



EARTH ENVIRONMENTAL
& GEOTECHNICAL

GeoEnvironmental Site Investigation

Kingsley Road

Northenden

February 2024

On behalf of

Kingsley Developments Manchester Ltd



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**GEOENVIRONMENTAL SITE
INVESTIGATION**

KINGSLEY ROAD

NORTHENDEN

Report Ref: A3939/23

FEBRUARY 2024

Prepared on Behalf of:

KINGSLEY DEVELOPMENTS MANCHESTER LTD

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GEOENVIRONMENTAL SITE INVESTIGATION REPORT

KINGSLEY ROAD, NORTHENDEN

Report Reference: A3939/23

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Prepared for: Kingsley Developments Manchester Ltd

Prepared by: Earth Environmental & Geotechnical Ltd
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1.0 EXECUTIVE SUMMARY

Appointment	A follow up site investigation has been commissioned to examine ground conditions for a proposed residential development (8no. units) at a former laundry located at 19 Kingsley Road, Northenden.
The Investigation	The investigation comprised windowless sample boreholes with associated sampling, in situ testing, and laboratory contamination testing. A total of 10no. windowless sample boreholes were drilled to depths of the 3.00 to 6.00m for groundwater monitoring installations, the remaining 10no. were drilled to a maximum depth of 1.00m for vapour monitoring.
The Site	The site is located in Northenden, Greater Manchester, approximately 0.5km south of Northenden Town Centre. The approximate National Grid Reference for the centre of the site is SJ 82903 89949 (X: 382903, Y: 389949). The site is underlain by Glaciofluvial Sheet Deposits underlain by the Tarporley Siltstone Formation.
Site History	Historically, the site was agricultural land until it was occupied by a steam laundry by 1910 with two smaller buildings in the southwestern corner of the site. From 1934 an additional two buildings are located in the south of the site, changing in size and shape through to 1981. From 1992, the buildings on site were unspecified. All laundrette infrastructure and industrial buildings have now been demolished and the site cleared of demolition materials.
Ground Conditions Encountered	The exploratory holes encountered Made Ground to a maximum depth of 1.30m bgl. Underlying the Made Ground were Superficial Deposits comprising sand to a maximum depth of 3.00m bgl and clay to a maximum depth of 5.60m bgl. Gravel was also encountered in boreholes WS204, WS207 and WS209 to a maximum depth of 3.90m bgl. Groundwater was encountered during the site investigation in borehole locations WS203, WS207, WS209, and WS210 between 180m and 2.50m bgl.
Contamination Assessment	Chlorinated solvents have been identified in soils and groundwater which pose a risk to future end users and remediation is required. Soil chemical exceedances - Tetrachloroethene (PCE) and Trichloroethene (TCE) Groundwater chemical exceedances - Tetrachloroethene (PCE) and Trichloroethene (TCE). No Vinyl Chloride was identified in the samples. Evidence of degradation is occurring on site due to the decrease in parent compound concentrations down gradient, and the presence of daughter products. Groundwater modelling demonstrates the risk to controlled waters are likely acceptable. Risks to on-site properties are potentially unacceptable but are expected to be of limited magnitude and therefore it should be possible to mitigate risks by installation of passive mitigation such as the proposed vapour membranes. Risks to off-site houses to the east are considered acceptable. Risks to houses to the west are also likely to be acceptable, subject to confirmation that groundwater impacted by PCE or TCE does not migrate westwards from the site towards the houses. Risks to the house adjacent south of the site are potentially unacceptable, primarily due to potential vapour ingress into the basement. This assessment is based on a number of conservative assumptions and there is limited confidence in the assessment with the current data.

	Risks to the house adjacent north of the site are considered to be potentially unacceptable, primarily due to combination of the expected floor construction (suspended timber floor) and potential for groundwater impacted by PCE or TCE to be present beneath or near to the house. Details of the remedial works and validation process are included within the Remediation Strategy.
<i>This sheet is intended to provide a summary only of the report. It does not provide a definitive engineering analysis for the purposes of costing or construction and is subject to the limitation of the agreed brief.</i>	

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2.0 INTRODUCTION

2.1 Background

An additional Site Investigation has been commissioned by Kingsley Developments Manchester Ltd to further examine ground conditions for the new residential development at a site off Kingsley Road, Northenden.

The additional Site Investigation was advised by Manchester City Council and the Environment Agency after reviewing the previous Site Investigation Report by EEG Ltd, dated October 2022.

This report has been written to support the discharge of planning conditions 5 (contaminated land), attached to planning permission 125144/FO/2019.

2.2 Site History

Historically the site was used as a clothing launderette by Northern Laundry Services Ltd. An Environmental Permit (PPC/DC/RM/17/07), granted 12th February 2007, was held by Northenden Laundry Services Ltd for the dry cleaning of curtains and specialist fabrics.

The license allowed for the use of a Fibromatic machine (installed in 1999) with Perchloroethylene (Tetrachloroethene) as the cleaning solvent.

There has been a steam laundry on the site for over 100 years. As the laundry element of business shrank, parts of the factory were let as industrial units.

Figure 1 shows a historical photograph of part of the former laundry.

Figure 1: Historical Photograph of Laundry



Planning permission was granted on the 5th of March 2021 by Manchester City Council for the erection of 8no dwelling houses comprising of 2no. two storey semi-detached and 6no. three storey terraced townhouses together with associated car parking, landscaping, and boundary treatment.

At the time of this investigation, all laundrette infrastructure and industrial buildings have been demolished and the site cleared of demolition materials.

2.3 Previous Investigations

The following reports have previously been prepared for the site by REC and Earth Environmental & Geotechnical Ltd and should be read in conjunction with this Site Investigation Report:

2.3.1 Resource and Environmental Consultants (REC) Ltd, Phase I GeoEnvironmental Assessment (106065p1r1), dated November 2018.

Historical archives show the site to have been first occupied by various parcels of agricultural land until pre-1910, thereafter a steam laundry building occupied most of the northern section of the site with two smaller buildings in the southwestern corner. From 1934 an additional two buildings are located in the south of the site, changing in size and shape through to 1981. From 1992, the buildings on site were unspecified.

Potential sources of contamination were identified as Made Ground from on and off-site development (including an infilled pond located off the site) and contaminants associated with the on-site laundry/dry cleaners including multiple solvents, polychlorinated biphenyls (PCBs) and total petroleum hydrocarbons (TPHs).

An Initial Conceptual Site Model was constructed and the risk to future land users was considered **MODERATE to LOW**. The risk to controlled waters was considered **LOW**.

An intrusive investigation was recommended to confirm the findings of the of the initial Conceptual Site Model and to access the anticipated depths of Made Ground.

2.3.2 Earth Environmental & Geotechnical Ltd, Geotechnical & Environmental Site Investigation (Reference: A3939/21/B.0), dated May 2021.

An intrusive Site Investigation was conducted by EEG Ltd between 31st March and 1st April 2021 and comprised eight window sample boreholes. Standard Penetration Tests were conducted in-situ in accordance with BS EN ISO 22476-3. A photo ionisation detector (9.8eV lamp) was used to measure the concentration of volatile organic compounds in the soil headspace.

50mm monitoring wells were installed in all window sampling boreholes. A total of 4no. monitoring visits were conducted to measure ground gas concentrations and groundwater levels after the field work period.

The boreholes revealed a sequence of Made Ground at depths between ground level and 2.00m bgl comprising asphalt hardstanding, concrete and rebar, cobbles of brick, and sand with man-made inclusions of brick, plastic, clinker, timber, concrete, ash, and metal fixings.

Beneath the Made Ground were Glaciofluvial Deposits comprising a clayey gravelly SAND or gravelly SAND at depths between 0.30m and 6.00m bgl. Cohesive deposits comprising a sandy gravelly CLAY and gravelly CLAY were also encountered at depths between 1.60m and 5.00m bgl.

Groundwater was encountered at depths between 3.0m and 5.00m bgl during the site work. Subsequent monitoring encountered groundwater in the monitoring wells at depths between 1.43m and 2.10m bgl.

A range of geotechnical testing was conducted on soil samples retrieved from the site. It was concluded that shallow strip/pad foundations were suitable for the proposed development with localised deepened trench footings in areas of deep Made Ground.

Chemical analyses were conducted on fourteen soil samples retrieved from the exploratory holes. Testing included the CLEA soil suite, asbestos screen, Speciated Petroleum Hydrocarbons, Speciated Polycyclic Aromatic Hydrocarbons, Volatile Organic Compounds and Semi-Volatile Organic Compounds. Results were compared to a Residential End Use with Plant Uptake criteria.

The soil contaminant exceedances included:

- **Arsenic** in 1no. sample: WS08 (0.60m)
- **Lead** in 2no. samples: WS05 (1.20m) and WS08 (0.60m)
- **Tetrachloroethene (PCE)** in 3no. samples: WS04 (0.25m), WS06 (0.50m), and WS08 (0.60m)
- **Trichloroethene (TCE)** in 2no. samples: WS04 (0.25m) and WS08 (0.60m).

The report concluded that any soils removed from the site would need to be taken to a suitable landfill facility, soils were classified as Non-Hazardous waste.

Chemical analyses were conducted on five groundwater samples retrieved from exploratory holes WS01, WS04, WS05, WS06 and WS08. Testing included the CLEA water suite, Speciated Petroleum Hydrocarbons, Speciated Polycyclic Aromatic Hydrocarbons, Volatile Organic Compounds and Semi-Volatile Organic Compounds. Results were compared to DWQ and EQS guideline values.

The groundwater contaminant exceedances included:

- **Tetrachloroethene (PCE)** in 5no. samples: WS01, WS04, WS05, WS06, and WS08
- **Trichloroethene (TCE)** in 3no. samples: WS01, WS04, and WS06.

A risk to human health from volatile compounds in shallow groundwater in accordance with the SOBRA groundwater vapour GAC (GAC_{gwwap}) were found at WS01, WS04, WS05 and WS06.

Ground gas monitoring was conducted in the monitoring wells over a period of four weeks. The Carbon Dioxide GSV was calculated to be 0.0063 litres/hour, with the Methane GSV calculated as 0.00 litres/hour. These results suggested that the site can be given a "Gas Regime A, Negligible to Very Low risk".

The contamination assessment concluded that remedial measures will be required which could take the form of in-situ soil treatment or by the introduction of a vapour barrier in the foundations. Any remedial works would need to be described within a Remediation Strategy.

2.3.3 Earth Environmental & Geotechnical Ltd, Remediation Strategy – Delineation of Contamination Hotspots (Reference: A3939/22/RMS), dated May 2022.

As part of the original Remediation Strategy, a delineation exercise was carried out in the vicinity of the Tetrachloroethene (PCE) and Trichloroethene (TCE) hotspots encountered in the initial Site Investigation, to determine the extent of clean cover and vapour membrane placement.

The delineation sampling was conducted by EEG Ltd on 14th April 2022 and comprised 15no. hand dug pits. Sampling locations were positioned at 2.00m spacings outwards, where possible, from the contamination hotspots.

Chemical analyses were conducted on fifteen soil samples retrieved from the hand dug pits. Testing included the Volatile Organic Compounds and Semi-Volatile Organic Compounds. Results were compared to a Residential End Use with Plant Uptake criteria.

The soil contaminant exceedances included:

- **Tetrachloroethene (PCE)** in 2no. samples: Sample 10 (WS06 hotspot), Sample 14 (WS04 hotspot)
- **Trichloroethene (TCE)** in 4no. samples: Sample 12 (WS04 hotspot), Sample 13 (WS04 hotspot), Sample 14 (WS04 hotspot), and Sample 15 (WS04 hotspot)
- **Cis-1,2-Dichloroethene** in 2no samples: Sample 13 (WS04 hotspot), Sample 14 (WS04 hotspot).

The original RMS strategy states that the rear garden plots of the southern semi-detached properties will need a clean cover capping system to break the pollutant linkage. The cover system will comprise a minimum of 600mm clean imported soil in rear gardens, reduced to 450mm in front gardens, and a geotextile membrane at the base of the clean cover. Clean cover may comprise a combination of subsoil and topsoil, with no less than 150mm topsoil.

To prevent the ingress of VOC vapours into the new buildings, the RMS stated that vapour gas protection measures will need to be installed. Reference should be made to BS8485:2019 for details. However, as a minimum a pre-cast suspended segmental floor (i.e., beam and block) and a 0.40mm thick reinforced membrane which is impervious to VOC vapours and hydrocarbon immersions in accordance with CIRIA C748 should be installed.

2.4 Terms of Reference

Earth Environmental and Geotechnical Ltd (EEG) have been commissioned by the Client, to undertake a Site Investigation of the site in accordance with proposal A3939/23 dated 15th August 2023. The objectives of this investigation are as follows:

- *Factual information on the work undertaken including sampling location plan, borehole logs, monitoring, and chemical testing.*
- *Tier 1 (semi-quantitative) risk assessment will be undertaken. This will compare the concentrations of soil, gas and groundwater contaminants identified against current and appropriate published guidelines, in relation to identified receptors, e.g., future end users and site neighbours.*

- *Updated assessment of risk to controlled waters from volatile organic and semi-volatile organic compounds. A quantitative risk assessment would be performed by use of the Environment Agency Remedial Targets Worksheet V3.2.*
- *Vapour risk assessment for the different chlorinated solvents.*
- *Revised ground gas risk assessment using CIRIA C665 and British Standard guidance.*
- *A cross section to show the gas/vapour risks as part of the conceptual model.*
- *Revised Remediation Strategy, including any remediation to controlled waters after delineating the plume of chlorinated solvents.*

2.5 Report Scope

This report presents full factual records of the site work carried out, the ground conditions encountered in the exploratory holes, the in situ and laboratory test results. All information collected has been used to provide an interpretation of the ground conditions, with recommendations on geotechnical design and potential ground contamination risks for the proposed development.

