Transport, Environment & Design

Zig Zag Quarry
Hydrogeological Risk Assessment

July 2026

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Revision	Author	Description	Date
1	Alex Large	Table 8-3 updated with data from 13No. groundwater monitoring events between March 2025 and March 2026.	25-June-2026
2	Jamie Howourth	Report updated following Schedule 5 response from the Environment Agency plus additional round of groundwater monitoring results.	22-July-2026

Glossary of Abbreviations

AOD	Above Ordnance Datum
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
BTJ	BT Jenkins Limited
CIRIA	Construction Industry Research and Information Association
CL:AIRE	Contaminated Land: Applications in Real Environments
CoPC	Contaminant of Potential Concern
CQA	Construction Quality Assurance
CSM	Conceptual Site Model
DCC	Devon County Council
DEFRA	Department for Environment, Food & Rural Affairs
DOWCOP	Definition of Waste Code of Practice
EA	Environment Agency
EAL	Environmental Assessment Level
EPH	Extractable Petroleum Hydrocarbons
EQS	Environmental Quality Standard
ESSD	Environmental Setting & Site Design Report
Horizon	Horizon Consulting Engineers Limited
HRA	Hydrogeological Risk Assessment
LRL	Laboratory Reporting Limit
LOQ	Limit of Quantification
MPP	Monitoring Point Plan
MRV	Minimum Reporting Values
PAH	Polycyclic Aromatic Hydrocarbon
RTD	River Terrace Deposits
SRA	Stability Risk Assessment
TPH	Total Petroleum Hydrocarbons
TPH CWG	TPH Criteria Working Group
WAC	Waste Acceptance Criteria
WFD	Water Framework Directive
WFD-UKTAG	Water Framework Directive United Kingdom Technical Advisory Group
WFS	Water Features Survey
WHO	World Health Organisation
WQS	Water Quality Standard

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1. Introduction

1.1 Commission

1.1.1 Horizon Consulting Engineers Limited (Horizon) was commissioned by the Operator, BT Jenkins Limited (BTJ) on behalf of the Permit Holder (Harleyford Aggregates Limited) to prepare an updated Hydrogeological Risk Assessment (HRA) for Zig Zag Quarry in support of an application to vary the existing Environmental Permit (Reference: HB03705XG). Zig Zag Quarry is located to the north of the town of Kingskerswell, Newton Abbot, Devon, TQ12 5AT.

1.1.2 A variation is required to the existing Environmental Permit to facilitate the final restoration of the Site under Devon County Council (DCC) Planning Permission Reference DCC/4339/2023.

1.1.3 The overarching aim is to infill the void, restoring the Site to pre-quarrying levels. The Site is to be restored to a long-term end use of pastoral grazing fields separated by Devon hedge banks together with scrub and woodland habitats.

1.1.4 A previous HRA report[1] was prepared by JH Groundwater in September 2021 to support the original environmental permit application. This version of the HRA report has been prepared by Horizon to support a substantial variation to the existing permit increasing the mass of material to be deposited to circa 1.5 M tonnes, in line with both the approved 2024 Waste Recovery Plan (WRP[2]) and Planning Permission.

1.1.5 This HRA has been updated in July 2026 (Revision2) to respond to comments made in a Schedule 5 Notification received from the EA on 26 June 2026[3].

1.2 Aims and Objectives

1.2.1 The aim of this assessment is to provide the EA with sufficient detail in relation to the potential impacts of the proposed restoration works on the water environment. To achieve the above aim, this hydrogeological assessment provides the following:

(i) a controlled waters risk assessment to quantify the likely magnitude of environmental impacts from the deposition of materials within the quarry as part of the restoration works;

(ii) a description of the design, engineering and material acceptance principles that will underpin the proposed restoration scheme and how these features will help protect the water environment; and

(iii) recommendations for monitoring, engineering decisions and waste acceptance procedures as appropriate.

1.3 Report Structure

1.3.1 The remainder of this report is structured as follows:

- **Section 2** summarises the Conceptual Site Model (CSM) and restoration proposals;
- **Section 3** sets out the details of existing material placed to date forming the geological barrier;
- **Section 4** presents details of the contaminant linkages identified and assessed as part of this hydrogeological risk assessment;

[1] JH Groundwater (20 September 2021) Zig Zag Quarry Restoration. Hydrogeological Risk Assessment. Ref: 1164/001_r1_Rev3
[2] Horizon (April 2024) Zig Zag Quarry. Waste Recovery Plan. Ref: HCE0269.WRP.Rev2
[3] Environment Agency (2026). Notice of Request for More Information. Application number: EPR/HB3705XG/V003. 26 June 2026

- **Section 5** sets out details of the quantitative modelling undertaken and the findings of the assessment;
- **Section 6** evaluates the potential risk from accidental releases;
- **Section 7** outlines the proposed essential and technical precautions to be adopted during the restoration works such that the assumptions in the hydrogeological assessment are met;
- **Section 8** set out the proposed scope and nature of monitoring including proposed trigger levels and compliance limits; and
- **Section 9** provides a summation of the site setting, proposed restoration works, key findings and recommendations.

2. Conceptual Site Model & Restoration Proposals

2.1 Conceptual Site Model

2.1.1 A standalone CSM report[4] has been developed for this project with reference to guidance on GOV.UK[5]. The CSM report[4] looks to establish the environmental setting of the Site along with potential hazards associated the proposed restoration and receptors that might be affected by the works.

2.1.2 The CSM report[4] includes details relating to:

- Historical activities at Zig Zag Quarry;
- The approved restoration works including proposed waste types, phasing plus outline management measures and technical controls;
- Precipitation data (i.e., rainfall record);
- Local surface water features;
- Geological and hydrogeological setting;
- Man-made pathways that may be affected by the restoration works; and
- Receptors in the vicinity of the Site including amenity, habitats and natural heritage.

2.1.3 Data and discussion presented in the CSM report[4] is generally not repeated in this HRA. The CSM report[4] should be read in conjunction with this HRA.

2.2 Restoration Proposals

2.2.1 Details of the restoration proposals are set out in Section 4 of the CSM report[4]. In summary, the restoration scheme requires the import of 1.5 million tonnes of inert wastes in order to provide a safe and stable landform that is in keeping with the surrounding landscape. All material used for the purposes of the restoration works is required to meet the following waste codes:

Waste Code	Description
01 04 08	Waste gravels and crushed rocks other than those mentioned in 01 04 07
01 04 09	Waste sand and clays
17 05 04	Soil and stones other than those mentioned in 17 05 03

Table 2-1: Waste Codes

[4] Horizon (November 2025) Zig Zag Quarry. Conceptual Site Model. Ref: HCE0269.CSM.Rev3
[5] https://www.gov.uk/guidance/landfill-operators-environmental-permits/plan-the-environmental-setting-of-your-site#conceptual-site-model [Accessed 07 November 2025]

3. Geological Barrier (Existing Materials)

3.1 September 2021 HRA

3.1.1 The 2021 HRA[1] prepared to support the original permit application envisaged that "*certain technical precautions might need to be considered where these are deemed appropriate to development proposals in order to provide adequate protection of groundwater and surface waters resources.*" This included potentially using in-situ materials to form a geological barrier.

3.1.2 The Environmental Setting & Site Design Report[6] (ESSD) prepared to support the original permit application stated that "*a suitable inert waste geological barrier formed from the indigenous mineral waste materials is to be initially considered. Where necessary, additional basal and side slope liner systems may be needed although details of this would be subject to design review during the environmental permitting process.*"

3.1.3 Prior to the permit being granted, part of the Site footprint was restored with indigenous and imported restoration material under the CL:AIRE Definition of Waste: Code of Practice (DOWCOP) scheme. Circa 145,785 tonnes clean naturally occurring soils were imported and placed as documented in the Verification Report[7] issued to the Environment Agency to summarise the material import under the DOWCOP scheme. The Verification Report[7] looked to demonstrate that only clean naturally occurring subsoil (and topsoil) was imported to Zig Zag Quarry under the CL:AIRE DOWCOP scheme, with material suitability evaluated based on reports, testing data and photos relating to each of the donor site.

3.1.4 The remainder of this section of the report looks to evaluate the nature of the soils imported and placed under the DOWCOP scheme with reference to their suitability to act as the geological barrier envisaged in the September 2021 HRA[1].

3.2 DOWCOP Soil Properties

3.2.1 **Table 3-1** below summarises available data on the soils imported and placed under the DOWCOP scheme with specific reference to the likely soil matrix and available data on permeability.

[6] Aardvark (April 2021) Zig Zag Quarry. Environmental Setting and Site Design Report. Ref: 1922-R005. FINAL v2
[7] Horizon (20 July 2021) Zig Zag Quarry. DOWCOP Verification Report. Ref: HCE0269.VR.Rev1

Donor Site Name	Quantity of Subsoil Imported (Tonnes)	Geology	Infiltration Testing
Penns Mount, Vicarage Hill, TQ12 3BA	10,155	Subsoil comprised a mixture of Whiteway Mudstone Formation (described as either a sandy very gravelly clay or slightly sandy, medium to coarse slate gravel) and Upper Greensand Formation (typically described as clayey very gravelly sand or very sandy clay).	5No. infiltration tests undertaken per DG365[8]. Ian Farmer Associates report[9] that "*the Whiteway Mudstone Formation (encountered in the northern section of the Site) is practically impermeable*." Furthermore, in relation to the Upper Greensand Formation, Ian Farmer Associates[9] state that "*the results of in-situ permeability tests in the Upper Greensand Formation did not discharge sufficiently to determine permeability. These indicate the Upper Greensand Formation to be of poor drainage characteristics*."
White Rock Residential Site.	25,065	Predominantly Devonian Saltern Cove Formation, described by Clarke Bond[10] as gravelly clay grading into a gravel with sparse matrix before the transition to bedrock. Ashprington Volcanic Formation encountered across the far southern part of the Site.	2No. infiltration tests undertaken during a previous phase of investigation were reported by Clarke Bond[10] to have infiltration rates of circa 3×10^{-5} m/s however details of these tests are not available to Horizon, in particular the geological strata targeted. It is assumed they will have targeted the deeper more permeable bedrock as opposed to the overlying weathered deposits.
Alphington Vistry	6,500	This is a large Site, however subsoil imported to Zig Zag was derived from a relatively small area. Reference was made to Hydrock's 2013 Combined Desk Study & Ground Investigation Report[11], Hydrock's 2017 Supplementary Ground Investigation[12] and Geotechnical Engineering's 2019 Ground Investigation[13] for details of ground conditions. The subsoil is interpreted to comprise Heavitree Breccia Formation, generally comprised a residual soil recovered as clayey slightly gravelly sand or sandy gravelly silt/clay over gravel with varying proportions of silt and sand.	1No. infiltration test undertaken in trial pit TP08 in area of Site where subsoil derived from. An infiltration rate was unable to be calculated due to poor infiltration of water into ground.
Premier Inn, Torquay	22,195	The Torquay Limestone Formation / Nordon Formation was recovered as slightly gravelly clay or extremely weak to medium strong shale/siltstone/mudstone.	Enygo 2019 report[14] states that "*preliminary soakaway testing in WS1 gave a soil infiltration value of approximately 8.6×10^{-7} m/s. Soakaway drainage is not considered to be feasible*." No details on the testing are provided (e.g., number of tests, falling or rising head test, geology targeted etc). With reference to the borehole log it is assumed that the test targeted the extremely weak slightly gravelly mudstone with rare shell fragments at the base of the borehole.

