental Permitting (England and Wales) Regulations 2016 and subsequent requirements for a hydrogeological risk assessment. Additional assessments include an Environmental Site Setting and Design Report, Site Stability Assessment, Landfill Gas Risk Assessment, and Amenity and Nuisance Risk Assessment which should be read in conjunction with this report.

The site entrance is located at National Grid Reference (NGR) SJ 47554 03875, the centre of the recycling area is SJ 74635 03869 and the centre of the landfill is at SJ 47680 03568, which lies approximately 9km south of Shrewsbury on the northern edge of Dorrington. The site is off the A49.

The site is a former quarry. The site is surrounded with large areas of agricultural land and the A49 is the west and a railway line to the east.

The Phase 1 area has one part which has being engineered but the resr has not. The old part will be taken to the inert recycling area and then infilled with inert waste after it has been processed in the recycling area. This report presents a review of the hydrogeological environment and impacts upon groundwater and surface water from the proposed operations.

This report presents a review of the hydrogeological relationship to the surrounding environment.

A conceptual hydrogeological model is presented and potential contaminant migration pathways have been identified. The conceptual model has been developed on site specific data and local data obtained from the British Geological Survey. A probabilistic risk analysis for potential groundwater contamination at Dorrington Quarry Landfill site has been undertaken based on the factual findings.

1.2 Conceptual Hydrogeological Site Model

1.2.1 Summary

The conceptual model for the site is based on the following context:

Source: is the potentially contaminating components of the leachate that will be generated and specifically Hazardous Substances and Non Hazardous polluting substances as defined in the Environmental Permitting (England and Wales) Regulations 2016, though due to the nature of the waste proposed hazardous substances will not be present in any significant concentration within the waste within the landfill site;

Pathway: includes the engineered geological barrier, unsaturated zone, which is the natural geological barrier consisting of the Quaternary Glaciofluvial Deposits in which the attenuation, ionic exchange and degradation processes may occur;

Receptor: is the receiving groundwater directly beneath the landfill at the base of the unsaturated zone for hazardous substances and the monitoring boreholes 1 and 3 on the perimeter of the site down hydraulic gradient, as shown on Drawing ESSD 9.

1.2.2 Source Term Characteristics

The site is permitted to accept up to 12,000 tonnes of inert waste per annum, which leaves 80,000m^3 in Phase1 and 87,500m^3 in Phase 2.

Decomposition of inert waste is not considered highly complex like a non-hazardous waste landfill, with microbiological, physical and chemical processes acting simultaneously within each operational and closed landfill phase, and acting in a relatively consistent manner within an inert landfill site. Leachate is formed by the percolation of water through the inert waste mass coupled with the decay and release of contaminants from the waste itself.

In assessing the risks posed by the site operations to groundwater, the source term has been derived from the waste analysis collected at the site when it accepted strictly inert wastes and from other local landfills to establish the source term component.

Specific species have been identified from the results for the risk assessment modelling and are presented in a statistical format used for the LANDSIM modelling.

The targeted species for the hydrogeological risk assessment are

Inorganic anion	Chloride
Inorganic cation	Ammonia (as Ammoniacal Nitrogen)
Metallic ion	Cadmium (Hazardous Substance)
	Mercury (Hazardous Substance)
	Nickel (Non-Hazardous Pollutant)

Ammonia (Ammoniacal Nitrogen) is attenuated during migration by cation exchange and biological uptake. Cation exchange is. The range of ammonia recorded in leachability tests is typically less than 0.1mg/l with the upper limit set as the drinking water standard at 0.5mg/l. As the detection limit was not lower this is the value that has been used for the model. This would seem a reasonable value as previously stated no methane gas has been detected within the waste mass indicating that no biodegradation is taking place. All top soils on site have always been segregated for resale and reuse. The review of ammonium attenuation in soil and groundwater by NGCLC states an average decay half-life for ammonia as 6 years. The Kd value used for ammonia is based on a loam soil for the waste mass and for sands for the unsaturated zone based on the CONSIM database. Ammoniacal Nitrogen was chosen in case small quantities of wood or other biodegradable material are accidentally placed into the landfill. Although bio-degradable material will not be deliberately disposed of in the landfill, it is possible that some residual bio-degradable material may be placed in the landfill. Therefore, it is possible that some degradation products, such as ammonium may be produced. The purpose of including ammonium in the risk model is to demonstrate that, even if it is present in the leachate, is does not pose a risk
to groundwater.

Adsorption is the primary attenuation mechanism for Cadmium and Zinc. All Kd values for the inputs are contained in Table HRA 6 below. The statistical range of data is presented at Appendix HRA 5. Cadmium is a hazardous substance prevented from entering groundwater. Cadmium is a hazardous substance and tends to be more common that arsenate or mercury and is slower to be removed in the water environment with smaller Kd values. Zinc is a highly mobile metal again associated with local sources of pollution. Zinc is selected as an indicator metal. Zinc is toxic to ecological receptors. Of the metals, it has one of the lower sorption coefficients, making it a conservative selection for the risk assessment model.

Chloride is a conservative inorganic substances that may be expected to reach receptors quickly and indicate potential problems. Inert waste is often characterised by chloride concentrations that are elevated compared to background.

1.2.3 Landfill Design

The conceptual site model is presented in Drawing HRA 1 with the proposed engineering design summarised in Table HRA1.

Table HRA1: Landfill Engineering Components

Inert Landfill Component	Description
Landfill Cap	Not Required
Leachate Drainage	Not Required
Artificial Sealing Liner	Not Required
Basal Mineral Liner	Minimum 1m thick with of $1x10^{-7}$ m/s
Sidewall Mineral Liner	Minimum 1m thick with of $1x10^{-7}$ m/s
Groundwater Control	Not required
Construction Quality Assurance	All work subject to independent CQA

The landfill will be constructed as 2 No. sequential phases as shown in drawing ESSD 4 and detailed in Table HRA2.

All basal and side wall geological barrier engineering will be by use of suitable imported soils and clays that have a minimum 8% clay fraction and will achieve at least 1 x 10^{-7}m/s permeability and have a shear strength when placed in excess of 50kPa.The base and side wall seal will be at least 1.0 metre thick. Cell wall stability has been assessed in the SRA.