2.6 Limitations of the Study

The report is written in the context of an agreed scope of work and budget and should not be used in a different context. New information, improved practices or changes in legislation may require a reinterpretation of the report in whole or in part. EEG reserve the right to amend either conclusions or recommendations in light of any further information that may become available. The report is provided for the sole use by the client and is confidential to them.

Recommendations within this report are also based on exploratory records and examination of samples and, where applicable, laboratory tests. No liability can be accepted for conditions not revealed by the boreholes particularly at intervening locations. Whilst every effort is made to ensure accuracy of data supplied, all opinions expressed as to the spatial distribution of strata between sampling locations is for guidance only and no responsibility is accepted as to its accuracy.

3.0 SITE LOCATION & DESCRIPTION

The site is located in Northenden, Greater Manchester approximately 0.5km south of Northenden town centre. The approximate National Grid Reference for the centre of the site is SJ 82903 89949 (X: 382903, Y: 389949) with the closest postcode being M22 4NL.

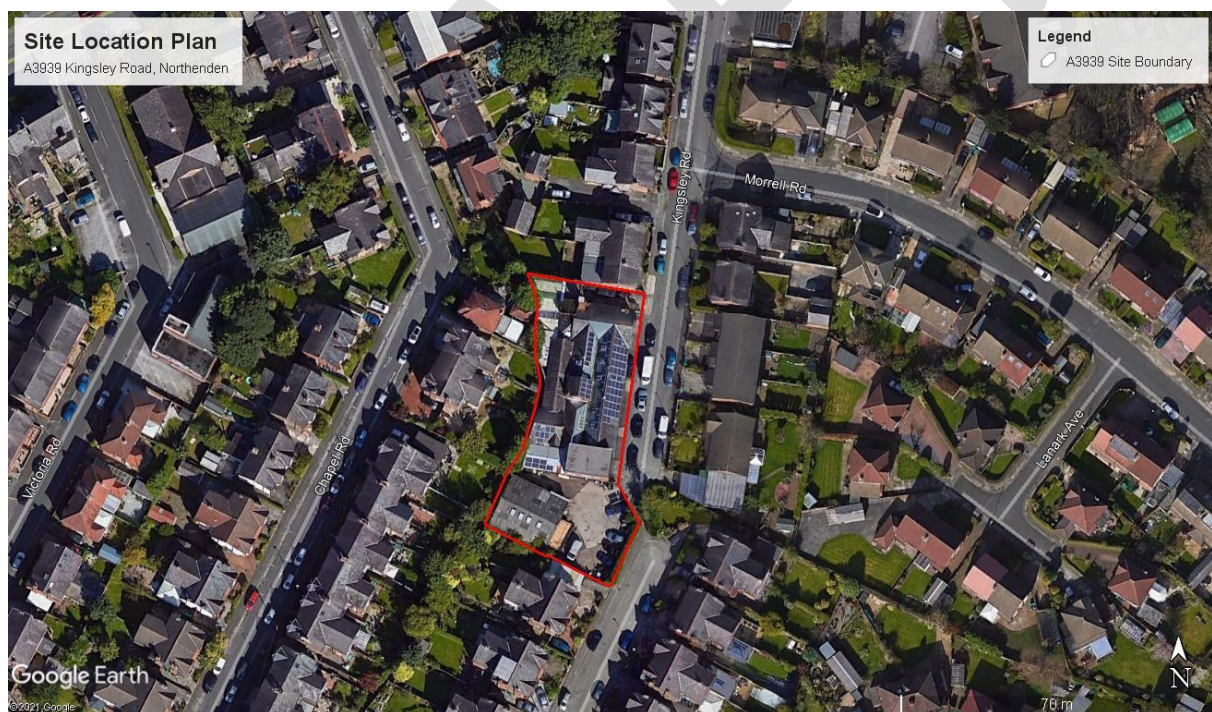
The site is an irregular shaped parcel of land currently accessible via Kingsley Road to the northeast of the site. The site currently comprises partially built residential. The site is surfaced in bare ground, hardcore and areas of concrete. A small stockpile of soil is located in the southwest corner of the site. A site cabin is located in the southeast corner of the site.

The maximum dimensions of the proposed site are 70m north to south and 34m east to west. The site occupies an area of approximately 0.15 hectares with a generally flat and level topography.

The general surrounding area comprises predominantly of residential dwellings.

The site location is shown in the aerial photograph presented as Figure 2, below.

Figure 2: Aerial Photograph Showing Site Location



General site photographs are presented in Figure 3 overleaf.

Figure 3: General Site Photographs

View facing south showing the window sample rig setup adjacent the dwellings under construction



View facing west showing the window sample rig setup within the new garage with restricted access



View showing the Made Ground and superficial deposits encountered in borehole location WS204



View showing the two monitoring installs, one for shallow 1m vapour installation and a deeper groundwater installation



3.1 Proposed Development

It is understood that the Client intends to build eight residential properties on site with associated soft landscaping and parking. Access will be provided via Kingsley Road and Beech Avenue.

The proposed development layout details are shown in Figure 4 below.

Figure 4: Proposed Development Plan



4.0 SITE INVESTIGATION

4.1 Exploratory Fieldwork

The fieldwork was carried out by EEG between Monday 9th and Wednesday 11th October 2023 and comprised:

- Ten window sample boreholes (designated WS201 to WS210 inclusive) were sunk to depths of between 3.00m and 6.00m below existing ground level depending on refusal. An additional ten shallow window sample boreholes were drilled adjacent to the others to a maximum depth of 1.00m for vapour monitoring (designated WS201a to WS210a). Window sampler boring is carried out with a small, track-mounted rig, which uses a chain-driven trip hammer to drive sampling tubes or penetrometers into the ground. These tools are coupled to the anvil of the hammer by solid drill rods. Sampling tubes comprise “windowless samplers”, which are plain sampler tubes in which a continuous disturbed sample is recovered within a semi-rigid plastic liner. In order to reduce friction within the borehole, sampling tubes of progressively smaller diameter are used as the borehole depth increases. Sampler diameters generally range from between approximately 90mm to 50mm. Standard Penetration Tests (SPTs) were undertaken in the boreholes in accordance with BS EN ISO 22476-3. Groundwater observations were noted where possible. These observations relate to the time of the investigation only, and do not necessarily reflect seasonal fluctuations. Exploratory hole logs and sections are included in Appendix 1.
- 50mm diameter monitoring wells were installed in all window sample boreholes (except WS205 due to a concrete obstruction). Where possible, the response zones for monitoring wells WS201 to WS204 and WS206 to WS210 were placed in the granular superficial deposits for groundwater sampling. A geotextile wrap was used to wrap the response zone for each groundwater installation with a 1m thick bentonite seal above. Monitoring wells WS201b to WS210b were installed to a depth of 1.0m for shallow vapour monitoring. The Installation and backfill details are shown with the appropriate borehole log sheet. EEG carried out ground gas, vapour, and groundwater monitoring in the monitoring wells after the fieldwork period on the 31st October, 9th November and 11th December 2023, the results of which are presented in Appendix 2.

Exploratory hole locations were selected on-site by an EEG engineer based on the proposed development layout and targeting areas of potential contamination to determine whether the chlorinated solvents extend off-site.

Each exploratory location was scanned using a Cable Avoidance Tool (CAT) in order to locate unrecorded underground services, and the exploratory locations were repositioned if necessary.

A power washer was used to decontaminate the drilling rods and sampling equipment between borehole locations.

A photo ionisation detector (10.6eV lamp) was used to measure the in-situ concentration of volatile organic compounds in the headspace of soil samples. Samples were placed in amber jars and the peak measurement recorded over the duration of 20 minutes. The measurements are shown on the borehole logs in Appendix 1.

Soil samples of approximately 250g were recovered in amber jars for volatile analysis at the laboratory. On the first monitoring visit, groundwater samples were recovered in 40ml vials, 100ml glass bottles and 1L glass bottles (where possible) for volatile analysis at the laboratory.

Groundwater collection was undertaken using a Van Walt low flow peristaltic pump. During the sampling process the water pH, electrical conductivity, total dissolved solids, oxygen content and redox were measured.

The water levels and the thickness of any dense non-aqueous phase liquid (DNAPL) or light non-aqueous phase liquid (LNAPL) were monitored by use of an interface meter.

The soil and groundwater samples were labelled and stored in cool boxes with ice packs prior to being collected by courier at the end of the day for delivery to the DETS laboratory. Samples were tracked using appropriate Chain of Custody forms provided by DETS.

On the third monitoring visit, vapour samples were recovered from 4no. monitoring wells using 450ml BottleVacs which are vacuumed bottles. The BottleVacs were attached to the monitoring well using 200ml/min gas sample trains.

A photo ionisation detector was used to measure the concentration of volatile organic compounds in the monitoring well. The PID measurement needed to be above 1ppm for vapour analysis using BottleVacs.

The BottleVacs were labelled and stored in cool boxes prior to being collected by courier at the end of the day for delivery to Element laboratory. Samples were tracked using appropriate Chain of Custody forms provided by Element.

All site investigation work was supervised full time by a representative of EEG. The logging of soils and rocks has been carried out in accordance with BS5930^(2015+A1:2020) except where superseded by the soil and rock description methodology in BS EN14688-1⁽²⁰⁰²⁾, BS EN 14688-2⁽²⁰⁰⁴⁾ and BS EN 14689-1⁽²⁰⁰³⁾.

All sampling locations were surveyed by use of a hand-held Trimble R1 GPS instrument that is capable of surveying to an accuracy of less than 10mm depending on satellite coverage, proximity to trees and building structures.

An Exploratory Hole Location Plan is presented as Figure 5, overleaf.

Figure 5: Exploratory Hole Location Plan



A summary of exploratory holes undertaken during the investigation are presented in Table 1 below.

Table 1: Summary of Exploratory Holes Undertaken

Hole	Type*	Depth (m)	Date Started	Date Finished	Easting (m)	Northing (m)	Elevation (mAOD)	Backfill Details**
WS201	WS	4.00	11/10/2023	11/10/2023	382907	389920	33.75	MW
WS201b	WS	1.00	11/10/2023	11/10/2023	382907	389919	33.75	MW
WS202	WS	4.00	11/10/2023	11/10/2023	382892	389924	33.23	MW
WS202b	WS	1.00	11/10/2023	11/10/2023	382892	389925	33.23	MW
WS203	WS	6.00	11/10/2023	11/10/2023	382885	389922	33.25	MW
WS203b	WS	1.00	11/10/2023	11/10/2023	382884	389922	33.25	MW
WS204	WS	4.00	11/10/2023	11/10/2023	382889	389930	33.24	MW
WS204b	WS	1.00	11/10/2023	11/10/2023	382889	389931	33.24	MW
WS205	WS	1.00	10/10/2023	10/10/2023	382892	389945	33.41	A
WS205b	WS	1.00	10/10/2023	10/10/2023	382892	389943	33.41	MW
WS206	WS	4.00	10/10/2023	10/10/2023	382893	389962	33.17	MW
WS206b	WS	1.00	10/10/2023	10/10/2023	382893	389959	33.14	MW
WS207	WS	4.00	10/10/2023	10/10/2023	382892	389973	32.99	MW
WS207b	WS	1.00	10/10/2023	10/10/2023	382892	389974	32.99	MW
WS208	WS	4.00	10/10/2023	10/10/2023	382906	389961	32.98	MW
WS208b	WS	1.00	10/10/2023	10/10/2023	382907	389961	32.98	MW
WS209	WS	4.00	09/10/2023	09/10/2023	382904	389947	33.14	MW
WS209b	WS	1.00	09/10/2023	09/10/2023	382905	389947	33.14	MW
WS210	WS	3.00	09/10/2023	09/10/2023	382903	389940	33.29	MW
WS210b	WS	1.00	09/10/2023	09/10/2023	382904	389940	33.29	MW
*WS = Window Sample Borehole **MW = Monitoring Well, A= Arisings								

4.2 Laboratory Testing

4.2.1 Environmental Testing

The environmental chemistry of the ground was investigated by specialist chemical analysis of selected samples, scheduled by EEG, and carried out by DETS, a UKAS and MCERTS accredited laboratory.

Chemical analyses were carried out on ten soil samples and were submitted for the following suite of determinants:

Volatile Organic Compounds (VOCs) and Semi-Volatile Organic Compounds (SVOCs).

Chemical analyses were carried out on groundwater samples retrieved on two monitoring visits. Eight groundwater samples were submitted for the following suite of determinants:

Volatile Organic Compounds (VOCs) and Semi-Volatile Organic Compounds (SVOCs).