[8] BRE (2016) Soakaway Design. Design Guide 365
[9] Ian Farmer Associates (April 2018) Penns Mount, Vicarage Hill. Ground Investigation Report. Contract: C61461
[10] ClarkeBond (UK) Ltd (June 2013) White Rock Residential, Eastern Site, Paignton. Phase II Geoenvironmental Investigation. Report No. WB03050
[11] Hydrock (July 2013) Desk Study and Ground Investigation at Alphington, Exeter. Ref: R/12525/001
[12] Hydrock (May 2017) South West Exeter – Alphington. Supplementary Ground Investigation. Ref: R/12525/003 Issue 2
[13] Geotechnical Engineering (23 April 2019) South West Exeter. Factual Report on Ground Investigation. Ref: 35103.
[14] Enzygo (September 2019) Terrace Car Park, Torquay. Geo Environmental Report. Ref: CRM.248.003.R.001.A

Donor Site Name	Quantity of Subsoil Imported (Tonnes)	Geology	Infiltration Testing
Torbay Hospital	6,570	Red Rock's 2020 Ground Investigation Report[15] described residual soil in all exploratory holes to depths of between 0.6 m and 4.9 m. These materials comprised: • Slightly sandy gravelly clay. • Slightly clayey sandy gravel • Slightly gravelly clayey sand • Sandy clay. The Torbay Breccia Formation was encountered in all exploratory holes between 1.0 m and 5.2 m. This stratum comprised: • Slightly sandy gravelly clay. • Slightly sandy gravelly clay. • Gravelly clayey sand.	1No. trial pit was used for soakaway testing in generally accordance with DG365[8]. Red Rock[15] noted that "*the in-situ soakaway tests produced insufficient infiltration rate values. This relatively slow rate of infiltration, indicates that soakaways are unlikely to form an effective method for surface water drainage for this site.*"
Seabrook Orchard	23,770	Details on ground conditions have been sourced from Red Rock's Ground Conditions Report[16]. River Terrace Deposits (RTD) were encountered in all exploratory holes, comprising both granular and cohesive strata. The cohesive RTD typically comprised gravelly sandy silt or silty sandy occasionally gravelly clay. The granular RTD typically comprised silty sandy gravel or silty sand and gravel with occasional cobbles.	Red Rock report that "*Infiltration tests were conducted at ten locations across the main Housing Area with infiltration rates ranging from 2.5 x 10^{-7} m/s to 3.4 x 10^{-6} m/s. These low values if infiltration rates are such that drainage via soakaways is unlikely to be suitable.*" It is not known if the infiltration tests targeted cohesive or granular RTD.

[15] Red Rock Geo (January 2020) Torbay Hospital – Adult Ward. Geoenvironmental and Geotechnical Ground Investigation Report. Ref: RP7208.

[16] PBA (July 2014) Seabrook Orchards Housing Area, Topsham. Ground Conditions Report. Ref: 30037/3502. Rev 00.

Donor Site Name	Quantity of Subsoil Imported (Tonnes)	Geology	Infiltration Testing
Glenthorne	17,380	Ground conditions summarised in a 2017 Ground Investigation Report[17]. "*Material interpreted as Head Deposits was encountered across the lower half of the site and locally on the upper half of the site to depths of between 0.60 and 1.40 m below existing ground levels. These materials typically comprised firm and stiff, slightly gravelly, clay.* *Material interpreted as Residual Soil was encountered in all exploratory holes to proven depths of between 0.90 and >4.55 m, comprising generally firm to stiff and stiff, light and yellow brown, slightly sandy, slightly gravelly, clay, and very clayey, very sandy, grave. Gravel clasts were seen to be angular to subangular mudstone and siltstone fragments.*"	No infiltration testing undertaken, however low rates assumed due to cohesive nature of soils.
Bloor, Pinhoe	3,420	The December 2010 ground investigation report[18] describes the following units: • **Head**. Materials interpreted as cohesive Head deposits were encountered to depths of between 0.6 m and 1.2 m comprising medium strength clay. • **Cohesive Residual Soil.** Encountered to total depths of between 0.7 m and 3.0 m comprising generally high strength, some medium strength, slightly sandy clay. In places the residual soil comprises slightly gravelly slightly cobbly clay. • **Granular Residual Soil.** More granular residual soil was encountered to depths of between 0.8 m and 3.0 m comprising generally medium dense silty fine to medium sand. These soils are derived from weathering of the underlying Dawlish Sandstone.	Infiltration testing was undertaken in a number of trial pits across the Site. Yeandle report[18] that "*infiltration rates were generally slow, such that generally one incomplete testing was undertaken over a two to four day period within most of the trial pits.*"

[17] Red Rock (January 2017) Site at Glenthorne Road, Exeter. Geotechnical and Geoenvironmental Investigation Report. Ref: RP6488

[18] Yeandle Geotechnical Ltd (December 2010) Pinn Court Farm, Pinhoe. Phase II – Preliminary Geotechnical Soakaway and Environmental Investigation Report. Ref: BC8179.

Donor Site Name	Quantity of Subsoil Imported (Tonnes)	Geology	Infiltration Testing
Persimmon, Cranbrook	10,460	An intrusive investigation was reported on in May 2019[19] on this greenfield site, reporting RTD, over Mudstone. • **RTD (Cohesive)**. Soft to stiff clay with varying proportions of sand and gravel. • **RTD (Granular)**. Fine to coarse gravel with varying proportions of clay and sand. • **Aylesbeare Mudstone Group**. Firm to stiff clay with varying proportions of sand and gravel.	No infiltration testing undertaken.
Mayfield Gardens. Monkerton	16,810	The ground investigation reported in the 2018 GICAR[20] identified superficial head deposits overlying the weathered Monkerton Formation, Whipton Formation and Dawlish Sandstone Formation. • **Head**. Encountered as both cohesive and granular strata. Described as silty (gravelly) sandy silty clay / clayey silty sand / sandy clayey silt. • **Monkerton Formation**. Variably sandy and silty clay with sandstone and mudstone lithorelicts. • **Whipton Formation.** Gravelly sandy and silty clay becoming clayey silty sand with sandstone and mudstone lithorelicts with depth. • **Dawlish Sandstone Formation**. Slightly clayey, slightly silty sand.	No infiltration testing data available.

[19] CGL (May 2019) Cranbrook Phase 4 / Galileo Phase 6. Geoenvironmental & Geotechnical Interpretative Report. Ref: CGE/16305.
[20] Ruddlesden (September 2018) Phase 2: Geotechnical Investigation and Contamination Assessment Report. Mayfield Gardens, Monkerton, Exeter. Ref: CR/SR/18357/GICAR

Donor Site Name	Quantity of Subsoil Imported (Tonnes)	Geology	Infiltration Testing
Bewick Avenue, Topsham	2,380	A series of Ground Investigations have been undertaken at the site, including initial investigations in 2016[21] and 2017[22] followed by an additional investigation in 2020[23]. Ground conditions generally comprised: • **RTD**. Encountered as both cohesive and granular strata. Where cohesive, described as slightly clayey slightly cobbly gravelly sand. • **Weathered Dawlish Sandstone Formation**. Described as slightly gravelly sand. • **Dawlish Sandstone Formation**. Slightly sandy gravelly cobbles.	Infiltration results variable. Where undertaken in cohesive deposits, in some instances a permeability was unable to be calculated, whilst in others low to moderate permeability rates typically recorded up to 1 x 10^{-5} m/s (albeit in the second test the infiltration rate was much lower). More consistent rates recorded in sandy and gravel deposits, up to 2 x 10^{-5} m/s.
Aller Gardens, Kingskerswell	1,080	The natural geology described in Ruddlesden's Ground Investigation Report[24] included: • **Head**. Variable deposits, generally comprising (slightly to very) sandy (slightly to very) gravelly clay / slightly (very) gravelly slightly clayey silty sand / sandy (slightly) clayey gravel. • **Bovey Formation**. Slightly to very sandy slightly to very gravelly silty clay. • **Aller Gravel Formation**. Gravelly slightly clayey silty sand or very sandy clayey to very clayey silty gravel.	No infiltration rate was able to be calculated (4No. tests attempted).

Table 3-1: Anticipated Soil Properties – DOWCOP Imports

[21] GCE (August 2016) Phase 2A Intrusive Investigation Report. Land North of Exeter Road, Topsham. Ref: GCE00426/R2

[22] GCE (March 2017) Phase 2B Intrusive Investigation Report. Land North of Exeter Road, Topsham. Ref: GCE00426/R3

[23] Ridge (27 March 2020) Ground Condition Assessment. Exeter Road, Topsham. Project: 5012114

[24] Ruddlesden (February 2020) Aller Gardens, Kingskerswell, Newton Abbot, Devon. Phase 2: Geotechnical Investigation and Contamination Assessment Report. Ref: TN/GD/SR/19459/P2GICAR

3.2.2 The material imported generally comprised soils of the local area, commonly head deposits, weathered breccia, residual soils plus both cohesive and granular RTD. Infiltration testing was undertaken on many of these soils in-situ per DG365[8]. In many instances the test was unable to be successfully completed; elsewhere in the main infiltration rates calculated were generally low.

3.3 DOWCOP Soil Placement

3.3.1 Soils placed under the DOWCOP scheme were not placed under any formal CQA procedures. Imported soils were typically tipped at the point of deposition, then spread and compacted by plant including bulldozers and excavators. Photos of the soils during placement and compaction are provided in Appendix Q of the Verification Report[7].

3.3.2 Surcharging load generated from overlying imported soils will provide further consolidation pressure, thereby minimising the air voids and permeability of the placed material.

3.3.3 Following visual inspections of the soils placed under the DOWCOP scheme in December 2025, JH Groundwater concluded that "*the material has been described as being generally cohesive and is interpreted to be generally of a low permeability. It is proposed that where this is greater than 1 m in thickness, the currently placed material would form the geological barrier on which the new restoration materials would be placed, subject to some confirmatory permeability testing prior to tipping in those areas. Newly imported material would be placed directly on this.*"

3.4 Future Engineering Proposals

3.4.1 Part of the base of the Site footprint has been restored with indigenous and imported restoration material that is generally cohesive and interpreted to be of low permeability. Where this is greater than 1 m thickness it is proposed this remain in-situ and form the geological barrier over which new materials be placed as per the previous recommendation from JH Groundwater (Section 3.3).

3.4.2 In areas where material is yet to be placed, or where existing restoration is less than 1 m thickness, the use of compacted indigenous, greenfield derived or other suitably clean imported materials is proposed in order to form a suitable geological barrier before placement of other materials.

4. Hydrogeological Risk Assessment

4.1 Risks to Controlled Waters

4.1.1 Development and refinement of a conceptual model underpins the process through which risks associated with contaminated sites are evaluated in the UK irrespective of the context (e.g. whether the site is being developed under planning, assessed under Part 2A of the Environmental Protection Act 1990, or being evaluated under the environmental permitting regime). The conceptual model identifies the possible relationships between contaminants, pathways and receptors and is used to identify relevant contaminant linkages that may warrant further assessment and/or remedial actions.

4.1.2 Consistent with DEFRA guidance[25]:

- *"A "contaminant" is a substance which is in, on or under the land and which has the potential to cause significant harm to a relevant receptor, or to cause significant pollution of controlled waters;*
- *A "receptor" is something that could be adversely affected by a contaminant, for example a person, an organism, an ecosystem, property, or controlled waters; and*
- *A "pathway" is a route by which a receptor is or might be affected by a contaminant."*

4.1.3 The remainder of this report presents a site-specific evaluation of individual contaminant linkages to further evaluate potential risks to controlled waters receptors from material imported and placed on-Site during the restoration works.

4.2 Contaminant Linkages

4.2.1 The relevant contaminant linkages (presented in **Table 4-1** below) are based on Horizon's current understanding of the Site; theses are subject to development and refinement throughout a project as additional data becomes available. An indicative drawing showing the model developed for the purposes of this HRA is presented as **Drawing 0269.112** in **Appendix A**.

Primary Source	Secondary Source	Hazard	Pathway	Receptor	Discussion
Imported restoration material	Contaminated soils [Impacts within imported soils including both low levels of contaminants that meet the Site-specific acceptance criteria plus unacceptable material that bypasses the checking process].	Degradation of water quality	Vertical / horizontal migration through the attenuation layer.	Controlled waters (groundwater)	The risks associated with these potential contaminant linkages have been evaluated further in the model.
		Degradation of water quality	Migration via groundwater	Controlled waters (surface water)	
Notes: Scope of hydrogeological risk assessment limited to evaluating risks to water environment associated with activities related to proposed restoration works as per 2023 Planning Permission.					