The total landfill void is 167,500m^3 which with an average conversion using HMRC for inert waste at 1.5 tonnes per m3 gives a total tonnage for the inert landfill of 251,250 tonnes of inert waste to infill the void. Table HRA 2 shows the void capacity of each phase.

Table HRA2: Cell construction volumes.

	Phase No.	Waste Cells Volume (m³)	Purpose
Disposal	1	120000	Inert Waste Disposal Cell
Disposal	2	131250	Inert Waste Disposal Cell
Disposal	Inert Treatment Area	40,000m²	Inert Treatment to remain in perpetuity

Two disposal scenarios are considered for Dorrington Quarry Landfill assuming filling operations commence during 2021 following removal w of inert waste from Phase 1 used to restore the area to the south as a tree area.

Scenario 1 – Inert waste input of 12,000 m^3/yr (18,000 tonnes per annum), with completion of landfilling operations by the mid of 2028.
Scenario 2 - Inert waste input of 8,000,000 m^3/yr (12,000 tonnes per annum) with completion of landfilling operations by the end of 2025.

Table HRA3: Operational life of inert waste disposal cells

	Phase Life (yrs)	
Phase No.	**12,000 m³/yr**	**8,000m3/year**
1	6.66	10
2	7.29	10
TOTAL	13.5	20

1.2.4 Source Term Leaching Model

Decomposition of inert waste is not considered highly complex like a non-hazardous waste landfill, with microbiological, physical and chemical processes acting simultaneously within each operational and closed landfill phase, and acting in a relatively consistent manner within an inert landfill site. Leachate is formed by the percolation of water through the inert waste mass coupled with the decay and release of contaminants from the waste itself.

In order for inert waste to be accepted at a landfill site, the holder or operator must be able to show that the waste meets the permit conditions and the waste acceptance criteria (WAC). To do this a set process to characterise and test the waste is required.

Waste acceptance criteria have been agreed by the European Council. They applied from 16 July 2005 under the Landfill (England and Wales) (Amendment) Regulations 2004 transposed under the Environmental Permitting Regulations 2010. These criteria are referred to as 'full waste acceptance criteria'. For inert landfills, there is a limited list of wastes presented at Table HRA4 below that are deemed to meet the criteria for inert waste. These wastes are acceptable if:

- they are single stream waste of a single waste type (although different waste types from the list may be accepted together) and are from a single source; and
- they are not contaminated and do not contain other material or substances such as metals, asbestos, plastics, chemicals, etc to an extent which increases the risk associated with the waste sufficiently to justify their disposal in other classes of landfill.

Table HRA 4: Inert Wastes List

01 WASTES RESULTING FROM EXPLORATION, MINING, QUARRYING, AND PHYSICAL AND CHEMICAL TREATMENT OF MINERALS

01 04 wastes from physical and chemical processing of non-metalliferous minerals

01 04 08	waste gravel and crushed rocks other than those mentioned in 01 04 07
01 04 09	waste sand and clays

17 CONSTRUCTION AND DEMOLITION WASTES (INCLUDING EXCAVATED SOIL FROM CONTAMINATED SITES)

17 01 concrete, bricks, tiles and ceramics

17 01 01	concrete
17 01 02	bricks
17 01 03	tiles and ceramics
17 01 07	mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06

17 05 soil (including excavated soil from contaminated sites), stones and dredging spoil

17 05 04	soil and stones other than those mentioned in 17 05 03
17 05 06	dredging spoil other than those mentioned in 17 05 05
17 05 08	track ballast other than those containing dangerous substances

19 WASTES FROM WASTE MANAGEMENT FACILITIES, OFF-SITE WASTE WATER TREATMENT PLANTS AND THE PREPARATION OF WATER INTENDED FOR HUMAN CONSUMPTION AND WATER FOR INDUSTRIAL USE

19 12 wastes from the mechanical treatment of waste (for example sorting, crushing, compacting, pelletising) not otherwise specified

19 12 05 glass, (excluding residual fines from mechanical treatment of mixed wastes at transfer stations)
19 12 09 minerals (for example sand, stones)

20 MUNICIPAL WASTES (HOUSEHOLD WASTE AND SIMILAR COMMERCIAL, INDUSTRIAL AND INSTITUTIONAL WASTES) INCLUDING SEPARATELY COLLECTED FRACTIONS

20 02 garden and park wastes (including cemetery waste)

20 02 02 soil and stones

[a]*Selected construction and demolition waste (C & D waste): with low contents of other types of materials (like metals, plastic, organics, wood, rubber, etc). The origin of the waste must be known.*

No C & D waste from constructions, polluted with inorganic or organic dangerous substances, e.g. because of production processes in the construction, soil pollution, storage and usage of pesticides or other dangerous substances, etc., unless it is made clear that the demolished construction was not significantly polluted.

No C & D waste from constructions, treated, covered or painted with materials, containing dangerous substances in significant amounts.

The source term leaching model is based on the inert WAC suite as presented in Table HRA 5. Source terms are also considered ammonium. Reasonable worst-case estimates of leaching source terms for ammonium have been assumed to be 0.1-0.5-5.0 mg/l respectively.

A declining source term leaching model for assessing the potential emissions to groundwater from landfills through the use of kappa values has been used. The source term leaching model is set at inert WAC thresholds with a considered statistical spread of results as not all of the material deposited on site will leach at the maximum inert WAC limit. This approach hence assumes that all waste accepted would generate leachate at threshold concentrations during the entire operational phase of the landfill, which we recognise as suitably conservative.

By comparison of inert WAC source terms with the relevant Water Quality Standards (WQS) and maximum observed background groundwater concentrations, proposed Environmental Assessment Limits (EALs) have been generated for the subject site.

The bedrock aquifer provides groundwater to the secondary aquifer but this is not in a protection zone.

The derivation of EAL's are based on the condition that, where groundwater concentrations already exceed the relevant WQS, the relevant EALs are set at 1.5 x background concentrations to account for the natural variability of groundwater quality. The attenuation factor for the geological barrier and unsaturated zone is approximately 10.

