ENVIRONMENTAL PERMIT VARIATION APPLICATION
HYDROGEOLOGICAL RISK ASSESSMENT

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CONTENTS

1.0 INTRODUCTION 1
1.1 Scope & Background 1

2.0 HYDROGEOLOGCIAL CONCEPTUAL SITE MODEL SUMMARY 2
2.2 Source 2
2.3 Pathways 4
2.4 Receptors 6

3.0 HYDROGEOLOGICAL RISK ASSESSMENT 9
3.1 Nature of the Risk Assessment 9
3.2 Proposed Assessment Scenarios 9
3.3 Technical Precautions 9
3.4 Numerical Modelling 10
3.5 Emissions to Groundwater 13

4.0 REQUISITE SURVEILLANCE 15
4.1 Groundwater Monitoring Schedule 15
4.2 Surface Water Monitoring Schedule 16

5.0 CONCLUSIONS 17
5.1 Summary 17
5.2 Compliance with the Schedule 22 of the Environmental Permitting Regulations 2016 17

REFERENCES 18

LIST OF DRAWINGS

CL5/1	Preliminary Material Movements
CL5/2	Phase 1 Import/Restoration
CL5/3	Phase 2A Import/Restoration
CL5/4	Phase 2B Import/Restoration
CL5/5	Phase 3 Final Restoration
MG1002/14/03	Outline Engineering
MG1002/14/06	Regional Hydrogeology
MG1002/14/07	Conceptual Site Model
MG1002/14/08	Bedrock Geology
MG1002/14/09	Monitoring Points Plan
MG1002/14/11	Water Management Plan

LIST OF APPENDICES

Appendix HRA1 Model Input Parameters
Appendix HRA2 Model files

LIST OF TABLES

Table HRA1: Proposed WAC Leachable Thresholds 3
Table HRA2: Proposed Environmental Assessment Levels 8
Table HRA3: Rogue Load Leachate Source Term Parameters 12
Table HRA4: Accident Risk Assessment 12
Table HRA5: Predicted 95%ile percentile diluted groundwater concentrations of hazardous substances at the edge of the restoration area (monitoring well)..............13
Table HRA6: Predicted 95%ile percentile diluted groundwater concentrations of non-hazardous pollutants at the edge of the restoration area (monitoring well) 14
Table HRA7: Proposed Groundwater Monitoring Schedule...15
Table HRA8: Proposed Groundwater Compliance Limits 15
Table HRA9: Surface Monitoring Schedule 16

1.0 INTRODUCTION

1.1 Scope & Background

1.1.1 Sirius Environmental Limited (Sirius) has been commissioned by Mick George Limited to prepare a Hydrogeological Risk Assessment (HRA) in support of an application to vary the Environment Permit held to support the restoration of Cross Leys Quarry, Thornhaugh, Peterborough.

1.1.2 Mick George Ltd are seeking to re-focus the waste recovery operations from the south-eastern section of the former mineral workings to the northwest of the pipeline corridor that bisects the site. The new focus area includes the area partially restored via previous Paragraph 9 exemptions.

1.1.3 The revised restoration scheme has been designed in order to preserve and enhance biodiversity and habitats within the southern section. The revised plans would still retain an element of the approved scheme, with the northern area remaining agricultural.

1.1.4 To achieve agricultural restoration in the northern section of the site, the proposal seeks to import around 395,000m^3 of inert restoration materials to raise the levels within the quarry void to create a gentle domed profile which would improve the surface water drainage and resultantly provide a superior quality of agricultural grazing land.

1.1.5 A full description of the conceptual site model is detailed in the Environmental Setting and Site Design (ESSD) Report (Doc. Ref.: MG1002/06) prepared in the support of the application. A summary of the CSM developed in the ESSD is included in **Section 2.0**.

2.0 HYDROGEOLOGCIAL CONCEPTUAL SITE MODEL SUMMARY

2.1.1 This section will provide an overview of the Hydrogeological Conceptual Site Model (CSM) for Cross Leys Quarry. A full description of the CSM can be found in the ESSD report prepared in support of this application.

2.2 Source

Site Design and Construction

2.2.1 The recovery operation is currently permitted on the edges of the pipeline buffer bund and the south-eastern section of the quarry. The future waste operations will support the restoration of the north-western section of the quarry to agriculture.

2.2.2 The waste to be deposited within the quarry void will be inert in nature and comprise mineral, construction demolition and excavation wastes (e.g. bricks, ceramics, tiles and concrete, quarry fines/wastes, soils and stones). A full list of wastes is presented in Appendix 1 to the ESSD Report.

2.2.3 To achieve agricultural restoration in the northern section of the site it is estimated that the infilling of the site will require the import and deposit of c. 395,000m^3 (or *c.*790,000 tonnes) of suitable fill material over an anticipated period of between 2 and 10 years, depending on material availability. It is proposed that up to 400,000 tonnes of waste will be imported to the site each year. Restoration will be completed in five distinct phases, including a preliminary materials movement phase and four importation and restoration phases. The details of each of the phases are presented in **Drawing Nos: CL 3/1 to CL 3/5**.

2.2.4 A large proportion of the northernmost section future operation area has already received restoration materials, including site-won materials and wastes previously imported under historic Paragraph 9 exemptions. These areas will be re-graded, and a final restoration soil profile created mainly using a site-won topsoil and subsoils that were stockpiled as part of the former mineral related activities. Suitable imported waste subsoils and topsoil may be used to supplement these site-won materials if necessary.

2.2.5 Future imported wastes will mainly be used to infill the central and eastern section of the future restoration area, with a limited number of wastes also likely to be required to supplement site-based topsoil and sub-soil/overburden materials to create the final restoration soil profile across all areas of the restoration footprint.

