Wasing Quarry: Hydrogeological Risk Assessment

Prepared for Tarmac Trading Ltd.

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CONFIDENTIAL

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1 INTRODUCTION

1.1 Background

Tarmac Trading Ltd (Tarmac) has planning permission to work sand and gravel mineral in three phases and restore to agricultural land using inert restoration materials at Wasing Quarry (the Site) near Woolhampton, Berkshire. Tarmac 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 Tarmac. Full details of the proposed infilling operation and Site restoration are set out in the Environmental Site Setting and Design (ESSD) report that accompanies the application (Envireau Water, 2023).

Tarmac has engaged Envireau Water to prepare a quantitative Hydrogeological Risk Assessment (HRA) to support the Environmental Permit application (this report).

1.2 Scope of Work

The objective of this HRA is to use the hydrogeological conceptual site model developed and set out in the ESSD 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 (Envireau Water, 2023) 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 Tarmac;
- Geological data from mineral exploration boreholes and monitoring well drilling provided by Tarmac;
- Previous reports for the Site by Envireau Water (2022 and 2023);
- British Geological Survey (BGS) mapping; and
- Ordnance Survey mapping.

2 HYDROGEOLOGICAL CONCEPTUAL SITE MODEL

2.1 Overview

The conceptual Site model and supporting geological, hydrological, and hydrogeological data is described in the ESSD report that accompanies this application (Envireau Water, 2023).

Tarmac has planning permission to extract sand and gravel of the Beenham Grange Gravel Member of the Kennet Valley Formation and overlying alluvium (herein collectively referred to as the sand and gravel aquifer), which overlies the London Clay Formation at the Site. The Site will be worked in three phases (A, B and C), with the mineral excavated dry through dewatering. Abstracted water will be discharged via settlement lagoons to the River Enborne under a discharge activity permit (an application was submitted on 8 April 2022 and is being processed by the Environment Agency with application reference EPR/YB3797AN).

Restoration material is to be emplaced within the worked excavation areas to restore the Site to agricultural land. An engineered Attenuation Layer will be placed at the sides of the restoration material in each phase. Further detail on the proposed installation design and site infrastructure is provided in the ESSD.

An 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 model accounts for the physical ground conditions as well as the main hydrological and hydrogeological inputs and outputs.

The hydrogeological conceptual model has been developed based upon the proposed site layout, construction and detailed geo-environmental setting described in the ESSD (Envireau Water, 2023). 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.

As the Site is being worked in three phases, and the local conditions are different for each phase, different models have been formulated for each of the three phases; Phase A, Phase B and Phase C. The conceptual model is shown in plan view on Figure 1 and in section view in Figure 2

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.

Rainfall

Of incident rainfall, a proportion will infiltrate into the restoration material and the remainder will runoff. Of the portion that infiltrates, some will be lost to evaporation and transpiration (evapotranspiration), with the remainder percolating into the deeper restoration material, where it will flow laterally through the restoration material as saturated flow. This water will discharge into the sand and gravel aquifer at the phase boundaries. The portion that does not infiltrate and runs off will flow over the surface of the restoration material from where it will either discharge into a surface water feature or infiltrate into the sand and gravel 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 Enborne at Brimpton (ID: 39025) (600 m upstream and southwest of the Site) and the catchment area draining to this point. Based on this, the estimated annual effective rainfall of the catchment is 284 mm.

The Standard Annual Average Rainfall (SAAR) for the River Enborne at Brimpton is 789 mm, and the effective rainfall is 36% of the SAAR. The SAAR for the Site is 709 mm (HR Wallingford, 2023). Assuming that effective rainfall is the same proportion of the SAAR, the estimated annual effective rainfall at the Site is 255 mm.

In the water balance, it is assumed that up to 255 mm/yr of water is available for infiltration into the restoration material and that the remainder will runoff and either discharge to a surface water feature or infiltrate to the sand and gravel at the edges of the three phases.

Permeability of restoration material

The restoration material will be comprised of low permeability clays and silts. Consequently, it will be less permeable than the sand and gravel aquifer. The underlying London Clay Formation is of low permeability and will prevent downward migration of groundwater from the restoration material. Beneath the London Clay Formation is the Reading Formation, which is in turn underlain by the Chalk Group. The London Clay Formation is at least 10 m thick at the Site meaning these units are hydraulically separated from the sand and gravel aquifer. These units are screened out of the HRA and are not considered further.

Onsite surface water features

As part of the restoration plans, there will be a pond in each phase, formed above the restoration material. These ponds should receive water from, or lose water to, the restoration material dependant on the head gradient that forms between them. They will also receive water from direct rainfall and runoff.

The River Enborne, Stream A and Stream B also flow through the Site. Groundwater from the restoration material will discharge to these features via the sand and gravel aquifer.

Site Inflows and Outflows

The rate of discharge from the restoration material to the surrounding sand and gravel aquifer in each phase will be dependent on the difference in head between the restoration material and the sand and gravel aquifer at the phase boundary. Due to the low permeability of the restoration material and the underlying London Clay Formation, infiltrating water will create a mound of water in the restoration material. This will cause groundwater within the restoration material to discharge to the sand and gravel aquifer through the sides in all directions.

Heads within the restoration material will be limited by ground level and at this level, flow through the sides of the restoration material into the sand and gravel aquifer will reach the maximum possible. Flow through the sides will equal inflows to the restoration material from rainfall. The maximum inflow is therefore limited by the minimum of the effective rainfall (254 mm) or the maximum flow through the sides.

Should groundwater levels reach ground surface, incident rainfall will runoff without infiltrating into the restoration material and, due to the inert nature of the restoration materials, this runoff will be uncontaminated. Most of the time, heads in each phase 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.

At the up-gradient side of each phase, due to the low permeability, the restoration material will act as barrier to groundwater flow, and groundwater will preferentially flow around the phase along the path of least hydraulic resistance within the sand and gravel aquifer. As such, any inflow to the restoration material from the sand and gravel aquifer will likely be negligible and is not considered further.