Table HRA5: Inert WAC Screening Typical Spread & Recommended EALs.

Component	WAC Source Term Mg/l	DWS	WHO
Cd (mg/l)	0.0001,0.0002, 0.004	0.005	0.003
Zn (mg/l)	0.02, 0.01,0.4	5	3
Cl (mg/l)	10,25,80	250	250
SO4 (mg/l)	10,50,100	250	250
Ammonium (mg/l)	0.1,0.25,0. 25	0.5	1.5

Table HRA 6 shows the site with a 10% WAC breach.

Table HRA 6: Maximum leachate source term input values under normal operating scenario

Component	WAC Source Term mg/l
Cd (mg/l)	0.0001-0.0002-0.04
Zn (mg/l)	0.02-0.01-0.4
Cl (mg/l)	10-25-80
SO4 (mg/l)	10-50-100
Ammonium (mg/l)	0.1-0.25-0.5

A failure scenario has been considered taking account of the leachate levels being exceeded..

Table HRA 7: Rogue load input assessment

Component	WAC Source Term mg/l	Unsaturated Zone
Cd (mg/l)	0.00011-0.00022-0.044	3.0
Zn (mg/l)	0.022-0.011-0.44	3.0
Cl (mg/l)	11-27.5-88	3.0
SO4 (mg/l)	11-55-110	3.0
Ammonium (mg/l)	0.11-0.275-0.55	3.0

Table HRA 8 sets out the anaerobic half-life values and Kd values used for the modelling and source term reference data.

Table HRA 8. Anaerobic Half Life Values and Kd values

Determinant	Parameter	Value/Range	Justification
Ammonia	**Kd (l/kg)GB** **Kd (l/kg)**	**6** **6**	**Conservative as figures are quoted**
Cadmium	**Kd (l/kg) GB** **Kd (l/kg) AQ**	**250-500**	**LANDSIM Manual 2.5 and Golders**
Zinc	**Kd (l/kg) GB** **Kd (l/kg) AQ**	**62** **200**	
Chloride	**Kd (l/kg) GB** **Kd (l/kg) AQ**	**0** **0** **0**	**LANDSIM Manual 2.5**
Sulphate	**Kd (l/kg) GB** **Kd (l/kg) AQ**	**0** **0** **0**	**LANDSIM Manual 2.5**

1.2.5 Pathways

Enviroarm Limited recognise that different pathways may exist for leachate migration from the site at differing times of the site lifecycle. In identifying possible pathways for leachate migration from the site, Enviroarm have considered the following time periods in the life of the site:

1. Standard Operation of the site during the construction period and operation prior to restoration.

Primary possible pathway include;

- Advective migration of leachate through the geological barrier into the groundwater

2. Failure of the site during leachate level increase.

Increased leachate head to 3 metres which is the point of overtopping at the lowest pojnt of the site:

- Advective migration of leachate through the lower basal low permeability materials and the geological barrier into the groundwater

3. Failure of the site during groundwater level fluctuation.

Reduced unsaturated zone caused by the rise in groundwater:

- Advective migration of leachate through the lower basal low permeability materials and the geological barrier into the groundwater

1.2.6 Receptors

In the foregoing discussion about the pathway component of risk, it has been implicitly assumed that the receptor is the groundwater in the Glaciofluvial Deposits directly beneath the landfill, (described as a principal aquifer). This is a conservative approach because the detrimental affects of leachate entering the groundwater are unlikely to be realised immediately adjacent to the site or beneath the site. The site based on the source term leachability testing indicates that no hazardous substances are present in any significant concentrations or are likely if the site complies with inert WAC.

The “secondary” or “off-site “receptor is considered to be groundwater in the Glaciofluvial Deposits at the edge of the quarry, which is 175 metres from the edge of the inert landfilling.

The specification of appropriate Environmentally Acceptable Levels (EALs) for this site are set as the minimum reporting values (MRV) for Hazardous substances, and the Drinking Water standards for Non-Hazardous Pollutants, based on the source protection zoning.

The substances assessed in the model are also those that have been monitored in the groundwater and the average background concentrations have been included in the LANDSIM modelling.

1.2.7 Hydrogeology

The hydrogeological conditions at the site have also been input to develop the conceptual model.

The Environment Agency has confirmed that the site is within Secondary aquifer and is not in a protection zone. The Groundwater Vulnerability map shows the site to lie on a Secondary aquifer that is highly vulnerable.

Permeability testing has been carried out on the clay used in Phase 1.

There has also been a test carried out on the Glaciofluvial Deposits.

Hydraulic conductivity in the Glaciofluvial Deposits is related directly to the porosity. The lower the porosity the lower the permeability of the sandstone. Typical porosity values have been obtained from the BGS Aquifer Properties Manual previously referred to and the values range from 10.1% to 31.8% with an overall area average value of 20% under the geological barrier is Phase 2.

Geological logs are presented at Appendix 6.

1.2.8 Geological Barrier

An assessment has been made of the natural unsaturated zone as a single entity in comparison to the requirements of the Environmental Permitting Regulations. The principle for the calculation was taken from “Geotechnical Aspects of Landfill Design and Construction” Qian, Koerner, Gray 2002.

Flow rates through a compacted mineral liner is calculated using Darcy’s law, which is the basic equation used to describe the flow of fluids through porous materials. Darcy’s law states that;

$Q= k_s.i.A$

Where Q= flow rate through the liner, m^3/s
k_s= hydraulic conductivity of the soil, m/s
i= hydraulic gradient; and
A= area over which flow occurs m^2

If the soil is saturated and there is no soil suction, the hydraulic gravity is given by

i= (h=D)/D

where i=hydraulic gradient;
h=leachate head over the liner
D=thickness of mineral liner

If one assesses the requirement under the landfill regulations for a liner at an inert facility to have an equivalent liner to a 1 metre thick geological barrier with a permeability of 1 $x10^{-7}$m/s this is set out below as;

Geological Barrier Requirements Landfill Regulation requirements/Extension Area

Leachate Head	**h =1**
Landfill liner	**D = 1= 1x 10-7m/s**

A=area-assume per 1m²

The calculation to determine the seepage rate of a mineral liner has been

$$\mathbf{Q=K\frac{(h+D)}{D}a}$$

$$Q= 1\times10^{-7}\frac{(1+1)}{1}1$$

$Q= 2 \times 10^{-7}\ m^2/s$

The permeability values of the unsaturated zone and thickness of one metre have been input into this equation as follows using the highest permeability value proposed for the mineral liner at 1 x 10^{-9}m/s obtained during the testing.

