Two Oaks Quarry: Hydrogeological Risk Assessment

Prepared for Mansfield Sand Company Ltd

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CONFIDENTIAL

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Quality Control Sheet

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Revision History

Revision	Details	Prepared by	Checked by	Approved by	Issue Date
REV01	Draft HRA for Planning	MT	JFR	DT	09/02/2024
REV02	Revised draft	JFR	CDW	CDW	05/03/2024
REV03	Final HRA for planning	JFR	CDW	DB	15/03/2024
REV04	Final HRA for permit	JFR	CDW	DB	25/03/2024

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1 INTRODUCTION

1.1 Background

Mansfield Sand Company Ltd (Mansfield Sand) has planning permission (ref: 4/2010/0178) to extract silica sand and gravel in four phases at Two Oaks Quarry (the Site) near Mansfield, Nottinghamshire. Phase 1 is divided into 11 units/lagoons and work began in 2015. Part of Phase 1 will be restored to agricultural land and heathland using inert and non-hazardous waste restoration materials.

Mansfield Sand proposes to carry out the backfilling and Site restoration under the terms of a Deposit for Recovery Environmental Permit within Phase 1 only. Lagoons 7, 8, 9 and 10 (see Waste Recovery Boundary in Figure 1) are proposed to be restored to no more than original ground levels by using Site-derived soils/soil forming materials (1,474,362 tonnes silt and 11,600 tonnes of sand) and importing inert and suitable non-hazardous restoration materials. Mansfield Sand estimates that up to 296,000 tonnes of imported material will be needed to complete the Site restoration requirements.

A planning application (ref: LT/2023/128154/01-L01) has been submitted to Nottinghamshire County Council for the use of imported waste material (inert and non-hazardous wastes) to enable the restoration of Lagoons 7, 8, 9 and 10 (outlined in purple as Waste Recovery Boundary on Figure 1).

Mansfield Sand proposes to carry out the backfilling and Site restoration under a deposit for recovery Environmental Permit. The application for the Environmental Permit is being made by Envireau Water on behalf of Mansfield Sand. Full details of the proposed filling operation are set out in the Environmental Setting and Site Design (ESSD) Report that supports the application (Envireau Water, 2024).

Mansfield Sand has engaged Envireau Water to prepare a quantitative Hydrogeological Risk Assessment (HRA) (this report) to support the permit application.

1.2 Scope of Work

The objective of this HRA is to develop a hydrogeological conceptual site model to assess the risk of contamination to neighbouring receptors from the proposed recovery operation. This HRA report should be read in conjunction with the ESSD report (Envireau Water, 2024) and includes the following:

- A summary of key elements of the hydrogeological conceptual site model (Section 2);
- Details of the modelling approach taken in this HRA and the modelling results (Section 3); and
- A summary setting out the key conclusions (Section 4).

1.3 Data Sources

The information and assessments in this report are based on:

- Proposed development and restoration plans provided by Mansfield Sand;
- Baseline data presented in the ESSD (Envireau Water, 2024).

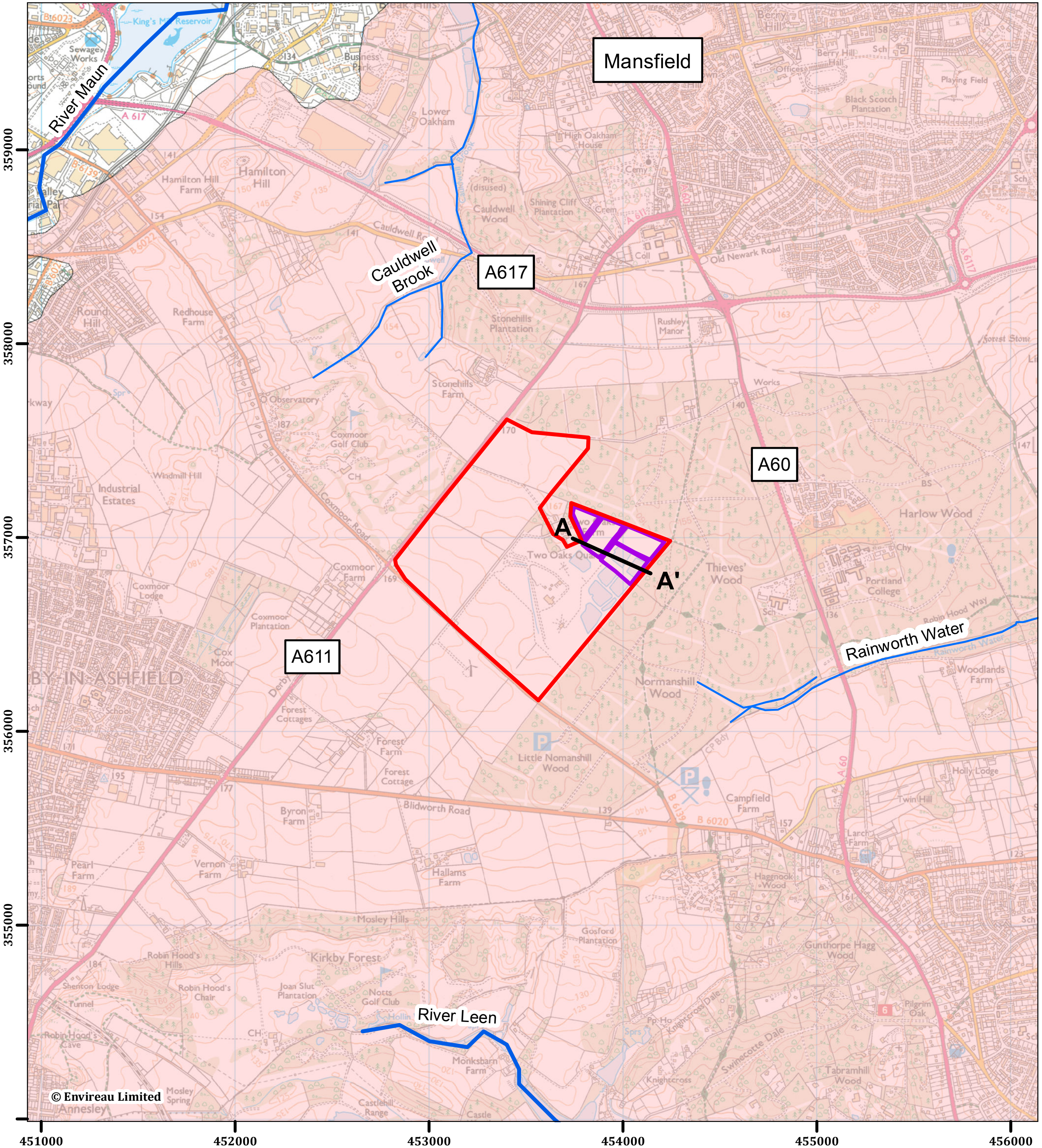

Figure 1: Site Location and Setting

Mansfield, Nottinghamshire

- Site Boundary
- Waste Recovery Boundary
- Source Protection Zone 3 (Total Catchment)

Notes:

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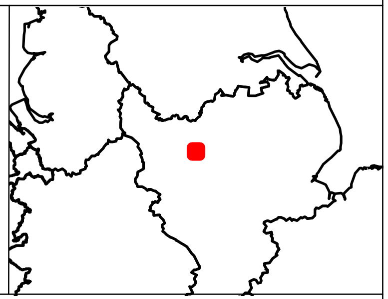

0 250 500 750 1,000 Meters

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15 March 2024

NGR: 453,536 E / 356,874 N

Project No. 3490476

Client: Mansfield Sand Company Ltd

Drawn by: JH

Ref: FIG Site Location and Setting

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2 HYDROGEOLOGICAL CONCEPTUAL SITE MODEL

2.1 Overview

The conceptual site model has been defined using data collected collated for the ESSD to support the permit application. The baseline site setting is set out within the ESSD report (Envireau Water, 2024).