Table 4-1: Relevant Contaminant Linkages

4.3 Receptor / Compliance Point

4.3.1 The following are considered to represent potential receptors for contaminants emanating from the deposited waste mass:

[25] DEFRA (2012) Environmental Protection Act 1990: Part 2A Contaminated Land Statutory Guidance

- Groundwater present in the underlying Secondary A and Principal Aquifers; and
- The Aller Brook located approximately 250 m south-west of the Site.

4.3.2 The Environmental Permitting Regulations 2016 require that the entry of hazardous substances to groundwater must be prevented, with the entry of non-hazardous substances minimised. In order to ensure compliance with the Environmental Permitting Regulations 2016 and provide the highest degree of conservatism two theoretical compliance points have been utilised, with reference to UK guidance[26].

4.3.3 The compliance points proposed are virtual points for the purpose of undertaking the modelling exercise as opposed to physical monitoring points (e.g. monitoring well or spring).

4.3.4 The compliance points, located immediately downgradient of the Site along the groundwater flow pathway, have been used in the hydrogeological assessment for the purposes of assessing risks to the water environment.

4.4 Background Water Quality

4.4.1 Detail on background water quality is provided in the CSM report[4]. Elevated concentrations of contaminants were not generally detected other than chloride in downgradient monitoring well BH02.

4.5 Proposed Environmental Assessment Levels

4.5.1 **Table 4-2** and **Table 4-3** below set out the adopted Environmental Assessment Levels (EALs) for hazardous substances and non-hazardous pollutants. The adopted EALs are based on the lowest concentration of the following water quality standards (WQS), taking into account background water quality where applicable:

- Minimum Reporting Values (MRV) as published on UK.GOV[27];
- The Limit of Quantification (LOQ) as set out in the UK Technical Advisory Group's (UKTAG) Technical Report on Groundwater Hazardous Substances[28].
- UK Environmental Quality Standards (EQS);
- UK Drinking Water Standards (DWS);
- World Health Organisation (WHO) drinking water standards (for TPH constituents only); and
- Finally, the Element laboratory LRL has been used to provide a conservative screening measure in the absence of alternative criteria.

4.5.2 Although background concentrations have been considered in the selection of EALs, the EALs selected were based on the WQS given the absence of contaminants in upgradient boreholes. Background concentrations have been taken into account in the derivation of control levels (i.e., levels used to identify negative trends in groundwater monitoring data) and trigger levels (i.e. limits for groundwater concentrations set out in a permit). Exceedance of these limits is a non-compliance and breach of the permit). Proposed trigger and control levels are set out in Section 8.

[26] https://www.gov.uk/guidance/land-contamination-groundwater-compliance-points-quantitative-risk-assessments [Accessed 20 November 2025]

[27] https://www.gov.uk/government/publications/values-for-groundwater-risk-assessments/hazardous-substances-to-groundwater-minimum-reporting-values [Accessed 20 November 2025]

[28] UKTAG (January 2017) Technical Report on Groundwater Hazardous Substances. Ref: 11b(iii)v12

Contaminant	WQS (mg/l)					Natural Background	EAL	
	LRL	EQS	MRV	UKTAG LOQ	DWS		Adopted EAL (mg/l)	Rationale
Arsenic	0.0025	0.05	-	0.005	0.01	Dissolved arsenic not detected above LRL in any samples from upgradient boreholes BH03 and BH04.	0.005	Adopted EAL based on UKTAG LOQ.
Lead	0.0004	0.0012	-	0.0002	0.01	Dissolved lead not detected above LRL in any samples from upgradient boreholes BH03 and BH04.	0.0002	Adopted EAL based on UKTAG LOQ.

Notes:
COPC – Contaminant of Potential Concern
LRL – Laboratory Reporting Limit
EQS – Environmental Quality Standard
MRV – Minimum Reporting Value
LOQ – Limit of Quantification
DWS – Drinking Water Standard

Table 4-2: Adopted EALs (Hazardous Substances)

Contaminant	WQS (mg/l)			Natural Background	EAL	
Contaminant	LRL	EQS	DWS		Adopted EAL (mg/l)	Rationale
Cadmium	0.0005	0.00025	0.005	Not detected above LRL in upgradient boreholes BH03 and BH04. Typically detected at trace concentrations in boreholes BH01 and BH02 on western boundary of Site, apart from spike (37.4 µg/l) in borehole BH01 in October 2025 sampling visit. Additional sampling is ongoing to confirm if the spike is an outlier.	0.00025	Adopted EALs based on EQS.
Copper	0.007	0.001	0.002	Dissolved copper detected at or below the LRL in samples from boreholes BH03 and BH04, with slightly higher concentrations (up to a maximum of 15 µg/l) in downgradient boreholes BH01 and BH02.	0.001	Adopted EAL based on EQS. Note the EQS is based on the bioavailable concentration.
Chromium (Total)	0.0015	-	0.05	Low concentrations typically detected in all boreholes apart from spike of 50.3 ug/l in sample from BH02 in July 2025. Additional sampling of this sample by the laboratory confirmed the chromium detection to comprise chromium III, with chromium VI below the LRL.	0.05	Adopted EAL based on DWS.
Nickel	0.002	0.004	0.02	Low concentrations typically detected in all boreholes, up to a maximum of 28.6 µg/l in borehole BH02.	0.004	Adopted EAL based on EQS, noting this is the bioavailable concentration.
Zinc	0.003	0.0109	-	Low concentrations typically detected in all boreholes, up to a maximum of 23 µg/l in borehole BH02.	0.0109	Adopted EAL based on EQS, noting this is the bioavailable concentration.
Chloride	0.3	250	250*	Consistently detected above LRL in water samples, however concentrations generally relatively low apart from isolated hotspot around borehole BH02 (refer to Section 7.5 of CSM report[4]).	125	Adopted EAL based on 50% of EQS given relatively low concentrations recorded in upgradient groundwater samples to date
Ammoniacal Nitrogen	0.03	-	0.5*	Not detected above LRL in any samples from borehole BH01 to date. Detected above the LRL (0.03 mg/l) in 4No. samples from borehole BH02, up to a maximum of 0.05 mg/l. In upgradient boreholes maximum concentration of 0.06 mg/l detected in borehole BH03.	0.5	Adopted EAL based on DWS.
Phenol	0.00015	0.0077	-	Total phenols not detected above LRL in groundwater samples to date.	0.0077	Adopted EAL based on EQS.

Notes:
* Guide value

Table 4-3: Adopted EALs (Non-Hazardous Pollutants)

5. Model Selection & Assessment Scenarios

5.1 Model Selection

5.1.1 The computer program LandSim v2.5 has been used to consider potential impacts to the water environment. LandSim was developed by Golder Associates on behalf of the Environment Agency to *"track leachate production, chemistry, migration and leakage through engineered and non-engineered structures, followed by leachate migration through the unsaturated zone to assess the ultimate impact on the aquifer*." The model predicts the fate and transport of contaminants from source concentrations, through the unsaturated zone and within the aquifer/groundwater system.

5.1.2 The use of the software is identified in Environment Agency guidance on undertaking groundwater risk assessment for your environmental permit as an appropriate tool for undertaking probabilistic calculations.

5.1.3 Zig-Zag Quarry is located on a Principal aquifer (Upper Greensand Formation) and a Secondary A aquifer (Aller Gravel Formation), with shallow groundwater / surface water runoff interpreted to be in hydraulic continuity with the Aller Brook located approximately 250 m south-west. The model has been set-up with LandSim to simulate the anticipated ground conditions and planned restoration works. Although the LandSim software is originally designed for landfills, the principles of contaminant transport contained within the modelling software are appropriate in assessing risk associated with this restoration project.

5.2 Conceptual Site Model Domain

5.2.1 The Site comprises an existing sand and gravel quarry, separated into two parts, namely Aller Quarry located to the north and Zig Zag Quarry located to the south. The permit boundary encompasses both Aller Quarry and Zig Zag Quarry and is to remain unchanged as part of this permit variation. However the majority of Aller Quarry has been restored with all but one of the historic silt lagoons reinstated. The remaining silt lagoon continues to be used for cleaning water from the processing plant on Zig Zag Quarry and is to be reinstated as a separate task to be addressed at a later stage once final aggregate processing has been completed at Zig Zag Quarry.

5.2.2 Zig Zag Quarry is now subject to Devon County Council Planning Consent DCC/4339/2023 which requires the import of 1.5 million tonnes of inert wastes in order to provide a safe and stable landform that is in keeping with the existing landscape. Zig Zag Quarry forms the conceptual site model domain for the purposes of this HRA.

5.2.3 The materials that will be deposited at the Site comprise imported inert materials (classified in accordance with WM3[29]), to be imported and placed under strict waste acceptance procedures.

[29] Environment Agency (October 2021) Guidance on the Classification and Assessment of Waste. Technical Guidance WM3. Version 1.2.GB

5.3 Source Term Chemistry

5.3.1 In order to inform understanding of the anticipated contaminants in the waste stream, reference has been made to data for the nearby Trood Lane Inert landfill, also operated by BTJ. BTJ's intention is to fill the void space at the Site with a waste stream analogous to that used at Trood Lane. This approach is consistent with UK.GOV guidance[30].

5.3.2 **Table B01** of **Appendix B** summarises the concentrations of contaminants in leachate samples obtained in relation to material proposed to be imported Trood Lane between 2017 and 2020. This database, comprising over 100 samples, is a conservative representation of the imported waste stream on the basis that material from greenfield sites, deemed inert by default, often did not have WAC testing undertaken.

5.3.3 In addition, for the purposes of deriving statistics as presented in **Table B01** (**Appendix B**), where a contaminant was reported at a concentration below the LRL, this was assumed to be at the LRL for the purposes of the data assessment, thereby adding a further layer of conservatism. The following observations are made in relation to the dataset:

- No phenols, BTEX nor PCBs were detected above the applicable LRL in any of the samples tested.
- Mineral oil and PAHs were below the LRL in 92% and 80% of the samples respectively. The mean mineral oil concentration was 27 mg/kg (inert WAC limit 500 mg/kg) and PAHs 2.8 mg/kg (inert WAC limit 100 mg/kg).
- The concentrations of metals were below the LRL in more than 50% of the samples. The mean concentrations were typically less than 20% of the applicable inert WAC limit.

5.3.4 Suitable contaminants for assessment have been selected based on the anticipated nature of the waste (i.e. predominantly inert soil and stones). As a first tier of assessment, equivalent leachability concentrations from the data in **Table B01** (**Appendix B**) have been derived by back-calculation from the leachable contaminant concentration (in mg/kg), assuming a liquid to solid ratio of 10 l/kg.

5.3.5 **Table B02** of **Appendix B**, sets out the priority contaminants and assumed source concentrations modelled in the HRA. A uniform distribution has typically been adopted ranging from the LRL to the inert WAC limit. **Table B02** of **Appendix B** shows this to be a conservative assumption given the mean of the Trood Lane dataset is typically skewed towards the minimum (LRL). The following exceptions are:

Lead

5.3.6 Following preliminary model runs and feedback from the EA[3] it was apparent that the model was sensitive to source lead concentrations being modelled with a uniform distribution between the LRL (0.0004 mg/l) and the inert WAC limit (0.05 mg/l). Horizon has reviewed the Trood Lane dataset summarised in **Table B01** of **Appendix B** to assess the whether the modelled source concentrations are appropriate. In summary, the maximum concentration of leachable lead was recorded as 0.004 mg/l, equivalent to only 8% of the inert WAC limit. The model has subsequently been adapted with a source concentration ranging between the LRL and 50% of the inert WAC limit (0.025 mg/l).

[30] https://www.gov.uk/guidance/landfill-developments-groundwater-risk-assessment-for-leachate [Accessed 17 November 2025]

Antimony

Antimony is commonly detected at concentrations around the inert WAC limit in samples from the Exeter area. This is evident in the dataset from **Table B01** (**Appendix B**) with the 90th percentile concentration at the inert WAC limit (0.006 mg/l). Therefore antimony has been modelled at 2x the inert WAC limit. A derogation to the inert WAC limit for antimony would be beneficial for the Site given the occasional minor exceedances recorded for this contaminant (when all other testing results and information present would suggest the source material is not contaminated and suitable for inert disposal). Horizon has adopted kappa value constants and a partition coefficient (Kd) based on available sources[31,32].