Geological Barrier Requirements Landfill Regulation with proposed geological barrier

Leachate Head	**h =1**
Landfill liner	**D = 1= 1x 10-10m/s**

A=area-assume per 1m^2

The calculation to determine the seepage rate of a mineral liner has been

$$Q=K\frac{(h+D)}{D}a$$

$$Q= 1 \times 10^{-7}\frac{(1+1)}{1}1$$

$$Q= 2 \times 10^{-7}\ m^2/s$$

For the purpose of the LANDSIM assessment the assumption has been made that the geological barrier would be 2 x 10^{-7}m^2/s.

Selective soils will be imported and used for the geological barrier. The West Midlands region tends to get a large amount of excavation which are clays or silts which are used for the barrier.

The geological barrier is Phase 1 is 2 metres deep and will be 1 metre deep in Phase 2.

2.0 HYDROGEOLOGICAL RISK ASSESSMENT

2.1 The Nature of the Hydrogeological Risk Assessment

2.1.1 General

Analytical models of leachate migration through the engineered geological barrier and underlying unsaturated zone and dispersion in hydrogeological environment, and probabilistic analysis have been used to provide an evaluation of the possible likelihood and consequences of leachate release and migration from the base of the inert landfill site at the Dorrington Quarry Landfill into the groundwater, based on differing concentrations.

The effect of contamination on receptors (water users or sources) is related to concentration of the particular contaminants at the point of contact and water usage.

The receptor considered in the risk assessment, is water directly beneath the site for Hazardous substances (1.0 metre) of unsaturated Glaciofluvial Deposits and a low permeability 1 metre engineered geological barrier. Due to the sensitivity of the aquifer the geological barrier will have a maximum permeability of 1 x 10^{-7}m/s.

2.1.2 Probabilistic Analysis of Leachate Leakage and Migration

Analytical models, based on theoretical considerations or empirical observations of the processes of landfill liner leakage, unsaturated zone containment transport and dispersion, and contaminant dispersion within a saturated zone have been interlinked to form the risk assessment model of landfill performance. The results of the modelling are presented at Appendices HRA 1 to HRA 3 of this report.

Probabilistic analysis of an analytical model allows the uncertainty in processes or uncertainty in parameters controlling processes to be quantified. Using mathematical sampling techniques a direct estimate of risk associated with the model and assessed parameter uncertainty can be produced. The results combine magnitude of event (consequence) with likelihood of occurrence and define a probability density function for the model and parameters.

In the case of the LANDSIM 2.5, used for the unsaturated zone, the results are the range of possible leachate leakage from the site and contaminant concentration levels and breakthrough times at a receptor beneath the site at a given time after the commencement of leachate leakage. Using these results, it is possible to quantify the likelihood of a certain leakage rate or concentration occurring.

The concepts and usage of probabilistic analysis in the assessment of landfill sites is described more fully in the LANDSIM 2 manual (EA, R&D Publication 120, 2001), and has further been developed by the Environment Agency in the Guidance Document entitled ”Hydrogeological Risk Assessments for Landfills and Derivation of Groundwater Control and Trigger Levels, (May 2002).

The process of probabilistic assessment of landfill sites has been validated by others (LANDSIM Manual, EA, 1996 and 2001) and has been shown to be a conservative approach to the assessment of environmental impact.

The quantitative risk assessment for the impacts during the rebound lifecycle phases (hydraulic containment) is also based on a (probabilistic) Monte Carlo simulation package (Crystal Ball). This also allows the uncertainties within the input parameters to be addressed by assigning probability distribution to the parameter range. The range of input data has been developed in the previous sections.

2.1.3 Risk Estimation Model for Dorrington Quarry Landfill Site.

LANDSIM 2.5 was used to evaluate both magnitude and likelihood of leakage rate, the potential containment concentration at the critical receptor and breakthrough time to the critical receptor for the operational and development phases at the Dorrington Quarry landfill site.

The model uses the statistical Monte Carlo methodology. The risk of leachate migration to the receptor was estimated by the range of concentrations of the selected chemical species in the groundwater at the receptor at an infinite time after the commencement of leachate leakage.

The calculated concentration at the receptor at infinite time thus represents a conservatively high estimate of the concentration that could develop at the receptor given the scenario assessed. In reality any reduction in the leachate source concentration in time will reduce the ultimate concentration that could reach and impact on the receptor.

Uncertainty in the natural processes of leachate migration through the base and the unsaturated zone and contamination transportation in groundwater were incorporated in the modelling process by the inclusion of stochastic values to represent certain controlling parameters (e.g. permeability of the basal soil material and underlying strata). The stochastic values were defined by probability density functions based on the findings of the field investigations carried out at the site and appropriate published information such as BGS Aquifer Property data presented at Appendix ESSD 4 taken from the BGS Technical Report WD/97/34 Environment Agency R&D Publication 8. Uniform (represented by a minimum and maximum value) and triangular distributions (represented by a minimum, most-likely and maximum value) have been used to incorporate judgements on parameter values into the modelling. Triangular distributions are appropriate for representing judgements on values for risk analysis (Megill, 1984). Logarithmic triangular distributions have been used where the uncertainty relates to order of magnitude.

Fixed values were used for some parameters where uncertainty in value is known to have limited effect or in scenarios where certain conditions were assumed.

Hydraulic Properties of Underlying Strata; values for the properties of the underlying strata were derived from tests carried out on the Glaciofluvial Deposits and the BGS source test data. Hydraulic gradients are based on the groundwater contours monitored on site and presented at Drawing ESSD 10.