Mansfield Sand has planning permission to extract silica sand and gravel of the Chester Formation, which overlies the Lenton Sandstone Formation and Edlington Formation at the Site. The Chester Formation forms part of the Sherwood Sandstone, a Principal Aquifer, and the Site lies within groundwater Source Protection Zone 3. The Site is being worked in four phases, with the mineral excavated dry. Water is managed around various on-site lagoons with no off-site discharge (Envireau Water, 2024). Restoration material is to be emplaced within silt lagoons that have been developed within the worked excavation areas to restore the Site to original ground levels. In Lagoons 7, 8, 9 and 10 the restoration material will be composed of 25% suitable non-hazardous waste, and 75% inert waste material (soils, subsoils, and sands) (Mansfield Sand Company Limited, 2023). All materials to be deposited at the Site will be chemically inert (RSK Geosciences, 2024).

The restoration material will be placed at least 3.5 m above the water table, within partially filled excavations into the Chester Formation. Site-derived silt material of low permeability will effectively form a basal attenuation layer. A sidewall attenuation layer will be constructed on the sides of the lagoons using low permeability restoration material.

A conceptual understanding of the key physical components of the groundwater system has been developed prior to undertaking any modelling to assess the possible risk of contamination. To simplify the complexity of observed geological and groundwater conditions, a conceptual model has been developed. The conceptual model accounts for the physical ground conditions as well as the main hydrological and hydrogeological inputs and outputs.

The conceptual model has been used to derive a set of potential source-pathway-receptor linkages. These are described in this section and are used to assess the risk to controlled waters from the restoration materials deposited at the Site.

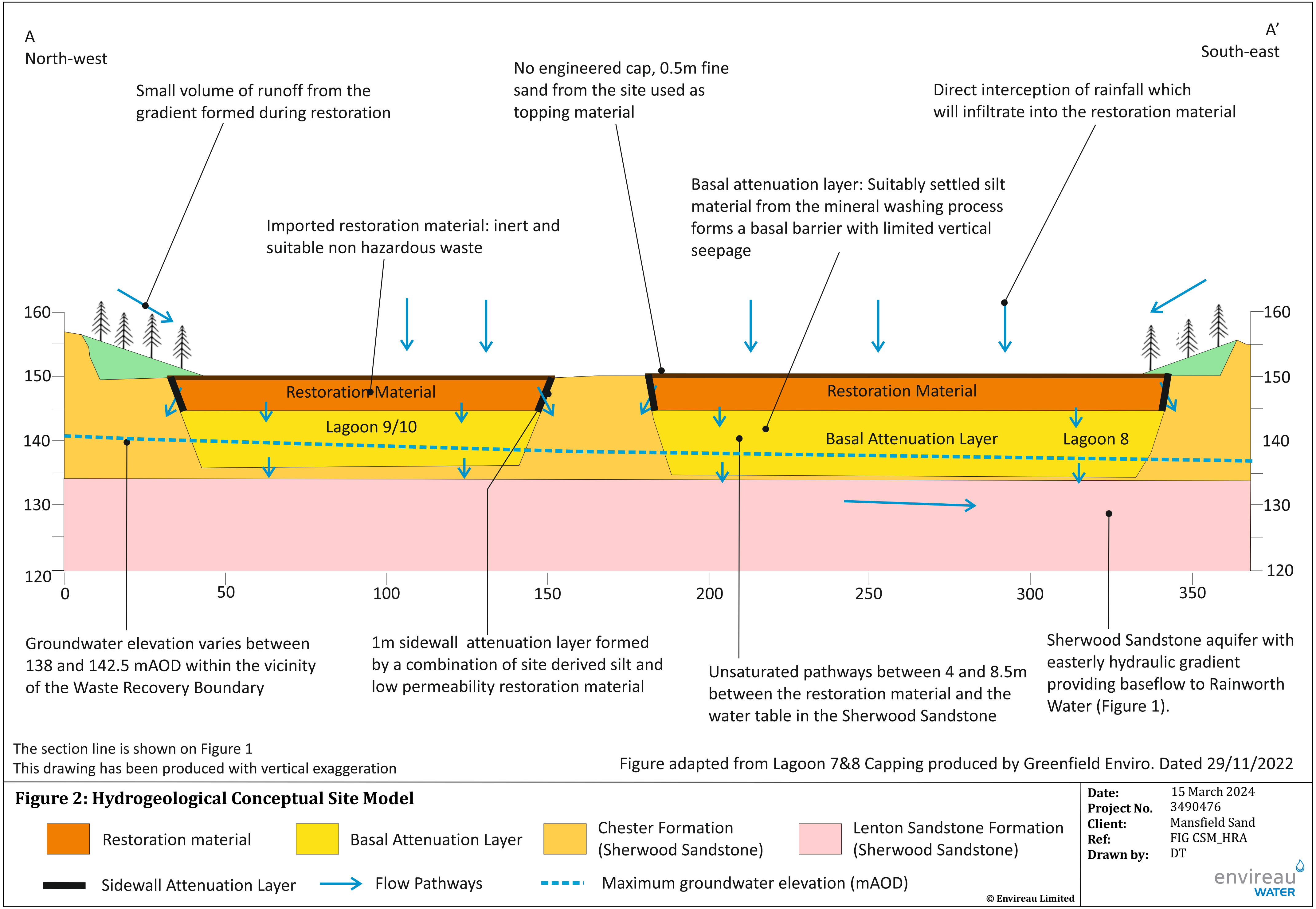

Figure 2: Hydrogeological Conceptual Site Model

2.2 Site Water Balance

In this section, the fluxes of water into and out of the restoration material are identified and considered to formulate a Site water balance. The conceptual model is shown in cross-section view in Figure 2. The key elements of the Site conceptualisation are set out below.

Rainfall

There will be no engineered cap and a proportion of incident rainfall will infiltrate into the restoration material and the remainder will runoff. Of the portion that infiltrates, some will be lost to evapotranspiration, with the remainder percolating into the deeper restoration material. This water will discharge into the Sherwood Sandstone through the lagoon sides and base, after passing through either the sidewall attenuation layer or settled silt at the base. The portion that does not infiltrate and runs off will flow over the surface of the restoration material from where it will infiltrate into the Sherwood Sandstone aquifer.

The effective rainfall is the difference between total precipitation and actual evapotranspiration and represents the amount of water that is available for infiltration into the restoration material. An estimation of the effective rainfall has been made using the mean measured flow at the Centre for Ecology and Hydrology (CEH) flow gauge on the River Erewash at Pinxton (ID: 28113) (approximately 8.2 km southwest of the Site), which drains a catchment with similar shallow geological conditions to the Site. Based on the mean flow and the catchment area for this gauging station, the estimated annual effective rainfall of the catchment is 339 mm.

The Standard Annual Average Rainfall (SAAR) for the River Erewash at Pinxton is 727 mm; therefore, the effective rainfall is 47% of the SAAR. Assuming that effective rainfall is the same proportion of the SAAR at the Site, the estimated annual effective rainfall at the Site is also 339 mm.

In the water balance, it is assumed that up to 339 mm/yr of water is available for infiltration into the restoration material and any of the effective rainfall that does not infiltrate will runoff and infiltrate into the Sherwood Sandstone aquifer at the edge of Site.

Settled Silt and Restoration Material

The restoration material will be dominantly composed of low permeability clays and silts. Consequently, it will be less permeable than the Sherwood Sandstone aquifer.