Dewatering during construction/restoration

Each void will be dewatered during extraction and filling operations. Dewatering will cease when the phases have been fully backfilled. As filling progresses, the restoration material will be allowed to saturate, but heads will be maintained below the active filling level through dewatering from a sump. Following the operational phase, groundwater will be allowed to rebound to natural levels.

2.3 Source

The Waste Recovery Plan states that the quarry will be infilled with imported restoration material, which will be inert (RSK Geosciences, 2022). Details of the waste acceptance procedures that will be in place at the Site to ensure that the accepted materials will be inert are provided in the Waste Acceptance Plan (RSK Geosciences, 2023). The total quantity of imported material required to fill the three phases is estimated to be 1,153,000 m^3 (RSK Geosciences, 2022). Around the perimeter of the phases an attenuation layer will be constructed.

The potential source of contamination is the inert restoration material. Envireau Water (2023) reviews 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 phase will discharge through the sides passing through the attenuation layer. As the recharging water flushes through the restoration material, any contaminants will be mobilised. The source term contaminant mass will reduce at a rate proportional to the infiltration flux.

The Site will be worked and filled in three phases which are hydraulically separated by the watercourses flowing across the Site. The source has therefore been divided into three areas: Phase A, Phase B and Phase C which are considered separately.

2.4 Pathways

The Site is located in the Beenham Grange Gravel Member, a Secondary A Aquifer and is underlain by the London Clay Formation. Alluvium overlies the Beenham Grange Gravel Member around the River Enborne and River Kennet and, collectively, these units comprise the sand and gravel aquifer. Groundwater within the sand and gravel aquifer will be controlled by dewatering during the operational phase (quarry and in-filling). Post-restoration, dewatering will cease, and groundwater levels will recover.

Based on the conceptual understanding, the pathways associated with each phase are presented below.

The pathways associated with Phase A are:

- Rainwater infiltrating into the restoration material and then:
    - flow from restoration material through the attenuation layer to the sand and gravel aquifer;
    - flow from restoration material through the attenuation layer and sand and gravel aquifer to the River Enborne; and
    - flow from restoration material through the attenuation layer and sand and gravel aquifer to Stream A.

The pathways associated with Phase B are:

- Rainwater infiltrating into the restoration material and then:
    - Flow from restoration material through the attenuation layer to the sand and gravel aquifer;
    - Flow from restoration material through the attenuation layer and sand and gravel aquifer to the River Enborne; and
    - Flow from restoration material through the attenuation layer and sand and gravel aquifer to Spring Ditch.

The pathways associated with Phase C are:

- Rainwater infiltrating into the restoration material and then:
    - Flow from restoration material through the attenuation layer to groundwater in the sand and gravel aquifer; and
    - Flow from restoration material through the attenuation layer and sand and gravel aquifer to the River Enborne.

Groundwater flow within the sand and gravel aquifer is broadly north-eastwards. The north-eastern and eastern sides of each phase are in the "shadow" of the restoration material. Due to this, dilution from the upgradient groundwater flux is ignored and the only dilution is from runoff from the restoration material that infiltrates into the sand and gravel at the edges. This is a conservative approach as there would be natural dilution from the groundwater flux upgradient of each phase.

Following discharge to Stream A, Stream B, Spring Ditch and the River Enborne, the contaminants will be subject to dilution from natural flows within these features.

2.5 Receptors

The potential receptors have been identified as follows:

- Hazardous Substances: edge of the Attenuation Layer adjacent to groundwater in the sand and gravel aquifer at each phase boundary. Instantaneous dilution is applied as detailed in Section 3.3.
- Non-Hazardous Substances:
    - Groundwater in the sand and gravel aquifer at the Site boundary or closest borehole;

  - Stream A for Phase A;
  - Spring Ditch for Phase B;
  - Stream B for Phase C; and
  - The River Enborne for all phases.