Distance to Critical Receptor: for the purpose of Hazardous substances, this is directly beneath the landfill with a 1.0 metre unsaturated zone of Sherwood Sandstone and 1 metre engineered geological barrier on the base above this, based on the groundwater level plan levels shown on ESSD 10. For Non-Hazardous Polluting Substances, the distance has been assessed at the same point and at the receptor, which is located at the perimeter edge of the site, namely Boreholes 1 and 3 used to assess impact on the water at the edge of the site boundary.

2.2 The Proposed Assessment Scenarios

The hydrogeological risk assessment has been carried out for the whole lifecycle of the landfill, i.e. from the start of the operational phases until the point at which the landfill is no longer capable of posing an unacceptable environmental risk. Different scenarios have been considered, to assess the hydrogeological risks at different stages of the landfill's lifecycle.

2.2.1 Lifecycle Phases

The tight controls that will be set by the Waste Acceptance Criteria and the lack of biodegradable matter within the waste mean that the site will be stable and inert. The waste will not degrade and the restoration of the site will reduce further infiltration due to the formation of the sloped landform allowing free drainage off the surface. The vegetated cover will also help to reduce surface water runoff and increase interception and evapotranspiration from the surface.

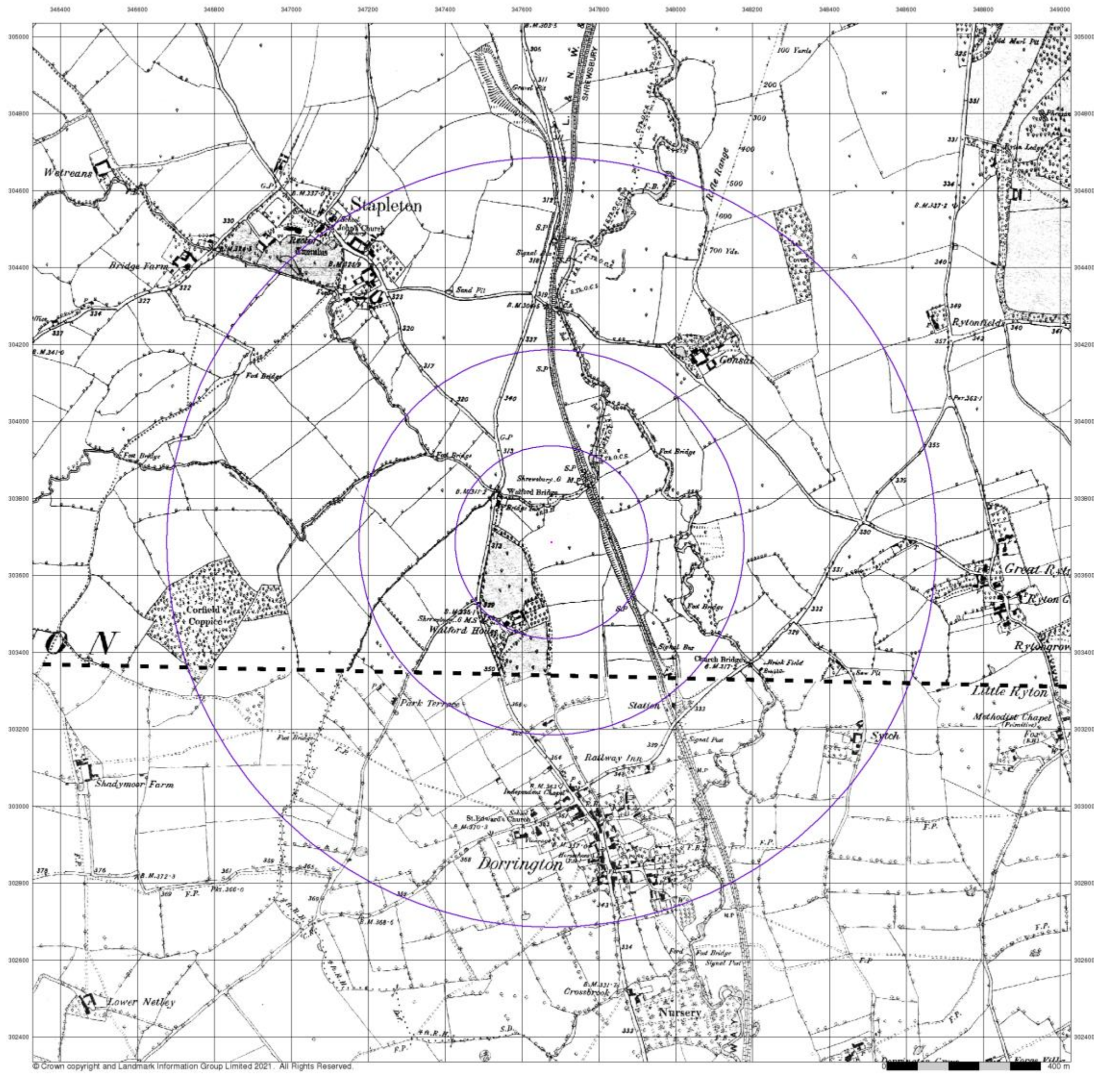
No mining has been carried out and no instability has ever been reported to the BGS so the site and surrounding environs will not suffer from settlement of instability.

Therefore there is very little change considered for the unsaturated zone. The nature of the ground falling away from the site to the north is to the brook which goes into the Cound Brook east of the site.

Figure 1 below shows the OS map of 1889 level of 125.5m AOD. It is noted that the road is not reported as flooding. A full set on enlarged Ordnance Survey maps are presented at Appendix ESSD 1 in the ESSD.

There is therefore little fluctuation on the overall hydraulic gradient from that modelled and all boreholes tend to behave and respond the same. It is also considered that global warming is unlikely to have any impact locally of the water table. However the site has been modelled with only a 0.5 metre unsaturated zone.

Figure 1: OS Map 1884-1885



2.3 The Priority Contaminants to be Modelled

The priority contaminants modelled are discussed within Section 1.2.2 with justifications for their inclusion.