Settled silt material will form the base of the excavated lagoons, on which the restoration material will be deposited. The silt material will be of low permeability, on-site testing indicates permeability of between 2.3×10^{-9} and 4.2×10^{-10} m/s (Kiwa CMT, 2023) (see Appendix A). The basal silt layer will be at least 7.5 m thick with a minimum unsaturated thickness of 4 m. Consequently, it will form a basal layer that will be between four to five orders of magnitude less permeable than the Sherwood Sandstone aquifer. Therefore, the silt material will retard the downward flow of water from the restoration material which will be deposited above the water table.

Each active quarried phase will be dewatered to allow the mineral to be excavated dry; dewatering will continue while quarrying is ongoing. Groundwater will be allowed to rebound to natural levels once quarrying is complete, but these will remain below the level of the restoration material within the basal settled silt(see Figure 2). The silt material will act as barrier to groundwater flow, and natural lateral groundwater flow within the Sherwood

Sandstone will preferentially flow around the silt lagoons along the path of least hydraulic resistance within the Sherwood Sandstone aquifer. Therefore, lateral inflows to the silt material from the Sherwood Sandstone aquifer will likely be relatively small.

For the purpose of this assessment, the Chester Formation and Lenton Formation are considered as a single aquifer (the Sherwood Sandstone aquifer), bounded at the base by the Edlington Formation, which is comprised of mudstones. Therefore, the Edlington Formation is screened out of the HRA and is not considered further in this assessment.

Surface water features

The proposed restoration only includes one small waterbody which, when formed, will lie outside of the Waste Recovery Boundary. This waterbody will be formed from surface water from the western area of the Site and will not receive water from the Waste Recovery Boundary.

The nearest surface water feature outside the Site boundary is Rainworth Water, which flows north-eastwards. At its closest, Rainworth water lies 600 m from the Waste Recovery Boundary. This feature receives groundwater baseflow from the Sherwood Sandstone aquifer.

Site Inflows and Outflows

Due to the low permeability of the restoration material and the underlying basal settled silts, infiltrating water will create a mound of groundwater in the restoration material perched above the regional water table in the Sherwood Sandstone. This will cause groundwater within the restoration material to discharge to the Sherwood sandstone aquifer through the sides in all directions and the base. That fraction of water passing through the sides of the restoration material will pass through the unsaturated zone in the Sherwood sandstone before reaching the saturated aquifer.

Heads within the restoration material will be limited by ground level and, at this level, outflows into the sandstone aquifer will reach the maximum possible. The maximum infiltration is therefore limited by the minimum of the effective rainfall (339 mm) or the maximum outflow through the sides and base.

Should heads in the restoration material reach ground surface, incident rainfall will runoff without infiltrating into the restoration material and, due to the nature of the overlying site-won topsoils, this runoff will be uncontaminated. Most of the time, heads in each lagoon will not reach ground level, allowing rainfall to infiltrate into the restoration material and the infiltrating flux into each phase will be balanced by the outflows to the aquifer.

Part of the silt material and all the restoration material lies above the regional groundwater table; therefore, there will be no inflow to the restoration material from the Sherwood Sandstone aquifer, and thus it is not considered further in the water balance.

Dewatering during construction/restoration

Dewatering occurs within the lower 3 to 8 m of each excavation/lagoon, within the Chester Formation, to allow the mineral to be excavated dry. Dewatering effluent is managed on site under abstraction (transfer) licence MD/028/0070/012, with no discharge occurring off-site. As filling progresses, the settled silt material will be allowed to saturate; however, heads will not reach the restoration material level.

2.3 Source

The Waste Recovery Plan states that the lagoons within Waste Recovery Boundary will be infilled with imported restoration material, which will be inert or suitable non-hazardous material (Mansfield Sand Company Limited, 2023). The total quantity of imported restoration material required to fill the Lagoons 7, 8, 9 and 10 is estimated to be 296,000 tonnes (Mansfield Sand Company Limited, 2023), or 204,138 m^3 (based on a material density of 1.45 tonnes/m^3).

The potential source of contamination is the inert and suitable non-hazardous waste restoration material. The non-hazardous material to be accepted at the Site will be chemically inert (RSK Geosciences, 2024). Envireau Water (2024) has reviewed other potential sources of contamination and found that, of the nearby sources, there are none that are upgradient and hydraulically connected to the Site. Given this, no consideration has been given to other existing contamination sources.

Rainwater that infiltrates into each restored lagoon will discharge either through the sides of the lagoons passing through the sidewall attenuation layer, or through the bottom of the lagoons through the settled silt at the base of the lagoons. As the recharging water flushes through the restoration material, contaminants will be mobilised. The source term contaminant mass will reduce at a rate proportional to the infiltration flux.

Four (7, 8, 9 and 10) lagoons within the Waste Recovery Boundary will be filled within restoration materials. Although physically separate lagoons, for simplicity, these have been considered together. Since the silt material is composed of residues from on-site materials, it is not a source of contamination.

2.4 Pathways

The Site is located in the Chester Formation, part of the Sherwood Sandstone Group which is a Principal Aquifer. Groundwater within the sandstone aquifer will remain below the filling level during operations and following restoration.

Based on the conceptual understanding, the pathways are:

- Rainwater infiltrating into the restoration material and then:
  - Either, vertical percolation through the restoration material and then through the basal settled silt material into the underlying Sherwood Sandstone aquifer;
  - Or, vertical percolating into the restoration material, then outflow through the sidewall attenuation layer into the unsaturated sandstone and then into the underlying Sherwood Sandstone aquifer; and
  - Followed by flow through the Sherwood Sandstone aquifer and discharge to Rainworth Water as baseflow.

Sherwood Sandstone groundwater elevations vary between 138 and 142.5 m AOD around the waste recovery area. This forms an unsaturated pathway of between 3.5 and 8 m between the restoration material and the water table in the Sherwood Sandstone aquifer. At the Site, groundwater flow within the Sherwood Sandstone aquifer broadly eastwards and the flux infiltrating into the Sherwood Sandstone will be diluted by natural groundwater flow from upgradient.

Following discharge to Rainworth Water, the contaminants will be subject to dilution from natural stream flow.

2.5 Receptors

The potential receptors have been identified as follows:

- Hazardous Substances: water table in the Sherwood Sandstone aquifer. Instantaneous dilution is applied as detailed in Section .
- Non-Hazardous Substances: Groundwater in the Sherwood Sandstone aquifer at the Site boundary. Instantaneous dilution and dilution in the aquifer are applied as detailed in Section .

Provided there is no impact on the Sherwood Sandstone aquifer at the two receptors outlined above, there will be no impact on Rainworth Water. Therefore, due to the additional dilution available in the Rainworth Water and distance from the Site, this has been screened out as a receptor.

3 HYDROGEOLOGICAL RISK ASSESSMENT

3.1 Modelling Approach

Inert restoration materials will be placed 3.5 – 8 m above the recovered groundwater level at the Site. The HRA has been undertaken to demonstrate compliance with the Groundwater Directive (GWD) of the Water Framework Directive (WFD). The GWD prohibits the discharge of hazardous substances to groundwater and the pollution of groundwater with non-hazardous pollutants. To ensure compliance with the GWD, an attenuation layer composed of selected cohesive restoration materials will be constructed on the sides of the restoration material. As the base of the restoration material will be underlain by low permeability settled silt, no attenuation layer is required at the base.

From the conceptual model described in Section 2, it is considered that the risk to groundwater posed by the proposed operation is low. However, the Site is located over a Principal aquifer, and within a groundwater SPZ3 with surface water receptors. There is no specific guidance for the level of detail required for HRAs undertaken in support of waste recovery permit applications, but there is guidance for waste disposal permit applications (Environment Agency, 2021). Therefore, it is considered that a Generic Quantitative Risk Assessment (GQRA) is required to assess the potential of contamination from the restoration material (Environment Agency, 2021).

3.2 Assessment Scenario

This HRA reviews the potential environmental impacts of the post-closure phase of inert and chemically inert non-hazardous material restoration. The waste recovery design does not include any leachate or water management, cap, nor basal engineering.