Sixteen groundwater samples were submitted for the following suite of determinants:

Sulphate, nitrate, dissolved iron, dissolved manganese, chloride, and dissolved organic carbon.

The results of the laboratory contamination tests are discussed in Section 6 and Section 7 and included in Appendix 3.

DRAFT

5.0 GROUND CONDITIONS ENCOUNTERED

5.1 Soil Profile Encountered

BGS digital mapping shows the site is underlain by superficial deposits of Glaciofluvial Sheet Deposits, comprising Devensian sand and gravel. The solid geology beneath the site is the Tarporley Siltstone Formation, comprising siltstone, mudstone, and sandstone. The sequence of strata encountered beneath the site was as follows:

- **Made Ground –** Variable Made Ground was encountered in all the exploratory holes to a maximum depth of 1.30m bgl, comprising:
 - CONCRETE
 - Sandy GRAVEL containing ash, slag, concrete, and red brick
 - Sandy clayey GRAVEL containing red brick and sandstone
 - Relict slightly sandy slightly gravelly TOPSOIL containing red brick and sandstone
 - Slightly gravelly sandy clayey TOPSOIL containing red brick
 - Slightly gravelly SAND containing sandstone
 - Slightly sandy gravelly CLAY containing ash and slag.

- **Superficial Deposits –**

Sand was encountered in exploratory hole locations WS201, WS202, WS203, WS206, WS208, WS209 and WS210 to a maximum depth of 3.00m bgl, comprising:

- Slightly clayey gravelly SAND containing sandstone and quartz
- Gravelly SAND containing sandstone and quartz
- Slightly gravelly SAND containing sandstone.
- SAND.

Gravel was encountered in exploratory hole locations WS204, WS207 and WS209 to a maximum depth of 3.90m bgl, comprising:

- Sandy GRAVEL containing sandstone
- Clayey sandy GRAVEL containing sandstone.

Clay was encountered exploratory hole locations WS201, WS202, WS203, WS204, WS207, WS207b WS208, WS208b, WS209, and WS210, to a maximum depth of 5.60m bgl, comprising:

- Slightly sandy CLAY
- Slightly gravelly sandy CLAY containing sandstone.

- **Bedrock –**

Bedrock was not encountered. In previous investigation, drilling refusal at 5.8m bgl was interpreted as the bedrock surface.

The depths of the various materials encountered in the exploratory holes are summarised in Table 2 overleaf. Fence diagrams showing the strata encountered across the site are included in Appendix 4, with cross section lines shown in Figure 6, overleaf.

Table 2: Summary of Ground Conditions Encountered

Hole	Depth to Stratum (m bgl)							GROUNDWATER (m bgl)
	MADE GROUND				SUPERFICIAL DEPOSITS			
	CONCRETE	GRAVEL	SAND	TOPSOIL	GRAVEL	SAND	CLAY	
WS201	GL – 0.05	0.05 – 0.80	-	0.80 – 1.10	-	1.10 – 3.00	3.00 – 4.00	-
WS201a	GL – 0.05	0.05 – 1.00	-	-	-	-	-	-
WS202	-	0.25 – 1.00	GL – 0.25	-	-	1.00 – 2.00 2.60 – 3.00	3.00 – 4.00	-
WS202b	-	GL – 1.00	-	-	-	-	-	-
WS203	-	0.30 – 0.70	GL – 0.30	-	-	0.70 – 3.00	3.00 – 5.60	1.80
WS203b	-	GL – 1.00	-	-	-	-	-	-
WS204	-	0.65 – 0.90	GL – 0.65	-	1.40 – 2.40 3.00 – 3.20	-	0.90 – 1.40 2.40 – 3.00 3.20 – 4.00	-
WS204b	-	0.45 – 1.00	GL – 0.45	-	-	-	-	-
WS205	0.90 – 1.00	GL – 0.90	-	-	-	-	-	-
WS205b	-	GL – 0.85	0.85 – 1.00	-	-	-	-	-
WS206	-	GL – 1.00	-	-	-	1.00 – 2.00 2.70 – 3.00	-	-
WS206b	-	GL – 1.00	-	-	-	-	-	-
WS207	0.25 – 0.30	-	-	GL – 0.25	2.90 – 3.00 3.75 – 3.90	-	3.90 – 4.00	2.50
WS207b	-	GL – 0.60	-	-	-	-	0.60 – 1.00	-
WS208	-	GL – 0.45	-	-	-	1.00 – 1.80	0.45 – 1.00 1.80 – 3.00 3.30 – 3.80	-

Hole	Depth to Stratum (m bgl)							GROUNDWATER (m bgl)
	MADE GROUND				SUPERFICIAL DEPOSITS			
	CONCRETE	GRAVEL	SAND	TOPSOIL	GRAVEL	SAND	CLAY	
WS208b	-	GL – 0.60	-	-	-	-	0.60 – 1.00	-
WS209	-	GL – 1.15	-	-	1.70 – 2.00	1.15 – 1.70	2.00 – 4.00	1.90
WS209b	-	GL – 1.00	-	-	-	-	-	-
WS210	-	GL – 1.30	-	-	-	1.30 – 2.00	2.00 – 3.00	1.95
WS210b	-	GL – 1.00	-	-	-	-	-	-

Figure 6: Cross Section Lines



5.2 Observable Indications of Contamination

Ash and slag were encountered in the Made Ground at locations WS021, WS201b and WS207b.

A slight hydrocarbon odour was observed within the groundwater at locations, WS206 and WS208 on the first groundwater sampling visit. However, no hydrocarbon sheens were observed in the groundwater, and no light non-aqueous phase liquids (LNAPL) detected with the interface meter.

No dense non-aqueous phase liquids (DNAPL), such as chlorinated solvents, which tend to sink into aquifer materials below the water table were detected in the groundwater using the interface meter.

5.3 Obstructions

Concrete was encountered at ground level in borehole locations WS201, WS201b, and at 0.25m in WS207, therefore a breaker was used to advance the hand pit.

Concrete was encountered in borehole location WS205 at a depth of 0.90m, and subsequently the hole was abandoned at 1.00m bgl.

No other man-made obstructions were encountered in the exploratory hole locations aside from cobbles of red brick encountered in the Made Ground.

5.4 Groundwater

All historical boreholes were removed or damaged during the earlier phases of construction and therefore ten new boreholes were drilled for the installation of groundwater monitoring wells (WS201 to WS204, WS206 to WS210). A concrete obstruction was encountered at 0.90m in WS205, therefore no groundwater monitoring well was installed at this location.

Groundwater was encountered in borehole locations WS203, WS207, WS209 and WS210 during the field work at depths of between 1.80m and 2.50m bgl.

Shallow groundwater has been found in most of the deeper monitoring wells, with depths ranging from 0.98m to 2.28m bgl on 3no. monitoring visits. However, no groundwater was encountered at borehole location WS204 on 2no. visits, and therefore no samples were taken from this location.

No groundwater samples could be retrieved using the Hex peristaltic pump at borehole locations WS202, WS206 and WS210 on the first monitoring visit due to low volumes of water in the monitoring wells. A bailer was used at these locations instead of the hex pump, although the recharge was poor. In subsequent visits the Hex pump was used.

Subsequent monitoring in the deeper monitoring wells on 3no. visits encountered groundwater at depths between 0.98m (WS209) and 2.28m (WS208). However, no groundwater was encountered at borehole location WS204 on 2no. visits.

The shallow monitoring wells were dry or wet at the base and were installed for the purpose of vapour monitoring and sampling, not groundwater.

6.0 CONTROLLED WATER RISK ASSESSMENT

6.1 Hydrogeological Setting

The BGS 1:50,000 Draft and Solid sheets for the area¹ show that the site is underlain by superficial deposits of Glaciofluvial Sheet Deposits, Devensian - Sand And Gravel, then bedrock of Tarporley Siltstone of the Mercia Mudstone group.

The Tarporley Siltstone is underlain by Wilmslow Sandstone of the Sherwood Sandstone group.

The site is located approximately 310m west of a fault that marks the eastern extent of the Tarporley Siltstone, and where the Wilmslow Sandstone is upthrown.

In other directions the Tarporley Siltstone extends approximately 600m north, 2.6km west and 1.9km south.

In previous investigations on site, drilling refusal at 5.8m bgl was interpreted as the Tarporley Siltstone surface.

The DEFRA MAGIC map viewer² accessed 19th January 2024 shows that the superficial deposits are classified as a Secondary A aquifer, the Tarporley Siltstone is classified as a Secondary B aquifer, and the Wilmslow Sandstone is a Principal Aquifer.

No Source Protection Zones or Drinking Water Protected Areas are shown within 5km of the site.

The bands of clay encountered within the superficial deposits will provide some protection to the Tarporley Siltstone from vertically migrating contaminants, while the Tarporley Siltstone is expected to provide further protection to the Wilmslow Sandstone.

The geological memoir for the area 'Geology of the Country around Stockport and Knutsford', BGS, 1963³, which refers to the Tarporley Siltstone as Keuper Waterstone, notes that *'the Waterstones as a whole are in the vertical sense an almost impervious formation owing to the abundance of mudstone bands. Nevertheless, when these rocks are found outcropping on the site of stream gullies it is almost invariably found that water, held up by the numerous shale partings, oozes out at numerous points over the rock face'*.

Thus, the Tarporley Siltstone has limited potential to support lateral migration of groundwater but significant vertical migration of contaminants through it is unlikely.

The thickness of the Tarporley Siltstone beneath the site has not been proven and there are no BGS borehole logs of sufficient depth to prove the thickness in the immediate vicinity of the site.

The geological memoir does not report the thickness of the Tarporley Siltstone in Northenden, with the nearest reported thickness being the Maple Road bore at Timperley, approximately 3.3km west of the site which refers to the Waterstones being *'at least 147 ft'* (45m) thick.

¹ <https://largeimages.bgs.ac.uk/iip/mapsportal.html?id=1002779>

² <https://magic.defra.gov.uk/MagicMap.aspx>

³ <https://pubs.bgs.ac.uk/publications.html?pubID=B01555>

The nearest BGS log of sufficient depth and detail to identify the Tarporley Siltstone and located within the same area of Tarporley Siltstone is BGS Log SJ88NW20⁴ which is located approximately 1.01 km south-east of the site and is approximately 20m west of the fault that marks the eastern boundary of the Tarporley Siltstone.

The borehole was drilled to 92m bgl and the log reports a total thickness of 2.9m 'Clay' or 'Sandy Clay and Gravel' which were reported from 3.45m bgl and are inferred as being Tarporley Siltstone.

Therefore, the Tarporley Siltstone is expected to be over 3m thick beneath the site, since it thickens significantly from east to west.

The BGS borehole SJ89SW71⁵ is located approximately 800m north-west of the site and reports '*red marl with bands of shale and sandstone*' which are interpreted as Tarporley Siltstone, was over 6.1m thick and was encountered from 4.9m bgl to 11.0m bgl, the base was not proven.

It is therefore concluded that the Tarporley Siltstone is of sufficient thickness both beneath and down-hydraulic gradient of the site to provide protection to the Wilmslow Sandstone Principal Aquifer from vertically migrating contamination in the superficial deposits.

The existing Groundsure report presented in the Preliminary Risk Assessment for the site indicates there are one active and two historical groundwater abstraction licences within 2km of the study site. The active license is located at Didsbury Golf Club, Northenden 1.1km northeast of site, used for spray irrigation, and is assumed to abstract from the Wilmslow Sandstone aquifer.

The two historical licenses are located 1.2km southeast and 1.9km southeast used for laundry use and spray irrigation. None of these are considered likely to receive groundwater from the site, or influence groundwater flow direction in the aquifers beneath the site.

The nearest surface water identified on Ordnance Survey mapping is the River Mersey approximately 485m north-east of the site which flows north-west. The Groundsure report indicates there are no active surface water abstraction licenses within 2km of the study site.

Groundwater flow direction in the Secondary A and B aquifers is expected to follow local topography and therefore to flow north towards the River Mersey. This assessment is supported by the groundwater flow direction observed in the 2022 EEG investigation.

6.2 Tier 2 Generic Risk Assessment

In the absence of specific UK guidelines regarding groundwater quality in the UK, chemical results obtained by EEG have been compared with the following statutory and non-statutory standards:

- Environmental Quality Standards (EQS); and
- UK Drinking Water standards⁽²⁰⁰⁰⁾.

The environmental setting of the site with respect to controlled waters is therefore one of relatively low risk due to an absence of specific controlled waters receptors in the vicinity of the site.

⁴ <https://api.bgs.ac.uk/sobi-scans/v1/borehole/scans/items/914672>

⁵ <https://api.bgs.ac.uk/sobi-scans/v1/borehole/scans/items/864955>

The concentrations of potential contaminants of concern in the groundwater samples recovered from the monitoring wells have been compared to Environmental Quality Standards (EQS) and UK Drinking Water Standards to be protective of both the future resource potential of the Secondary A and Secondary B aquifers, and of baseflow supplied to surface waters.

Screening has been completed for tetrachloroethene (PCE) and its degradation products, which have been identified as the contaminants of concern from previous phases of investigation at the site.

No EQS or DWS are available for *cis*12DCE.