2.4 Review of Technical Precautions

In the context of a hydrogeological risk assessment, the necessary essential and technical precautions required by the Environmental Permit are likely to include limitations on the rates of input and concentrations of permitted waste types. The waste types to be accepted the site are strictly inert wastes as detailed in Waste Types.

WAC testing will be carried out for inert waste. The waste should also not exceed the leachability values used in the LANDSIM modelling.

Monitoring is also considered to be a technical precaution, and additional boreholes have been installed as part of the groundwater monitoring site protection plan.

The site has been assessed with the following variations

Normal leachate inputs and normal operation scenario.
10% exceedance
3m head

All C&D wastes will be sent to the inert treatment area and pre-treated prior to landfilling.

All waste will be accepted in accordance with the Waste Acceptance Criteria Protocol for the site as per the EMS.

2.5 Numerical Modelling

2.5.1 Justification for Modelling Approach and Software

The input parameters for the model and output values are presented at Appendix HRA1 to HRA 3.

Analytical models, based on theoretical considerations or empirical observations of the processes of landfill liner leakage, unsaturated zone containment transport and dispersion, and contaminant dispersion within a saturated zone have been interlinked to form the risk assessment model of landfill performance.

Probabilistic analysis of an analytical model allows the uncertainty in processes or uncertainty in parameters controlling processes to be quantified. Using mathematical sampling techniques a direct estimate of risk associated with the model and assessed parameter uncertainty can be produced. The results combine magnitude of event (consequence) with likelihood of occurrence and define a probability density function for the model and parameters.

In the case of the LANDSIM 2.5, used for the unsaturated zone, the results are the range of possible leachate leakage from the site and contaminant concentration levels and breakthrough times at a receptor beneath the site at a given time after the commencement of leachate leakage. Using these results, it is possible to quantify the likelihood of a certain leakage rate or concentration occurring.

The concepts and usage of probabilistic analysis in the assessment of landfill sites is described more fully in the LANDSIM 2 manual (EA, R&D Publication 120, 2001), and has further been developed by the Environment Agency in the Guidance Document entitled "Hydrogeological Risk Assessments for Landfills and Derivation of Groundwater Control and Trigger Levels, (May 2002).

The process of probabilistic assessment of landfill sites has been validated by others (LANDSIM Manual, EA, 1996 and 2001) and has been shown to be a conservative approach to the assessment of environmental impact.

The model allows for the source term components established from the leachability tests to be input directly. Groundwater baseline data has also been used. The site models the lower compacted layer of soils input in the engineering component. The unsaturated zone is at least 1 metre above the water table at its highest recorded elevation and the aquifer properties are based on local observations. The LANDSIM model is the best simulation program for this type of site, however, the nature of the inert waste and its low permeability and high field capacity need to be considered in full when assessing the results.

The quantitative risk assessment for the impacts during the lifecycle phases is also based on a (probabilistic) Monte Carlo simulation. This allows the uncertainties within the input parameters to be addressed by assigning probability distribution to the parameter range. The range of input data has been developed in the previous sections.

The results from the probabilistic analysis using LANDSIM 2.5 are presented as Appendices HRA 1 to HRA 3 and show the range of predicted leachate leakage rate and dilution due to underflow predicted for each scenario considered. The range in predicted concentration of the selected chemical species at the receptor for reach scenario is considered in detail. The results of the risk analysis are inclusive of the assessment of parameter uncertainty.

The 95 percentiles are shown on the results at 30, 100, 300, 1000 and infinity, i.e. greater than 1000 years to describe the range and likelihood of these values. The 95 percentile is considered as an appropriate confidence criterion by which the impact of leachate leakage and migration can be assessed (LANDSIM Manual, EA, 2001).

The 95 percentile represents the value for which there is only a 5% probability of exceedance; this 5% probability is considered as unlikely. In order to provide reasonable results, 501 iterations of the model were carried out in the probabilistic sampling for the normal operating scenario.

A summary of the output concentrations at the base of the unsaturated zone are presented in Tables HRA1 to HRA 3.

For each of the considered scenarios, the hydrogeological risk assessment must demonstrate that the technical precautions would "*prevent substances in Hazardous Substances List from entering groundwater*". Consequently, it must consider whether there is likely to be a discernible discharge of these Substances to groundwater. The test shall be applied at the point at which leachate enters groundwater and shall not take account of the effect of dilution in that groundwater.

The predicted concentrations of Hazardous Substances at the point that they enter the groundwater from the modelling presented in Appendices HRA1 to HRA3 are summarised below and are compared to the Minimum Reporting Values set out in the Environment Agency Guidance on Hydrogeological Risk Assessment.

Three model scenarios have been considered, the operational one with all results under the WAC criteria and one with results at 10% more that used in the first model and one with a three metre leachate head.

For each of the considered scenarios, the hydrogeological risk assessment has demonstrated that the technical precautions clearly limit the introduction of Hazardous and Non-Hazardous Substances into groundwater so as to avoid pollution.

2.5.2 Model Parameterisation

To include details relating to the following.

- The nature of the parameterisation process including all model inputs, probability density functions and model calibration where appropriate are presented in the Appendices.
- The justification for using model defaults against providing field measurements.
- All model inputs are presented in the Tables at Appendix HRA 6.

2.5.3 Sensitivity Analysis

The purpose of a sensitivity analysis is to quantify the variation in the model output caused by uncertainty in the input parameters. A sensitivity analysis has been performed by considering variability in leachate head and leachate strength. Leachate head has been chosen as the parameter to determine the likely sensitivity of the impact assessment models, as leachate levels are not fixed with time.

The inert nature of the waste is a limiting factor and the field capacity. Increasing the leachate head increases flows into the aquifer as expected.

Due to the inert nature of the site and that upper acceptance limits had been used in the models for maximum leachability values it was not considered that use of multiple model runs to simulate different justifiable ranges of input parameters was necessary.

Failure models have included a 3 metre head and a 10% increase in eluate concentration and reduction of the unsaturated zone.

There is no consideration for safety factors as the environmental conditions and the landfill conditions are stable.