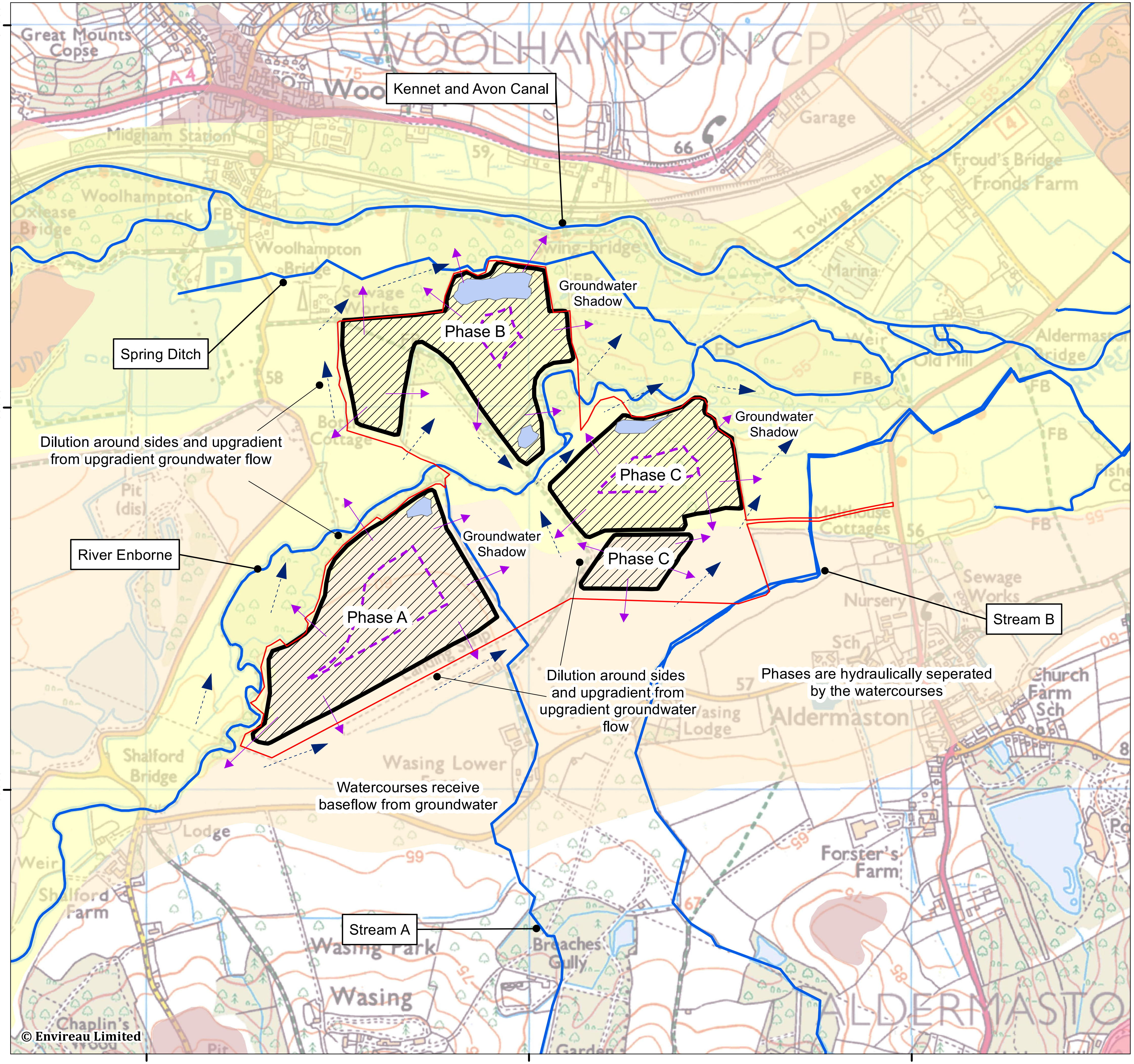

Figure 1: Restoration Conceptual Model (Plan View)

Woolhampton, West Berkshire

N

- ▭ Environmental Permit Application Boundary
- ▨ Void to be filled with restoration material
- ▭ Attenuation Layer
- ⬚ Groundwater Mound
- → Contaminant Flux (Qs)
- ➤ Post Restoration Groundwater Flow
- ▭ Restoration Ponds

Superficial Deposits

- ▭ Alluvium - Clay, Silt, Sand and Gravel
- ▭ Head - Clay, Silt, Sand and Gravel
- ▭ Beenham Grange Gravel Member - Sand and Gravel
- ▭ River Terrace Deposits, 1 to 2 - Sand and Gravel

Notes:

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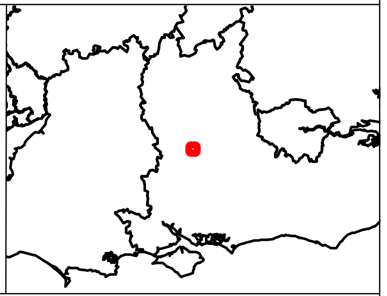

0 130 260 390 520 Meters

Scale: 1:10,000 at A3

29 March 2023

NGR: 458,108 E / 165,684 N

Project No. 3490176

Client: Tarmac Trading Ltd

Drawn by: JH

Ref: FIG - Restoration CSM Plan

envireau WATER

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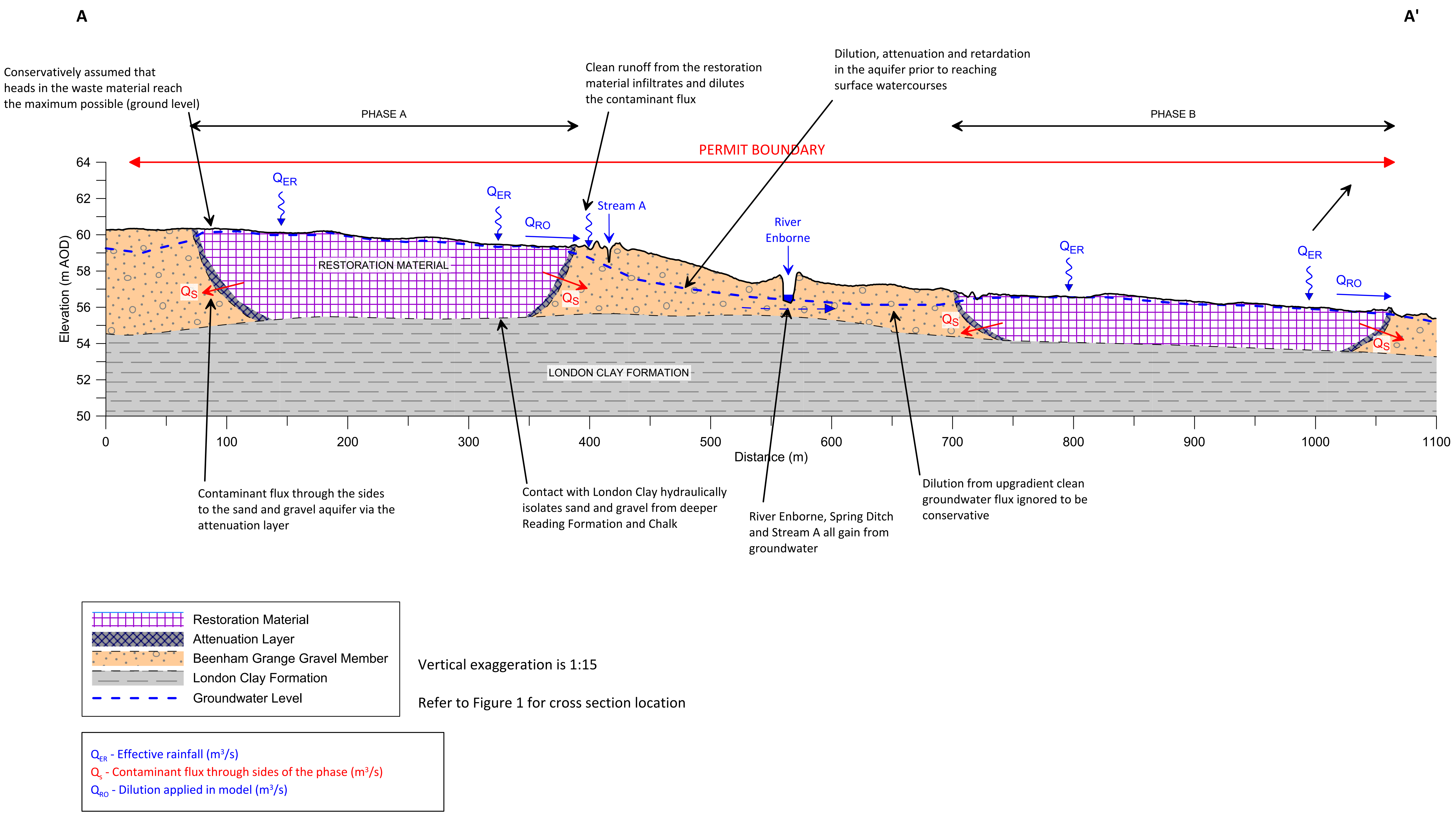