The results from the groundwater samples retrieved in October 2023 are summarised in Table 3 (overleaf). The screened chlorinated volatile organic compounds (CVOCs) were all below the 5µg/litre MDL in WS206, and at WS207 only PCE was detected at 6µg/litre, indicating no significant CVOC impact at either location which are both adjacent to the north-western site boundary.

Chlorinated solvents (including PCE & TCE) have been found in the shallow groundwater samples recovered from the monitoring wells.

The groundwater contaminant exceedances of DWS/ EQS include:

- **Tetrachloroethene (PCE)** in 6no. sample locations: WS201, WS202, WS203, WS208, WS209 and WS210.
- **Trichloroethene (TCE)** in 6no. sample locations: WS201, WS202, WS203, WS208, WS209 and WS210.

The maximum recorded PCE concentration was found at WS210 (30,740µg/litre), the maximum recorded TCE concentration was found at WS209 (403µg/litre), and the maximum recorded *Cis*-DCE concentration was found at WS209 (997µg/litre).

No vinyl chloride was detected in the groundwater samples, the MDL of 5 µg/litre is greater than the DWS of 0.5µg/litre, however the absence of detectable vinyl chloride at all locations in both water and in soil vapour (see section 7.2) indicates that there is unlikely to be significant vinyl chloride impact at the site.

It should be noted that only Vinyl Chloride and Trichloroethene (TCE) are listed as **Hazardous Substances** according to JAGDAG, 2017. Data from previous investigations indicates that these substances entered the groundwater historically under previous ownership of the site.

Contour plots showing the distribution of soil and groundwater contaminants across the site are included in Figures 7 & 8, overleaf. The groundwater plot shows the concentrations of PCE, TCE and *cis*12DCE in the groundwater samples retrieved in October 2023.

Inferred groundwater elevation contours are shown on Figure 9 overleaf.

Table 3: Groundwater Results Comparisons with EQS/Drinking Water Quality Values (µg/l)

Determinand	EQS Value (1) µg/l	Drinking Water Quality (DWQ) Value (2) µg/l	WS201	WS202	WS203	WS206	WS207	WS208	WS209	WS210	No. of Exceedances
Volatile Organic Compounds											
1,2-Dichloroethane	10 ^(A)	3	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	0
Trans 1,2-Dichloroethene (<i>trans</i> -DCE)	-	-	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	0
Cis 1,2 Dichloroethene (<i>cis</i> -DCE)	-	-	9	49	85	< 5	< 5	926	997	19	0
Tetrachloroethene (PCE)	10	10*	194	3824	2727	< 5	6	794	688	30,740	6 for (1+2)
Trichloroethene (TCE)	10	10*	23	171	220	< 5	< 5	279	403	104	6 for (1+2)
Vinyl Chloride	-	0.5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	0
All values in µg/l unless otherwise stated *Concentration is the sum of TCE and PCE. EQS Standards – (M) = Maximum Allowable Concentration Standard, (A) = Annual Average Standard. Values in red are elevated above the recommended guidance value											

Figure 7: Soil Contamination Plans

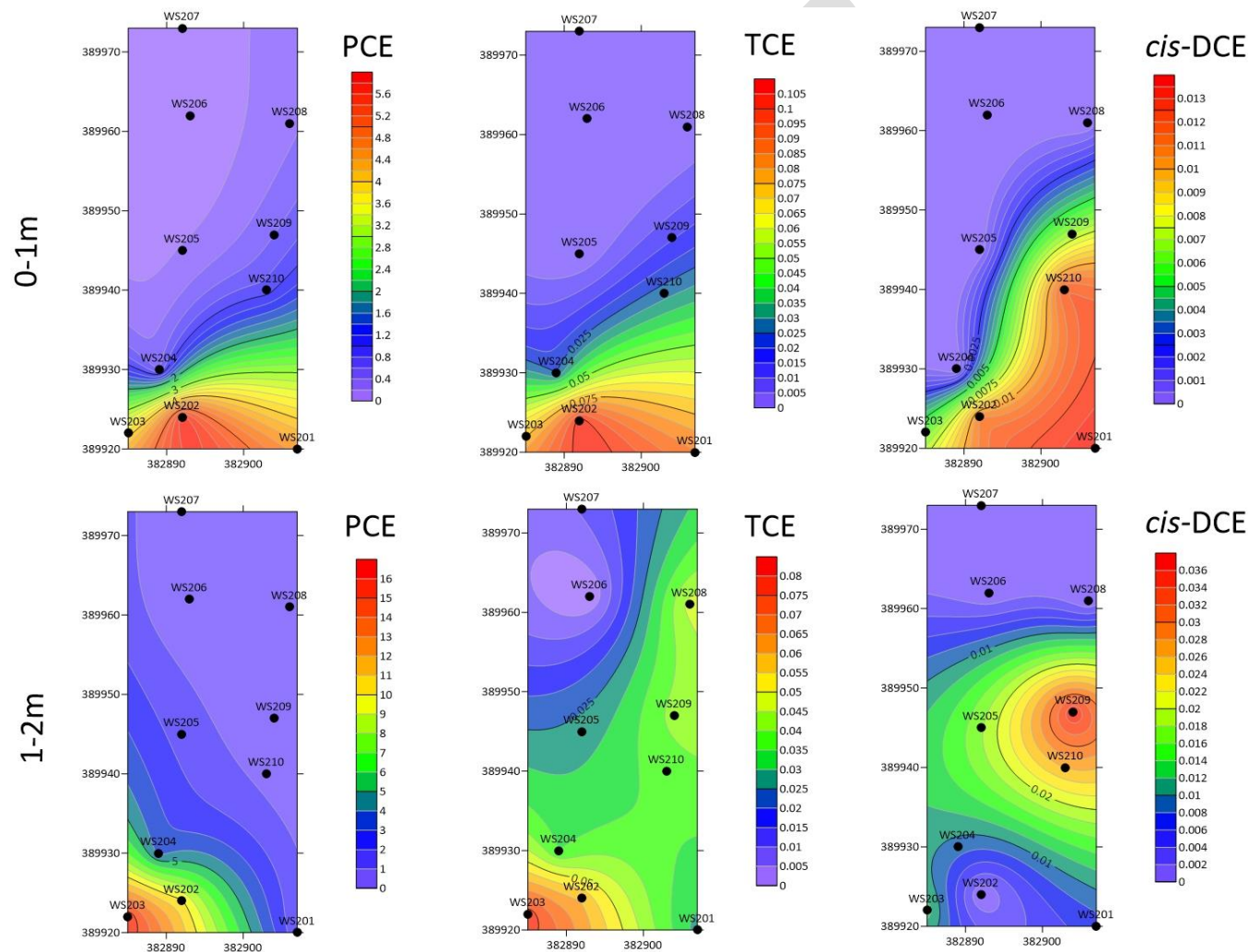


Figure 8: Groundwater Contamination Plans

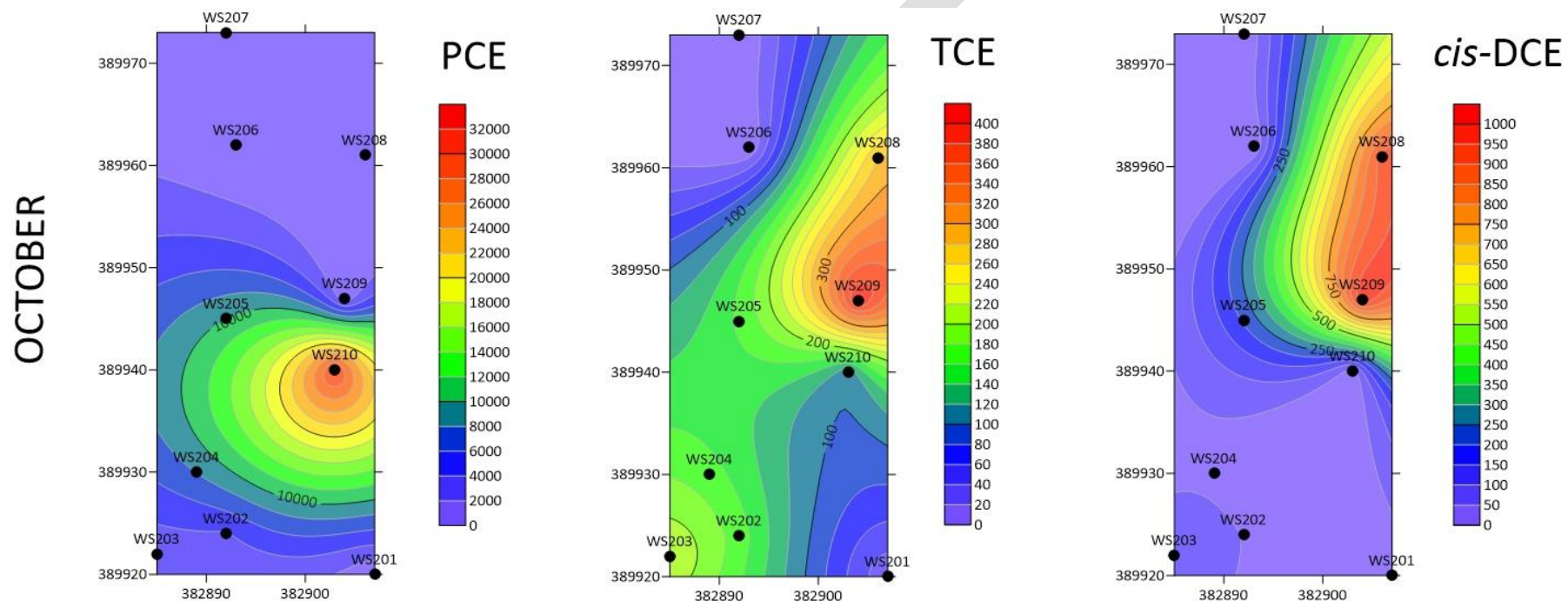
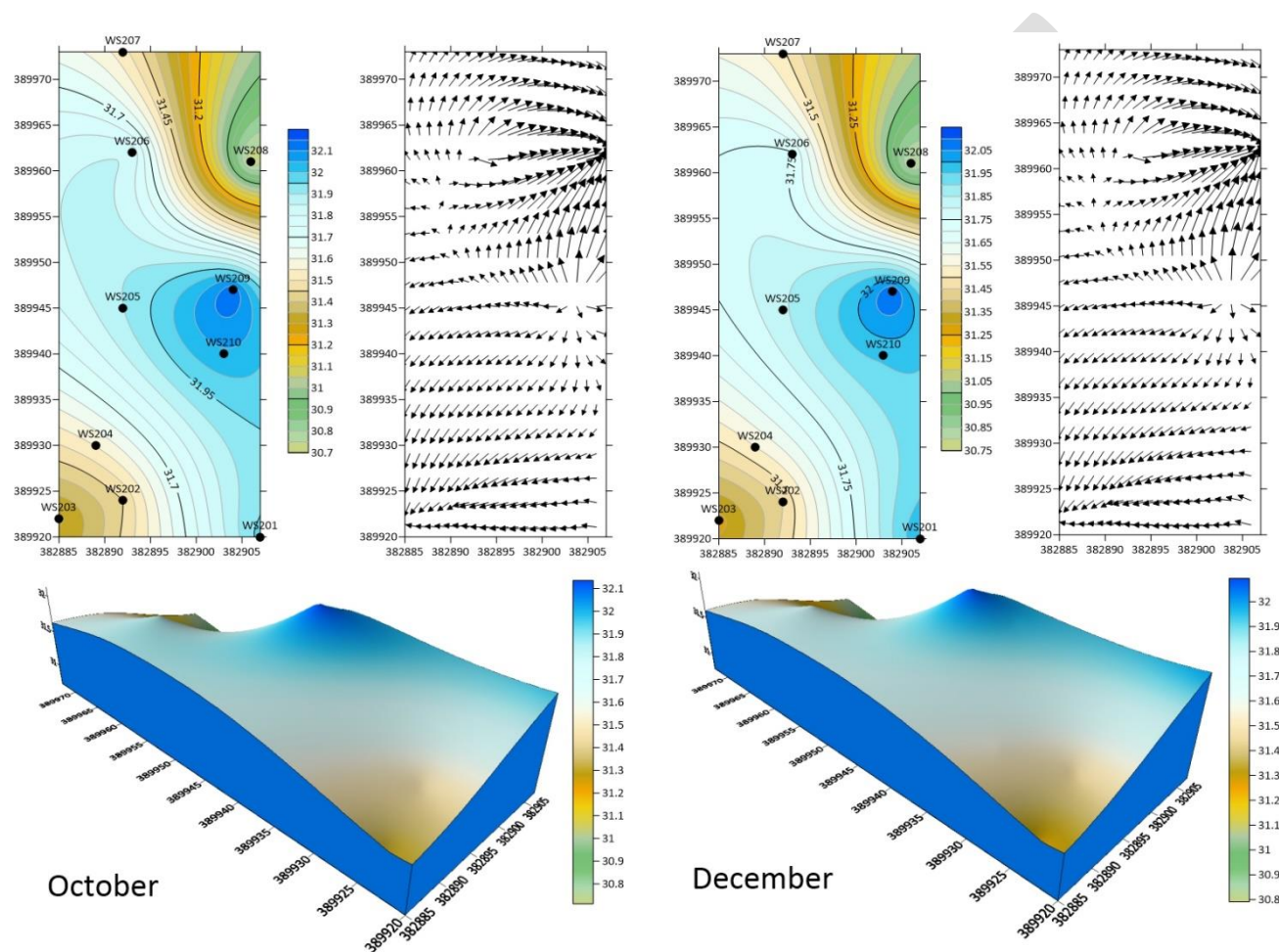


Figure 9: Contour Plans Showing Groundwater Elevations, October & December 2023



6.3 Distribution of Soil CVOC Impacts

PCE

The greatest magnitude PCE soil impacts in the top 0 – 1m bgl are at WS202 in the southern area of site where 5.7mg/kg were identified, and concentrations are shown to exceed 1mg/kg in WS201 and WS203 which are also in the southern area.