2.2.6 The basal level of the central quarry void is approximately 65mAOD, extending to below the water table to ~62.5mAOD in the western and southern edges. The preliminary works will extend to the transfer of existing site-won material stockpiles and crushed concrete from breaking of engineered site surfacing associated with the former mineral activities. These materials will be used to infill the deepest areas of the area located along the western and southern edges of the quarry to a level at least 1m above the water table (>65.5mAOD). final levels in these areas will be subsequently restored to final levels using import wastes. The final restoration profile will range between 70mAOD along the periphery of the restoration void areas to ~75mAOD within the central region, as illustrated on **Drawing No: CL 3/5.** The restoration materials will range between ~5 and ~11 metres in thickness.

<u>Waste Acceptance Criteria</u>

2.2.7 Only inert wastes will be imported to support the restoration of the quarry. The definition of inert adopted for this waste recovery activity has been taken from that presented in the Landfill Directive (LFD), which is:

> *"Waste that does not undergo any significant physical, chemical, or biological transformations. It will not dissolve or otherwise physically or chemically react, biodegrade, or adversely affect other matter with which it comes into contact in a way likely to give way to environmental pollution of harm human health. The total leachability and pollutant content of the waste and the ecotoxicity of the leachate must be insignificant, and in particular not endanger the quality of surface water and/or groundwater."*

2.2.8 The total leachability and pollutant content of the wastes, and the ecotoxicity of the leachate must be insignificant and in particular not endanger the quality of groundwater.

2.2.9 The Waste Acceptance Criteria (WAC) proposed for the waste recovery operations have been based on the limits set out for inert waste landfills under the Council Decision of 19th December 2002 (2003/33/EC), increased by up to 3 times where the risk factors are sufficiently low whereby dilution alone will. These threshold limits define the upper limits to the leachable and pollutant content of the wastes for deposit at the site. Leachable concentrations are determined by a ratio of 10 litres of distilled water to 1 kg of waste, with the result quoted as concentration per unit of mass i.e., mg/kg. The WAC leachable limits proposed of the site and their equivalent concentration per liquid volume are presented in **Table HRA1**, together with the equivalent risk factors relative to baseline groundwater quality.

Table HRA1: Proposed WAC Leachable Thresholds

Parameter	Inert Waste WAC (L/S 10L/S 10l/kg) [mg/kg]	Equivalent Liquid Concentration [mg/l]	EAL (mg/l)	Risk Factor
Arsenic	1.5	0.15	0.005	30
Cadmium	0.04	0.004	0.00015	26.7
Chloride	2400	240	100	2.4
Chromium	0.5	0.05	0.001	50
Copper	2	0.2	0.0046	43.5
Fluoride	30	3	0.65	4.6
Lead	0.5	0.05	0.0002	250
Nickel	1.2	0.12	0.0045	27
Selenium	0.3	0.03	0.002	15
Sulphate	3,000	300	250	1.2
Zinc	12	1.2	0.034	35.3

2.2.10 As restoration activities progress across the site, run-off from engineered and wastes filled areas will be directed to the surface infiltration ponds located in the north-western and south-western corners of the site (refer to **Drawing Nos. CL3/1-3/5**). These ponds will be in hydraulic continuity with groundwater in the underlying limestone aquifer.

<u>Attenuation Layer</u>

2.2.11 Due to the limited attenuation capacity of the underlying limestone strata any basal areas where waste will be deposited over less then 0.5m of existing deposits of waste or quarry fines/waste materials, will be engineered with an attenuation layer. The attenuation layer will be constructed to a minimum thickness of 500mm to achieve a maximum permeability of $1x10^{-7}$m/s. The estimated footprint of quarry void that will require the construction of an attenuation layer is depicted in **Drawing No. MG1002/14/03.** This footprint amounts to ~2.1Ha requiring the importation of ~10,500m^3 (c. 18,000 tonnes) of suitable material.

2.2.12 This attenuation layer will be constructed using suitable imported cohesive waste soils or similar wastes. Due to the anticipated quantity of soils necessary to construct the attenuation layer it is likely that the materials will be sourced from several sources.

2.2.13 The wastes used to construct the attenuation layer will be selected based on source evaluation of the materials, including assessment of their physical, chemical and biological characteristics. As with the restoration wastes, the materials used to construct the attenuation layer will comprise inert cohesive wastes. Materials will mainly be sourced from sites with a low contaminative use risk e.g. soils from greenfield or low-risk brownfield development site. Any suspected contaminative history would invoke chemical testing to demonstrate that they are not hazardous and meet with inert criteria defined under the Council Decision of 19th December 2002 (2003/33/EC).

2.3 Pathways

<u>Geology</u>

2.3.1 A review of the British Geological Society (BGS) Geology of Britain Viewer[1] determines the bedrock underlying the site comprises Lincolnshire Limestone. The south-eastern area of the quarry is underlain by the upper Lincolnshire Limestone Member which overlies the Lower Lincolnshire Limestone Member as observed in the north-western area of the quarry. An overview of the regional bedrock geology is depicted on **Drawing No.: MG1002/14/08.** A summary of the regional geology presented in **Table ESSD3** to the accompanying ESSD Report *(Doc. Ref.: MG1002/06*).

2.3.2 The basal beds rest quasi-conformably on the Grantham Formation which comprise of mudstones, sandy mudstone, and argillaceous siltstone-sandstones, which are subsequently underlain by the Northampton Sand Formation (Sandstones and Ironstones) and the Whitby Formation (Lias Clay). The Rutland Formation outcrops along the southern boundary of the site and beneath Wittering Coppice to the south-west. Regionally the limestones dip at an angle of approximately 1 degree to the east.

2.3.3 BGS exploratory hole logs identify the presence of 3.5-5m of brown/running sands at the boundary between Limestone Lower Lincolnshire Limestone Formation and Grantham Formation. These sands are likely to be in hydraulic continuity with the limestone aquifer. Based on the descriptions provided in the available boreholes logs, it has not be possible to accurately defined if these sands are wholly or partially part of the Lincolnshire Limestone Formation or Grantham Formation, they are in hydraulic continuity with the groundwater recorded across the quarry.