Ammoniacal Nitrogen

Ammoniacal nitrogen is included in **Table B02** as a priority contaminant, however no source WAC data is available for this contaminant. On that basis, reference has been made to groundwater and leachate data for the Trood Lane landfill Site as reported in recent Annual Reports[33,34,35,36,37] submitted whilst the Trood site was operational as part of permit compliance. The statistics are based on ammoniacal nitrogen data in 58 samples obtained between 2017 and 2020.

5.3.7 Waste deposited at the Site is assumed to be unsaturated (i.e. above the water table), with the models assuming a uniform thickness based on the deposition areas and estimated volumes. It is assumed the deposited waste will vary in nature, however will generally comprise a cohesive soil. The model assumes a constant and non-depleting source term acting as an ongoing source for contamination in the dissolved phase.

5.4 Model Pathways

5.4.1 The following distinct pathways within the model are summarised below with full details presented **in Table B03 of Appendix B**:

- **Clay Liner** - Underlying the imported waste, a clay layer (equivalent to a 1 m layer with maximum permeability 1 x 10^{-7} m/s) is present.
- **Unsaturated Zone** – For modelling purposes, the Site is assumed to be underlain by deposits of the Upper Greensand Formation. Although the Aller Gravel Formation is present above the Upper Greensand Formation, the majority of this strata has been quarried with little remaining. The depth to groundwater is assumed to range between the minimum and maximum recorded levels during groundwater monitoring within the Site. No vertical pathway has been included in the model beneath the unsaturated zone.

31 Environment Agency (2003). The Development of LandSim 2.5

32 US EPA (1996). Soil Screening Guidance: Technical Background Document.

33 Exeter Environmental Consulting Group (March 2017) Trood Lane Landfill Site Annual Review. Permit No. VP3231SU. Report Number 0009.

34 Horizon (April 2018). Trood Lane Landfill Site - Permit VP3231SU. Annual Monitoring Review (April 2017 – March 2018). Ref: HCE0236.TL.AEMR.2018

35 Horizon (December 2018). Trood Lane Landfill Site - Permit VP3231SU. Annual Monitoring Review (March 2018 – December 2018). Ref: HCE0236.TL.AEMR.2018.02

36 Horizon (February 2020). Trood Lane Landfill Site - Permit VP3231SU. Annual Monitoring Review 2019. Ref: HCE0236.TL.AEMR.2019

37 Horizon (February 2021). Trood Lane Landfill Site - Permit VP3231SU. Annual Monitoring Review 2020. Ref: HCE0236.TL.AEMR.2020

- **Aquifer** – The model assumes the Upper Greensand Formation is of low to moderate permeability. For modelling purposes the aquifer thickness is assumed to be between 16 m and 52 m based on BGS records and ground investigation data from the Site.

5.4.2 A number of different mechanisms including advection, dispersion, retardation and degradation are included within the LandSim model to support the evaluation of contaminant migration from the source to the receptor. A discussion in relation to the principal mechanisms, and their applicability to the Zig Zag Quarry, is provided below:

- **Advection**: This is the principal mechanism that contaminants migrate through groundwater. It is assumed that the rate of contaminant migration is consistent with rate of groundwater velocity, subject to other mechanisms discussed below. Groundwater flow direction, for the purposes of the model, is assumed to be south-westerly with differences in head calculated on the basis of groundwater level data.
- **Dispersion**: Dispersion of contaminants (i.e. the process whereby contaminants migrate both longitudinally (i.e. within the direction of groundwater flow) and laterally/transverse (i.e. perpendicular to groundwater flow)) whereby contaminants move around the soil/rock particles. No site-specific dispersion data is available; the recommended parameters in LandSim adopted (i.e. 10% longitudinal and 3% transverse dispersion of overall pathway length).
- **Dilution**: Contaminants leached from the deposited waste assumed to migrate vertically through the clay liner and underlying saturated zone prior to dilution within groundwater.
- **Retardation**: For the purposes of the model, a degree of retardation is assumed to occur in the underlying unsaturated zone and aquifer. Retardation parameters adopted in the model are set out in **Table B04** (**Appendix B**).
- **Degradation:** Degradation within the mineral liner and unsaturated pathway only have been considered for this model. No degradation is modelled within the aquifer.

5.5 Distributions

5.5.1 For the purposes of the hydrogeological assessment the most appropriate value or range has been adopted with reference to available information to take into account uncertainty associated with input parameters. Statistical distributions or probability density functions (PDFs) are therefore used to select model input parameters in LandSim. Each time a calculation is carried out, one value from the defined input distribution is selected with a concentration at the compliance point calculated. Repeating the calculation many times provides an output distribution for the concentration at the compliance point.

5.5.2 The models have been set to perform with 1,001 iterations thus enabling a 95th percentile result to be calculated. The 95th percentile (95%ile) value indicates that there is a 95% probability that the actual concentration which will ultimately reach the receptor will be below the predicted 95%ile result. Use of the 95th percentile concentration is consistent with Environment Agency guidance and is considered to be sufficiently precautionary taking into account the Site setting.

5.5.3 **Table B03** (**Appendix B**) summarises the key model input parameters and associated rationale for each of the models. Horizon has followed Environment Agency Guidance in Assigning Value to Uncertain Parameters in Subsurface Contaminant Fate and Transport Modelling[38]. In general, the following principles have been adopted:

[38] Environment Agency (June 2001) Guidance on Assigning Values to Uncertain Parameters in Subsurface Contaminant Fate and Transport Modelling. Reference: NC/99/38/3

- A normal distribution has been adopted where data is available to describe the dataset and there is the potential, albeit low, for extreme values. LandSim constrains the normal distribution between zero and infinity to prevent negative values being used. Examples where the normal distribution has been adopted include:
  - If only a single value is available (e.g. effective rainfall / infiltration to waste mass) this has typically been used as a normal distribution with a mean of the value and standard deviation typically of 10% of the value. As noted by the Environment Agency, "*the normal distribution is the best distribution for very many observations in nature*."[38]
- A uniform distribution defines probability equally between two extreme values. Uniform probability distributions have been applied where insufficient data is considered to exist to identify normal or triangular distributions or to adopt a more conservative distribution than normal / triangular. Examples where the uniform distribution has been adopted include:
  - Porosity and dry bulk density of deposited waste. Adopting a uniform distribution in these instances is considered appropriate because the distribution assumes there is an equal chance of concentrations across the range as opposed to a grouping around a theoretical mean.

5.5.4 The source of literature values adopted is presented in **Table B03** of **Appendix B**. Where available, values have been primarily sourced from LandSim. In the absence of appropriate data in LandSim, reference has been made to other sources as identified in the tables including the ConSim software package.

5.6 Findings and Risk Evaluation

5.6.1 The results of the modelling are presented in **Table B05** of **Appendix B**. Horizon has modelled a range of contaminants (selected metals, phenols, chloride and ammoniacal nitrogen) and considered the concentrations at both the Site boundary (for hazardous substances only) and at the off-site compliance point, 50 m from the Site.

5.6.2 The results of the modelling show that mean time to peak concentration for hazardous substances at the base of the unsaturated zone (arsenic and lead) is in the region of 16-17 years.

5.6.3 However, mean time to peak concentration at the 50 m compliance point was in the region of 600 years to 2,600 years for all metals with peak concentrations below the EAL at the 50 m compliance point.

5.6.4 The concentrations of hazardous substances have also been considered at the Site boundary (represented by the monitoring well in the model). The results show the concentrations of lead, arsenic and chromium to be below the EAL at this point and therefore compliant with Schedule 22 of the Environmental Permitting Regulations:

- Lead: actual 95%ile peak concentration – 0.00014 mg/l after 210 years
- Arsenic: actual 95%ile peak concentration – 0.0012 mg/l after 231 years

5.6.5 Chloride, phenol and ammoniacal nitrogen are considered to be more mobile with the mean time to peak concentrations at the 50 m compliance point of 14 years, 18 years and 35 years respectively. The peak concentrations for these contaminants is below the adopted EAL.

5.6.6 With respect to chloride, the higher mobility is not unexpected given no retardation is applied in the model for this contaminant. In reality, a degree of retardation would be expected for chloride. A conservative concentration range is also modelled for the minimum (LRL) and maximum (upper inert WAC limit) values.

5.6.7 With respect to phenol, this has been modelled between the minimum (LRL) and maximum (upper inert WAC limit) values. In Horizon's experience, this is a conservative assumption as leachate testing results for phenol are typically at the minimum end of the range (LRL) as per the Trood dataset (**Table B01**, **Appendix B**).

5.6.8 With respect to ammoniacal nitrogen, the input concentrations have been conservatively modelled using historical groundwater monitoring data from an inert landfill site. Based on the distribution of the results, a normal distribution is considered to be the most applicable for modelling this particular leachate parameter.

5.6.9 With a source concentration of twice the inert WAC limit, the model has also shown that concentrations of antimony are below the EAL at the compliance point. On this basis, a higher acceptance criteria for antimony could be adopted; this is discussed further in Section 7.2.

5.6.10 Trigger levels to be adopted for downgradient monitoring points (boreholes BH01 and BH02) are set out in Section 8.0 and take into account background water quality and the results of the modelling.

5.7 Sensitivity Analysis

5.7.1 The sensitivity analysis has been conducted to assess confidence in the adopted values so as to identify parameters which have the greatest effect on the predicted contaminant concentration at the compliance point. Only parameters where literature values were assigned, where uncertainty in the adopted value is identified and/or where variation in the adopted value might result in a less conservative model were considered. Examples of parameters not considered as part of the sensitivity analysis are discussed below:

- **Site Area, Waste Thickness**. These values are based on Site drawings and earthworks modelling and therefore understood with a high degree of confidence.
- **Hydraulic Conductivity (Liner)**. The liner will be constructed and tested under strict CQA procedures. The hydraulic conductivity of the liner will be a maximum of $1x10^{-7}$ m/s (the single value adopted in the model), and in practice is likely to be lower.
- **Retardation Partition Coefficients**. Whilst these are based on literature values, only low-end (i.e. conservative) values were utilised in the assessment.
- **Source Concentration**. The source concentration is potentially the most sensitive parameter, however is not considered as part of the sensitivity analysis. The contaminant distribution in the deposited waste mass is typically assumed to be uniformly distributed however the source term assessment carried out in Section 5.3 shows the mean to be skewed towards the minimum. In addition, a rogue load assessment has been undertaken to evaluate the potential risk from unacceptable materials bypassing the stringent control measures and being deposited at the Site.

5.7.2 For the purposes of this report, the sensitivity analysis has only modelled selected contaminants (ammoniacal nitrogen, chloride and lead). The model has been run using the expected values mode, with each parameter varied in turn using the high and low values set out in **Table 5-1**.

Determinand	Units	Original Model Distribution			Sensitivity Analysis Values	
		Distribution	Low	High	Low	High
Waste Porosity	Fraction	Uniform	0.3	0.4	0.2	0.5
Waste Dry Density	kg/l	Uniform	1.0	1.8	0.8	2.0

Moisture Content (Liner)	Fraction	Uniform	0.3	0.4	0.2	0.5
Hydraulic Conductivity (Unsaturated Zone and Aquifer)	m/s	Triangular	4.6 x10^{-9}	5.5 x10^{-5}	4.6 x10^{-9}*	5.5 x10^{-5}*
Aquifer Thickness	M	Uniform	16.5	52	5	-**
Regional Gradient	-	Uniform	0.07	0.08	0.05	0.10
Pathway Porosity	Fraction	Uniform	0.226	0.326	0.2	0.4
* Given the already conservative range originally modelled the low and high values have been selected for the sensitivity analysis **The model already considers a conservatively high aquifer thickness						

Table 5-1: Summary of Sensitivity Analysis Parameters Adopted

5.7.3 The output of the sensitivity analysis is presented in **Table 5-2** below. For a few parameters (e.g. water filled porosity in the unsaturated zone), Horizon has adopted values based on professional experience on earthwork projects. Sensitivity analysis of these parameters indicates that the parameters are not sensitive, with changes in the parameter typically resulting in little change in the predicted concentrations.