No soil sample was collected between 0 – 1.0 m bgl at WS203 therefore the concentration there is inferred from the contouring software. Across the remainder of site, the reported concentrations in the top 0 – 1m bgl are below 1mg/kg.

Between 1.0 – 2.0 m bgl, concentrations of PCE were between 8.9 - 15.8 mg/kg in WS202 and WS203, confirming the presence of a soil PCE source in the southern area of site.

The source of these impacts is unclear since the drycleaning machines are understood to have been located close to WS210, nearer to the centre of the site.

The soil impact could be the result of a different historical site layout, migration from the drycleaning machines to the southern area via a preferential pathway such as a drain (no drainage records of the former site are available for review), historical disposal of waste PCE in that area, or a secondary source such as the former car repair garage in that area of site.

TCE

The greatest magnitude TCE impacts between 0 – 1m bgl are also at WS202 and closely follow the distribution of PCE impacts, although concentrations are lower with a maximum of 0.1mg/kg as WS202, less than 0.03mg/kg in WS204 and WS210, and below detection limits across the rest of the site.

Between 1 – 2 m bgl the maximum TCE concentration of 0.08mg/kg is at WS203, and spreads north-eastwards from WS203.

TCE is produced as a degradation product of anaerobically degrading PCE and therefore the soil impacts likely represent PCE degradation within perched water in the upper metre, and in the capillary zone of the shallow groundwater which is between 1 – 2 m bgl.

There may also be degradation of PCE in damp cohesive unsaturated soils where oxygen recharge is limited.

The lower soil concentrations of TCE compared to PCE may represent a combination of more rapid degradation of TCE than PCE, and removal of the more volatile and soluble TCE from shallow soils by volatilisation and leaching.

cis1,2DCE

Between 0 – 1m bgl *cis1,2DCE* was detected in WS202 and WS201 only, at concentrations of 0.01mg/kg.

Between 1 – 2m bgl the greatest concentration is 0.04mg/kg at WS209, located north of WS210 in the central-northern area of site.

*cis*1,2DCE is produced from microbial degradation of TCE, and the greater impact at WS209 is consistent with a plume of impact in shallow groundwater moving northwards.

Vinyl Chloride

Vinyl chloride was not detected in soil at any location on site during the current investigation.

Vinyl chloride is produced from anaerobic degradation of *cis*1,2DCE and therefore is expected to have been produced from the *cis*1,2DCE impact.

Vinyl chloride is highly volatile and degrades aerobically, therefore the absence in shallow soils likely represents rapid aerobic degradation due to the recharge of oxygen from the surface and losses by volatilisation.

Summary

The primary soil source of CVOCs is located in the south-western area of site, with the exception of *cis*1,2DCE which is located towards the central-northern area of site. This distribution is consistent with the findings of the 2022 site investigation.

The greatest PCE impacts of between 1.0 – 15.8mg/kg were identified at depths between 0.9 and 1.8mbgl, shallower impacts were <1mg/kg.

The TCE and *cis*DCE impacts show less variation with depth, with concentrations below 0.15mg/kg at all depths.

Samples for laboratory analysis were not collected within the clays at greater depth. Limited PID data are available to demonstrate changes in concentrations with increasing depth through the clays.

At boreholes WS203 and WS209 the decreases in PID concentrations over one vertical metre within the clay are by factors of approximately six and three, respectively.

At borehole WS208 the concentration increases by a factor of 1.6 over one metre which may reflect sampling variability but indicates less reduction than at the other locations, or slight increase with depth.

6.4 Distribution of Groundwater CVOC Impacts

PCE

The greatest PCE groundwater concentration was at WS210 towards the centre of site where 30.7 mg/l was reported.

The next greatest concentrations are at WS202 and WS203 where 3.8mg/l and 2.7mg/l, respectively, were reported.

Groundwater samples could not be collected from WS204 and WS205, therefore concentrations at these locations are inferred from the contouring software.

At WS208 and WS209, north and down-hydraulic gradient of WS210, the concentration is between 0.7 and 0.8mg/l.

The reported concentrations are consistent with a localised high magnitude source, but not an extensive plume.

The location of the maximum groundwater impact at WS210 does not directly correlate with the maximum soil impacts at WS202 and WS203, which are approximately 20m south-west, and potentially up-hydraulic gradient of WS210, but does correlate with the location of the former drycleaning unit.

It is unclear whether the impact at WS210 is derived from the soil impacts, however given the relatively shallow groundwater level at between 1.8 – 2.0m bgl reported in these wells during October 2023 monitoring, some then groundwater impact would be anticipated to result from the soil concentrations which were reported between 1.1 – 1.5m bgl.

TCE

The greatest TCE concentration is at WS209 where 0.4mg/l were reported, and the next greatest concentration is at WS209, north of WS209, where 0.3mg/l are reported. These are located north of WS210 and therefore are consistent with TCE being formed from degrading PCE at WS210 within groundwater that is flowing northwards.

The relatively low concentrations of TCE compared to PCE may indicate that TCE is being degraded more rapidly than PCE, or that TCE is being lost at a greater rate by volatilisation.

cis1,2DCE

The greatest *cis1,2DCE* concentrations are at WS209 and WS208 where 1.0 and 0.9mg/l were reported, respectively. Across the rest of the site concentrations were below 0.05mg/l. The location of the maximum concentrations is consistent with *cis1,2DCE* being formed from degrading TCE at WS209 within groundwater that is flowing northwards.

Concentrations of *cis1,2DCE* are greater than TCE whereas it would be expected that they would be lower since each molecule of TCE that degrades produces one molecule of *cis1,2DCE*, and the molar mass of *cis1,2DCE* is approximately 33% lower than that of TCE.

Thus, if the degradation rates of TCE and *cis1,2DCE* were the same and sorption to aquifer materials were similar then *cis1,2DCE* concentrations should be approximately 33% lower.

Therefore, it appears that the *cis1,2DCE* degradation rate is slower than the TCE degradation rate.

Summary

The greatest PCE impacts in groundwater are towards the central and possibly central-southern areas of the site, while TCE is greatest in the central-northern area and *cis1,2DCE* is greatest within the northern area.

The distribution of groundwater impacts relative to soil impacts, and the distribution of PCE degradation products relative to the PCE source, suggest a northerly groundwater flow direction.

6.5 Groundwater Flow Direction Modelling

The groundwater direction was modelled using Surfer® software. Contour maps were created using the Kriging Tool by inputting the groundwater depths observed in the monitoring wells over two visits in October (visit 1) and December 2023 (visit 3).

Vector plots were created from the grid file to determine the groundwater flow direction. The contour maps are presented as Figure 9.

The plots suggest that there is a central area around WS208 and WS209 with groundwater flowing both north-east and south-west from that area.

Groundwater elevation at these locations is approximately 0.7m higher than in WS203 near the south-west boundary.

However, that is inconsistent with the surrounding topography, the distribution of dissolved contaminants relative to the source and the observations of groundwater flow direction in 2022.

Review of the logs for WS208 and WS209 has not identified an obvious cause of elevated groundwater in these wells since both are installed in sands and gravels that should not result in perching of groundwater.

The WS200 series wells could not be surveyed for ground or well casing elevations using the GPS level because some are within buildings, and most are adjacent to buildings that interfere with the GPS signal; therefore, elevations have been estimated from ground levels during previous survey.

It is therefore considered likely that the ground elevations have changed slightly since the previous survey, resulting in the apparently elevated groundwater in the central area.

Therefore, groundwater flow direction and gradient cannot be reliably determined from the 2023 groundwater contour plots.

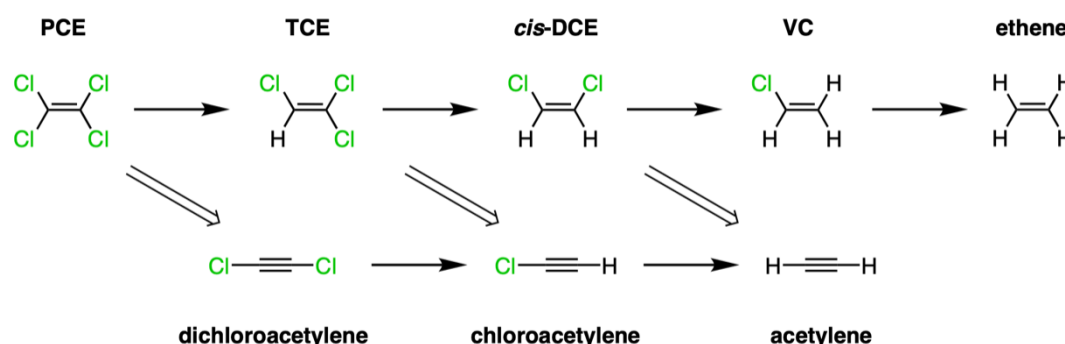
The hydraulic gradient for the site based on 2022 data was previously calculated to be approximately 0.0377 m/m (EEG, 2022), based on a northwards groundwater flow between WS109 and WS101. The boreholes were installed after removal of the former hardstanding and construction of the new foundations, both of which could have potentially influenced groundwater flow; therefore, groundwater flow direction and gradient are unlikely to have changed since 2022 and the previous data are considered more reliable for the current assessment.

6.6 CVOC Natural Attenuation Assessment

6.6.1 Background

Chlorinated solvents such as PCE and TCE are common contaminants of soil and groundwater at numerous sites of active and historical dry-cleaning facilities and industrial operations.

Chlorinated solvents are dense non-aqueous phase liquids (DNAPLs), and this character gives them a unique dispersal pattern and complex distribution that is controlled by local geological settings. As these substances are harmful and have been proved or are considered to be carcinogens, sites contaminated with these solvents often require remediation.



The top pathway with single line arrows represents the reductive de-chlorination (hydrogenolysis) pathway. The lower pathway with downward facing double line arrows represent an additional beta-elimination pathway which is not typically assessed in the UK due to lack of commercially available laboratory analysis for the degradation products in soil and groundwater samples.

Trichloroethene (TCE) is a highly volatile solvent which has high mobility in water and is used in manufacturing and engineering to clean grease from machinery. In groundwater, TCE can undergo reductive de-chlorination by anaerobic bacteria that yields *cis*-1,2-dichloroethene (*cis*-1,2DCE), which can be degraded to vinyl chloride which can then be degraded to ethene.

In groundwater *cis*-12DCE and vinyl chloride can be degraded by both anaerobic and aerobic microbial degradation (EA Report 228, 2001).

6.6.2 Natural Attenuation Assessment

A review has been completed for evidence of natural attenuation of CVOCs at the site, with reference to the approach set out in Environment Agency Report R&D95 Guidance on Assessment and Monitoring of Natural Attenuation of Contaminants in Groundwater (2000).

The observations below are based on groundwater along the plume line of:

- WS201 (up-hydraulic gradient, near southern site boundary)
- WS210 (PCE source zone)
- WS209 (down-hydraulic gradient of WS210)
- WS208 (down-hydraulic gradient of WS209). Nearest well on the plume line to the down-hydraulic gradient (northern) site boundary.

Primary Lines of Evidence

The primary evidence of degradation is that PCE concentrations in groundwater decrease rapidly with distance from the source. A reduction by an order of magnitude over 10m is observed, which is considered greater than would be expected from attenuation by other mechanisms such as sorption and dilution.

TCE concentrations also show reduction in concentrations in down-hydraulic gradient wells, by a factor of approximately two over 15m. The DCE source area reaches the well furthest down-hydraulic gradient therefore a decrease cannot be observed.

The presence of daughter products TCE and cis1,2DCE provides strong evidence that there is biodegradation of CVOCs at this site.

The DCE is present as the cis1,2DCE isomer only, which is produced only by microbial degradation.

Concentrations of TCE are lower than the PCE concentrations which is consistent with the TCE being produced by degradation of PCE rather than a secondary source of TCE.

VC has not been detected which could either indicate that cis1,2DCE is not degrading to VC, or that VC is degrading more rapidly than it is being produced and therefore is not being detected.

Considering that the aquifer conditions on the plume fringes are likely to be aerobic and are otherwise considered suitable for VC degradation (see below) then it is considered more likely that the VC is being rapidly degraded and therefore not detected.

There is no time-series contaminant concentration data from the same wells, therefore conclusions cannot be drawn on whether the plumes are stable.

Concentrations of all the CVOCs are in the ranges where biodegradation has been observed at other sites (Environment Agency report P2-228/R The Effects of Contaminant Concentration on Potential for Natural Attenuation (2002)).