2.3.4 BGS boreholes logs from around the perimeter of the quarry and the borehole log for the historic on-site water supply well (WS1) indicates that the Limestone and underlying Grantham Formation, Northampton Sand and Whitby Formation dip to the east/southeast, with the base of the limestone (marked by basal

[1] BGS Geology of Britain Viewer *(Accessed 13/11/2020)* http://mapapps.bgs.ac.uk/geologyofbritain/home.html

sands) at around 58 mAOD along the northern boundary of the quarry (c. 7m thick) to around 53 mAOD (c. 10m thick) along the south eastern boundary. To the south of the quarry the limestone strata dips beneath clays of the Rutland formation. To the south of the quarry the limestone strata dips beneath clay deposits of the Rutland formation. Details of the geology from boreholes surrounding the site are summarised in the ESSD.

Aquifer Characteristics

2.3.5 The EA classify the Rutland Formation as a '*Secondary B Aquifer'*; the Lincolnshire Limestone series as a '*Principal Aquifer'*; whilst the underlying Grantham Formation is classified as a '*Secondary (Undifferentiated) Aquifer'*.

2.3.6 BGS mapping confirms that the limestone beneath the application site is classified as a highly productive aquifer. The limestone is characterised by a low intergranular porosity (13% - 21%) and corresponding low permeability of around $3x10^{-4}$m/d, because of this groundwater flow is primarily through fractures which have been developed by karstic weathering. These fractures are typically located within the upper 30m of the aquifer unit.

2.3.7 It is reported that the transmissivity of the limestone can often exceed 1,000 m^2/day and can be as high as 5,000 to 10,000 m^2/day. Highest transmissivities are typically found within the confined limestone (where it dips beneath the Rutland Formation) and are likely to be lower in unconfined aquifers such as at the site. For the unconfined limestone the transmissivity has been modelled as 100-250m^2/day (Rushton, 1975).

2.3.8 Literature values of the matric porosity have been recorded as 13-18%, the fracture porosity which is of importance to the aquifer is estimated to be approximately 1% (Allen, et. al, 1997).

2.3.9 The underlying Grantham Formation typically acts as an aquitard between the limestone aquifer and the underlying Northampton Sand Formation. However, where the Grantham Formation is thin hydraulic continuity between the two units can be expected. Available boreholes logs suggest the "black clay" associated with the Grantham Formation is between 0.3m and 1m in thickness which indicates that there is potential for some connection between the two units. BGS logs located around the periphery of the site also identify the present of between 3.5-5m of brown or running sands at the boundary between the Lower Lincolnshire Limestone and Grantham Formation. These sands are likely to be in hydraulic continuity with the limestone aquifer.

2.3.10 Groundwater vulnerability at the application site is identified by the EA as "Major Aquifer High". The site does not lie within a groundwater Source Protection Zone (SPZ).

2.3.11 A pumping test was undertaken in support of an abstraction license application in September 1999 (Bardon Aggregates, 1999) for a water supply for the quarry. The results of this pumping test have been used to estimate the in-situ permeability of the limestone near Cross Leys Quarry. The results and analysis of the pumping test are appended to the ESSD Report. These indicate the following range of permeabilities:

- Pump Test (Theis): $2.5x10^{-5}$ m/sec (2.21m/day)
- Rising Head Test 1 (Bouwer & Rice): $1.17x10^{-4}$m/sec (10.11m/day)
- Rising Head Test 2 (Bouwer & Rice): $1.65x10^{-5}$m/sec (1.42m/day)

2.3.12 The pumping test data and the proven borehole yield (0.15 l/s) indicates that the limestone beneath Cross Leys Quarry has a relatively high permeability. A review of the well logs and water levels recorded during the test indicates that these permeability values are representative of the basal sands and not the solid limestone strata. The transmissivity value of 6.3m^2/d derived from WS1 is significantly lower than the anticipated transmittivity values for the solid limestone strata of 100-250 m^2/d.

Groundwater Levels and Flows

2.3.13 Groundwater flow follows the regional dip of the strata in an easterly direction with monitoring water levels indicating a hydraulic gradient of ~0.01.

2.3.14 The saturated thickness of the unconfined limestone can be highly variable due to the rapid response to rainfall recharge. The data from 2021-2024 indicates that the average saturated depth of the aquifer is typically ~6.5m beneath at the north edge of the quarry increasing to ~8.5m in the southern edges. The presence of ~3.5 to 5m of brown/running sands at the boundary between Lower Lincolnshire Limestone Formation and Grantham Formation would indicate that a proportion of groundwater flow occurs through the basal sands with the remaining flow through the secondary permeable features of hard limestone strata.

2.4 Receptors

2.4.1 Potential receptors of waterborne contaminants from Cross Leys Quarry are:

- Groundwater Resources (including abstractions)
- Surface water

Groundwater

2.4.2 The groundwater within the Upper Lincolnshire Limestone forms the primary receptor to potential pollutants that may be released as a consequence of the waste recovery operations. This groundwater resource is currently used as a supply for numerous licensed and private abstractions. The nearest groundwater abstractions are located ~420m south and ~1.6km north of the edge of the future operational area although these are not located downgradient of the quarry relative to the direction of groundwater flow and so not deemed to be receptor to the waste recovery activity. Another groundwater abstraction is located at Rose Lodge located ~2km to the southeast of the quarry, which whilst is downgradient of the operational area of the site, the substantial distance between the two locations renders the risk to this receptor insignificant. Two private abstractions are also located ~2km and ~2.3km to the southeast from the edge of the proposed operational area and once again not deemed at any significant risk due to the distance between them and the site.