5.7.4 Other than source concentration, the most sensitive parameters are considered to be the aquifer properties, in particular aquifer thickness and hydraulic conductivity. Although limited site specific data is available on these parameters, a broad range with a uniform distribution was adopted for modelling purposes to reflect the regional topography and wider understanding of anticipated hydrogeological properties.

5.7.5 The results of the sensitivity analysis show that a conservative approach has been utilised in the HRA, with the predicted outputs anticipated to be greater than those likely to occur during operation of the Site.

Contaminant	**Ammoniacal Nitrogen**		**Chloride**		**Lead**		**Sensitivity**	**Discussion**
Parameter Change	**Low**	**High**	**Low**	**High**	**Low**	**High**		
Expected Value [50 m Compliance Point]	0.18 [100 Years]		43.4 [30 Years]		3.10×10^{-17} [1,000 Years]		-	Expected value (compliance point) at time distribution stated.
Sensitivity Analysis								
Waste Porosity	0.18	0.18	42.7	46.67	2.12×10^{-17}	6.23×10^{-19}	Low	The porosity of the waste will vary depending on the nature of the deposited material, the moisture content at the time of placement and the compaction effort. In addition, the porosity will be dependent on where the material is placed within the waste mass area with deeper material having a lower porosity as a result of surcharging from the overlying waste. Given the waste thickness is expected to be high across the Site, the typical porosity is likely to be relatively low. Notwithstanding this, a higher waste porosity value has been utilised for the upper sensitivity analysis range.
Waste Dry Density	0.13	0.21	34.3	47.9	2.99×10^{-17}	3.29×10^{-17}	Low	Consistent with porosity, the dry density will depend on the nature of the material, the compaction effort and the degree of surcharging. A wide range of values is adopted in the model to take into account uncertainty in this parameter.
Moisture Content (Liner)	0.18	0.18	42.6	43.1	3.01×10^{-17}	3.17×10^{-17}	Low	At the time of compaction, moisture content of the material will be tightly controlled as part of CQA procedures. Moisture contents around 1-2% of the optimum moisture content are typically required to achieve the greatest compaction (and hence lowest hydraulic conductivity).
Hydraulic Conductivity	10.8	0.007 [30 years]	7,832	0.24	2.04×10^{-14}	1.12×10^{-5}	High	Other than source concentration, the hydraulic conductivity of the aquifer is the most sensitive parameter. A wide range of values were adopted in the model based on literature reports to reflect uncertainty in this parameter.
Aquifer Thickness	3.24 [30 years]	-	134	-	8.4×10^{-12}	-	Medium	Aquifer thickness is shown to be reasonably sensitive however there is high confidence in the modelled range of values based on site specific borehole data and literature research.
Regional Gradient	0.22	0.15	67.2	30.9	3.60×10^{-17}	2.55×10^{-17}	Low	In general, lower hydraulic gradients are associated with more permeable deposits and vice versa. The range adopted reflects the relatively low permeability of the Upper Greensand Formation
Regional Porosity	0.18	0.17	36.7	43.6	3.12×10^{-17}	3.21×10^{-17}	Low	Sensitivity analysis indicates this is not a sensitive parameter.

Table 5-2: Parameters Varied as Part of Sensitivity Analysis

6. Accidental Releases

6.1 Rogue Load Analysis

6.1.1 There is no current UK guidance or set methodology to undertake an assessment of the risk of rogue loads (i.e., placement of material that does not comply with the Site-specific assessment criteria) within the waste mass.

6.1.2 At Zig Zag Quarry technical precautions are included in the engineering design to minimise the impact of accidents on the water environment. Given the intended stringent testing and visual inspection regime to be adopted, any rogue loads (i.e., unacceptable material) will be limited in volume.

6.1.3 A geological barrier is to be constructed beneath the imported waste soils, thereby reducing the risk of any placed material directly impacting groundwater. Visual inspections (both at the weighbridge and during deposition) will allow any potentially unacceptable material to be identified and quarantined / removed as appropriate.

6.1.4 Notwithstanding the above, a quantitative assessment has been undertaken, using data provided by the EA[39].

Contaminant	Assumed Maximum Source Concentration at Zig Zag Quarry	EA Data		
		Minimum	Most Likely	Maximum
Arsenic	0.05	0.001	0.007	0.06
Lead	0.025	0.002	0.007	0.15
Ammoniacal Nitrogen	-*	0.3	8	25
Chloride	80	100	300	800
Nickel	0.04	0.002	0.02	0.12
Notes: Horizon adopted a normal distribution for ammoniacal nitrogen around a mean of 0.65 mg/l with a standard deviation of 2.23 mg/l				

Table 6-1: Possible Range of Leachate Quality Adopted for Rogue Load Analysis (mg/l)

6.1.5 **Table B05** (**Appendix B**) sets out the rogue load analysis, using the same methodology and compliance points as per Section 5 above.

6.2 Summary

6.2.1 A rogue load analysis has been undertaken with data provided by the Environment Agency using the same LandSim model that was developed in Section 5. Leachate concentrations have been given a triangular distribution.

6.2.2 In general, results were at the same order of magnitude or one order of magnitude higher as per Horizon's source concentrations adopted. Ammoniacal nitrogen is the only contaminant which exceeded the EAL (0.5 mg/l) at the compliance point with a mean concentration of 0.55 mg/l and 95th percentile concentration of 1.54 mg/l after 30 years.

[39] https://www.circularonline.co.uk/guidance/environment-agency-advice-series-completing-hydrogeological-risk-assessments-for-inert-waste-deposit-permit-applications/ [Accessed 21 November 2025]

6.2.3 Although ammoniacal nitrogen is considered to be a mobile contaminant and a potential threat from rogue loads, given it is a non-hazardous substance and the EAL is based on a Drinking Water Standard, the risks are not considered to be material with respect to overall environmental risk.

6.2.4 Based on the various lines of evidence evaluated, the predictive modelling undertaken as part of the rogue load analysis does not indicate a significant risk to controlled waters from contaminants within the fill material.

7. Engineering Design Features (Review of Technical Precautions)

7.1 Preamble

7.1.1 This section of the report outlines the proposed essential and technical precautions to be adopted during the restoration works such that the assumptions in this HRA are met.

7.2 Material Acceptability and Acceptance Procedures

7.2.1 Strict acceptance procedures have been prepared to safeguard against taking material that does not meet the Site-specific acceptance limits. These procedures will identify the actions and procedure to be taken including:

- All waste deliveries will be pre-arranged and will come from known sources from licensed hauliers;
- Initial source checking of the waste characterisation data provided by the waste producer will be undertaken by a responsible person. Data to be reviewed to include details of source site history, locations of any samples, description of material and results of any laboratory testing;
- During waste delivery, confirming that the waste are as described, within agreed quantities and are permitted within the Environmental Permit; and
- If waste not permitted by the Environmental Permit is delivered to the Site it will be turned away from the Site immediately or retained in a defined quarantine area awaiting collection.

7.2.2 Full criteria for waste acceptance is set out int the WAP[40]. Based on the assessment carried out in this HRA, in addition to imported material being non-hazardous and inert, the following criteria also apply. It is considered that these amendments to the default inert WAC limits would still meet the definition of inert waste.

Contaminant	Applicable Waste	Inert WAC Limit (mg/kg)	Proposed Limiting Value at Zig-Zag Quarry (mg/kg)	Discussion
Lead	17-05-04 Brownfield sites only	0.5	0.25	Modelling has shown the Site to be sensitive to lead. Given typical waste accepted at the Site is not expected to be close to the inert WAC limit, a lower limit is proposed which should not have an impact on the availability of soils for import. The lower limit of 50% of the inert WAC limit is intended to ensure protection of controlled waters receptors associated with the Site.
Antimony	17-05-04	0.06	0.09	Antimony naturally elevated within soils within the local area (based on historic dataset). Modelling has shown an increase in the leachate concentration (twice the inert WAC limit) will not cause detriment to groundwater. A value of 150% of the inert WAC limit is proposed.
Notes: Limiting values are based on compliance leaching test using BS EN 12457-2 at L/S 10 l/kg				

Table 7-1: Proposed Amendments to Default *Inert* WAC Limits

[40] Horizon (2026). Zig Zag Quarry. Waste Acceptance Procedures. Ref: HCE0269.WAP.Rev1

7.3 Site Engineering – Capping

7.3.1 Only clean inert soils are to be imported onto Site meeting the criteria set out in the Waste Acceptance Procedures in order to allow the Site to return to beneficial use. A capping layer is not required over above the replacement of the topsoil. Details of the restoration proposals are set out in Section 4 of the CSM report[4].

7.4 Site Engineering – Geological Barrier

7.4.1 Unlike a landfill, there is no regulatory requirement for a geological barrier at the Zig Zag Quarry restoration project. However, given the Site setting, a geological barrier is proposed to mitigate any potential risk to the underlying Principal Aquifer.

7.4.2 The geological barrier is to provide protection equivalent to a layer 1 m thick with a permeability of less than or equal to $1x10^{-7}$ m/s. The geological barrier must be at least 500 mm thick.

7.4.3 The liner system will be constructed under strict Construction Quality Assurance (CQA) procedures. In areas of the Site where deposition is yet to take place, the liner will be constructed of or alternatively from imported low permeability cohesive soils. In areas of Site underlain by soils placed historically under the DOWCOP scheme, these will be tested to confirm they meet the specification with localised reworking if required prior to placement of additional waste soils.

7.5 Groundwater Management

7.5.1 No active groundwater management is considered to be necessary based on the anticipated depth to groundwater.

7.6 Leachate Management

7.6.1 No long-term leachate management measures are planned as part of the restoration works.

7.7 Accidental Releases

7.7.1 The rogue load assessment is presented in Section 6. Technical precautions are included in the engineering design to minimise the impact of accidents (for the purposes of this risk assessment assumed to comprise placement of material that does not comply with the Site-specific assessment criteria) on the water environment. Given the intended stringent testing and visual inspection regime to be adopted any unacceptable material will be limited in volume. Combined with the construction of the geological barrier beneath the placed material, the potential risk of accidents or impact of a rogue load is considered to be low.

8. Requisite Monitoring and Surveillance

8.1 Surface Water Monitoring (Aller Brook)

8.1.1 Water quality samples have been obtained from the two locations on the Aller Brook on at least a quarterly basis since July 2021 (results presented in Appendix G of CSM report[4]). Quarterly water sampling of the Aller Brook at two locations is a condition of the existing permit and is to continue as part of the proposed variation. The sample locations are shown on the MPP (Appendix D of the CSM report[4]). The proposed monitoring regime is set out in **Table 8-1** below:

Monitoring Point	Parameter	Monitoring Frequency	Water Quality Monitoring Parameters	Method
During Restoration & Post-Completion				
Aller Brook (SW01 & SW02)	Water quality	Quarterly	Al, As, Ba, Ca, Cd, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Na, Zn, Cl, P, SO_4 Alkalinity and Hardness Ammoniacal N Bicarbonate Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Dissolved Organic Carbon (DOC), Electrical Conductivity (EC), pH, Total Oxidised Nitrogen (TON) Fluoride Nitrate and Nitrite Phenols - Total (Monohydric) Extractable Petroleum Hydrocarbons (EPH) (C_{10} – C_{40})	Grab samples.
Notes: All testing to be undertaken at a UKAS accredited laboratory.				

Table 8-1*:* Surface Water Monitoring (Aller Brook)

8.1.2 The water quality monitoring parameters in **Table 8-1** are consistent with the existing Environmental Permit. There is a good dataset for Aller Brook providing a long-term record against which changes can be monitored.

8.1.3 Horizon has reviewed the water quality monitoring parameters in **Table 8-1**. The suite is considered to comprise a broad range of analytes including contaminants that may commonly be found in waste soil and stones plus other contaminants (e.g. ammoniacal nitrogen) that are indicator compounds for biodegradation. No changes are proposed to the testing suite at this time.

8.1.4 Historically surface water monitoring from Aller Brook formed the principal means of evaluating permit compliance with compliance limits set out in the permit. Moving forwards compliance with control and trigger levels for groundwater quality in downgradient boreholes BH01 and BH02 is considered to be more important.