Q_{ER} - Effective rainfall (m³/s)
Q_s - Contaminant flux through sides of the phase (m³/s)
Q_{RO} - Dilution applied in model (m³/s)

Vertical exaggeration is 1:15

Refer to Figure 1 for cross section location

Figure 2: Conceptual Cross Section

Date: 21 March 2023
Project No. 3490176
Client: Tarmac Trading Ltd
Ref: FIG Cross Section HRA
Drawn by: CDW

3 HYDROGEOLOGICAL RISK ASSESSMENT

3.1 Modelling Approach

Inert restoration materials will be placed below 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 will be constructed on the sides of the restoration material. As the base of the restoration material is naturally underlain by the low permeability London Clay Formation, which is classified as unproductive, 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 below the water table in a Secondary A aquifer, and within a groundwater Source Protection (SPZ) Zone 3 with surface water receptors. The Environment Agency guidance for HRAs undertaken in support of waste recovery permit applications has been followed (Environment Agency, 2023). Following this guidance, a Generic Quantitative Risk Assessment (GQRA) is required. Therefore, this is the approach taken here.

3.2 Assessment Scenarios

3.2.1 Operational Phase

Each phase will be dewatered by pumping from a sump. During restoration, construction of the attenuation layer at the perimeter of the phase and infilling with restoration materials will begin from the base of the void and work upwards. No attenuation layer will be placed on the base as the London Clay Formation provides a natural hydraulic barrier to the underlying Reading Formation and Chalk Group aquifers. Dewatering will be undertaken from a sump in the topographically lowest part of the quarry void to keep the working area dry. As restoration continues the sump will move to progressively higher levels within the void.

As each phase is filled, the rate of dewatering will decrease as the creation of a low permeability attenuation layer and reduced drawdown (as the sump moves to higher levels) will result in a lower rate of groundwater inflow. Throughout the operational quarrying and backfilling phases the groundwater head in the phases will be less than those in the surrounding sand and gravel aquifer, resulting in an inwards hydraulic gradient. Consequently, there will be no advection of contaminants into the sand and gravel aquifer.

Water that is abstracted from the void during dewatering will be discharged to the River Enborne in accordance with the discharge activity permit (to be obtained, see Section 2.1). Water that collects in the sump and is subsequently abstracted and discharged will have a very low residence time in contact with the restoration material and, therefore, will not have time to equilibrate. It is therefore at very low risk of containing hazardous substances or non-hazardous pollutants and is not considered further.

3.2.2 Fully Restored Phase

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, and result in an outwards advective flux as heads in the restoration material rise above those in the sand and gravel aquifer. This is the scenario which is considered in the HRA model.

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 from 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 restoration material has been averaged across each phase.
- 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 several 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 source term declines at the same rate as the rate of infiltrating rainfall.

3.3.3 Representation of the conceptual model

The conceptual model is based on the hydrogeological understanding of the Site, and the proposed restoration plans. The restoration conceptual model is shown in plan view for all phases on Figure 1 and in section view in Figure 2 for phases A and B.

As described above, there will be a 'doming' of water within each phase due to the infiltrating rainfall and low permeability of the imported restoration material compared to the sand and gravel aquifer. Water will discharge from the restoration material through the sides of each phase. As the sand and gravel aquifer is underlain by the London Clay Formation, there will be no groundwater flux through the base.

Based on the above, the water balance for each phase can be represented by the following equation:

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

Where:

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

Q_S is the groundwater flux through the sides of the phase; and

Q_{RO} is the excess water that does not infiltrate through the restoration material, runs off and infiltrates at the edges.

All the parameters are measured in m^3/s.

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 only necessary to estimate one of these components, in this case Q_S. For each phase, the maximum value of Q_S has been calculated as:

- The flow through the restoration material, assuming a hydraulic gradient controlled by a maximum head equivalent to the maximum elevation of the restoration material surface and a conservative head at the perimeter of the phase falling over the distance from the centre of the phase to the edge;
- A permeability of the restoration material and attenuation layer (assumed to be the same permeability in this model);
- The average thickness of the restoration material; and
- The perimeter of the filled phase.

This maximum value of Q_S cannot exceed effective rainfall. The maximum inflow is therefore limited to the minimum of the effective rainfall or the maximum Q_S.

Water that flows out of the phase must pass through the attenuation layer. As the restoration material that will be placed in the void will be cohesive, the permeability of the attenuation layer is assumed to be the same as the restoration material.

When the contaminant flux (Q_S) reaches the groundwater receptor at the edge of the phase, it is instantaneously diluted by Q_{RO}. It is conservatively assumed that there is no dilution from upgradient groundwater flow. At the groundwater receptor, predicted concentrations are assessed against the relevant Environmental Assessment Limits (EALs).

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. The results of the screening assessment are set out below.

For the screening assessment, it is assumed that the source term concentration (the concentration of the determinand in the restoration material) is the C_0 (percolation test) limit as given in the final column of the table in Section 2.1.2.1 of European Union Council Decision 2003/33/EC. 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 are likely to be placed at the Site. Controls will be in place as set out in the Waste Acceptance Plan (RSK Geosciences, 2023).

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 waste concentration (mg/l)

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

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

The pathway with the least dilution is that from the restoration material to the sand and gravel aquifer. This is the only pathway that has used for this screening assessment. The DF has been calculated using the following equation:

$$DF = \frac{Q_S}{Q_{ER}}$$

The greater the dilution, the lower the DF. DFs for each phase have been calculated and the values used in the assessment are shown in Table 1.