2.4.3 The locations of these abstractions relative to the site are shown on **Drawing No.: MG1002/14/06**.

2.4.4 For hazardous substances and non-hazardous pollutants the point of compliance will be downgradient edge of the future restoration area.

Groundwater Quality

2.4.5 The BGS Baseline Report for the Lincolnshire Limestone (Griffiths et al, 2006) indicates the groundwater is mainly of the Ca-HCO3-SO4-Cl water type. The water quality in the unconfined aquifer at is typically hard (high in mineral content; particularly calcium, carbonate, and sulphate) and becomes progressively softer towards the east as the aquifer becomes confined by clay.

2.4.6 Conversely, the unconfined aquifer typically records low concentrations of trace metals, which typically increase down dip as the aquifer becomes confined.

2.4.7 Typical groundwater chemistry for key determinands within the unconfined Lincolnshire Limestone, as presented within the baseline series report, is summarised in Table ESSD10 of the supporting ESSD Report *(Doc. Ref.: MG1002/06),* with monitored background concentrations at the quarry summarised in Table ESSD11.

2.4.8 The average concentrations for each variable recorded from groundwater quality monitoring undertaken from Cross Leys quarry are generally comparable to or below those presented in the baseline groundwater quality recorded for unconfined Lincolnshire Limestone concentrations within the region. The only exceptions to this are chromium and iron concentrations in the groundwater recorded from all boreholes on site, as well as the average sodium in BH3 and sulphate in BH3 and BH1A which exceed their respective regional median values in. Regardless of this, none of the variables monitored on site exceed their respective UK Drinking Water standards (where standards exist).

<u>Surface Water</u>

2.4.9 As discussed within the hydrology section, the Quarry lies within the sub-catchment of the River Nene, an EA Main River situated c. 4.5km to the south-east of the site at its closest. The quarry lies within the sub-catchment of Wittering Brook, although the direction of groundwater flow beneath the site is to the ESE, where any contribution to river baseflow limited to the east of Bedford Purlieus, where surface elevations reduce significantly beyond the edge of the Rutland Formation and Upper Lincolnshire Limestone formation into the Cooks Hole Quarry. Groundwater will also provide flow in this location via the spring at Cook's Hole, located approximately 2.5km ESE of the site. Protection of groundwater quality close to the quarry is considered provide sufficient protection to surface water quality to the tributary of the River Nene that flows in the vicinity of Cook's Hole.

<u>Environmental Assessment Levels</u>

2.4.10 The setting of Environmental Assessment Levels (EALs) is necessary in order to access whether the requirements of the Environmental Permitting Regulations 2016 are likely to be met.

2.4.11 For Hazardous Substances, to demonstrate that a discernible input to groundwater has been prevented the EALs have been set the highest of either the Minimum Reporting Value/Limit Of Quantification or the baseline groundwater concentration.

2.4.12 For Non-Hazardous Pollutants, the EALs has been derived to prevent any significant deterioration of the groundwater quality. The following principles have therefore been adopted fo the selection of EALs for non-hazardous pollutants:-

- Where the baseline groundwater quality is less than 75% of the DWS, the EAL is set at the 25% above the baseline concentration;
- Where the baseline groundwater quality is more than 75% of the DWS and less than the DWS, the EAL is set at the DWS; and

- Where the baseline groundwater quality is greater than the DWS, the EAL is set at the maximum recorded groundwater concentration.

2.4.13 A summary of the proposed EALs is presented in **Table HRA7.**

Table HRA2: Proposed Environmental Assessment Levels

Parameter	MRV/LoQ	DWS/EQS	Background Concentrations	Proposed EAL
Hazardous Substances				
Arsenic	0.005	0.01 / 0.05	0.0006[a]	0.005
Lead	0.0002	0.01	<0.0005	0.0002
Non-Hazardous Pollutants				
Ammoniacal Nitrogen	-	0.39 / -	1.4	1.4
Cadmium	-	0.005 / 0.00025	<0.00011	<0.00011
Chloride	-	250 / 250	74	100
Chromium	-	0.05 / 0.0047	0.00083	0.001
Copper	-	2 / *0.001*[b]	0.0037	0.0046
Fluoride	-	1.5 / 5	0.52[a]	0.65
Nickel	-	0.02 / 0.034[c]	0.0045	0.0056
Selenium	-	0.01 / -	0.0014	0.002
Sulphate	-	- / 400	200[e]	250
Zinc	-	5[d] / 10.9 [b]	0.029	0.034

[a] – based on the 97.7th percentile regional concentration specified in Griffiths et al, 2006.
[b] – bioavailable fraction only
[c] – Maximum Allowable Concentration
[d] – recommended DWS for aesthetic effects
[e] – elevated concentration recorded in BH1A have not used due to potential influence from an external source.

3.0 HYDROGEOLOGICAL RISK ASSESSMENT

3.1 Nature of the Risk Assessment

3.1.1 As set out within the Environment Agency's guidance for "Waste recovery plans and deposit for recovery permits" (June 2023), a tiered approach must be used is assessing the risk to the hydrogeological environment. This means that the greater the risk of pollution, the more complex an assessment you must carry out. Where the activity is located in the sensitive location a quantitative risk assessment may also be required.

3.1.2 The site will accept inert waste, which is defined as follows;

- it does not undergo any significant physical, chemical or biological transformations;
- it does not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm to human health; and
- total leachability, pollutant content and the ecotoxicity of its leachate are insignificant and, in particular, do not endanger the quality of any surface water or groundwater.

3.1.3 Based on this definition of inert waste, the site should not produce any leachate that could result in any significant discharge of Hazardous Substances or Non-Hazardous Pollutants throughout the lifecycle of the site.