2.5.4 Model Validation

The comparison of modelled output against what is observed in the field would indicate that the values reported for the outer groundwater monitoring boreholes reflect the model output values and would indicate that the correct model parameters have been used, including the source term components,

2.5.5 Accidents and their Consequences

Quantifiable changes from normal operating conditions have been identified to include the possibility of deterioration of the capping systems and leachate head build up in the waste mass.

2.5.5.1**Fluctuations in Groundwater Elevations**

If groundwater levels rise, the unsaturated zone thickness would decrease reducing attenuation capacity and time.

It is not predicted that the water table will increase above the figures used and presented on ESSD 10. If groundwater levels fall the unsaturated zone would increase and the risk would be reduced further. Provision for continual leachate and groundwater level monitoring has been made.

2.5.5.2 Leachate Migration Rates Through a Sidewall

This is not considered likely and is not considered further.

2.5.5.3 Failure of the Leachate Extraction System

No leachate extraction is required in an inert landfill and is not considered further as part of this assessment.

2.5.5.4 Differential Settlement

Differential settlement across the landfill is considered unlikely due to the inert nature of the waste. The geological barrier will use natural soils and clays and the site will not have a cap. The inert nature of the waste means that movement will be minimal to structures within the waste mass (such as leachate abstraction risers or shafts), and is therefore not considered further as part of this assessment. Pre and post settlement contours are presented at ESSD 5.

The risk of differential settlement cannot be completely eliminated from a site design. However, monitoring for the effects of differential settlement would be undertaken through:

- Regular site surveys of completed and restored areas of the site;
- Completion of walk over surveys across restored areas;

Remedial measures to repair and reinstate the cap where differential settlement occurs would be undertaken by the H Evason & Co as part of the aftercare management of the restored site.

Should leachate monitoring points be damaged through excessive or differential settlement within the waste mass, retrospectively installed wells will be constructed adjacent to the damaged monitoring point using conventional drilling techniques for drilling into inert waste (i.e. open hole air flush). Given the maximum thickness of the waste in the site (typically less than 10m), the retrospective installation of such wells is not considered to be problematic.

2.5.5.5 **Clogging or Deterioration of the Leachate Drainage Systems**

No leachate drainage system is required and so is not considered further as part of this assessment.

2.5.5.6 **A line of weakness in the mineral liner/geological barrier**

A mineral liner is proposed at Dorrington Quarry landfill site to supplement the geological barrier artificially. To achieve a line of weakness thorough the full 1.0 metres of mineral liner/ soil base would require a minimum of four consecutive weak points to occur directly above each other. This in itself is extremely unlikely and with a CQA program in place for future phases, this is not considered to be a likely scenario.

The ground beneath the base of the quarry has not been mined and so differential settlement is not considered a failure scenario at Dorrington Quarry.

Models have been run to account for potential variability of the imported materials used go for the geological barrier.

2.5.5.7 **Failure of the Side Wall Lining System**

A side wall liner is required, but is to be constructed in Phases and held in place with inert waste and a firm outer sub grade of in situ sandstone. Side wall failure is not considered likely and a line of weakness would be similar to that for the base.

Table HRA9: Risks and consequences summary table

Potential Accident	Likelihood	Implication	Consequence	Likelihood of Non-compliance
Flooding	Unlikely	Inundation of waste cell	Negligible/marginal	Unlikely
Subsidence	Unlikely	Breach of engineered mineral barrier	Marginal / significant	Unlikely
Fires / subterranean combustion	Extremely Unlikely	Damage to mineral liner / desiccation & increased permeability	Significant	Fairly Probable
Explosions	Extremely Unlikely	Loss of structural integrity of cell walls and breach of mineral liner	Significant	Probable

2.6 Emissions to Groundwater

The hydrogeological risk assessment has established whether the predicted discharge from the landfill complies with the requirements of the Environmental Permitting (England and Wales) Regulations 2016. This has been carried out for each of the considered scenarios (i.e. the different modelled phases of the lifecycle and the potential impact of accidents) and has included both Hazardous and Non Hazardous Substances.

2.6.1 Hazardous Substances

- The predicted concentration of Hazardous Substances at the point that they enter the groundwater from the modelling presented at Appendices HRA 1 to HRA 5 and are summarised below and are compared to the Minimum Reporting Values set out in the Environment Agency Guidance on Hydrogeological Risk Assessment and is set out in Table HRA 10. The hazardous substances also are not reported above MRV at the monitoring wells.

Table HRA 10: Hazardous Substance values at Base of Unsaturated Zone

Determinant	Normal Operating Scenario	Failure Scenario WAC Exceedence	Failure Scenario 3.0metre head of leachate	Minimum Reporting Value	Drinking Water Standard
Cadmium	1.00E-5,4.86E-5	3.91E-5,4.86E-5	1.00E-5,4.86E-5	1E-4	0.001

- Therefore the concentrations are discernible and the site has no Hazardous substance release into the environment. It is also noted that in each model the concentration of hazardous substances at the compliance point off site at Dorrington Quarry is zero.
- The increase in leachate head to the pojnt of breakout has no impact on the groundwater quality at the base of the unsaturated zone. The reduction in the unsaturated zone increases the concentrations by extremely small.

2.6.2 Non-Hazardous Polluting Substances

The predicted concentrations of Non-Hazardous Substances are not likely to exceed relevant Drinking Water Standards at the monitoring boreholes and are summarised below in Table HRA 11 and HRA 12 which have the various permeability considerations. The Drinking Water Standards have been used as the Environmental Acceptable Levels (EAL) based on the Bourne Vale Pubic Water Supply borehole and has taken account of baseline concentrations recorded in the downgradient boreholes within the models.

Table HRA 11: Concentrations of Non-Hazardous substances at monitoring well

Determinant	Normal Operating Scenario	Failure Scenario WAC exceedence	Failure Scenario 3.0metre head of leachate	Drinking Water Standard mg/l
Ammonia	0.50,0.50	0.50,0.50	0.50,0.50	0.5
Chloride	22.1,26.2	22.3,26.2	22.8,26.2	250
Sulphate	43.1,48.6	43.4,48.6	43.2,48.6	250
Zinc	0.003,0.003	0.003,0.003	0.003,0.003	5.0

The maximum LS10 model has also been assessed at the edge of the landfill and the results are reported below as Table HRA12.