Table 1 Dilution Factors for screening assessment

Pathway	Notation	Value	Unit
Phase A			
Contaminant flux through attenuation layer	Q_S	2.37 x10^{-5}	m^3/s
Effective rainfall	Q_{ER}	1.54 x10^{-3}	m^3/s
Dilution Factor	DF	0.0154	-
Phase B			
Contaminant flux through attenuation layer	Q_S	2.76 x10^{-5}	m^3/s
Effective rainfall	Q_{ER}	1.30 x10^{-3}	m^3/s
Dilution Factor	DF	0.0213	-
Phase C			
Contaminant flux through attenuation layer	Q_S	2.82 x10^{-5}	m^3/s
Effective rainfall	Q_{ER}	1.21 x10^{-3}	m^3/s
Dilution Factor	DF	0.0233	-

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

- The 95th percentile baseline groundwater quality in the Site monitoring wells north of the River Enborne (for Phase B) and south of the River Enborne (for Phases A and C);
- The UK Technical Advisory Group (UKTAG) Quantification Limit (hazardous substances only); 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. These determinands have been carried forward to the HRA model.

Table 2, Table 3, and Table 4 present the results of the source term screening assessment for each phase. Only chromium VI is a hazardous substance, however the source term concentration taken from European Union Council Decision 2003/33/EC is for total chromium. It is conservatively assumed that all chromium present in the restoration material is chromium VI and is a hazardous substance. 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, organic species, such as BTEX, PCB , mineral oils and PAH are not expected to be present and are not considered in the assessment.

Small amounts of biodegradable material may be accidently included within the restoration material, which then degrade to produce biproducts, including ammoniacal nitrogen. For this reason ammoniacal nitrogen has also been included in the screening assessment with a conservative concentration of 1 mg/l.

Based on the screening assessment, the following determinands have been simulated in the HRA models:

- Arsenic (Phase C only)’
- Barium;
- Cadmium;
- Chromium;
- Copper;
- Mercury;
- Molybdenum;
- Lead; and
- Antimony.

Table 2 Source term screening assessment (groundwater south of the River Enborne, Phase A)

Determinand	Haz /Non Haz	Result	Source Term Concentration (mg/l)	Max Acceptable Concentration (mg/l)	Target Concentration to assess against (mg/l)	UK DWS (mg/l)	UKTAG Quantification Limit (mg/l)	Baseline 95th Percentile concentration (mg/l)	Comment
Arsenic	Haz	Pass	0.06	0.0964	0.0015	0.01	5.00E-03	0.0015	Based on monthly samples from 7 boreholes screened across sand and gravels (2016 – present)
Barium	Non Haz	FAIL	4.00	1.97	0.046			0.046	
Cadmium	Non Haz	FAIL	0.02	0.0130	0.0002	5.00E-03		2.0E-04	
Total Chromium	Haz	FAIL	0.100	0.0326	0.0005	0.05	1.00E-03	5.0E-04	Chromium VI hazardous. Most WIF's only include total chromium so assume all chromium is chromium VI which is very conservative.
Copper	Non Haz	FAIL	0.600	0.298	0.0046	2.00		0.0046	Based on monthly samples from 7 boreholes screened across sand and gravels (2016 – present)
Mercury	Haz	FAIL	0.002	0.0013	2.00E-05	0.001	2.00E-05	5.00E-05	Almost all results less than LOD
Molybdenum	Non Haz	FAIL	0.200	0.117	0.0018			0.0018	Based on monthly samples from 7 boreholes screened across sand and gravels (2016 – present)
Nickel	Non Haz	Pass	0.120	0.39	0.006	0.02		0.006	
Lead	Haz	FAIL	0.150	0.0013	2.00E-05	0.01	2.00E-05	0.002	
Antimony	Non Haz	FAIL	0.100	0.0326	0.0005	5.00E-03		5.00E-04	Concentrations in all but one sample were below LOD
Selenium	Non Haz	Pass	0.04	0.117	0.0018	0.01		0.0018	Based on monthly samples from 7 boreholes screened across sand and gravels (2016 – present)
Zinc	Non Haz	Pass	1.20	2.65	0.041			0.041	
Chloride	Non Haz	Pass	460	3,440	52.8	250		52.8	
Fluoride	Non Haz	Pass	2.50	13.03	0.20	1.50		0.20	
Sulphate	Non Haz	Pass	1,500	16,288	250.0	250		454	
Ammoniacal nitrogen	Non Haz	Pass	1	25.4	0.39	0.39		0.9	Based on monthly samples from 7 boreholes (2022 – present)

[1] Assumed to be bioavailable

Table 3 Source term screening assessment (groundwater north of the River Enborne, Phase B)

Determinand	Haz /Non Haz	Result	Source Term Concentration (mg/l)	Max Acceptable Concentration (mg/l)	Target Concentration to assess against (mg/l)	UK DWS (mg/l)	UKTAG Quantification Limit (mg/l)	Baseline 95th Percentile concentration (mg/l)	Comment
Arsenic	Haz	Pass	0.06	0.0939	0.0020	0.01	5.00E-03	0.002	Based on monthly samples from 5 boreholes screened across sand and gravels (2016 – present)
Barium	Non Haz	FAIL	4.00	2.35	0.045			0.05	
Cadmium	Non Haz	FAIL	0.02	0.012	2.5E-04	5.00E-03		2.5E-04	
Total Chromium	Haz	FAIL	0.100	0.0235	5.0E-04	0.05	0.001	5.0E-04	Chromium VI hazardous. Most WIF's only include total chromium so assume all chromium is chromium VI which is very conservative.
Copper	Non Haz	FAIL	0.600	0.197	0.0042	2.00		0.0042	Based on monthly samples from 5 boreholes screened across sand and gravels (2016 – present)
Mercury	Haz	FAIL	2.00E-03	0.0009	2.00E-05	1.00E-03	2.00E-05	5.1E-05	Concentrations in all samples were below LOD
Molybdenum	Non Haz	FAIL	0.200	0.0470	0.001			0.001	Based on monthly samples from 5 boreholes screened across sand and gravels (2016 – present)
Nickel	Non Haz	Pass	0.120	0.376	0.008	0.02		0.008	
Lead	Haz	FAIL	0.150	0.0009	2.00E-05	0.01	2.00E-05	0.004	
Antimony	Non Haz	FAIL	0.100	0.0470	0.001	5.00E-03		0.001	Concentrations in all samples were below LOD
Selenium	Non Haz	Pass	0.04	0.235	0.005	0.01		0.005	Based on monthly samples from 5 boreholes screened across sand and gravels (2016 – present)
Zinc	Non Haz	Pass	1.20	2.95	0.063			0.063	
Chloride	Non Haz	Pass	460	1,550	33.0	250		33	
Fluoride	Non Haz	Pass	2.50	9.39	0.2	1.50		0.2	
Sulphate	Non Haz	Pass	1500	2,922	62.2	250		62.2	
Ammoniacal nitrogen	Non Haz	Pass	1	18.3	0.39	0.39		1.3	Based on monthly samples from 5 boreholes (2022 – present)