3.1.4 However, notwithstanding the above, it is considered that a quantitative risk assessment is required given sensitive nature of the local hydrogeological setting i.e. Principal Aquifer with limit natural attenuation capacity and a proven groundwater resource potential locally.

3.1.5 In order to assess the risk to the environment, it is considered appropriate to assess the potential worst-case leachate quality that could potentially be generated based on the proposed Waste Acceptance Criteria and the deposit of a rogue load at the site.

3.2 Proposed Assessment Scenarios

3.2.1 Based on the Conceptual Site Model outlined in **Section 2.0** it is considered appropriate to assess the potential risk to groundwater within the underlying limestone aquifer and basal sands.

3.2.2 The assessment considers risk from the active tipping phase and post-restoration phase of the recovery activity. The assessment also considers the potential risk from the deposit of a rogue load at the site.

3.2.3 There are no degradable engineering solutions or long-term changes in groundwater levels anticipated that need to be considered by the risk assessment.

3.3 Technical Precautions

<u>Capping</u>

3.3.1 There is no requirement to limit the infiltration of waters through the surface of the waste deposits. No surface capping will therefore be constructed.

Basal Lining Design

3.3.2 In areas where wastes are deposited upon bare limestone an attenuation layer will need to be constructed as shown on **Drawing No.: MG1002/14/03.** The attenuation layer will be constructed at a thickness of 0.5m with a max permeability of $1x10^{-7}$m/s.

Surface Water Run-Off Control

3.3.3 As areas of the site are engineered and filled are achieved any run-off will be collected by a network of perimeter ditches that will drain to infiltration lagoons that will form part of the final restoration scheme.

Groundwater Management

3.3.4 All imported wastes to support the quarry restoration will be deposited above the water table. The flooded areas along the western edges of the quarry will be infilled (excluding a small section to be retained as part of the restoration scheme) during the preliminary restoration phase using site-won materials only. No groundwater management will therefore be necessary to support the restoration activities.

3.4 Numerical Modelling

Justification for Modelling Approach and Software

Dilution Assessment

3.4.1 An initial assessment or risk posed by the deposits of inert wastes has been taken using generic quantitative assessment methods. This method incorporates a review of the potential flow in the underlying aquifer and potential leakage rates (based on infiltration through the waste mass) to determine the dilution available to determine the risk posed by the leachable concentrations of potential pollutants form the inert wastes.

Rogue Load Assessment

3.4.2 As assessment of the risk posed by the deposit of a rogue load at the site has been carried out using conservative assumptions regarding the source, pathways and receptors. Site specific data have been used wherever possible to parameterise the risk assessment.

3.4.3 The Environment Agency's LandSim software (version 2.5.17) has been used to provide an estimate of the potential risks associated with the proposed site. This software was used for the following reasons:-

- it uses Monte Carlo (stochastic) techniques and so allows a probabilistic appreciation of the site's performance;
- it provides a consistent approach to the estimation of hydrogeological risks;
- it provides an audited and verified code that is widely accessible;
- it allows the estimation of the potential attenuation of contaminants through the mineral element of the liner;
- it allows dilution of contaminants in the saturated zone;
- it allows the attenuation of Non-Hazardous Pollutants within the saturated horizon; and
- it aids comprehensive reporting of input values, assumptions and results.

3.4.4 All modelling carried out for this risk assessment has been carried out in a stochastic fashion. Throughout this assessment the acceptable probability of an undesirable outcome occurring is set at the 95%ile for stochastic estimations carried out for a complex hydrogeological risk assessment. In addition, the 95%ile is commonly selected as a reasonable worst case, against which it is acceptable to make decisions taking into account the assumptions and limitations of the modelling process.

Model Parameterisation

Dilution Assessment

3.4.5 The conceptual model identifies the groundwater flow beneath the site occurs within basal sands (~3.5-5m thick) and the overlying competent limestone. Intergranular flow is likely to dominant within the basal sands whilst fracture flow dominates in the overlying limestone. The over saturated depth is between ~6.5m and ~8.5m.

3.4.6 Based on Darcy's law the flow within the basal sands and limestone immediately below the base of the site is calculated to be:

$$Q = kiA$$

Where for the basal sands:-

k = 4.32m/day

i = 0.01 (groundwater contours)

A = 4.25m (average basal sands thickness) x 375m (width of perpendicular to groundwater flow)

Q = 68.9m^3/day

And where for the limestone:-

k = 53.8m/day (transmissivity of 175m^2/d divided by average saturated thickness of limestone – 3.25m)

i = 0.01 (groundwater contours)

A = 3.25m (average saturated thickness of limestone) x 375m (width of perpendicular to groundwater flow)

Q = 655.7m^3/day

Weighted mean ground water flow beneath the quarry:-

$$\frac{(68.9m^3/day \times 4.25m) + (655.7m^3/day \times 3.25m)}{7.5m}$$

Q = 323.2m^3/day.

3.4.7 Under steady state conditions, the potential leakage from the site will be controlled by the infiltration through the overlying restoration soils.

3.4.8 Based on the long term annual rainfall figures taken from Met Office climate data 1991-2020 from RAF Wittering located to the north of the site of 613.6mm and a potential evaporation rates for MORECS square 127 are between 600-710mm/yr. Allowing for a 20% increase in rainfall due to climate change and a run-off coefficient of 0.53 (SLR, 2018) the potential infiltration rate is calculated at ~38mm/yr. The principal void footprint that will receive a thickness of more than ~2m of imported waste fill equates ~7.5Ha. The leakage rate across this footprint equates to **~7.8m^3/day.**

3.4.9 The groundwater flow beneath the site is approximately **41.4** times that of the volume of leakage from the waste deposits.

3.4.10 Using the risk factors risk factors presented in **Table HRA1**, the proposed waste acceptance thresholds for most substances will be adequately attenuated through dilution alone. The exception is lead, which has been taken forward for further quantitative assessment in the event of the deposit of a roque load.