The fully restored Site will have no cap or artificial sealing. Instead, the Site will be overlain with natural soils. When restoration is complete and dewatering ceases, an excess head will build up in the restoration material from rainfall, and result in a radially outwards advective flux from the restoration material into the attenuation layer, then into the unsaturated zone, and finally into the Sherwood Sandstone aquifer and flow through basal settled silt into the Sherwood Sandstone aquifer.

Two scenarios have been considered as follows:

1. Hazardous pollutant simulation including:
    a. No dilution;
    b. Sorption, diffusion, and dispersion through the basal silt layer only (which represents the largest contaminant flux (see Section 3.3.3 for the water balance);
    c. Receptor is the water table in the Sherwood Sandstone beneath the Site.
2. Non-hazardous pollutant model run including:
    a. Instantaneous dilution from runoff/infiltration flux;
    b. Dilution in the Sherwood Sandstone aquifer; and
    c. Sorption, diffusion, and dispersion through the sidewall attenuation layer and sandstone aquifer.

The hazardous pollutant simulation considers flow through the basal silt layer only because this is the largest contaminant flux (see Section 3.3.3) and there will be no instantaneous dilution from Site runoff before the flux reaches the water table. Such dilution will act on the flux from the sides to reduce concentrations before the receptor is reached and therefore this approach is conservative.

For modelling simplicity, and as a conservative assumption, contaminant transport and processes through the unsaturated zone of the Sherwood Sandstone have been excluded from the model. Therefore, before the contaminant flux reaches the Sherwood sandstone aquifer, the only attenuation and retardation is assumed to occur within the sidewall attenuation layer (for non-hazardous pollutants) and basal silt (for hazardous pollutants). This approach is conservative as, in reality, attenuation and retardation will also occur in the unsaturated sandstone which is at least 4 m thick above the Sherwood Sandstone aquifer.

3.3 Restored Phase Modelling Approach

3.3.1 Approach

Modelling has been undertaken using the Risk Assessment Model version 3 (RAM3) commercial software package (ESI, 2008). This modelling approach uses a spreadsheet model to solve a site-specific water balance and simulates contaminant transport along the identified pathways using a numerical solution of the 1D Advection-Dispersion-Retardation-Degradation (ADRD) equation. The equations used by RAM3 have been verified by comparison between direct evaluation of an analytical solution and the semi-analytic transform approach applied for more complex pathways (ESI, 2008). The modelling approach has been chosen to provide a robust assessment of risk using the source-pathway-receptor methodology.

Possible contaminant mitigation pathways are identified from the conceptual model. The risk of groundwater contamination is evaluated by considering:

- contaminant release from the source providing the input flux to the pathway; and
- contaminant flux along the pathway providing the contaminant load to the receptor.

A screening assessment has been undertaken to determine the species and source concentrations to be modelled (see Section 3.4).

3.3.2 General assumptions

To simplify the model, the following conservative assumptions have been made:

- The thickness of the restoration material and the attenuation layer have been averaged.
- The entire mass of restoration material is assumed to be present at the start of the model. This means that the model predicts that the peak contaminant flux will occur within the first few years. In reality, the infill operation will take place over around 15 years, and the actual initial source term will be less than that represented in the model. The model is therefore conservative in this respect.
- Retardation and degradation are not considered within the inert restoration material.
- The rate of decline in the source term is controlled by the rate of infiltrating rainfall.

3.3.3 Representation of the site water balance

As described in 2.2, a mound of water will form within the restoration material due to the infiltrating rainfall from the top of the restoration material, and the low permeability of the silt material / attenuation layer, which will reduce the percolation of groundwater into the Sherwood Sandstone aquifer. Water will discharge from the restoration material through the base and the sides of the lagoons.

Based on the above, the water balance can be represented by the following equation, where all the parameters are measured in m^3/s:

$$Q_{ER} = Q_{CAP} + Q_{RO}$$

Where:

Q_{ER} is the effective rainfall over the surface of the restoration material;

Q_{CAP} is the infiltrating flux into the restoration material through the top; and

Q_{RO} is the excess water that does not infiltrate through the restoration material, instead forming runoff which infiltrates at the edges.

The water balance assumes that the flux infiltrating the restoration material must balance the flux discharging from the restoration material. On this basis, it is necessary to estimate the flux infiltrating through the base and sides of the restoration material. These have been calculated as:

$$Q_{CAP} = Q_{Base} + Q_{Side}$$

Where the flow through the base is represented by:

$$Q_{Base} = \left(\frac{h + t_{silt}}{t_{silt}}\right) \times k_{silt-b} \times A_{base}$$

Where:

Q_{Base} is the flow through the basal attenuation layer;

h is the head in the restoration material above the basal silt;

t_{silt} is the unsaturated silt thickness at the base;

k_{silt-b} is the hydraulic conductivity of the settled silt; and

A_{base} is the area of the base of the lagoon.

The flow through the sides of the attenuation layer is represented by:

$$Q_{Side} = k_{AL} \times Perim \times h \times \left(\frac{h}{W}\right)$$

Where:

Q_{Side} is the flow through the sidewall attenuation layer;

Perim is the perimeter of the Waste Recovery Boundary;

k_{AL} is the hydraulic conductivity of the sidewall attenuation layer; and

W is half the width of the Waste Recovery Boundary.

In the conceptualization of this model, it has been assumed that the restoration material and silt material / attenuation layers have the same permeability.

The maximum value of Q_{CAP} cannot exceed the Q_{ER}. The maximum inflow is therefore limited to the Q_{ER}.

Water that flows out of the restored Site must pass through the attenuation layer formed by selected cohesive low permeability restoration material. The settled silt at the base of the restoration material has been differentiated from the sidewall attenuation layer on the sides of the lagoons, as the permeability of the sidewall attenuation layer is expected to be equivalent to that of the wider restoration material. Therefore, a permeability of 1.0×10^{-7} m/s has been assumed for the sidewall attenuation layer, while the permeability of the settled silt at the base is known to be around 1.0×10^{-9} m/s.

When the infiltrating flux (Q_{CAP}) passes through the sides of the restoration material and reaches the Sherwood Sandstone, it is assumed to be instantaneously diluted by Q_{RO}. h. At the groundwater receptor, predicted concentrations are assessed against the relevant Environmental Assessment Limits (EALs). The estimated values for the water balance are presented in Table 1.

3.4 Contaminant Screening

To select the determinands to be modelled, a screening assessment has been undertaken for each determinand listed in Section 2.1.2.1 of European Union Council Decision 2003/33/EC (European Union , 2002), assuming that the source term concentration (the concentration of the determinand in the restoration material) is the C_0 (percolation test) limit as given by the European Union Council Decision 2003/33/EC (European Union , 2002).

The nature of the restoration material and Waste Acceptance Criteria (WAC) procedures that will be in place at the Site means that no discernible concentrations of substances in excess of inert WAC limits will be placed at the Site (RSK Geosciences, 2024). Controls will be in place as set out in the Waste Acceptance Plan.

The maximum acceptable waste concentration has been back calculated based on dilution alone using the following equation:

$$C_{max} = \frac{C_{trg}}{DF}$$

Where:

C_{max} is the maximum acceptable concentration in leachate derived from the restoration material (mg/l);

C_{trg} is the target concentration at the receptor (mg/l); and

DF is the dilution factor that is applied (see below).

As described in Section 3.2, dilution is only applied to non-hazardous pollutants. The non-hazardous pollutants are diluted from runoff from the restoration material that infiltrates into the unsaturated Sherwood Sandstone at the edges of the Waste Recovery Boundary, and from the groundwater flux in the Sherwood Sandstone aquifer. For hazardous pollutants, it is conservatively assumed that no dilution occurs, and hazardous pollutants (arsenic, chromium, mercury and lead) fail the screening assessment and are carried through to the HRA model.