[1] Assumed to be bioavailable.

Table 4 **Source term screening assessment (groundwater south of the River Enborne, Phase C)**

Determinand	Haz /Non Haz	Result	Source Term Concentration (mg/l)	Max Acceptable Concentration (mg/l)	Target Concentration to assess against (mg/l)	UK DWS (mg/l)	UKTAG Quantification Limit (mg/l)	Baseline 95th Percentile concentration (mg/l)	Comment
Arsenic	Haz	FAIL	0.06	0.064	0.0015	0.01	5.00E-03	0.0015	Based on monthly samples from 7 boreholes screened across sand and gravels (2016 – 2024)
Barium	Non Haz	FAIL	4.00	1.66	0.0388			0.0388	
Cadmium	Non Haz	FAIL	0.02	0.0086	2.0E-04	5.00E-03		2.0E-04	
Total Chromium	Haz	FAIL	0.100	0.0214	5.0E-04	0.05	1.00E-03	5.0E-04	Chromium VI hazardous. Most WIF's only include total chromium so assume all chromium is chromium VI which is very conservative.
Copper	Non Haz	FAIL	0.600	0.20	0.0046	2.00		0.0046	Based on monthly samples from 7 boreholes screened across sand and gravels (2016 – 2024)
Mercury	Haz	FAIL	2.00E-03	0.0009	2.00E-05	1.00E-03	2.00E-05	5.00E-05	Concentrations in all but one sample were below LOD
Molybdenum	Non Haz	FAIL	0.200	0.077	0.0018			0.0018	Based on monthly samples from 7 boreholes screened across sand and gravels (2016 – 2024)
Nickel	Non Haz	Pass	0.120	0.257	0.006	0.02		0.006	
Lead	Haz	FAIL	0.150	0.0086	2.00E-05	0.01	2.00E-05	0.002	
Antimony	Non Haz	FAIL	0.10	0.0214	0.0005	5.00E-03		5.00E-04	Concentrations in all samples were below LOD so the value used is half the LOD
Selenium	Non Haz	Pass	0.04	0.077	0.0018	0.01		0.0018	Based on monthly samples from 7 boreholes screened across sand and gravels (2016 – 2024)
Zinc	Non Haz	Pass	1.20	1.75	0.041			0.041	
Chloride	Non Haz	Pass	460	2,264	52.8	250		52.8	
Fluoride	Non Haz	Pass	2.50	8.57	0.20	1.50		0.20	
Sulphate	Non Haz	Pass	1,500	10,718	250	250		454	
Ammoniacal nitrogen	Non Haz	Pass	1	16.7	0.39	0.39		0.9	Based on monthly samples from 7 boreholes (2022 – present)

3.5 Consideration of Surface Water Receptors

3.5.1 Surface watercourses

Impacts on the River Enborne, Stream A and Spring Ditch have been qualitatively screened out of this assessment. This is because the contaminant flux will be further diluted by flows in the watercourse. The Q_{95} flow in each of the three watercourses is as follows:

- River Enborne - 0.168 m^3/s (6 x 10^4 times greater than the maximum Q_S)
- Spring Ditch – 0.01 m^3/s (3.6 x 10^3 times greater than the maximum Q_S)
- Stream A – 0.01 m^3/s (3.6 x 10^3 times greater than the maximum Q_S)

Given that the dilution will be at least three orders of magnitude greater than the maximum contaminant flux, provided that the EAL is met at the groundwater receptor, there will be no impacts on these surface water features, and these have been qualitatively screened out of the GQRA.

3.5.2 Shallow surface waterbodies

Shallow waterbodies will form at the surface of the restoration material and will offer attenuation storge during storm events. These features will be shallow and the head gradient between them and the restoration material will therefore be minimal. This will mean any contamination flux into the ponds will be negligible. Furthermore, the ponds will receive diluting flux from direct rainfall and runoff. Given this, these features are at very low risk of being impacted and have been qualitatively screened out of the GQRA.

3.6 Model Parameterisation

3.6.1 Site Dimensions

A model has been developed for each phase. The model parameters specifying the dimensions of the restoration material to be placed in each phase are shown in Table 5.

Table 5 Site parameters

Description	Value	Unit	Data Source
Total Volume of restoration material	1,153,000	m^3	ESSD Report (Envireau Water, 2023)
Proportion of total volume in Phase A	412,336	m^3	Calculated based on areas and volumes
Proportion of total volume in Phase B	417,836	m^3	
Proportion of total volume in Phase C	322,828	m^3	
Total Areal Extent of Restoration Material	501,168	m^3	Calculated from GIS
Area of Phase A	191,007	m^2	Calculated from GIS
Area of Phase B	160,617	m^2	
Area of Phase C	149,544	m^2	
Distance from centre of Phase A to perimeter	245	m	

Description	Value	Unit	Data Source
Distance from centre of Phase B to perimeter	150	m	Representative value from approximate centre to edge of each phase parallel to groundwater flow
Distance from centre of Phase C to perimeter	220	m	
Perimeter of Phase A	1,977	m	Calculated from GIS
Perimeter of Phase B	2,332	m	
Perimeter of Phase C	2,159	m	
Proportion of water that would freely drain from the restoration material	0.3		Beavan (1996)
Maximum groundwater elevation Phase A	62.16	m AOD	Maximum elevation from LiDAR Data
Maximum groundwater elevation Phase B	57.33	m AOD	
Maximum groundwater elevation Phase C	58.59	m AOD	
Base of Phase A	55.86	m AOD	Mean elevation of London Clay and sand and gravel contact.
Base of Phase B	51.05	m AOD	
Base of Phase C	53.16	m AOD	
Thickness of restoration material Phase A	6.30	m	Difference between maximum ground elevation and mean top of London Clay Formation
Thickness of restoration material Phase B	6.28	m	
Thickness of restoration material Phase C	5.43	m	
Permeability of restoration material	1×10^{-7}	m/s	Restoration material will be cohesive clays with permeability indistinguishable from the Attenuation Layer.