Rogue Load Assessment

3.4.11 The 'leachate' source term parameters adopted for the assessment of the deposit of a rogue load at the site are based on a conservative range of concentrations derived by the EA from a review of inert waste datasets. These parameters are adopted from the possible range of leachate quality values identified by the EA for high sensitivity sites. The source term parameters utilised in the Rogue Load Modelling is present in **Table HRA7.**

Table HRA3: Rogue Load Leachate Source Term Parameters

Substance	Modelled Source Term Range (mg/l)		
	Minimum	Most Likely	Maximum
Ammoniacal Nitrogen	0.3	8	25
Lead	0.002	0.007	0.05
Sulphate	200	1200	1800

3.4.12 Full details of the model input parameters and justifications are presented in **Appendix HRA1.**

Accidents and their Consequences

3.4.13 Details of accidental occurrences at the site that could present a potential risk to groundwater adjacent to the site are provided in **Table HRA8.**

Table HRA4: Accident Risk Assessment

Hazard	Risk to Groundwater	Likelihood	Mitigation and Corrective Measures
Deposition of non-inert wastes	Generation of leachate containing Hazardous Substances or Non-Hazardous Pollutants.	**Low** – due to the essential and technical precautions.	Appropriate characterisation of wastes prior to delivery to the site will be provided by the customer, with the appropriate verification checks/tests performed wastes by the operator. Any incorrectly accepted wastes will be immediately returned to the customer or moved to a suitable storage area prior to removal to a suitable site.

Hazard	Risk to Groundwater	Likelihood	Mitigation and Corrective Measures
Spillage of fuels from storage tanks or vehicles.	Release of hydrocarbons (Hazardous Substances) into the ground and migration to groundwater.	**Low** – fuel stores will be bunded in accordance with regulation requirements. A traffic management system and speed limit will be imposed at the site to reduce both the risk of accidents and the likelihood of spillage occurring.	Any spillage will be cleaned up immediately and any resulting contaminated soils removed to a suitable installation.

3.4.14 With respect to the deposition of potentially contaminated wastes, it is considered that the risks and potential consequences of such accidents are extremely low for the following reasons:-

- all waste deliveries will be pre-arranged and come from known sources to ensure no contaminated material is delivered;
- if deemed necessary, characterisation testing will be undertaken to demonstrate that the waste will not give rise to polluting leachate, prior to the acceptance of waste at the site;
- if deemed necessary compliance testing will be undertaken to ensure the continued acceptability of the waste stream;
- visual inspection will be undertaken of every waste load deposited at the site; and
- in the event of suspicion regarding the acceptability of the waste, quarantine procedures will be enforced.

3.4.15 In the unlikely event of contaminants from a rogue load being deposited at the site, attenuation processes will occur within the waste body, and most organic hazardous substances are very likely to be degraded and/or retarded during migration through the surrounding inert wastes within the site and the attenuation layer.

3.4.16 Other processes such as volatilisation can also be expected for volatile and semi-volatile organic substances resulting in a loss of contaminant from the waste.

3.5 Emissions to Groundwater

3.5.1 A copy of the model files are presented in **Appendix HRA2.**

3.5.2 The model also notified of a decrease in leakage rate during the simulation. This decrease is due to the increase evapotranspiration following the establishment of vegetation across the site after a period of 5 years, which has been accounted for in the infiltration input parameters. This decrease if there acceptable and representative of the field conditions likely to be experienced.

Hazardous Substances

3.5.3 The predicted 95th percentile diluted groundwater concentrations of Hazardous Substances are presented in **Table HRA5.**

Table HRA5: Predicted 95%ile percentile diluted groundwater concentrations of hazardous substances at the edge of the restoration area (monitoring well)

Substances	EAL	Predicted Concentration (95th %ile)
Lead (mg/l)	0.0002	<0.00002

3.5.4 The model shows that the restoration of the quarry will not result in the discernible input of hazardous substances to groundwater.

Non-hazardous pollutants

3.5.5 The predicted diluted groundwater concentrations of non-hazardous pollutants are presented in **Table HRA6.**

Table HRA6: Predicted 95%ile percentile diluted groundwater concentrations of non-hazardous pollutants at the edge of the restoration area (monitoring well)

Substances	EAL	Predicted Concentration (95th %ile)
Ammoniacal Nitrogen (mgN/l)	1.4	0.77
Sulphate (mg/l)	250	175

3.5.6 The model shows that the restoration of the quarry will limit the input of non-hazardous pollutants to avoid pollution.

4.0 REQUISITE SURVEILLANCE

4.1 Groundwater Monitoring Schedule

4.1.1 The proposed groundwater monitoring schedule for Cross Leys Quarry is presented below in **Table HRA11**.

Table HRA7: Proposed Groundwater Monitoring Schedule

Monitoring Point	Parameter[1]	Frequency
Upgradient Monitoring Boreholes: BH1A	Water Level, Electrical Conductivity, Chloride, Ammoniacal Nitrogen, pH, Sulphate, Lead	Quarterly
	Magnesium, Potassium, Calcium, Sodium, Iron, Manganese, Total Alkalinity, Arsenic, Nickel, Sulphate, Cadmium, Chromium, Copper, Fluoride, Mercury, Selenium and Zinc	Annually
	Hazardous substances: Benzene, Toluene, Ethyl Benzene, Xylene, Polycyclic Aromatic Hydrocarbons (PAH)	Annually for the first six years of operation then every two years
Down and cross-gradient Monitoring Boreholes: BH2, BH3, BH3A, WS1	Water Level, Electrical Conductivity, Chloride, Ammoniacal Nitrogen, pH, Sulphate, Lead	Quarterly
	Magnesium, Potassium, Calcium, Sodium, Iron, Manganese, Total Alkalinity, Arsenic, Nickel, Sulphate, Cadmium, Chromium, Copper, Fluoride, Mercury, Selenium and Zinc	Annually
	Hazardous substances: Benzene, Toluene, Ethyl Benzene, Xylene, Polycyclic Aromatic Hydrocarbons (PAH)	Annually for the first six years of operation then every two years
All Perimeter Monitoring Boreholes	Base of Monitoring Point (mAOD)	Annually

[1] – metals will be analysed for their dissolved concentrations only

4.1.2 The proposed groundwater compliance limits are presented in **Table HRA12.** These are set at 25% above the maximum recorded baseline concentrations recorded in each borehole for chloride and sulphate. For ammoniacal nitrogen the limits are set at the maximum recorded baseline concentrations (excluding statistical outliers). The limits for lead are set at the method limit of detection returned during baseline monitoring to determine any increase in concentrations.