Secondary Lines of Evidence

The dissolved oxygen (DO) concentration in the well WS209 directly down-hydraulic gradient of the PCE source area was 0.19 mg/l which are lower than in other wells, indicating anaerobic conditions suitable for anaerobic degradation. Readings at other wells were between 1.0 – 5.1mg/l, indicating potentially anaerobic to aerobic conditions.

The pH in all wells is between 6.5 and 7.8 in all wells, indicating suitable conditions for microbial growth (Environment Agency report P2-228/R The Effects of Contaminant Concentration on Potential for Natural Attenuation (2002)).

The conductivity is between 25 – 30 mS in all wells indicating that the groundwater is all from the same aquifer.

There are no clear trends in pH or conductivity data along the plume.

The dissolved organic carbon (DOC) concentration ranges from 41.4 mg/l in WS201 to between 22.0 to 30.8 mg/l in the plume with no clear trend.

The reduction in DOC within the plume relative to the up-hydraulic gradient well could indicate use of the organic carbon by microbes degrading the CVOCs (Environment Agency report P2-228/R The Effects of Contaminant Concentration on Potential for Natural Attenuation (2002)). Concentrations >20 mg/l are considered indicative of sufficient supply of carbon to act as an

energy source for the microbes that dechlorinate CVOCs (Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water, USEPA 1998⁶).

Concentrations of nitrate decrease slightly along the plume line from 66.9 mg/l at WS210 to 47.7 at WS208, while sulphate increases slightly from 193 mg/l at WS210 to 334 mg/l at WS208. Neither are directly involved in microbial de-chlorination of CVOCs, but reductions compared to the up-hydraulic gradient wells would indicate conditions becoming more reducing.

Concentrations of total dissolved iron (analogous to Fe²⁺) and total dissolved manganese (analogous to Mn²⁺) both reduce slightly and are below 0.3 mg/l in all wells except WS201. Neither are directly involved in microbial de-chlorination of CVOCs, but increases would indicate reducing conditions, and concentrations >1 mg/l are typically considered indicative of reducing conditions. Concentrations of nitrate, sulphate, iron, and manganese indicate that conditions do not become more reducing within the plume.

Redox readings (corrected for groundwater temperature) were +243 in WS201 (background) and between +116 mV (WS209) and +207 mV (WS208) along the plume, indicating oxidising background conditions, becoming to mildly oxidising within the plume.

Concentrations of chloride increase from 20 mg/l at WS210 to 47 mg/l at WS208, potentially indicating the production of chloride from de-chlorination of CVOCs.

Tertiary Lines of Evidence

No laboratory analysis for microbial populations capable of degrading CVOCs has been completed. However, the presence of *cis*-1,2DCE is strong evidence that there are active microbial populations in groundwater at the site that are capable of degrading CVOCs.

6.6.3 Conclusions

The weight of the lines of evidence is that microbial degradation of CVOCs is occurring, with anaerobic degradation of PCE and TCE, followed by aerobic degradation of DCE and VC. This is consistent with degradation scenarios presented in Environment Agency report P2-228/R The Effects of Contaminant Concentration on Potential for Natural Attenuation (2002).

6.7 Detailed Quantitative Risk Assessment - Remedial Targets Methodology (RTM)

Modelling Approach

The risks to controlled waters were further assessed using the Environment Agency's Remedial Targets Methodology Hydrogeological Risk Assessment for Land Contamination (Environment Agency, 2006).

The RTM worksheet allows remedial target concentrations for groundwater to be derived for selected contaminants. The methodology is a tiered approach, with a remedial target being derived at the end of each tier, which would provide sufficient protection to controlled water resources based on the entered water target value and compliance point. The model can also be used to predict concentrations down-hydraulic gradient of the source.

⁶ <https://semspub.epa.gov/work/06/668746.pdf>

The model has been used to calculate soil and groundwater remedial targets for the CVOCs that exceed EQS/DWS, which are PCE and TCE. Targets were also calculated for *cis*12DCE which does not have UK EQS/ DWS, and for vinyl chloride which was not detected and therefore the remedial targets are for context. The previously presented EQS/ DWS were applied to the assessment. Since *cis*12DCE does not have a published UK EQS/DWS, the EQS of 10µg/litre for dichloroethane has been applied as a surrogate value, based both on the chemical similarity to *cis*12DCE, and equivalence of this value to the PCE/TCE criterion.

In the absence of specific controlled waters receptors within 250m of the site, the default compliance points of 50m for Hazardous substances (TCE and VC), and 250m for Non-hazardous substances (*PCE* and *cis*12DCE) apply. However, the EQS/DWS for PCE and TCE is for the sum of both substances therefore compliance points for both TCE and PCE have initially been set at 50m to assess whether their combined impact at 50m is likely to be unacceptable.

The RTM report notes that where possible site-specific contaminant degradation rates should be used rather than literature values.

To support this assessment, bulk attenuation rates (BAR) have been calculated based on the observed reductions in groundwater concentrations between source wells and the wells down-hydraulic gradient of sources.

The observed attenuation will be from a combination of processes including microbially mediated de-chlorination, sorption, vertical and lateral dispersion, and volatilisation.

The observed difference includes all attenuation mechanisms and therefore is referred to as a bulk attenuation rate rather than a degradation rate. Further information on the calculation of BARs is presented in Section 6.5. Since site-specific degradation rates have been used, the degradation switch has been set to 'Apply degradation rate to all phases', however the effect of applying 'dissolved phase only' degradation is assessed in the sensitivity analysis.

In the Level 3 Soil and Groundwater worksheets, the analytical solution was selected as Domenico - Steady State.

The model input parameters and sources of information are included in Tables 4 to 7 overleaf. The Remedial Target Worksheets for Tetrachloroethene (PCE), Trichloroethene (TCE), *cis*12dichloroethene (DCE), and Vinyl Chloride (VC) are included in Appendix 5.

Table 4: RTW Inputs & Justification

Parameter	Units	Value	Source
<i>Tier 1, Soil</i>			
Unsaturated soil water filled porosity O_w	Fraction	2.40E-01	EA report SR3, Sand soil. Typical of Made Ground and shallow superficial deposits at the site.
Unsaturated soil air filled porosity O_a	Fraction	3.00E-01	EA report SR3, Sand soil. Typical of Made Ground and shallow superficial deposits at the site.
Bulk density of soil zone P	g/cm ³	1.18E+00	EA report SR3, Sand soil. Typical of Made Ground and shallow superficial deposits at the site.
Henrys law coefficient H	Unitless	Varies	See Table 7
Fraction of organic carbon, soil FOC	Fraction	1.7E-02	Geomean of 11 samples unsaturated soils, range <0.001 to 0.049
Organic carbon partition coefficient K_{oc}	l/kg	Varies	See Table 7
<i>Tier 2, Soil</i>			
Infiltration	m/d	5.94E-04	20-year annual average at nearest Met Office weather station, Woodford, approximately 10km south-east. Reduced by 75% for partial building and hardstanding areas, evapotranspiration from soft landscaping. No soakaways have been reported on former site, proposed development will discharge surface water to sewer.
Area of contaminant source	m ²	Varies	See Table 5
Length of contaminant source	m	Varies	See Table 5
Saturated aquifer thickness	m	3.80E+00	Value from previous DQRA. Maximum proven depth of superficial deposits on site is 6.0m (WS110 which terminated in dense gravel), average depth to groundwater across all wells over three visits between October to December 2023 is 1.6m indicating aquifer thickness of 4.4m. 3.8m is based on groundwater monitoring data from September 2022 and selected as representative of low water table months. Thickness of superficial deposits likely to increase towards the River Mersey down-hydraulic gradient of the site.
Hydraulic conductivity of aquifer	m/d	9.8E-01	Value from previous DQRA – geomean from slug tests on 3 wells, further details below
Hydraulic gradient	fraction	3.77E-02	Difference between groundwater level (m AOD) in monitoring wells WS109 and WS101 (September 2022 visit) divided by distance (m) between the two wells.
Width of contaminant source	m	Varies	See Table 5
Background concentration of contaminant in groundwater	mg/l	0.00	No other potential sources of CVOCs in vicinity, site is in residential area
Mixing zone depth	m	Variable	Calculated by model
<i>Tier 3 Soil, Tier 3 Groundwater</i>			
Foc = Fraction of organic carbon in aquifer	fraction	1.70E-02	Geomean value calculated from the soil organic matter (SOM) concentrations identified in the previous report (<i>Reference: A3939/21B.0 Appendix 3</i>). FOC = SOM divided by 172
Soil source concentration	mg/kg	Varies	See Table 5
Groundwater source concentration	mg/l	Varies	See Table 6
Half life degradation in water $t_{1/2}$	days	Varies	See Table 7
Sz = Width of plume in aquifer at source (perpendicular to flow)	m	Varies	Set to same as soil source width, see Table 5.
Sy = Plume thickness at source	m	3.80E+00	Set to aquifer thickness
Saturated aquifer thickness	m	3.80E+00	As for Tier 2, see comments above
r = Bulk density of aquifer materials	g/cm ³	1.60E+00	Literature value for sand, R&D Technical Report P2-228/TR Table 3.1
N = Effective porosity of aquifer	fraction	1.50E-01	Literature value for medium sand (Domenico & Schwarz, 1990) representative of permeable aquifer materials in which contamination moves. Hydraulic conductivity data indicate porosity towards lower end of range for sands and gravels
i = Hydraulic gradient	fraction	3.77E-02	Difference between groundwater level (m AOD) in monitoring wells WS109 and WS101 (September 2022 visit) divided by distance (m) between the two wells. NB the RTM Tier 3 Soil sheet increases the gradient to account for infiltration across the source area.

K = Hydraulic conductivity of aquifer	m/d	9.80E-01	Geomean of the hydraulic conductivity from falling head tests on the 3no. monitoring wells during 2022 investigation, calculated from values 0.14, 2.08 & 3.22 m/d.
x = Distance to compliance point	m	5.00E+01, 2.50E+02	Environment Agency default compliance points: 50m for hazardous substances, 250m for non-hazardous substances
T = Time since pollutant entered groundwater	days	1.00E+100	The recommended value for time when calculating the remedial target is 9.9E+99.
Dispersivity	m	Variable	Longitudinal and transverse calculated by Xu & Eckstein based on compliance point distance, vertical set to 1e-09 because assumed plume thickness is same as aquifer thickness.

Table 5: Levels 1 - 3 (Soil) Assessment – Source Details

Parameter	Units	Value	Source
<i>Soil Source 1 – Site Wide</i>			
Width	m	2.00E+01	Site width in direction of groundwater flow
Length	m	6.00E+01	Site length in direction of groundwater flow
PCE source concentration	mg/kg	7.62E-01	Site wide average of WS2** wells, excluding the locations in hotspot described below. Range 0.023 to 3.69.
TCE source concentration	mg/kg	2.20E-02	Site wide average of WS2** wells, excluding the locations in hotspot described below. Range <0.005 to 0.047.
DCE source concentration	mg/kg	8.00E-03	Site wide average of WS2** wells, excluding the locations in hotspot described below. Range <0.005 to 0.020.
VC source concentration	mg/kg	5.00E-03	Not detected – set to laboratory detection limit
<i>Soil Source 2a Hotspot PCE, TCE, VC</i>			
Width	m	1.00E+01	PCE & TCE impacts at WS202, WS203 and WS108 in southern area of site. Indicative for VC which has not been detected. Delineated by WS204, WS107, WS09, WS107
Length	m	1.00E+01	As above
PCE source concentration	mg/kg	1.58E+01	Site maximum for WS2** wells, WS203, 1.1m bgl
TCE source concentration	mg/kg	1.03E-01	Site maximum for WS2** wells, WS202, 0.9m bgl
VC source concentration	mg/kg	5.00E-03	Not detected – set to laboratory detection limit
<i>Soil Source 2b – Hotspot cis12DCE</i>			
Width	m	1.00E+01	cis12DCE impacts at WS202, WS209 and WS210 measured in direction of groundwater flow
Length	m	2.50E+01	cis12DCE impacts at WS202, WS209 and WS210 measured in direction of groundwater flow
DCE source concentration	mg/kg	3.60E-02	Site maximum for WS2** wells, WS209, 1.5m bgl

Table 6: Level 3 (Groundwater) Assessment – Source Details

Parameter	Units	Value	Source
<i>Groundwater Source 1 – Site Wide</i>			
Width	m	2.00E+01	Site width in direction of groundwater flow
Length	m	6.00E+01	Site length in direction of groundwater flow
PCE source concentration	mg/l	1.12E+00	Site wide average of WS2** wells, excluding the locations in hotspot described below. Range <0.005 to 3.824.
TCE source concentration	mg/l	1.50E-01	Site wide average of WS2** wells, excluding the locations in hotspot described below. Range <0.005 to 0.279
DCE source concentration	mg/l	3.00E-02	Site wide average of WS2** wells, excluding the locations in hotspot described below. Range <0.005 to 0.085
VC source concentration	mg/l	5.00E-03	Not detected – set to laboratory detection limit
<i>Groundwater Source 2a Hotspot PCE, TCE, VC</i>			
Width	m	1.00E+01	PCE impact at WS210 and WS109, delineated by WS209, WS201, WS202 & WS107. TCE impact at WS209, delineated by WS208, WS210. Indicative for VC which has not been detected on site.