The volumes assigned to Phases A, B and C are based on their relative surface areal proportions.

3.6.2 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 6, taken from Section 2.1.2.1 of 2003/33/EC.

Table 6 Source term parameters

Determinand	Concentration (mg/l)	Comment
Arsenic (Phase C only)	0.06	C_0 percolation test limits (Section 2.1.2.1 of 2003/33/EC) used as an upper conservative source term concentration.
Barium	4	
Cadmium	0.02	
Chromium	0.1	
Copper	0.6	
Mercury	0.002	
Molybdenum	0.2	

Determinand	Concentration (mg/l)	Comment
Lead	0.15	
Antimony	0.1	

3.6.3 Hydrology

The modelled hydrological parameters are presented in Table 7.

Table 7 Hydrological parameters

Parameter	Value	Unit	Comment
Effective Rainfall	255	mm/yr	Section 2.2 and Envireau Water (2023)

3.6.4 Attenuation Layer Parameters

The parameters used to define the attenuation layer in the model are presented in Table 8. The hydraulic gradient between the restoration material and the sand and gravel aquifer has been calculated as follows:

- Head difference equivalent to maximum groundwater elevation in each phase (see Table 5) minus the head in the sand and gravel (see Table 9); and
- The distance over which the head falls is the distance from the centre of the phase to the perimeter.

The restoration material and attenuation layer have the same permeability and therefore the head gradient is calculated across the entire combined thickness.

Table 8 Attenuation layer parameters

Parameter	Value	Unit	Comment
Permeability	$1\text{x}10^{-7}$	m/s	Assumed value for the materials to be used to form the attenuation layer
Thickness	1	m	Minimum thickness to prevent discharge of hazardous substances
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.
Dispersivity	0.1	m	Assumed to be 10% of travel distance
Tortuosity	5	-	Conservative value (De Marsily, 1986)

3.6.5 Pathway parameters

The parameters used to define the hydrogeological pathway through the sand and gravel are shown in Table 9. These parameters are only used for non-hazardous pollutants.

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

Table 9 Sand and gravel pathway parameters

Parameter	Value	Unit	Comment
Sand and gravel aquifer bulk density	1,600	kg/m^3	Expert Judgement
Sand and gravel aquifer Permeability	122	m/day	Mean Permeability (Envireau Water, 2022)
Travel distance from Phase A to nearest monitoring borehole (WM3)	20	m	Distance between the restoration material and the groundwater receptor for non-hazardous pollutants, measured using GIS from the edge of the restoration material to the closest monitoring point or Site boundary.
Travel distance from Phase B to Site boundary	10	m	
Travel distance from Phase C to Site boundary	1	m	
Sand and gravel effective porosity	0.2	-	Estimate based on geological descriptions
Sand and gravel Hydraulic Gradient	0.003		Based on current groundwater contours across the Site (Envireau Water, 2023)
Dispersivity	10% of travel distance		Typical modelling assumption
Tortuosity	5		Conservative value (De Marsily, 1986)
Average groundwater head at perimeter of Phase A	57.5	m AOD	Conservative estimate from minimum groundwater contours in Envireau Water (2023).
Average groundwater head at perimeter of Phase B	54.5	m AOD	
Average groundwater head at perimeter of Phase C	54.5	m AOD	

3.6.6 Contaminant Transport Parameters

The contaminant transport parameters that have been applied to the HRA model are shown in Table 10. Different transport parameter values have been applied to the Attenuation Layer and the sand and gravel aquifer due to their different compositions, as specified in Table 10. Sorption is related to the partition coefficient (K_d).

None of the modelled determinands degrade naturally.

Table 10 Contaminant transport parameters

Parameter	Value	Unit	Comment
Free water diffusion coefficient	2.0 x10^{-9}	m^2/s	Conservative assumption based on value for chloride
Arsenic K_d (Attenuation Layer)	137	l/kg	Mid-range value (Golder Associates, 2007)
Arsenic K_d (Sand and gravel)	25	l/kg	Minimum value (Golder Associates, 2007)
Barium K_d (Attenuation Layer)	17	l/kg	Value for unspecified material (Golder Associates, 2003)
Barium K_d (Sand and gravel)	17	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003)
Cadmium K_d (Attenuation Layer)	222	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003)
Cadmium K_d (Sand and gravel)	74	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003)
Chromium K_d (Attenuation Layer)	966	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003)
Chromium K_d (Sand and gravel)	67	l/kg	Value for sand (Golder Associates, 2003)
Copper K_d (Attenuation Layer)	126.8	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003)
Copper K_d (Sand and gravel)	295	l/kg	Value for unspecified conditions (Golder Associates, 2003)
Mercury K_d (Attenuation Layer)	2,142	l/kg	Mid-range value (Golder Associates, 2007)
Mercury K_d (Sand and gravel)	450	l/kg	Value for sand (Golder Associates, 2003)
Molybdenum K_d (Attenuation Layer)	110	l/kg	Value for unspecified material (Golder Associates, 2003)
Molybdenum K_d (Sand and gravel)	110	l/kg	Value for unspecified material (Golder Associates, 2003)
Lead K_d (Attenuation Layer)	434.6	l/kg	Value for glacial till (representative of clay) (Golder Associates, 2003)
Lead K_d (Sand and gravel)	270	l/kg	Value for sand (Golder Associates, 2003)
Antimony K_d (Attenuation Layer)	140	l/kg	Geometric mean value for clay (Sheppard, Long, Sanipelli, & Sohlenius, 2009)
Antimony K_d (Sand and gravel)	17	l/kg	Value for sand (Golder Associates, 2003)

3.6.7 Environmental Assessment Levels

Environmental Assessment Levels (EALs) used to assess impacts on the receptor are presented in Table 11. Baseline water quality exists for the groundwater in the sand and gravel Aquifer, the River Enborne and Spring Ditch. For non-hazardous pollutants, baseline concentrations have been used where these are lower than the UK DWS (for groundwater). For hazardous substances, the UKTAG limit has been used, unless baseline concentrations are lower than this value.