Table HRA8: Proposed Groundwater Compliance Limits

Monitoring Point	Parameter	Compliance Limit
BH2	Ammoniacal Nitrogen mgN/l)	1.4
	Lead (ug/l)	0.5
	Chloride (mg/l)	90
	Sulphate (mg/l)	225
BH3	Ammoniacal Nitrogen mgN/l)	0.93
	Lead (ug/l)	0.5
	Chloride (mg/l)	93
	Sulphate (mg/l)	288

Monitoring Point	Parameter	Compliance Limit
BH3A	Ammoniacal Nitrogen mgN/l)	0.86
	Lead (ug/l)	0.5
	Chloride (mg/l)	83
	Sulphate (mg/l)	250

4.2 Surface Water Monitoring Schedule

4.2.1 The proposed surface water monitoring schedule for Cross Leys Quarry is presented below in **Table HRA13.** The location of the monitoring points are presented in **Drawing No. MG1002/14/09.**

Table HRA9: Surface Monitoring Schedule

Monitoring Point	Parameter[1]	Frequency
SW1, SW2 and SW3 (as each pond is developed)	Ammoniacal Nitrogen, Chloride, Suspended Solids, Visual Oil and Grease, pH, Electrical Conductivity	Monthly
	Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Zinc	Quarterly

[1] – metals will be analysed for their dissolved concentrations only

5.0 CONCLUSIONS

5.1 Summary

5.1.1 This Hydrogeological Risk Assessment has been undertaken in line with the Environment Agency guidance on “Groundwater risk assessment for your environmental permit”.

5.1.2 The purpose of this HRA is to assess the potential impact associated with the scheme of restoration for the north-western section of Cross Leys Quarry via the permanent deposit of wastes

5.2 Compliance with the Schedule 22 of the Environmental Permitting Regulations 2016

5.2.1 The results of this risk assessment have established the proposed waste recovery operations will comply with the relevant requirements of Schedule 22 to the EPR2016 as follows:

- this assessment forms a review of the “prior investigation” that must be carried out for this type of development;
- the proposed technical precautions are considered appropriate and reasonable to prevent the potential entry of Hazardous Substances into groundwater throughout the lifecycle of the facility;
- the proposed technical precautions will limit the introduction of Non-hazardous Pollutants into groundwater to avoid pollution throughout the lifecycle of the facility; and
- groundwater and surface water monitoring schedules will be used in accordance with the requisite surveillance requirements of the Schedule 22 to the EPR2016.

REFERENCES

Allen DJ, Brewerton LJ, Coleby LM, Gibbs BR, Lewis MA, MacDonald AM, Wagstaff SJ and Williams AT., 1997. *The physical properties of major aquifers in England and Wales*. British Geological Technical Report WD/97/34 312pp. Environment Agency RD Publication 8.

Griffiths KJ, Shand P, Marchant P, and Peach (2006). *Baseline Report Series 23: The Lincolnshire Limestone.* British Geological Survey Commissioned Report No. CR/06/060N.

Rushton, K.R. 1975. Aquifer analysis of the Lincolnshire Limestone using mathematical models. J.Inst. Water Engr and Sci. 29 (8), 373-390.

SLR Consulting (2001) *Cross Leys Quarry: Review of Mineral Permissions under the Review of Mineral Permissions under the Environment Act 1995 Application for Determination of Conditions – Environmental Statement*. Ref 4C/275/001 (March 2001).

SLR Consulting, 2018*. Cross Leys Quarry: Flood Risk Assessment & Drainage Strategy*. Report Ref.: 403-00275-00233 Version no:1; November 2018.

Sheppard S, Sohlenius G, Omberg L-G, Boorgiel M, Grolander S, and Norden S (2011). *Solid/liquid partition coefficients (Kd) and plant/soil concentration ratios (CR) for selected soils, tills and sediments at Forsmark.*

DRAWINGS

APPENDICES

APPENDIX HRA1

Model Input Parameters

Calculation Settings

Number of iterations: 1001

Results calculated using sampled PDFs

Full Calculation

Clay Liner:

Retarded values used for simulation

Biodegradation

Unsaturated Pathway:

Unretarded values used for simulation

Biodegradation

Saturated Vertical Pathway:

No Vertical Pathway

Aquifer Pathway:

Unretarded values used for simulation

Biodegradation

Timeslices at: 3, 10, 30, 100

Decline in Contaminant Concentration in Leachate

Ammoniacal_N
c (kg/l): 0.59

Non-Volatile
m (kg/l): 0

Lead
c (kg/l): 0.0171

Non-Volatile
m (kg/l): 0.0443

Sulphate
c (kg/l): 0.1209

Non-Volatile
m (kg/l): 0.0166

Contaminant Half-lives (years)

Unsaturated Pathway:

Sulphate	SINGLE(1e+009)

Aquifer Pathway:

Sulphate	SINGLE(1e+009)

Background Concentrations of Contaminants

Justification for Contaminant Properties

Amm N degradation from Buss et al (2004)

Baseline groundwater concentrations derived from baselline monitoring data.