Table HRA 12: Non- Hazardous Substance values at edge of landfill in monitoring wells

Determinant	Normal Operating Scenario	Failure Scenario WAC exceedence	Failure Scenario 3.0metre head of leachate	Drinking Water Standard mg/l
Ammonia	0.5	0.5	0.5	0.5
Chloride	28.7	28.8	28.7	250
Sulphate	52.3	52.5	52.3	250
Zinc	0.003	0.003	0.003	5.0

The determination of whether the introduction of Non-Hazardous Polluting Substances to groundwater has been sufficiently limited so as to avoid pollution. The models have used a declining source terms, but no cationic exchange and the maximum values have been used which for some are reported as less than which means the actual concentrations would be less than reported. It is noted that there already exists ammonia in the down gradient boreholes associated with previous landfilling and agricultural activity. It is noted that South Staffordshire Waters Works Company have a de-nitrification plant fitted as there is an issue with elevated nitrates from historic agricultural operations generally in this region.

2.6.3 Surface Water Management

Surface water runoff will be directed to a surface water lagoon on site with no discharge off site.

3.0 REQUISITE SURVEILLANCE

3.1 The Risk Based Monitoring Scheme

The hydrogeological risk assessment has been developed based on a risk-based monitoring plan containing both objectives and a sampling plan.

Appropriate assessment and compliance criteria, as well as compliance limits are discussed below.

3.1.1 Leachate Monitoring

Leachate monitoring is not required at inert landfill sites. The only monitoring will be to ensure that no significant head develops above the geological barrier to support the HRA input model.

3.1.2 Groundwater Monitoring

It is essential to monitor groundwater adjacent to the site for quality to assess the integrity of the performance of the site and to ensure that there is no impact on groundwater.

Boreholes are located both up and down hydraulic gradient. Borehole locations are presented on Drawing No ESSD 11 and background groundwater quality collected from these boreholes is summarised in the ESSD.

The nature and location of the groundwater monitoring boreholes is set out on Table HRA 13.

Table HRA 13: Groundwater monitoring points

Perimeter	**BH1**	Perimeter Down Hydraulic Gradient	Level and Quality
Perimeter	**BH2**	Perimeter Middle Hydraulic Gradient	Level
Perimeter	**BH3**	Perimeter Down Hydraulic Gradient	Level
Perimeter	**BH5**	In quarry Up Hydraulic Gradient	Level

It is recommended that the compliance levels are reviewed on an annual basis or as appropriate. If, for example, the trigger levels are exceeded on three consecutive times, then this should be highlighted and discussed within any annual review of monitoring data. Such an occurrence may be the result of contaminant breakthrough or a change in the upgradient groundwater quality. The groundwater sampling regime is set out in the ESSD.

Table HRA 14: Groundwater Monitoring Schedule

Parameter	Landfilling Phase		Closure/ Aftercare Phase
	Quarterly	Six Monthly	Six Monthly
pH	•+	•+	•+
Temperature	•*	•*	•*
Electrical conductivity 20°C	•+	•+	•+
Dissolved oxygen	•+	•+	•+
Ammoniacal nitrogen	•	•	•
Chloride	•	•	•
Sulphate		•	•
Alkalinity		•	•
Sodium		•	•
Potassium		•	•
Calcium		•	•
Magnesium		•	•
Iron		•	•
Manganese		•	•
Cadmium		•	•
Copper		•	•
Chromium		•	•
Lead		•	•
Nickel		•	•
Zinc		•	•
Groundwater level	•	•	•
Hazardous Substance GC-MS scan		Annually for first six years then every four years	

The groundwater compliance limits are presented for groundwaters at Appendix HRA 4 and discussed in Section 3.1.3.

3.1.3 Groundwater Compliance Limits

Groundwater analysis summary spreadsheets and calculations of the compliance limits are presented at Appendix HRA 7 and summarized below as Table HRA 15.

Table HRA 15: Groundwater compliance limits for groundwater and Boreholes BH1 and BH3.

Determinant	BH 1 mg/l	BH 3 mg/l
Ammonia	1.008	0.157
Chloride	23.32	29.08
Sulphate	8	62.44
Cadmium	0.00012	0.00004
Zinc	0.004	0.002

3.1.4 Surface Water Monitoring

There is no surface water monitoring required from the landfill site but will be done for the recycling facility.

4.0 CONCLUSIONS

4.1 Compliance with the Environmental Permitting (England and Wales) Regulations 2016

The inert landfill site operated at Dorrington Quarry landfill complies with the following requirements of the Environmental Permitting (England and Wales) Regulations 2016.

- The geological barrier with an artificial sealing layer complies with the requirements. The present operational phase has a low permeability layer at the base, which acts as the artificial sealing layer. Future phases will have a CQA placed and compacted selective mineral layer to achieve an overall permeability of 1 X 10^{-7}m/s to as low as 1 x 10^{-10}m/s.
- The inert landfill liner to be constructed on all phases of the landfill and will be constructed in accordance with the Construction Quality Assurance Plan.

The summary requirements are set out in Table HRA 16.

Table HRA 16: Liner Requirements

Determinant	Requirement standard
Thickness	1.0m
Permeability	1E-7-1E-9m/s
Fines content	10%
Shear Strength	50kPa

- The compliance of the installation with the specified engineering standards
- The unsaturated zone has been demonstrated to control release of Non-Hazardous polluting substances into groundwater beneath the geological barrier and prevent release of Hazardous substances entering into the groundwater above minimum reporting values
- The derivation of compliance levels for groundwater quality have been set and the modelling and current sampling has shown no release of Hazardous substances and predicts no release of Hazardous substances in the short or long term.
- Non-Hazardous Substances released into the environment are in accordance with the Drinking Water Standards.
- Monitoring strategies are in place and recommended in line with the Environmental Permitting (England and Wales) Regulations 2016 for inert landfill sites.