The dilution factor for non-hazardous pollutants has been estimated by using the equation below.

$$DF_{non-haz} = \frac{Q_{CAP}}{Q_{ER} + Q_{GW}}$$

Where:

Q_{GW} is the groundwater flow in the Sherwood Sandstone aquifer;

Groundwater flow in the Sherwood Sandstone aquifer was estimated with Darcy's equation, which uses:

- The hydraulic gradient (0.0112) estimated from groundwater contours for the Site (Envireau Water, 2024);
- The minimum hydraulic conductivity (6.94 x 10^{-5} m/s) estimated from particle size distribution data of the Chester Formation obtained from exploration drilling;
- The width of the proposed fill area perpendicular to groundwater flow (270 m); and
- The expected mixing depth within the Sherwood Sandstone aquifer (20 m).

The estimated fluxes are presented in Table 1.

Table 1 Water balance parameters and dilution factors

Parameter	Notation	Units	Value
Effective Rainfall falling over the lagoon area	Q_{ER}	m^3/s	6.15 x10^{-4}
Runoff (i.e., component of effective rainfall that does not infiltrate)	Q_{RO}	m^3/s	4.96 x10^{-4}
Infiltrating flux through the top of the restoration material (sum of the below two values)	Q_{CAP}	m^3/s	1.19 x10^{-4}
Flow through the sidewall attenuation layer	Q_{Side}	m^3/s	1.19 x10^{-5}
Flow through the basal attenuation layer	Q_{Base}	m^3/s	1.07 x10^{-4}
Groundwater flow in the Sherwood Sandstone Aquifer	Q_{GW}	m^3/s	4.20 x10^{-3}
Dilution factor for non-hazardous pollutants	$DF_{non-haz}$	-	0.025

The target concentration for non-hazardous pollutants in groundwater is taken to be the minimum of:

- The 95th percentile baseline groundwater quality in the Site from nine samples taken from five monitoring boreholes screened across the Sherwood Sandstone (Envireau Water, 2024); and
- The UK Drinking Water Standard (DWS) concentration.

If the maximum allowable concentration (C_{max}), is higher than the source term concentration, dilution alone is sufficient to ensure that there will be no impact on the identified receptors. If it is lower than the source term concentration, the opposite is true and there may be a pollution risk to receptors, and these determinands should be carried forward to a HRA model.

Table 2 presents the results of the source term screening assessment. Phenol index, dissolved organic carbon, and total dissolved solids are not chemical determinands and have not been assessed. Based on the waste acceptance procedures that will be in place at the Site and the chemically inert nature of the non-hazardous waste to be accepted, organic species, such as total organic carbon, BTEX, PCBs, mineral oils and PAHs are not expected to be present and are not considered in the assessment (RSK Geosciences, 2024).

Small amounts of topsoil or biodegradable material may be accidently included within the restoration material, which will then degrade to produce biproducts, including ammoniacal nitrogen. For this reason, ammoniacal nitrogen has been included in the screening.

Based on the screening assessment, the source term concentration of arsenic, cadmium, total chromium, copper, mercury, molybdenum, lead, antimony, and zinc exceed their corresponding maximum allowable concentration (see Table 2) and have therefore been carried through to the HRA model.

Table 2 Source term screening assessment for non-hazardous pollutants

Determinand	Haz / Non Haz	Result	Source Term Concentration (mg/l)	Max Acceptable Concentration (C_{max})(mg/l)	Target Concentration to assess against (C_{trg})(mg/l)[2]	UK DWS (mg/l)	Baseline 95th Percentile concentration (mg/l)[1]	Comment
Barium	Non Haz	Pass	4.0000	5.68	0.141		0.1408	-
Cadmium	Non Haz	FAIL	0.0200	0.010	0.0003	0.005	0.00026	Only one sample above LOD.
Copper	Non Haz	FAIL	0.6000	0.14	0.004	2	0.0035	Concentrations in all samples were below LOD.
Molybdenum	Non Haz	FAIL	0.2000	0.040	0.001		0.001	Only one sample above LOD.
Nickel	Non Haz	Pass	0.1200	0.20	0.005	0.02	0.005	-
Antimony	Non Haz	FAIL	0.1000	0.040	0.001	0.005	0.001	Concentrations in all samples were below LOD.
Selenium	Non Haz	Pass	0.0400	0.061	0.0015	0.01	0.0015	Concentrations in all samples were below LOD.
Zinc	Non Haz	FAIL	1.2000	0.56	0.0138		0.0138	-
Chloride	Non Haz	Pass	460.0	2255	55.84		55.84	-
Fluoride	Non Haz	Pass	2.5000	6.06	0.15	1.5	0.15	Concentrations in all samples were below LOD.
Sulphate	Non Haz	Pass	1500	2104	52.12		52.12	Using 4 samples.
Ammoniacal Nitrogen as NH_3	Non-Haz	Pass	1	1.16	0.029		0.029	Only one sample above LOD.

[1] Results below the limit of detection (LOD) set to half the LOD as a conservative approach.

[2] C_{trg} is taken to be the lowest of UK Drinking Water Standard (DWS), and 95-percentile concentration of Sherwood Sandstone baseline groundwater concentration.

3.5 Model Parameterisation

3.5.1 Site dimensions

The combined area of Lagoons 7, 8, 9 and 10 was specified as the dimensions of the restoration material to be placed at the Site. These parameters are shown in Table 3.

Table 3 Site parameters

Description	Value	Unit	Data Source
Total Volume of restoration material	204,138	m^3	From Waste Recovery Plan (Mansfield Sand Company Limited, 2023).
Total Areal Extent of restoration material	57,262	m^2	Calculated from GIS.
Perimeter of restoration material	1,311	m	Calculated from GIS – measured as the perimeter of the combined lagoon system
Distance from centre of lagoons to perimeter	135	m	Approximate mean distance Calculated from GIS.
Proportion of water that would freely drain from the restoration material	0.3	-	(Beaven, 1996).
Maximum groundwater elevation at perimeter	142.5	m AOD	Maximum elevation from borehole WM/2 (located up-gradient of lagoons).
Ground elevation of restored surface	150	m AOD	Proposed final restored level (Mansfield Sand Company Limited, 2023).
Base of restoration material	146.5	m AOD	Mean elevation of the restoration material above the settled silt material.
Thickness of restoration material	3.5	m	Approximate mean thickness of restoration material.
Permeability of restoration material	1×10^{-7}	m/s	Restoration material will be cohesive clays with permeability indistinguishable from the Attenuation Layer.

3.5.2 Source Term Parameters

For the determinands that failed the screening assessment (see Section 3.4), the source term concentration has been estimated using the values in Table 4, taken from Section 2.1.2.1 of 2003/33/EC (European Union , 2002).

Table 4 Source term parameters

Determinand	Concentration (mg/l)	Comment
Arsenic	0.06	C_0 percolation test limits (Section 2.1.2.1 of 2003/33/EC) used as an upper conservative source term concentration.
Cadmium	0.02	
Total Chromium	0.1	
Copper	0.6	

Determinand	Concentration (mg/l)	Comment
Mercury	0.002	
Molybdenum	0.2	
Lead	0.15	
Antimony	0.1	
Zinc	1.2	

3.5.3 Hydrology

The modelled hydrological parameters are presented in Table 5.

Table 5 Hydrological parameters

Parameter	Value	Unit	Comment
Effective Rainfall	339	mm/yr	See Section 2.2.

3.5.4 Sidewall attenuation layer and basal silt parameters

The parameters used to define the attenuation layer in the model are presented in Table 6. As explained in Section 3.2, the non-hazardous pollutant simulation assumes that the flux from the restoration material all passes through the 1 m thick sidewall attenuation layer (although the fluxes calculated separately and set out in Table 1 have been used).