All units in milligrams per litre

Ammoniacal_N	LOGTRIANGULAR(0.04,0.16,1.4)
Sulphate	TRIANGULAR(36,110,200)

Phase: Cross Leys Quarry

Infiltration Information

Cap design infiltration (mm/year):	NORMAL(38,5)
Infiltration to waste (mm/year):	NORMAL(38.5,5)
End of filling (years from start of waste deposit):	5

Justification for Specified Infiltration

Based on annaul average rainfall value of 613.6mm/yr from RAF Wittering (1991-2020), a potential evaporation rate of 655mm/yr derived from the range of vlaues for MORECS sqaure 127, and a run-off coefficient of 0.53 (SLR,2018).

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

Cell dimensions

Cell width (m):	100
Cell length (m):	210
Cell top area (ha):	2.3
Cell base area (ha):	2.1
Number of cells:	1
Total base area (ha):	2.1
Total top area (ha):	2.3
Head of Leachate when surface water breakout occurs (m)	SINGLE(5)
Waste porosity (fraction)	UNIFORM(0.05,0.3)
Final waste thickness (m):	UNIFORM(5,11)
Field capacity (fraction):	UNIFORM(0.03,0.05)
Waste dry density (kg/l)	LOGUNIFORM(1.2,2)

Justification for Landfill Geometry

Based of estimated extent of engineered basal area

Source concentrations of contaminants

All units in milligrams per litre

Declining source term

Ammoniacal_N	LOGTRIANGULAR(0.3,8,25)
	Data are spot measurements of Leachate Quality
Lead	LOGTRIANGULAR(0.002,0.007,0.05)
Sulphate	LOGTRIANGULAR(200,1200,1800)

Justification for Species Concentration in Leachate

EA Rogue load PDFs. Maximum lead value increased to propsoed WAC limit specifed in Table HRA1.

Drainage Information

Fixed Head.

Head on EBS is given as (m):	SINGLE(1)

Justification for Specified Head

Nominal value. Leakage value to be restricted to infiltration volume.

Barrier Information

There is a single clay barrier

Justification for Engineered Barrier Type

Proposed attenuation layer design - compacted cohesive soils.

Design thickness of clay (m):	SINGLE(0.5)
Density of clay (kg/l):	UNIFORM(1.5,1.8)
Pathway moisture content (fraction):	LOGUNIFORM(0.15,0.25)

Justification for Clay: Liner Thickness

Deisgn proposal

Hydraulic conductivity of liner (m/s):	SINGLE(1e-007)
Pathway longitudinal dispersivity (m):	SINGLE(0.05)

Justification for Clay: Hydraulics Properties

Target maximum permemability.

Retardation parameters for clay liner

Uncertainty in Kd (l/kg):	
Ammoniacal_N	LOGTRIANGULAR(0.1,0.5,5)
Lead	LOGTRIANGULAR(1100,101100,700000)
Sulphate	SINGLE(0)

Justification for Liner Kd Values by Species

Sheppard et al (2011), Amm N from Buss et al (2004)

Lower Lincolnshire Limetone pathway parameters

Modelled as unsaturated pathway

Pathway length (m):	UNIFORM(2,5)
Flow Model:	porous medium
Pathway moisture content (fraction):	UNIFORM(0.01,0.05)
Pathway Density (kg/l):	UNDEFINED

Justification for Unsat Zone Geometry

difference between quarry base and monitored groundwater levels.

Pathway hydraulic conductivity values (m/s):	LOGUNIFORM(0.0001,0.001)

Justification for Unsat Zone Hydraulics Properties

Based on published transmissivity values form unconfined Linconlshire Limestone (~100 -250m2/d; Rushton, 1975).

Moisture content based on Sirius judgement for fractured strata.

Pathway longitudinal dispersivity (m):	UNIFORM(0.2,0.5)

Justification for Unsat Zone Dispersion Properties

1/10th of USZ thickness

Retardation parameters for Lower Lincolnshire Limetone pathway

Modelled as unsaturated pathway

No retardation values used in this simulation.

Check 'Unretarded Contaminant Transport' setting under simulation preferences.

Aquifer Pathway Dimensions for Phase

Pathway length (m):	UNIFORM(100,200)
Pathway width (m):	SINGLE(220)

pathway parameters

No Vertical Pathway

Limestone & Basal Sands pathway parameters

Modelled as aquifer pathway.

Mixing zone (m): UNIFORM(6.5,8.5)

Justification for Aquifer Geometry
Pathway width based on width of engineered footprint perpendicular to gorundwater flow.

Mixing zone thickness based on saturated thickness derived from monitoring water levels and broeholes logs.

Darcy flux (m/s): UNIFORM(1e-006,1.4e-005)
Pathway porosity (fraction): UNIFORM(0.05,0.1)

Justification for Aquifer Hydraulics Properties
Saturated thickness based fon difference between base of basal sands taken from borehole logs and mean groundwater levels.

Darcy flix based on weighed mean flow through basal sands (based on a permeability of 5e-5m/s) and the solid limestone (based on a transmissivity of 100-250m2/d - Rushton, 1975). Calculated using a hydraulic gradient of 0.01 as per groundwater contour plots presented on Drawing No MG1002/14/07.

Based fracture porosity of limestone (1-5%) and effective porosity values of basal sands (~10-40%).

Pathway longitudinal dispersivity (m): UNIFORM(10,20)
Pathway transverse dispersivity (m): UNIFORM(3,7)

Justification for Aquifer Dispersion Details
1/10th and 1/33rd of pathway length

Retardation parameters for Limestone & Basal Sands pathway

Modelled as aquifer pathway.

No retardation values used in this simulation.

Check 'Unretarded Contaminant Transport' setting under simulation preferences.

APPENDIX HRA2

Model Files (Please Refer to Associated Files)