PCE source concentration	mg/l	3.07E+01	Site maximum for WS2** wells, WS210 October 2023
TCE source concentration	mg/l	4.03E-01	Site maximum for WS2** wells, WS209 October 2023
VC source concentration	mg/l	5.00E-03	Not detected – set to laboratory detection limit
<i>Groundwater Source 2b – Hotspot cis12DCE</i>			
Width	m	1.00E+01	<i>cis12DCE</i> impact at WS208 and WS209. Delineated by WS206, WS210 and WS05.
DCE source concentration	mg/l	9.97E-01	Site maximum for WS2** wells, WS209 October 2023

Table 7: Contaminant Property Inputs

Parameter	Units	Contaminant	Value	Source
H = Henrys Law constant	unitless	Tetrachloroethene (PCE)	3.16E-01	Environment Agency Science Report: SC050021/SR7
		<i>cis12</i> Dichloroethene (DCE)	7.46E-02	EIC/CL:AIRE, 2009. The Soil Generic Assessment Criteria for Human Health.
		Trichloroethene (TCE)	1.87E-01	Environment Agency Science Report: SC050021/SR7
		Vinyl Chloride	7.47E-01	Environment Agency Science Report: SC050021/SR7
Koc = Organic carbon partition coefficient	l/kg	Tetrachloroethene (PCE)	2.69E+02	Environment Agency Science Report: SC050021/SR7, Log Koc values (cm ³ g ⁻¹) Table 3.49
		<i>cis12</i> Dichloroethene (DCE)	4.90E+01	R&D Technical Report P2-228/TR document Table 3.1
		Trichloroethene (TCE)	1.41E+02	Environment Agency Science Report: SC050021/SR7, converted Log Koc values (cm ³ g ⁻¹) Table 3.59
		Vinyl Chloride	1.66E+01	DCE value from R&D Technical Report P2-228/TR document table 3.12
t _{1/2} = Half-life for degradation of contaminant in water – for comparison to BAR	days	Tetrachloroethene (PCE)	5.00E+02	See Tables 8 and 9
		<i>cis12</i> Dichloroethene (DCE)	1.00E+02	See Tables 8 and 9
		Trichloroethene (TCE)	1.00E+03	See Tables 8 and 9
		Vinyl Chloride	1.00E+02	See Tables 8 and 9

6.8 Bulk Attenuation Rates

To assess site-specific attenuation, tentative Bulk Attenuation Rates (BAR) have been estimated.

These were calculated by identifying pairs of wells along the observed flow path, including WS210 to WS209 and WS209 to WS208. The number of half-lives required to achieve the observed reduction in concentration was calculated based on the COPC retarded flow rates simulated by RTM. This calculation makes the following assumptions:

- One well in each pair is directly down-hydraulic of the other.
- Both wells have response zones installed within strata in direct hydraulic connection.
- The plume is not expanding or shrinking and has not detached from the source.
- Degradation is an ongoing rather than historical process.
- Aquifer conditions to which they will be applied off-site are similar to those on site.

The BAR calculated during the previous investigation are also presented. Since there is no longer a well down-hydraulic gradient of the *cis12*DCE source zone, and vinyl chloride has not been detected in 2023 monitoring, then it has not been possible to update the BAR for these contaminants.

The estimated Bulk Attenuation Rates are shown in Table 8 below, and the degradation rates applied the RTM assessment are presented in Table 9 below.

Table 8: Updated Bulk Attenuation Rate (BAR) Calculations

COPC, Date	Flow Path Pairs & Concentrations (ug/l)		Path Length* (m)	Retarded Flow Rate (m/d)	Travel Time (days)	No Half lives Required** (No.)	Half life (days)	Tentative BAR (days)
PCE Sep '22	WS106	WS104	12	4.94E-03	2.43E+03	5.5	4.42E+02	500 days
PCE Oct '23	1499	34	8	4.95E-03	1.62E+03	5.48	2.95E+02	300 days
	WS210	WS209						
TCE Sep '22	WS109	WS106	17	9.25E-03	1.84E+03	2.2	8.35E+02	800 days
TCE Aug '22	228	51						
	174	no data						
	WS106	WS104						
TCE Sep '22	51	7	12	9.25E-03	1.30E+03	2.9	4.47E+02	400 days
	WS209	WS208						
TCE Oct '23	403	279	20	9.27E-03	2.16E+03	0.53	4.07E+03	4,000 days
DCE Sep '22	WS104	WS101	25	2.49E-02	1.00E+03	7.2	1.39E+02	100 days
	872	6						
	WS108	WS102						
DCE Au '22g	134	no data						
	WS104	WS101	25	6.14E-02	4.07E+02	6	6.79E+01	100 days
VC Sep '22	46	1						
Notes COPC - Chemical of Potential Concern *Distance between wells in line of groundwater flow **The number of half-lives required to achieve the observed attenuation between flow path pairs BAR - Bulk Attenuation Rate Half-lives were calculated by using Solver to adjust the half-life until observed attenuation was achieved								

Table 9: CVOC Degradation Rates Applied to Assessment

Contaminant	Observed BARs (days)	Literature Degradation Half Lives (Days) ¹	Values Applied to RTM	Justification
Tetrachloroethene (PCE)	500, 300	100 – 1,000	500	Consistent rapid attenuation observed in two separate investigations, slower observed rate is within literature range
Trichloroethene (TCE)	400, 800, 4,000	100 – 1,000	1,000	Observed rates are variable. Observed <i>cis</i> -1,2-DCE concentrations indicate rapid TCE degradation that is consistent with two out of three observations, therefore slowest literature value used. Effect of slowest observed value to be assessed in sensitivity analysis.
<i>cis</i> -1,2-dichloroethene (DCE)	100	50 – 3,000	1,000	Observed rate from single observation is within likely range of 50 - 350 days for aerobic aquifers as reported in the literature reference, data indicate this part of plume is aerobic. However, DCE concentrations are greater than TCE concentrations, indicating that DCE degradation is relatively slow, therefore set to same as TCE

Contaminant	Observed BARS (days)	Literature Degradation Half Lives (Days) ¹	Values Applied to RTM	Justification
Vinyl Chloride	100	50 – 500	200	Observed rate from single observation is within likely range of 50 – 200 days for aerobic aquifers as reported in the literature reference, site data indicate this part of plume is aerobic. Vinyl chloride has not been detected in any soil or groundwater samples in 2023 indicating that it is degrading. Slowest rate for aerobic degradation selected.

Notes

¹Range for UK Shallow Sand/Gravel Aquifers, all biogeochemical types, from EA Report P228

6.9 Risk Assessment Results

The calculated soil and groundwater remedial targets for each source area are presented in Table 10 overleaf, together with the hazard index (HI) for each.

The hazard index (HI) is calculated by dividing the source concentration by the remedial target, an HI >1.00 indicates potentially unacceptable risk.

In addition to the remedial targets, the predicted concentration at the compliance point is presented for the groundwater sources which are a more reliable indicator of potential risks to the aquifer than the soil sources, because they are based on the observed groundwater impacts.

Soil Sources

All soil sources report HI <1.00 indicating acceptable risks, and no individual soil samples exceed their respective remedial targets.

The greatest HI is for vinyl chloride in the site-wide source (HI = 3.76E-01), however that is based on the laboratory detection limit since vinyl chloride was not detected in site soils.

For contaminants in soil the greatest HI is for TCE in the site-wide source (HI = 2.37E-02). The soil risks are relatively low compared to the groundwater risks (see below), indicating either an undetected soil source or that the source is mainly within groundwater.

Groundwater Sources

All groundwater sources report HI <1.00, apart from TCE in the site-wide and hotspot sources HI= 1.20 and 2.22, respectively.

This indicates potentially unacceptable risk to the default 50m compliance point for a target concentration of 5ug/litre based on the DWS of 10ug/litre for combined TCE and PCE.

The site-wide source remedial targets were exceeded as WS202, WS203, WS208 and WS209, while the hotspot remedial targets were exceeded as WS203 and WS209.

The CWHI for other contaminants are <1.00 indicating acceptable risk.

Groundwater concentrations are screened against their remedial targets in Table 11, overleaf.

To further assess the potential impacts from combined TCE and PCE at GWS2a, the simulated concentrations at multiple steps along an extended flow path have been summed. The

assessment was completed for a 100m compliance point, and the distances shown are the default outputs from the RTM Tier 3 Groundwater sheet. The results are presented in Table 12 overleaf. The results indicate that compliance with the combined TCE and PCE standard could be achieved within 60m of the source.

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Table 10: Soil and Groundwater Remedial Targets

Parameter	Soil Source concentration	GW Source concentration	Tier 1 Remedial target soil	Tier 2 Remedial target soil	Tier 3 Remedial target soil	Tier 3 (GW) Remedial target groundwater	Tier 3 (GW) Predicted concentration at compliance point	Tier 3 Soil Hazard Index	Tier 3 GW Hazard Index
Units	mg/kg	mg/litre	mg/kg	mg/kg	mg/kg	mg/litre	mg/litre	-	-
<i>Site-wide Sources SS1, GWS1 - 50m Compliance Point</i>									
VC*	0.005	0.005	3.38E-04	1.67E-03	1.33E-02	6.27E-03	3.98E-04	3.76E-01	7.97E-01
TCE	0.022	0.15	1.32E-02	6.54E-02	9.28E-01	1.25E-01	6.01E-03	2.37E-02	1.20E+00
PCE	0.762	1.12	2.43E-02	1.20E-01	2.74E+02	4.73E+01	1.18E-04	2.78E-03	2.37E-02
<i>Site-wide Sources SS1, GWS2 - 250m Compliance Point</i>									
DCE	0.008	0.03	1.06E-02	5.21E-02	1.69E+01	9.58E+00	3.13E-05	4.73E-04	3.13E-03
<i>Hotspot Sources SS2a, GWS2a - 50m Compliance Point</i>									
VC*	0.005	0.005	3.38E-04	8.32E-03	1.39E-01	9.13E-03	2.73E-04	3.60E-02	5.48E-01
TCE	0.103	0.403	1.32E-02	3.26E-01	1.06E+01	1.82E-01	1.11E-02	9.70E-03	2.22E+00
PCE	15.78	30.74	2.43E-02	5.98E-01	6.26E+03	6.89E+01	2.23E-03	2.52E-03	4.46E-01
<i>Hotspot Sources SS2b, GWS2b - 250m Compliance Point</i>									
DCE	0.036	0.997	1.06E-02	1.10E-01	1.23E+02	1.85E+01	5.39E-04	2.93E-04	5.39E-02

Notes

*Source concentration is the laboratory detection limit, as vinyl chloride was not detected in soil or groundwater

Red text indicates HI > 1.00

Table 11: Groundwater Concentrations Screened Against Remedial Criteria

		Remedial Target		WS201	WS202	WS203	WS206	WS207	WS208	WS209	WS210
				Oct-23	Oct-23	Oct-23	Oct-23	Oct-23	Oct-23	Oct-23	Oct-23
Determinand	Unit	Site wide GWS1	Hotspots GWS2a, GWS2b								
Vinyl Chloride	ug/l	6.27E+00	9.13E+00	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
cis-1,2-Dichloroethene	ug/l	9.58E+03	1.85E+04	9	49	85	< 5	< 5	926	997	19
Trichloroethene	ug/l	1.25E+02	1.82E+02	23	171	220	< 5	< 5	279	403	104
Tetrachloroethene	ug/l	4.73E+04	6.89E+04	194	3824	2727	< 5	6	794	688	30740

NOTES

Bold values exceed site-wide remedial targets

Red values exceed hotspot remedial targets

Table 12: Combined Simulated PCE & TCE Concentrations

Distance from source (m)	Simulated PCE mg/l	Simulated TCE mg/l	Sum PCE & TCE mg/l
0	3.07E+01	4.03E-01	3.11E+01
5	1.34E+01	2.94E-01	1.37E+01
10	5.47E+00	2.02E-01	5.67E+00
15	2.22E+00	1.38E-01	2.36E+00
20	9.06E-01	9.43E-02	1.00E+00
25	3.73E-01	6.53E-02	4.39E-01
30	1.55E-01	4.55E-02	2.01E-01
35	6.49E-02	3.20E-02	9.69E-02
40	2.73E-02	2.26E-02	4.99E-02
45	1.15E-02	1.60E-02	2.76E-02
50	4.90E-03	1.14E-02	1.63E-02
55	2.08E-03	8.16E-03	1.02E-02
60	8.90E-04	5.85E-03	6.74E-03
65	3.81E-04	4.20E-03	4.58E-03
70	1.63E-04	3.03E-03	3.19E-03
75	7.02E-05	2.18E-03	2.25E-03
80	3.02E-05	1.58E-03	1.61E-03
85	1.30E-05	1.14E-03	1.15E-03
90	5.63E-06	8.28E-04	8.33E-04
95	2.43E-06	6.01E-04	6.03E-04
100	1.05E-06	4.36E-04	4.37E-04

6.10 Data Gaps and Uncertainties

Potentially significant data gaps and uncertainties are discussed below.

Shallow soil data from the upper 0 - 2 m bgl have been collected over three phases of investigation between 2021 – 2023 therefore shallow CVOC impacts are relatively well defined.