The hydraulic gradient between the restoration material and the Sherwood sandstone aquifer has been calculated assuming that the restoration material and attenuation layer have the same permeability and therefore the head gradient is calculated across the entire combined thickness.

These assumptions are considered conservative because in reality the basal attenuation layer is thicker and has a lower hydraulic conductivity than the one used in the model; therefore, contaminant transport times through it will be longer than in the model. At the same time, these assumptions are an effective simplification for the model.

Table 6 Attenuation layer parameters

Parameter	Value	Unit	Comment
Permeability of the sidewall attenuation layer	1×10^{-7}	m/s	Assumed value for the restoration material to be placed on the sides of the lagoon.
Thickness of the sidewall attenuation layer	1	m	Minimum thickness to prevent discharge of hazardous substances.
Hydraulic gradient of the sidewall attenuation layer	0.026	-	Calculated – see above

Parameter	Value	Unit	Comment
Permeability of the basal silt	1 x 10^{-9}	m/s	Measured basal silt permeability
Thickness of the basal silt	4	m	Unsaturated basal silt thickness.
Effective Porosity	0.05	-	Typical effective porosity for engineered attenuation layer comprised of cohesive clays.
Bulk Density	2,000	kg/m^3	Conservatively assumed that the density is the same as the restoration material, in reality the attenuation layer will be compacted and will be greater than this.
Sidewall attenuation layer Dispersivity	0.1	m	Assumed to be 10% of the travel distance
Basal silt Dispersivity	0.4	m	Assumed to be 10% of the travel distance
Tortuosity	5	-	Conservative value (De Marsily, 1986).

3.5.5 Pathway parameters

The parameters used to define the hydrogeological pathway through the Sherwood Sandstone aquifer are shown in Table 7. These parameters are only used for non-hazardous pollutants (cadmium, copper, molybdenum, antimony, and zinc) as processes in the unsaturated Sherwood sandstone aquifer have been conservatively ignored.

The hydraulic gradient for the Sherwood Sandstone aquifer has been estimated using groundwater contours across the Site. Along with the effective porosity and permeability, Darcy's Law has then been used to estimate the velocity of the contaminant plume in the aquifer.

Table 7 Sherwood Sandstone Aquifer pathway parameters

Parameter	Value	Unit	Comment
Sandstone aquifer bulk density	1,600	kg/m^3	Expert Judgement.
Sandstone Aquifer Permeability	6.94 x 10^{-5}	m/s	Minimum estimate from Site data (Envireau Water, 2024)
Travel distance to edge of Site receptor	135	m	Conservative representative distance between restoration material and edge of Site receptor, measured from centre of restoration material to eastern boundary
Sandstone effective porosity	0.25	-	Estimate based on geological descriptions.
Dispersivity (saturated sandstone)	13.5	m	Assumed to be 10% of the travel distance
Tortuosity	5		Conservative value (De Marsily, 1986).
Sandstone hydraulic gradient	0.0112	-	Conservative from contours shown in Envireau Water (2024).

3.5.6 Contaminant Transport Parameters

The contaminant transport parameters that have been applied to the HRA model are shown in Table 8. Different transport parameter values have been applied to the Attenuation Layer and the Sherwood Sandstone due to their different compositions, as specified in Table 8. Sorption is related to the partition coefficient (K_d). For the purposes of this assessment, it has been assumed that the sidewall attenuation layer and basal settled silt have the same properties.

Ammoniacal nitrogen degrades in aerobic conditions as it oxidises to nitrite and nitrate. It has been conservatively assumed that the conditions in the attenuation layer and the unsaturated and saturated zones of the Sherwood Sandstone are anaerobic. It has been assumed that all other modelled contaminants do not degrade naturally.

Table 8 Contaminant transport parameters

Parameter	Value	Unit	Comment
Free water diffusion coefficient	2.0 x10^{-9}	m^2/s	Conservative assumption.
Arsenic K_d (Attenuation Layer)	137.5	l/kg	Mid-range value (Golder Associates, 2003)
Arsenic K_d (Sandstone)	25	l/kg	Minimum value from range (Golder Associates, 2003)
Cadmium K_d (Attenuation Layer)	222	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003)
Cadmium K_d (Sandstone)	74	l/kg	Expected value for sand (Golder Associates, 2003)
Copper K_d (Attenuation Layer)	127	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003).
Copper K_d (Sandstone)	40	l/kg	Minimum value from range (Golder Associates, 2003).
Total Chromium K_d (Attenuation Layer)	966	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003).
Total Chromium K_d (Sandstone)	67	l/kg	Expected value for sand (Golder Associates, 2003).
Mercury K_d (Attenuation Layer)	2,143	l/kg	Mid-range value (Golder Associates, 2003).
Mercury K_d (Sandstone)	450	l/kg	Expected value for sand (Golder Associates, 2003).
Lead K_d (Attenuation Layer)	435	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003).
Lead K_d (Sandstone)	270	l/kg	Expected value for sand (Golder Associates, 2003).
Molybdenum K_d (Attenuation Layer)	110	l/kg	Value for unspecified conditions (Golder Associates, 2003).
Molybdenum K_d (Sandstone)	110	l/kg	Value for unspecified conditions (Golder Associates, 2003).
Antimony K_d (Attenuation Layer)	140	l/kg	Geometric mean value for clay (Sheppard, Long, Sanipelli, & Sohlenius, 2009).
Antimony K_d (Sandstone)	17	l/kg	Geometric mean value for sand (Sheppard, Long, Sanipelli, & Sohlenius, 2009).
Zinc K_d (Attenuation Layer)	21	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003).

Parameter	Value	Unit	Comment
Zinc K_d (Sandstone)	200	l/kg	Expected value for sand (Golder Associates, 2003).

3.5.7 Environmental Assessment Levels

Environmental Assessment Levels (EALs) used to assess impacts on the receptor are presented in Table 9. Baseline water quality exists for the groundwater in the Sherwood Sandstone Aquifer. For hazardous and non-hazardous pollutants, baseline concentrations have been used where these are lower than the UKTAG or the UK DWS.

Table 9 Groundwater EALs

Determinand	Concentration (mg/l)	Source
Arsenic	0.0013	Baseline 95th Percentile concentration.
Cadmium	0.00026	Baseline 95th Percentile concentration.
Total Chromium	0.0008	Baseline 95th Percentile concentration.
Copper	0.0035	Baseline 95th Percentile concentration.
Mercury	0.00002	UKTAG.
Molybdenum	0.001	Baseline 95th Percentile concentration.
Lead	0.00002	UKTAG.
Antimony	0.001	Baseline 95th Percentile concentration.
Zinc	0.0138	Baseline 95th Percentile concentration.

3.6 Model Results

3.6.1 RAM Model

Electronic copies of the RAM3 models are provided in Appendix B.

3.6.2 Water Balance Results

Infiltration into the restoration material is calculated based on the effective rainfall and represents the groundwater flux out of the restoration material and the attenuation layer into the Sherwood Sandstone. As the infiltrating flux is less than the runoff, the majority of the incident rainfall will runoff. These values are presented in Table 1.

3.6.3 Contaminant Concentrations

None of the modelled determinands show concentrations above their respective EAL (Table 10). Peak concentrations that are two orders of magnitude below the minimum EAL for each determinand are considered to be non-detectable, meaning 'no breakthrough'. Zinc is the only determinand that breaks through within a 1,000 year simulation time; however, its peak concentration is still significantly below the EAL.

Arsenic, cadmium, total chromium, copper, mercury, molybdenum, lead, and antimony are expected to sorb strongly and as a result no breakthrough occurs, which demonstrates that the attenuation layer will fulfil its purpose.