8.1.5 Notwithstanding the above, water quality in the downstream sample (SW02) during each sampling event will be evaluated with respect to the upstream sample (SW01).

8.2 Groundwater Monitoring Infrastructure & Groundwater Monitoring

8.2.1 Monitoring of groundwater quality will provide the principal mechanism for evaluating effectiveness of the engineering measures. The proposed groundwater monitoring regime is presented in **Table 8-2** below.

Monitoring Point	Parameter	Monitoring Frequency	Water Quality Monitoring Parameters	Method
During Restoration & Post-Completion				
Boreholes BH01*, BH02*, BH03, BH04, BH05** and BH06**.	Water quality	Quarterly	Al, As, Ba, Ca, Cd, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Na, Zn, Cl, P, SO_4 Alkalinity and Hardness Ammoniacal N Bicarbonate TDS, TSS, DOC, EC, pH, TON Fluoride Nitrate and Nitrite Phenols - Total (Monohydric) EPH (C_{10} – C_{40})	Groundwater samples as specified in EA Guidance LFTGN02[41].
Notes: All testing to be undertaken at a UKAS accredited laboratory. * Denotes location where compliance limits applied. ** Temporary borehole to be monitored until it is decommissioned during restoration.				

Table 8-2: Groundwater Monitoring

8.2.2 Control and trigger levels have been derived on a borehole-specific basis for downgradient monitoring wells BH01 and BH02.

8.2.3 It is not proposed to derive control and trigger levels for every determinand in **Table 8-2**, instead, as per Section 8.1 above, key indicator parameters have been identified that will be used to reflect the overarching dataset. As a starting point, monitoring data (set out in Appendix G of the CSM report[4]) have been used to develop a background understanding of water quality. For Zig Zag Quarry, this has included evaluation of the historic baseline from a particular borehole, plus comparison with upgradient monitoring points, in line with EA Guidance LFTGN02[41].

8.2.4 When selecting determinants to apply control and trigger levels it is important that these are representative of the contaminants that may be present in the waste fill (i.e. contaminants typically associated with inert soil and stone derived from development projects). They should be contaminants that may be present at elevated concentrations in the leachate, be particularly mobile in groundwater and/or indicative of the presence of non-conforming waste types.

- Lead is a hazardous substance and has been taken forward as a priority compound for monitoring purposes on the basis of confirming no deterioration in water quality moving forwards.
- Chloride is an inorganic compound, classified as a non-hazardous pollutant, that typically migrates rapidly in groundwater. Monitoring for chloride provides an early warning for the potential for other contaminants to be present.
- Ammoniacal nitrogen has been chosen in the event small quantities of organic materials with the potential to biodegrade (e.g. wood) are placed at the Site, notwithstanding the strict Waste Acceptance Procedures.
- Sum EPH has been included to on basis of representing organic contaminants.

[41] Environment Agency (2014) Guidance on Monitoring of Landfill Leachate, Groundwater and Surface Water. Ref: LFTGN02.

8.2.5 **Table 8-3** presents control levels and trigger values proposed to be adopted to evaluate the quality of groundwater for boreholes BH01 and BH02 respectively. These are based on 14No. monitoring rounds conducted between 31 March 2025 and 24 June 2026.

Determinand	Control Level		Rationale	Trigger Level		Rationale
	BH01	BH02		BH01	BH02	
Lead	0.4 µg/l	0.4 µg/l	Not detected above current LRL (0.4 µg/l) in samples to date. Control level based on LRL.	-	-	None proposed, however in the event sustained lead detections reported additional investigation and assessment to be undertaken.
Chloride	63 mg/l	1,340 mg/l	***BH01*** Chloride concentrations in samples from borehole BH01 ranged between 31.9 mg/l and 63.1 mg/l. Control limit based on mean for borehole BH01 plus 3No. standard deviations. ***BH02*** Elevated chloride concentrations consistently detected in samples from borehole BH02 between 373 mg/l and 1,037 mg/l to date as shown on **Figure C01** (**Appendix C**). Additional investigations (e.g. boreholes BH05 and BH06) have confirmed this is an isolated hotspot, not associated with restoration material placed to date. Control limit based on mean for borehole BH02 plus 3No. standard deviations.	125 mg/l	-	***BH01*** Chloride is a non-hazardous substance that has been detected at concentrations up to 63.1 mg/l in borehole BH01. The proposed trigger level is 50% of the EAL. ***BH02*** None proposed given elevated background concentrations associated with isolated hotspot in this area, however in the event a sustained increase in chloride concentrations reported additional investigation and assessment to be undertaken.
Ammoniacal Nitrogen (as N)	0.06 mg/l	0.06 mg/l	Not detected above LRL in any samples from borehole BH01 to date. Detected above the LRL (0.03 mg/l) in 4No. samples from borehole BH02, up to a maximum of 0.05 mg/l. In upgradient boreholes maximum concentration of 0.06 mg/l detected in borehole BH03. Control limit for both boreholes based on maximum concentration detected in borehole BH03 to date.	0.25 mg/l	0.25 mg/l	Trigger level based on 50% of drinking water standard.
Sum EPH	10 µg/l		Not detected above the LRL (10 µg/l) samples to date. Control level based on LRL.	-		None proposed, however in the event sustained EPH detections reported additional investigation and assessment to be undertaken.

Table 8-3: Proposed Control & Trigger Levels –BH01 & BH02

9. Discussion and Conclusions

9.1.1 This HRA has been prepared to assess impacts on the water environment associated with the proposed restoration works at Zig Zag Quarry. The HRA has been developed initially based on qualitative judgement taking into account the CSM and Environment Agency guidance. Given the site is situated on a Principal aquifer, a quantitative risk assessment using LandSim modelling software has been carried out for a range of contaminants. Horizon has provided justification for each of the model components.

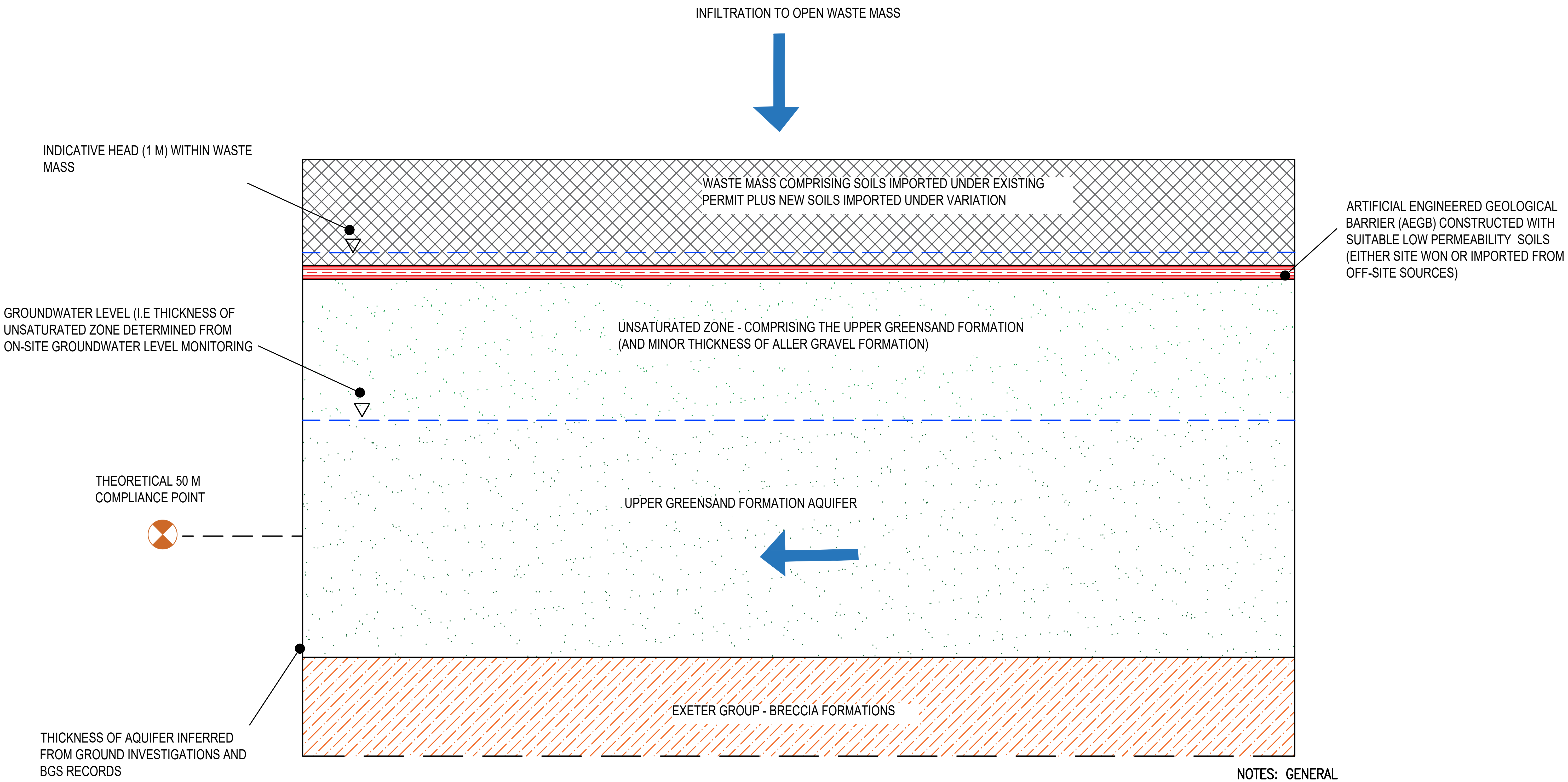
9.1.2 In general, a conservative range of parameters has been adopted in order to take into account extreme circumstances, i.e. rogue load deposits. Notwithstanding this, Horizon has carried out a separate rogue land assessment using data provided by the Environment Agency. The results of the rogue load assessment are considered to not materially change the results of the main DQRA.

9.1.3 The quantitative assessment considers that risks to receptors associated with the water environment are low notwithstanding the presence of sensitive receptors including a Principal Aquifer located directly beneath the Site.

9.1.4 A series of engineering design features are planned (see Section 7 for further details). These are to be adopted during the restoration works such that the assumptions in this hydrogeological assessment are met and include:

- Material Acceptance Procedures - *strict acceptance procedures have been prepared to safeguard against taking material that does not meet the Site-specific acceptance limits.*
- Specific Engineering Measures – *details of the specific engineering measures are set out in the ESSD. These include proposals for construction of the geological barrier.*
- CQA – the low permeability geological barrier is to be constructed, target 1 m thick, with an equivalent permeability of $1x10^{-7}$ m/s. *Installation and verification of the attenuation layer is to be undertaken in accordance with strict CQA procedures.*
- Requisite Monitoring and Surveillance - *the scope of the compliance monitoring is set out in the ESSD and this HRA.*

Appendix A
Drawings



NOTES: GENERAL

1. DO NOT SCALE FROM THIS DRAWING
2. THIS DRAWING SHALL BE READ IN CONJUNCTION WITH ALL RELEVANT SCHEME DRAWINGS AND SPECIFICATIONS
3. FINAL ELEVATIONS AS PER DRAWINGS IN PLANNING PERMISSION

Rev	Description	Drn	Chk	Date
A	Updated to reflect change in fill area	JH	AL	05.01.23

REVISIONS

Preliminary | Approval | Tender | Const.