Table 11 Groundwater EALs

Determinand	Concentration (mg/l)		Source
	South of River Enborne (Phases A and C)	North of River Enborne (Phase B)	
Arsenic (Phase C only)	0.00148	n/a	95th percentile groundwater quality
Barium	0.046	0.05	95th percentile groundwater quality
Cadmium	0.0002	0.00025	95th percentile groundwater quality
Chromium	0.0005	0.0005	UK TAG Quantification Limit (Phase A/C), 95th percentile groundwater quality (Phase B)
Copper	0.005	0.0042	95th percentile groundwater quality
Lead	0.00002	0.00002	UK TAG Quantification Limit
Mercury	0.00002	0.00002	UK TAG Quantification Limit
Molybdenum	0.0018	0.001	95th percentile groundwater quality
Antimony	0.0005	0.001	95th percentile groundwater quality

3.7 Model Results

3.7.1 RAM Models

Electronic copies of the RAM3 models for Phases A, B and C are provided in Appendix A.

3.7.2 Water Balance Results

Infiltration to the restoration material in each phase is calculated based on the effective rainfall and is presented on Table 12. The groundwater flux out of the restoration material into the sand and gravel aquifer is calculated for each phase and also presented on Table 12. As the groundwater flux is less than the infiltration, in each phase the majority of the infiltrating rainfall will runoff.

Table 12 Contaminant fluxes

Phase	Groundwater flux out of restoration material (m^3/s)	Runoff dilution flux (m^3/s)
A	2.37×10^{-5}	1.52×10^{-3}
B	2.76×10^{-5}	1.27×10^{-3}
C	2.82×10^{-5}	1.18×10^{-3}

3.7.3 Contaminant Concentrations

Table 13 to Table 15 present the model results for each phase. Only contaminants which have a breakthrough within 1,000 years have been presented. For these contaminants, the maximum concentrations, and the time it was reached are given. If the maximum concentration has not been reached by 1,000 years, the concentration at 1,000 years is given. Where concentrations are less than 1.0×10^{-5}mg/l, this is considered to be non-detectable, meaning 'no breakthrough'. This value was selected as it is less than the minimum EAL of 2.0×10^{-5}mg/l. The modelled metals sorb strongly to clays and, as a result, where breakthrough occurs it is at very low concentrations.

For all phases, there is no breakthrough of the hazardous substances (arsenic, chromium, mercury, and lead) at the edge of the Attenuation Layer (i.e., the receptor for hazardous substances). There is also no breakthrough of any modelled non-hazardous pollutant other than barium.

The results are set out below.

Phase A

The model predicts a breakthrough of barium only, with maximum groundwater concentrations reached at 570 years. The maximum concentration of barium is below the EAL.

Table 13 Maximum concentrations at receptors for Phase A

Determinand	Receptor / Pathway	Peak Concentration (mg/l)	Time to maximum concentration (years)	EAL (mg/l)
Barium	Groundwater in sand and gravel	0.015	570	0.046

Phase B

The model predicts a breakthrough of barium, with a maximum concentration in groundwater reached at 550 years. The maximum concentration of barium is below the EAL.

Table 14 **Maximum concentrations at receptors for Phase B**

Determinand	Receptor / Pathway	Peak Concentration (mg/l)	Time to maximum concentration (years)	EAL (mg/l)
Barium	Groundwater in sand and gravel	0.019	550	0.05

Phase C

In Phase C, the model predicts a breakthrough of barium, copper, and molybdenum, with a maximum concentration in groundwater reached at 430 years for barium. All maximum concentrations are below the EAL.

Table 15 **Maximum concentrations at receptors for Phase C**

Determinand	Receptor / Pathway	Peak Concentration (mg/l)	Time to maximum concentration (years)	EAL
Barium	Groundwater in sand and gravel	0.020	430	0.046
Copper	Groundwater in sand and gravel	3.09×10^{-5}	1,000	0.005
Molybdenum	Groundwater in sand and gravel	2.64×10^{-5}	1,000	0.0018

3.8 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, the Site monitoring data will be evaluated annually, and results will be submitted to the Environment Agency in an annual report. Control Levels and Compliance Limits for down-hydraulic gradient groundwater monitoring wells and surface water have been derived and the Scheme of Monitoring is presented in the Site Monitoring Plan (Envireau Water, 2023b).

The HRA for the site will be reviewed in line with Environment Agency guidance, currently every six years (Environment Agency, 2024). 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.

4 SUMMARY

Tarmac proposes to carry out the backfilling and Site restoration at Wasing 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, given the inert nature of the restoration material, has been used to parameterise a GQRA. The GQRA has been undertaken in accordance with both the GWD and the Landfill Directive.

Groundwater in the sand and gravel aquifer will be protected by a side wall Attenuation Layer and underlying low permeability London Clay Formation. The model does not consider groundwater dilution and instead assumes relies on runoff from the backfill material. A dilution screening assessment has been used to determine which contaminants to take through to the GQRA. Nine determinands were taken forward to the GQRA stage where attenuation in the Attenuation Layer and sand and gravel aquifer is considered. The model results show no impacts on the groundwater environment with predicted concentrations of non-hazardous pollutants being below the EALs and no discernible discharge of hazardous substances.

Risks to the underlying Reading Formation and Chalk have been qualitatively screened out from the assessment, on the basis of the underlying London Clay Formation which is at least 10 m thick.

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APPENDICES

Appendix A RAM3 Models (electronic appendix)