Table 10 Model results

Determinand	Receptor / Pathway	Peak Concentration (mg/l)	Time to maximum concentration (years)	EAL (mg/l)
Arsenic	Water table	No breakthrough within 1,000 years		1.3×10^{-3}
Cadmium	Groundwater in the Sherwood Sandstone Aquifer at the edge of the Site			2.6×10^{-4}
Total Chromium	Water table			8.0×10^{-4}
Copper	Groundwater in the Sherwood Sandstone Aquifer at the edge of the Site			3.5×10^{-3}
Mercury	Water table			2.0×10^{-5}
Molybdenum	Groundwater in the Sherwood Sandstone Aquifer at the edge of the Site			1.0×10^{-3}
Lead	Water table			2.0×10^{-5}
Antimony	Groundwater in the Sherwood Sandstone Aquifer at the edge of the Site			1.0×10^{-3}
Zinc	Groundwater in the Sherwood Sandstone Aquifer at the edge of the Site	4.0×10^{-5}	1,000	0.0138

3.7 HRA Review and Monitoring

There will be no engineered cap or artificial sealing liner at the Site and no managed phase once the Site has been restored. During operations, groundwater and surface water monitoring will continue in order to detect any changes in the water quality and to identify any rising trend in groundwater levels. Inspection and maintenance of the monitoring network will be done on a routine basis.

The HRA for the site will be reviewed in line with Environment Agency guidance, currently every six years (Environment Agency, 2022). These reviews will establish whether the Site performance is as predicted by the HRA and whether the HRA needs to be updated.

Following restoration, it is proposed to continue to monitor for five years in order to confirm that the Site is performing as predicted by the HRA and that it does not pose a threat to the environment.

4 CONCLUSIONS

Mansfield Sand proposes to carry out the backfilling and Site restoration at the Two Oaks Quarry under a Deposit for Recovery Environmental Permit. The potential impacts on the hydrogeological environment have been analysed through the development of a conceptual model, which has been used to parameterise a Tier 2 generic quantitative hydrogeological risk assessment. The generic quantitative risk assessment (GQRA) has been undertaken in accordance with both the GWD and the Landfill Directive.

Groundwater in the Sherwood Sandstone Principal Aquifer will be protected by a sidewall attenuation layer and underlying low permeability settled silt. A dilution screening assessment has been used to determine which contaminants to take through to the GQRA. Nine contaminants were taken forward to the GQRA stage where attenuation in the Attenuation Layer and attenuation and dilution in the Sherwood Sandstone aquifer are considered. The model results show no impacts on the groundwater environment with predicted concentrations being below the EALs and no discharge of hazardous substances.

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Sheppard, S., Long, J., Sanipelli, B., & Sohlenius, G. (2009). *Solid/liquid partition coefficieints (Kd) for selected soils and sediments at Forsmark and Laxemar-Simpevarp.* Svensk Karnbranslehantering AB - Swedish Nuclear Fuel and Waste Management Co.

APPENDICES

Appendix A Permeability Testing Results

Kiwa CMT

Client: Envireau Ltd.
Bank Chambers
39 Market Place
Melbourne
DE73 8DS

Kiwa CMT
Unit 5 Prime Park Way
Prime Enterprise Park
Derby
DE1 3QB

T +44 (0)1332 383333
E
uk.cmt.enquiries@kiwa.com

www.kiwa.co.uk/cmt

Date: 8th December 2023

Lab Ref: 71176

Originator: Alastair Rose

Order Ref: PEN20620

Site: Lagoon 8

Samples:

3No. samples weighing approximately 5kg each were sampled by the client and delivered to Kiwa CMT on 17th November 2023. A Sample certificate was not provided.

Requirements:

Carry out Triaxial Permeability on remoulded samples in accordance with **BS EN ISO 17892-11: 2019** (Subcontract test)

Results:

The individual results sheet may be viewed on pages 2 to 5 of this report and test results relate only to the items tested.

Kiwa CMT

Author: L. Anaz
Technical Administrator

Checked and Approved by: R. Cartlidge
Department Head

Kiwa CMT

Kiwa CMT Ltd
Unit 5
Prime Parkway
Prime Enterprise Business Park
Derby
DE1 3QB
For the attention of Daniel Newton

Page 1 of 1

Report No: C8639
Issue No 1

LABORATORY TEST REPORT

Project Name	**71176 LAGOON 8**		
Project Number	**C8639**	Date samples received	
Your Ref		Date written instructions received	21/11/2023
Purchase Order	351596	Date testing commenced	29/11/2023

Please find enclosed the results as summarised below

Item No	Test Quantity	Description	ISO 17025 Accredited
6.31	3	Triaxial permeability	Yes

Remarks :

Issued by : M Brown

Date of Issue : 08/12/2023

M.D.B

Approved Signatories : 08/12/2023

Key to symbols used in this report
S/C : Testing was sub-contracted

J.Hopkins (Laboratory Coordinator), M D Brown (Senior Quality Manager), R Norris (Supervisor), R Collett (Site Supervisor), M Bryan (Senior Lab Technician)

Unless we are notified to the contrary, samples will be disposed after a period of one month from this date.
All results contained in this report are provisional unless signed by an approved signatory
This report should not be reproduced except in full without the written approval of the laboratory.
Under multisite accreditation, testing in this report may have been performed at another Terra Tek Ltd (Trading as igne) laboratory.
The enclosed results remain the property of Terra Tek Limited (Trading as igne) and we reserve the right to withdraw our report if we have not received cleared funds in accordance with our standard terms and conditions

Only those results indicated in this report are UKAS accredited and any opinions or interpretations expressed are outside the scope of UKAS accreditation.

Feedback on the this report may be left via our website www.igne.com/contact

Kiwa CMT

igne	Site 71176 LAGOON 8	Contract No. C8639
	Client Kiwa CMT Ltd.	Sample 71176/S1/MS
	Engineer -	

Description: Reddish brown slightly sandy SILT.

Sample Details:	Initial:	Final:
Diameter:	102.2 mm	97.4 mm
Height:	99.2 mm	94.5 mm
Water content:	44.4 %	26.5 %
Bulk density:	1.78 Mg/m³	1.82 Mg/m³
Dry density:	1.23 Mg/m³	1.44 Mg/m³
Particle Density:	2.70 Assumed	
Final Degree of Saturation	137 %	
Sample condition:	Remoulded using 2.5kg compactive effort at the as-received moisture content	
Sample Orientation: N/A	Depth within sample: N/A	

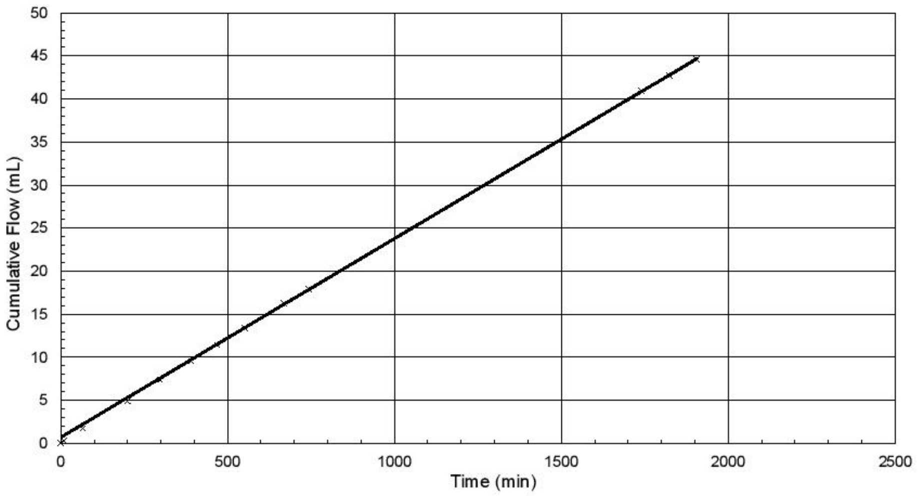
Equipment head loss at flow rates measured not significant therefore no corrections applied