DRAWING STATUS

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BT JENKINS LTD

JOB TITLE
ZIG-ZAG QUARRY
KINGSKERSWELL

DRAWING TITLE
LANDSIM MODEL

DATE	DRAWN	CHECKED	ISSUE CHECKBOX
NOV '25	JH	AL	

DRAWING No.	REV	SCALE	
0269.112	.	N.T.S	@ A4

Appendix B
Tables

Table B1

Summary WAC Data (Trood Lane Inert Landfill)

Zig-Zag Quarry

Test	Units	Element Laboratory LOD*	Count	Count (> LRL)	Inert WAC Limit	Maximum	Mean	St. Dev.	50th Percentile	75th Percentile	90th Percentile	95th Percentile
		mg/kg			mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Dissolved Arsenic	mg/kg	0.025	130	28	0.5	0.33	0.06	0.06	0.05	0.07	0.14	0.20
Dissolved Barium	mg/kg	0.03	130	52	20	1.45	0.18	0.22	0.09	0.20	0.50	0.50
Dissolved Cadmium	mg/kg	0.005	130	2	0.04	0.08	0.01	0.01	0.01	0.01	0.02	0.02
Dissolved Chromium	mg/kg	0.015	130	24	0.5	0.10	0.04	0.05	0.02	0.05	0.10	0.20
Dissolved Copper	mg/kg	0.07	130	21	2	0.19	0.10	0.12	0.07	0.08	0.12	0.50
Dissolved Mercury	mg/kg	0.01	130	1	0.01	0.005	0.008	0.0028	0.01	0.01	0.01	0.01
Dissolved Molybdenum	mg/kg	0.02	130	33	0.5	0.38	0.04	0.04	0.02	0.05	0.10	0.10
Dissolved Nickel	mg/kg	0.02	130	21	0.4	0.11	0.04	0.05	0.02	0.05	0.10	0.20
Dissolved Lead	mg/kg	0.05	130	16	0.5	0.04	0.05	0.05	0.05	0.05	0.05	0.20
Dissolved Antimony	mg/kg	0.02	130	11	0.06	0.07	0.03	0.02	0.02	0.03	0.06	0.06
Dissolved Selenium	mg/kg	0.03	130	4	0.1	0.08	0.04	0.03	0.03	0.04	0.06	0.10
Dissolved Zinc	mg/kg	0.03	130	51	4	0.15	0.13	0.17	0.04	0.15	0.50	0.50
Phenol	mg/kg	0.1	130	0	1	LRL	NC	NC	0.10	0.30	0.50	0.50
Fluoride	mg/kg	3	130	57	10	10.00	3.00	1.66	3.00	3.88	5.00	6.00
Sulphate as SO4	mg/kg	5	130	94	1000	618.00	47.73	86.63	20.00	45.15	102.62	181.55
Chloride	mg/kg	3	130	90	800	91.00	18.33	19.30	11.50	22.00	42.00	56.75
Dissolved Organic Carbon	mg/kg	20	130	107	500	270.00	63.94	47.95	50.00	74.75	130.00	168.80
Total Dissolved Solids	mg/kg	350	126	112	4,000	3,040	654	493	515	873	1,186	1,341
Total Organic Carbon	%	0.02	114	111	3	2.50	0.62	0.52	0.50	0.82	1.50	1.69
BTEX	mg/kg	0.025	126	0	6	LRL	NC	NC	0.03	0.05	10.00	10.00
Total 7 PCBs	mg/kg	0.035	126	0	1	LRL	NC	NC	0.04	0.10	0.10	0.30
Mineral Oil (C10-C40)	mg/kg	30	126	10	500	322.00	27.27	33.39	30.00	30.00	30.00	61.25
PAH 17 Total	mg/kg	0.64	126	25	100	57.00	2.76	6.84	0.90	2.00	3.89	8.80
pH	pH units	0.01	126	118	-	11.01	8.15	0.90	8.20	8.68	9.09	9.31

Notes:

* Different laboratories have different LRL. This can result in the mean concentration for some contaminants (e.g. Mineral Oil) being below the Element LRL.

Table B2

Source Term For Purposes of Hydrogeological Assessment

Zig-Zag Quarry

Determinand	**Hazardous Pollutant?**	**Source Term**						**Adopted EAL**	
		Distribution	**Minimum**	**Mean**	**St Deviation**	**Maximum***	**Rationale**	**Concentration**	**Rationale**
Units			**mg/l**	**mg/l**	**mg/l**	**mg/l**		**mg/l**	
Contaminants Considered Further as Part of Quantitative Assessment									
Antimony	Non-hazardous pollutant	Uniform	0.002	0.003	0.002	0.01	Range between LRL (Element Laboratory) and 2x inert WAC Limit (0.012 mg/l).	0.005	UK DWS
Arsenic	Hazardous substance	Uniform	0.0025	0.006	0.006	0.05	Range between LRL (Element Laboratory) and inert WAC Limit.	0.005	UKTAG MRV
Cadmium	Non-hazardous pollutant	Uniform	0.0005	0.001	0.001	0.004	Range between LRL (Element Laboratory) and inert WAC Limit.	0.00025	EQS
Chromium	Hazardous substance (Chromium VI)	Uniform	0.0015	0.004	0.005	0.05	Range between LRL (Element Laboratory) and inert WAC Limit.	0.001	UKTAG MRV
Copper	Non-hazardous pollutant	Uniform	0.007	0.010	0.012	0.2	Range between LRL (Element Laboratory) and inert WAC Limit.	0.001*	EQS
Nickel	Non-hazardous pollutant (Nickel III)	Uniform	0.002	0.004	0.005	0.04	Range between LRL (Element Laboratory) and inert WAC Limit.	0.004*	EQS
Lead	Hazardous substance	Uniform	0.0004	0.005	0.005	0.025	Range between LRL (Element Laboratory) and half of the inert WAC Limit (0.05 mg/l). This is still considered a conservative source concentration given emperical data dervied from the Trood WAC dataset (Table B01 - maximum lead equivalent leachate concentration from 130 samples is 0.004 mg/l).	0.0002	UKTAG MRV
Zinc	Non-hazardous pollutant	Uniform	0.003	0.013	0.017	0.4	Range between LRL (Element Laboratory) and inert WAC Limit.	0.0109*	EQS
Chloride	Non-hazardous pollutant (Chlorine)	Uniform	0.3	1.833	1.930	80	Range between LRL (Element Laboratory) and inert WAC Limit	250	EQS / DWS
Phenol	Non-hazardous pollutant (Phenol)	Uniform	0.01	LRL	LRL	0.1	Range between LRL (Element Laboratory) and inert WAC Limit	0.0077	EQS
Ammoniacal Nitrogen	Non-hazardous pollutant (Ammonia)	Log Normal	0.03	0.65	2.23	15.81	Dataset from Trood Lane leachate monitoring between 2017 and 2020. Minimum is LRL (Element Laboratory).	0.5	DWS

Notes

Adopted value within the model

COPC - Contaminant of Potential Concern

LRL - Laboratory Reporting Limit (Element Laboratory at time of report issue)

EQS - Environmental Quality Standard

DWS - Drinking Water Standard

UK - United Kingdom

AA - Annual Average

MRV - Environment Agency Minimum Reporting Value

UKTAG - UK Technical Advisory Group

EAL - Environmental Assessment Level

* Denotes maximum for purposes of model source term (i.e. inert WAC limit) as opposed to maximum detected in Trood Lane dataset.

Table B3
Model Assumptions - Hydrogeological Processes
Zig-Zag Quarry

Determinand	Units	Distribution	Minimum	Mean / Most Likely	Maximum	St. Dev.	Justification
Site Parameters							
Length Of Deposition Area	m	Single	-	315	-	-	Landfill geometry calculated from project drawings, assumed to be area over which basal liner installed and broadly consistent with top area (i.e. area over which infiltration falls, consistent with Drawing 0269.603).
Width of Deposition Area	m	Single	-	315	-	-	
Deposition Area Surface	Hectares	Single	-	9.92	-	-	Calculation (function of length and width). Approximately consistent with area from project drawings.
Time Offset	Years	Single	-	0	-	-	
Duration of Management Control	Years	Single	-	10	-	-	For the purposes of the model, assumed management control only during deposition not during closure.
Infiltration							
Infiltration to Open Waste	mm/year	Normal	-	354	-	35.4	Calculated from Met Office Annual Rainfall for a nearby weather station between 1991 and 2020 (873 mm/year), combined with CHESS potential evapotranspiration data (519mm/year for well watered grass surface). Given the short duration of filling (circa 10 years) plus nature of material deposited (soils) this is considered to be a reasonable approach. Restoration to be carried out in a phased approach over period of filling.
Cap Design Infiltration	mm/year	Normal	-	354	-	35.4	
End of Filling	Years	Single	-	10	-	-	Estimated time for filling
PE Cap Present?	-	-	-	-	-	-	No cap will be installed. Details of the restoration are set out within the permit documents.
Phase Geometry							
Phase Length at Base	m	Single	-	314	-	-	Based on the geometry of the waste mass it is assumed that basal area is the same area as the depoistion area.
Phase Width at Base	m	Single	-	314	-	-	
Base Area	Hectares	Single	-	9.86	-	-	Calculated based on base length and width.
Final Waste Thickness	m	Single	-	7.7	-	-	Waste thickness varies significantly across the Site, from a maximum of circa 25 m in the centre of the Site, tapearing to less than 1 metre at the boundaries. The total volume of waste to be deposited including material already deposited under the existing permit is 862,745 m3. On that basis, a uniform waste thickness of 7.2 m has been assumed across the Site for modelling purposes (volume divided by area).
Waste Porosity	Fraction	Uniform	0.3	-	0.4	-	Typical values for light to moderately compacted soils. Soils are expected to be predominantly cohesive in nature.
Waste Dry Density	kg/l	Uniform	1	-	1.8		Dry density of deposited waste will range depending on a number of factors including nature of original geology, degree of compaction and position within the overall waste mass (i.e. degree of surcharge based on overlying waste thickness).
Waste Field Capacity	Fraction	Uniform	0.2		0.3		Estimate based on loam soil [https://www.nature.com/scitable/knowledge/library/soil-water-dynamics-103089121/, Accessed 13 November 2025].
Head of Leachate when Surface Water Breakout Occurs	m	Single	-	1	-	-	A 1 m high geological barrier is proposed at the south-western edge of the Site.
Drainage System							
Specified Head	m	Single	-	1	-	-	A 1 m high geological barrier is proposed at the south-western edge.
Drainage System	-	-	-	-	-	-	No drainage system included at base of waste deposits for purposes of model.
Engineered Barrier							
Design Thickness of Layer	m	Single	-	1	-	-	Based on a 1 m thick liner with a permeability of less than or equal to $1x10^{-7}$ m/s.
Moisture Content	Fraction	Uniform	0.3	-	0.4	-	The optimum moisture content for compaction purposes of an inorganic clay is typically 20% to 35% (e.g. https://www.fao.org/fishery/docs/CDrom/FAO_Training/FAO_Training/General/x6706e/x6706e10.htm, Accessed 13 November 2025]. Moisture contents of clay soils post deposition will increase and can be quite high, up to 60% for saturated clays in some instances. Range proposed assumes that clay liner soils are not fully saturated, but an increase in moisture content has occurred post compaction as a result of leachate migration.
Hydraulic Conductivity	m/s	Single	-	1.00E-07	-	-	Maximum permitted hydraulic conductivity 1.0 x 10^{-7} m/s.
Longitudinal Dispersivity	m	Single	-	0.1	-	-	Based on 10% of the pathway length.
Unsaturated Pathway (Upper Greensand Formation)							
Geological Unit	-	-	-	-	-	-	Aller Gravel Formation present below the waste mass across the majority of the Site however for the purposes of the model the Upper Greensand Formation is the main geological unit. The properties of the Aller Gravel Formation and Upper Greensand Formation are considered to be broadly similar.
Pathway Length	m	Uniform	5.2	-	37.5	-	Pathway length based on results of monitoring. Range takes into account likely seasonal variation in water levels based on monitoring data available.
Moisture Content	Fraction	Triangular	0.08	0.23	0.4	-	Technical Report on the Engineering Geology of the Sidmouth District (1998) reports an BGS data reports a typical range of moisture content for the Upper Greensand Fomation of 8% to 40% with a median of 23%.
Hydraulic Conductivity	m/s	Triangular	4.60E-09	8.80E-07	5.50E-05	-	Hydraulic conductivities could vary with literature values reporting the equivalent minimum, maximum and median (modelled as triangular distribution within the model) [The physical properties of minor aquifers in England and Wales, BGS 2000]
Longitudinal Dispersivity	m	Uniform	0.52	-	3.75	-	Based on 10% of the pathway length.
Aquifer Pathway (Upper Greensand Formation)							
Geological Unit	-	-	-	-	-	-	Upper Greensand Formation (as per Unsaturated Pathway).
Pathway Length	m	Uniform	52.5		367.5		Calculated in Landsim based on phase geometry and length of landfill
Pathway Width	m	Single	-	315			Assumed groundwater flows in an south-westerly direction; therefore pathway width equal to width of landfill phase.
Calculate Mixing Zone?	-	-	-	-	-	-	Option Selected
Aquifer Thickness	m	Uniform	16.5	-	52	-	Conservatively assumes that the base of the Upper Greensand Formation is loated directly beneath termination depth of BH01 (16.5 m) and BH03 (52 m) which is an appropriate approximation given BGS literature values indicate the Upper Greensand Formation thickness to vary between 16 m and 76 m
Hydraulic Conductivity	m/s	Triangular	4.60E-09	8.80E-07	5.50E-05	-	Hydraulic conductivities could vary with literature values reporting the equivalent minimum, maximum and median (modelled as triangular distribution within the model) [The physical properties of minor aquifers in England and Wales, BGS 2000]
Regional Gradient	-	Uniform	7.00E-02	-	8.00E-02	-	Gradient based on differences in water elevation between boreholes BH01 and BH03
Pathway Porosity	Fraction	Uniform	2.26E-01		3.26E-01		Porosity could vary with literature values reporting a 25th and 75th percentile range of 22.6% and 32.6% [The physical properties of minor aquifers in England and Wales, BGS 2000]
Longitudinal Dispersivity	m	Uniform	5.03	-	36.8	-	Assumed 10% of pathway length. Pathway length calculated in LandSim.
Transverse Dispersivity	m	Uniform	1.58	-	11.03	-	Assumed 3% of pathway length. Pathway length calculated in LandSim.