De-aired tap water used

Saturation Stage: (Saturation by increments of cell pressure and back pressure)

Initial pore pressure coefficient, B:	1.00
Final pore pressure coefficient, B:	1.00
Duration of stage:	1 day
Consolidation stage:	
Drainage condition:	Double end drainage
Effective pressure:	100 kPa
Duration of stage:	1 day
Permeability stage:	
Pressure difference across specimen:	20 kPa
Mean effective stress:	100 kPa
Duration of stage:	2 days
Average Laboratory Temperature during test	21.5 °C

Coefficient of permeability at 20°C, Kv: 2.3×10^{-9} m/s



Originator	Checked & Approved	PERMEABILITY IN A TRIAXIAL CELL
MAB	M.D.B 07/12/2023	BS EN ISO 17892-11 : 2019 Permeability under constant head conditions in a flexible wall permeameter

Sheet 1 of 1

Kiwa CMT

igne	Site: 71176 LAGOON 8	Contract No. C8639
	Client: Kiwa CMT Ltd.	Sample: 71176/S2/MS
	Engineer: -	

Description: Reddish brown sandy SILT.

Sample Details:	Initial:	Final:
Diameter:	102.8 mm	96.8 mm
Height:	97.2 mm	91.5 mm
Water content:	48.1 %	26.8 %
Bulk density:	1.84 Mg/m³	1.91 Mg/m³
Dry density:	1.24 Mg/m³	1.51 Mg/m³
Particle Density:	2.70 Assumed	
Final Degree of Saturation	164 %	
Sample condition:	Remoulded using 2.5kg compactive effort at the as-received moisture content	
Sample Orientation: N/A	Depth within sample: N/A	

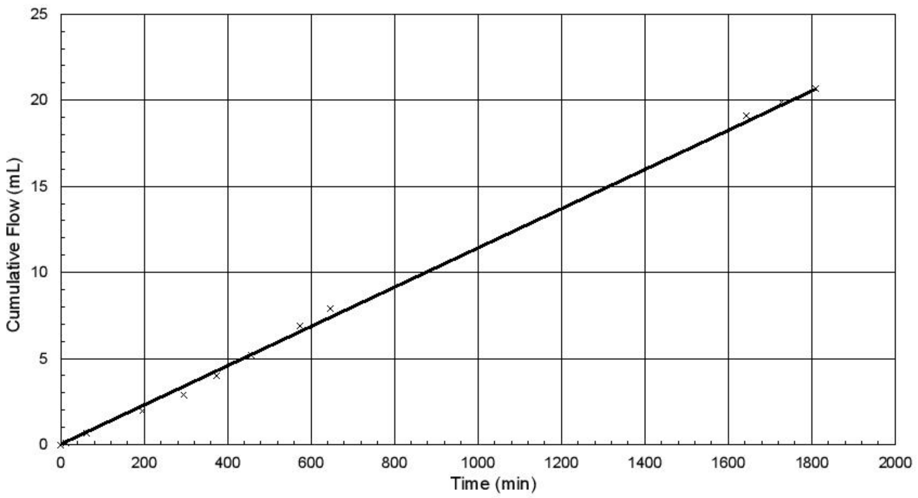
Equipment head loss at flow rates measured not significant therefore no corrections applied

De-aired tap water used

Saturation Stage: (Saturation by increments of cell pressure and back pressure)

Initial pore pressure coefficient, B:	1.00
Final pore pressure coefficient, B:	1.00
Duration of stage:	1 day
Consolidation stage:	
Drainage condition:	Double end drainage
Effective pressure:	100 kPa
Duration of stage:	1 day
Permeability stage:	
Pressure difference across specimen:	20 kPa
Mean effective stress:	100 kPa
Duration of stage:	2 days
Average Laboratory Temperature during test	21.5 °C

Coefficient of permeability at 20°C, Kv: 1.1×10^{-9} m/s



Originator	Checked & Approved	PERMEABILITY IN A TRIAXIAL CELL	
MAB	M.D.B 07/12/2023	BS EN ISO 17892-11 : 2019 Permeability under constant head conditions in a flexible wall permeameter	Sheet 1 of 1

Version 058 - 02/10/2023

Txl Perm 71176-S2-MS - C8639-391676.xls : Sample ID 391676

College Road North, Aston Clinton, Bucks, HP22 5EZ

Lab Project No C8639 : 07/12/2023 10:06:25

Kiwa CMT

igne	Site: 71176 LAGOON 8	Contract No.	C8639
	Client: Kiwa CMT Ltd.	Sample	71176/S3/MS
	Engineer: -		

Description: Reddish brown sandy SILT.

Sample Details:	Initial:	Final:
Diameter:	102.5 mm	95.8 mm
Height:	97.4 mm	91.0 mm
Water content:	62.7 %	33.1 %
Bulk density:	1.70 Mg/m³	1.73 Mg/m³
Dry density:	1.04 Mg/m³	1.30 Mg/m³
Particle Density:	2.70 Assumed	
Final Degree of Saturation	157 %	
Sample condition:	Remoulded using 2.5kg compactive effort at the as-received moisture content	
Sample Orientation: N/A	Depth within sample: N/A	

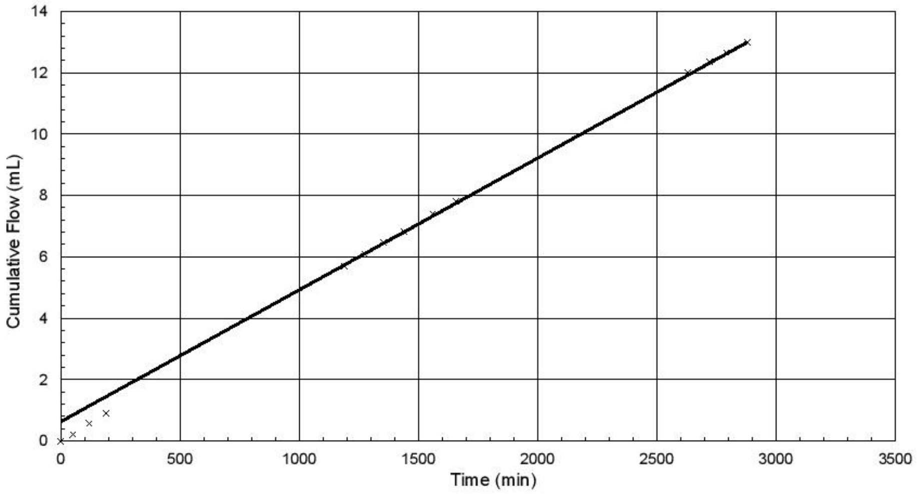
Equipment head loss at flow rates measured not significant therefore no corrections applied

De-aired tap water used

Saturation Stage: (Saturation by increments of cell pressure and back pressure)

Initial pore pressure coefficient, B:	0.97
Final pore pressure coefficient, B:	1.00
Duration of stage:	1 day
Consolidation stage:	
Drainage condition:	Double end drainage
Effective pressure:	100 kPa
Duration of stage:	4 days
Permeability stage:	
Pressure difference across specimen:	20 kPa
Mean effective stress:	100 kPa
Duration of stage:	2 days
Average Laboratory Temperature during test	21.5 °C

Coefficient of permeability at 20°C, Kv: 4.2×10^{-10} m/s



Originator	Checked & Approved	PERMEABILITY IN A TRIAXIAL CELL	
MAB	M.D.B 07/12/2023	BS EN ISO 17892-11 : 2019 Permeability under constant head conditions in a flexible wall permeameter	Sheet 1 of 1

Appendix B RAM3 Model (electronic)