Table B4

Retardation Parameters (Upper Greensand Formation)

Zig-Zag Quarry

Determinand	Parameter	Distribution	Units	Min	Max	Source	Source / Rationale
Partition Coefficients							
Antimony	Kd	Uniform	ml/g	45	250	US EPA	Ramge between observations of Kd for a sand (45 ml/g) to a clay (250 ml/g).
Arsenic	Kd	Uniform	ml/g	0	117	ConSim	Range between 0.1 (effectively no retardation) and relatively low value reported for unspecified conditions.
Cadmium	Kd	Uniform	ml/g	1.6	240	ConSim	Adopted range based on values suggested in ConSim. Minimum value based on a a loam (unspecified pH) and maximum value based on estimate for unspecified conditions. Alternative maximum values in ConSim for a loam estimated in ConSim at 990 ml/g and a sand (1,500 ml/g).
Chromium	Kd	Uniform	ml/g	1	35	ConSim	Adopted range based on values suggested in ConSim. Minimum value based on a sand (unspecified pH) and maximum value based on estimate for unspecified conditions. Alternative maximum values in ConSim for a loam estimated in ConSim at 999 ml/g and a sand (4,400 ml/g).
Copper	Kd	Uniform	ml/g	0	295	ConSim	Range from zero (i.e. no retardation) to value for unspecified conditions suggested in ConSim. Alternative high values suggsted in ConSim but not considered suifficiently conservative for the Heavitree Breccia are 10,000 ml/g and 27,500 ml/g.
Nickel	Kd	Uniform	ml/g	0.9	400	ConSim	Adopted range based on values suggested in ConSim. Minimum value based on a unspecified material (pH = 4.9) and maximum value based on estimate for sand. Alternative maximum values in ConSim, not considered sufficiently conservative for the Heavitree Breccia, range up to 8,100 ml/g.
Lead	Kd	Uniform	ml/g	0	434	ConSim	Range from zero (i.e. no retardation) to value for sand (unspecified pH) suggested in ConSim. Alternative maximum values in ConSim, not considered sufficiently conservative for the Heavitree Breccia, range up to 2.7×10^5 ml/g.
Zinc	Kd	Uniform	ml/g	1.1	200	ConSim	Adopted range based on values suggested in ConSim. Minimum value based on a sand (unspecified pH) and maximum value based on estimate for sand. Alternative maximum values in ConSim, not considered sufficiently conservative for the Heavitree Breccia, range up to 1.6×10^5ml/g.
Chloride	Kd	Single	ml/g	-	0	ConSim	No retardation assumed.
Phenol	Kd	Calculated	ml/g	-	-	ConSim	Calculated based on an FOC for a sand (uniformly distributed: 0.0001 to 0.001) and koc of 27 ml/g [values adopted from Consim]
Ammoniacal Nitrogen	Kd	Uniform	ml/g	0.5	2	ConSim	Values suggested in ConSim for sand (unspecified pH). Maximum value reported in ConSim of 3.2 ml/g (loam, unspecified pH).
Bulk Density							
Upper Greensand Formation	Bulk Density	Uniform	Mg/m^3	1.91	2.1	BGS	Range of values reported in BGS Technical Report. [Forster (1991) The Engineering Geology of the Exeter District. Technical Report WN/91/16].

Table B5

LandSim Modelling Results

Zig-Zag Quarry

Contaminant	EAL	Monitoring Well i.e Site Boundary *(Hazardous Substances)*				Mean Time to Peak Conc. at Compliance Point	Compliance Point (30 Years)		Compliance Point (1,000 Years)	
		Mean Conc.	95%ile Conc.	Time Slice	Mean Time to Peak Conc.		Mean Conc.	95%ile Conc.	Mean Conc.	95%ile Conc.
Antimony	0.005	-	-	-	-	3566	3.02E-15	2.14E-17	8.24E-05	2.89E-04
Arsenic	0.005	1.72E-04	6.37E-04	1000	607	831	3.65E-05	2.40E-05	2.50E-04	8.40E-04
Cadmium	0.00025	-	-	-	-	1457	2.02E-07	9.96E-10	4.85E-06	1.58E-05
Chromium	0.001	-	-	-	-	265	8.34E-05	5.60E-04	7.64E-05	2.94E-04
Copper	0.001*	-	-	-	-	1650	4.88E-05	4.35E-09	1.40E-04	5.60E-04
Nickel	0.004*	-	-	-	-	2359	3.29E-06	3.04E-12	4.11E-05	1.26E-05
Lead	0.0002	1.93E-05	7.44E-05	1000	1800	2517	1.71E-06	5.26E-13	1.83E-05	7.55E-05
Zinc	0.0109*	-	-	-	-	1159	6.46E-05	2.40E-06	0.00033	0.0013
Chloride	250	-	-	-	-	14	3.81	15.0	2.24E-11	8.46E-11
Phenol	0.0077	-	-	-	-	18	1.28E-06	3.50E-04	2.92E-15	1.04E-15
Ammoniacal Nitrogen	0.5	-	-	-	-	35	0.03	0.11	2.51E-07	2.15E-12

Notes:

*Based on bio-avialable concentration

Table B6

LandSim Modelling Results (Rogue Load Analysis)

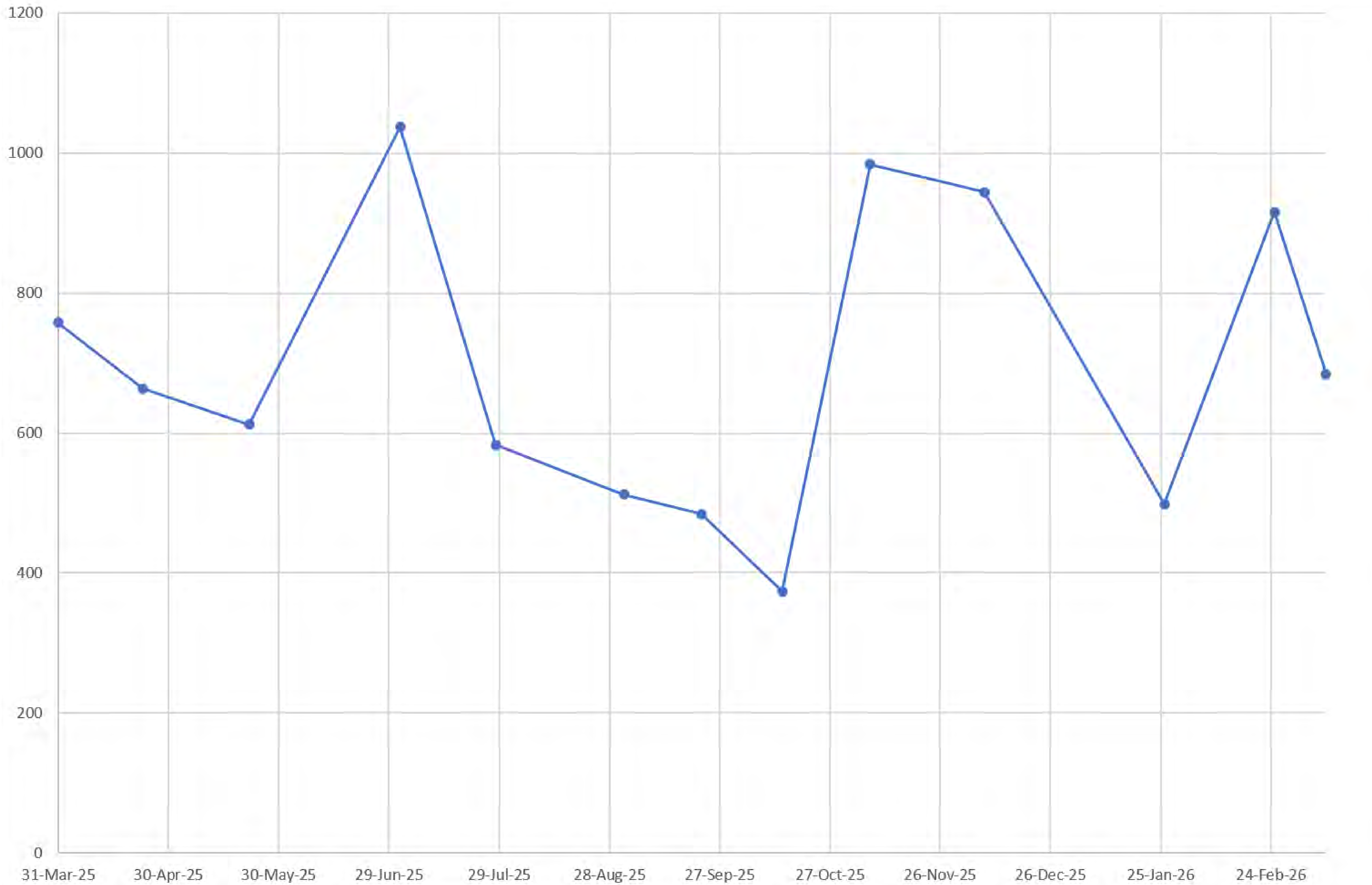
Zig-Zag Quarry

Contaminant	EAL	Monitoring Well i.e Site Boundary *(Hazardous Substances)*				Mean Time to Peak Conc. at Compliance Point	Compliance Point (30 Years)		Compliance Point (1,000 Years)	
		Mean Conc.	95%ile Conc.	Time Slice	Mean Time to Peak Conc.		Mean Conc.	95%ile Conc.	Mean Conc.	95%ile Conc.
Arsenic	0.005	3.60E-04	0.0012	300	590	809	4.47E-05	7.52E-05	2.40E-04	8.90E-04
Nickel	0.004*	-	-	-	-	2345	1.25E-05	3.27E-14	4.11E-05	1.26E-05
Lead	0.0002	6.59E-05	3.60E-04	100	1812	2563	2.82E-05	1.61E-12	4.36E-05	1.24E-04
Chloride	250	-	-	-	-	14	34.70	148.7	3.45E-10	1.20E-09
Ammoniacal Nitrogen	0.5	-	-	-	-	34	0.55	1.54	1.02E-08	3.67E-11

Notes:

*Based on bio-avialable concentration

Appendix C
Graphs



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JOB TITLE	DATE	DRAWN	CHECKED
ZIG ZAG QUARRY	JUNE 2026	AJL	JAH
FIGURE TITLE	FIGURE NUMBER	REV.	SCALE
CHLORIDE IN BOREHOLE BH02	FIGURE C01	1	NTS

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