Limited soil data are available from greater depths due to difficult drilling conditions, however the presence of low permeability clays below the sampled depths will reduce vertical migration, therefore the soil strata sampled are likely to represent maximum soil concentrations.

No DNAPL has been identified in monitoring wells. Therefore, the soil source is considered to be adequately defined.

During the current investigation access for the drilling rig was limited therefore it was not possible to install monitoring wells adjacent to the down-hydraulic gradient site boundary to confirm groundwater concentrations adjacent the down-hydraulic gradient boundary.

The nearest well to the northern (down-hydraulic gradient) boundary that is directly down-hydraulic gradient of the source area is WS208 which located approximately 14m from the boundary.

It was not possible to survey the current wells therefore groundwater flow direction and gradient are based on the 2022 data.

These are not expected to have changed significantly but can show seasonal variation.

Groundwater concentrations can vary over time due to seasonal variation or changes on site such as ground disturbance or changes to permeability of ground cover. The data from the current and previous investigation were collected between August to October in both years.

The foundations had been installed before the previous investigation and no significant groundworks are known to have taken place since.

The recent data report generally greater groundwater concentrations than were reported in 2022 (attributed to change in sampling method from bailers to peristaltic pump), therefore the assessment is based on the greater concentrations and is considered to be appropriately conservative.

The superficial deposits on site comprise bands of sands and clays that have varying permeability. The more permeable granular strata tend to overlie the cohesive material, however further granular bands are present within the cohesive material, evidenced on the borehole logs by lack of recovery, and some cohesive materials are sufficiently sandy that groundwater can be expected to move within them.

The RTM model assumes a homogeneous saturated aquifer in which contaminant migration occurs. The effect of the varying thicknesses of the most permeable strata has been simulated by assessing migration in the most permeable strata (the physical aquifer properties selected are for sand) and the effect of reduced saturated aquifer thickness has been assessed in the sensitivity analysis presented below.

The data are considered adequate for the current assessment, however there are some potentially significant uncertainties which have been assessed further in the sensitivity analysis presented below.

6.11 Sensitivity Analysis

Sensitivity analysis has been undertaken to assess the potential impacts of uncertainties in the input parameters. The analysis has been completed for TCE, which is simulated to present greatest risks. The assessment has been completed for the hotspot sources SS2a and GWS2a which were simulated to present greatest risks for TCE.

Input parameters assessed are presented in the Tables 13 & 14 below.

Table 13: Sensitivity Analysis Soil Source Inputs

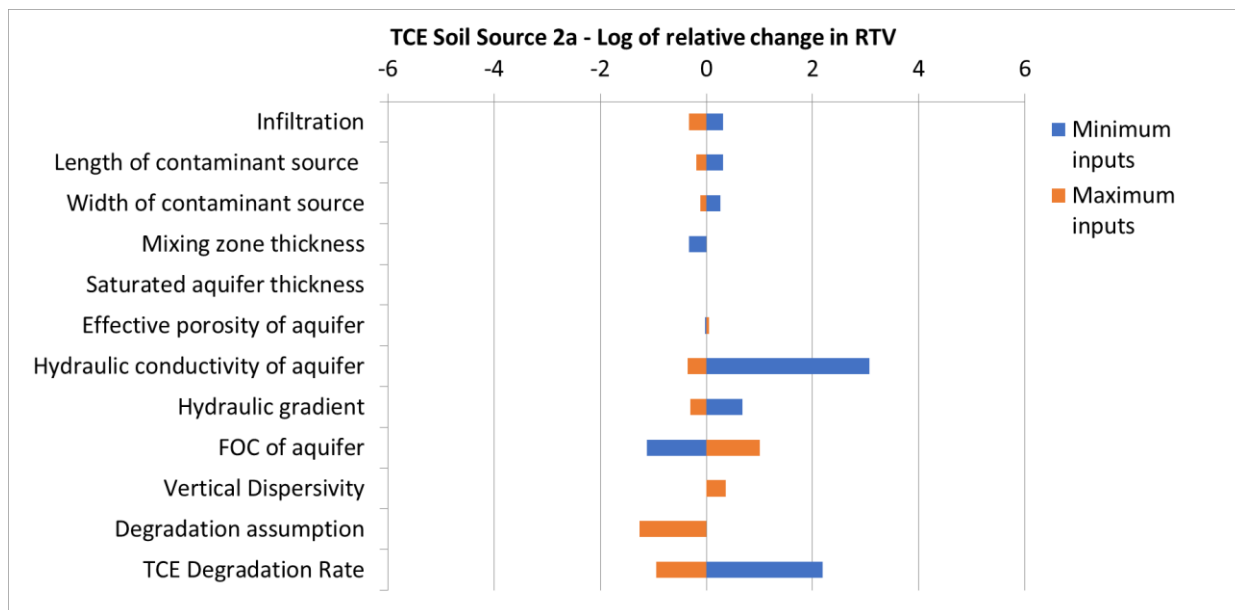
Parameter	Units	Original Value	Sensitivity Minimum	Sensitivity Maximum	Comment
Infiltration	m/d	5.94E-04	2.97E-04	1.19E-03	Half and double to account for potential variation in surface cover/run off.
Length of contaminant source	m	1.00E+01	5.00E+00	1.50E+01	50% greater or smaller to account for variation in source dimensions
Width of contaminant source	m	1.00E+01	5.00E+00	1.50E+01	50% greater or smaller to account for variation in source dimensions
Mixing zone thickness	m	3.80E+00	1.90E+00	n/a	Half to account for mixing from a shallow soil source. Default assumption was full aquifer thickness, which cannot be exceeded.
Saturated aquifer thickness	m	3.80E+00	1.90E+00	7.60E+00	Half and double to account for either groundwater migration within thinner bands, or thickening of the aquifer along the migration pathway
Effective porosity of aquifer	fraction	1.50E-01	7.50E-02	3.00E-01	Half and double to account for migration in low porosity cohesive strata, or high porosity sands and gravels, respectively
Hydraulic conductivity of aquifer	m/d	9.80E-01	1.40E-01	3.20E+00	Slowest and fastest conductivity tests in individual wells
Hydraulic gradient	fraction	3.77E-02	1.89E-02	7.54E-02	Half and double to account for potential variations in gradient within anticipated range for aquifer type
FOC of aquifer	fraction	1.70E-02	1.70E-03	3.40E-02	Minimum value based on literature data for shallow sand and gravel aquifers (ConSIM), maximum is double the value applied.
Vertical Dispersivity	m	1.00E-09	n/a	4.42E-01	Default set to near zero. Maximum is from the RTW 'Xu&Eckstein' calculation for a 50m compliance point
Degradation assumption	n/a	'all phases'	'dissolved phase only'	n/a	'Dissolved phase only' intended for laboratory derived degradation rates, which were not used for this assessment
TCE Degradation Rate	days	1.00E+03	8.00E+02	4.00E+03	Minimum is the fastest BAR observed in 2022, maximum is the only BAR observed in 2023

Table 14: Sensitivity Analysis Groundwater Source Inputs

Parameter	Units	Original Value	Sensitivity Minimum	Sensitivity Maximum	Comment
Plume width	m	1.00E+01	5.00E+00	1.50E+01	50% greater or smaller to account for variation in source dimensions
Plume thickness at source	m	3.80E+00	1.90E+00	n/a	Half to account for mixing from a shallow soil source. Default assumption was full aquifer thickness, which cannot be exceeded.
Saturated aquifer thickness	m	3.80E+00	1.90E+00	7.60E+00	Half and double to account for either groundwater migration within thinner bands, or thickening of the aquifer along the migration pathway
Effective porosity of aquifer	fraction	1.50E-01	7.50E-02	3.00E-01	Half and double to account for migration in low porosity cohesive strata, or high porosity sands and gravels, respectively
Hydraulic conductivity of aquifer	m/d	9.80E-01	1.40E-01	3.20E+00	Slowest and fastest conductivity tests in individual wells
Hydraulic gradient	fraction	3.77E-02	1.89E-02	7.54E-02	Half and double to account for potential variations in gradient within anticipated range for aquifer type
FOC of aquifer	fraction	1.70E-02	1.70E-03	3.40E-02	Minimum value based on literature data for shallow sand and gravel aquifers, maximum is double the value applied.
Vertical Dispersivity	m	1.00E-09	n/a	4.42E-01	Default set to effectively zero. Maximum is from the RTW 'Xu&Eckstein' calculation for a 50m compliance point
Degradation assumption	n/a	'all phases'	'dissolved phase only'	n/a	'Dissolved phase only' intended for laboratory derived degradation rates, which were not used for this assessment
TCE Degradation Rate	days	1.00E+03	8.00E+02	4.00E+03	Minimum is the fastest BAR observed in 2022, maximum is the only BAR observed in 2023

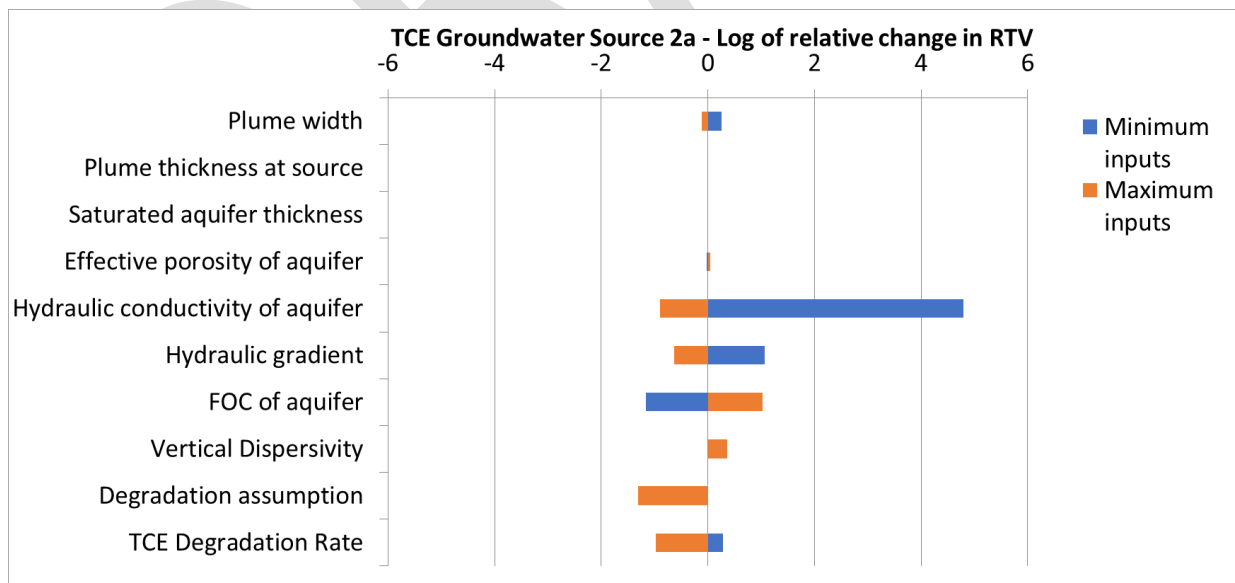
The outputs from the sensitivity analysis are presented in the figures below.

Figure 10 – Sensitivity Analysis Groundwater Source Inputs



For the soil source assessment, the parameters that resulted in greatest reduction of soil remedial targets were FOC, degradation assumption and the TCE degradation rate, each of which results in over an order of magnitude reduction in the remedial target. The factors that resulted in greatest increase of soil remedial targets are hydraulic conductivity and degradation rate. The TCE source concentration in the soil source is over two orders of magnitude below the base-case remedial target, therefore amending individual parameters within their likely ranges would not result in exceedances of the soil remedial target in the base-case scenario.

Figure 11 – Groundwater Source Sensitivity Analysis Outputs



For the groundwater source assessment, the parameters that resulted in greatest reduction of soil remedial targets were hydraulic conductivity, hydraulic gradient, FOC, degradation assumption and TCE degradation rate, each of which reduces the remedial target by

approximately an order of magnitude. The factors that resulted in the greatest increase in remedial targets are hydraulic conductivity, hydraulic gradient and FOC, which results in increases by one to four orders of magnitude. The minimum hydraulic conductivity value applied is representative of the sandy clay strata in the aquifer and therefore representative of flow in that part of the aquifer but unlikely to be representative of groundwater flow across the whole of the aquifer.

Since the TCE source concentrations applied in the base-case exceed the remedial target by a factor of 2.2 then amending individual parameters within their likely ranges has the potential to either increase the modelled risks, or to result in an acceptable risk outcome

Sensitivity Analysis Conclusions

The analysis indicates that altering individual parameters within their likely ranges is unlikely to significantly impact the assessed risk from soil sources but could significantly impact the assessed risk from groundwater sources such that simulated risks could either increase or become acceptable. Given the similarity in chemical properties between TCE and the other CVOCs assessed, these findings should apply to the other CVOC also.

As described in section 6.3 and section 6.5, natural attenuation processes have been demonstrated at this site and the degradation rates have been selected based on site-specific data.

Therefore, use of the 'degradation in dissolved phase only' switch is not appropriate for this site since the RTM report advises that it should be used where only laboratory study degradation rates are being applied. Laboratory degradation rates are typically one to two orders of magnitude faster than rates observed in the field.

The physical aquifer properties that were most sensitive in the groundwater sensitivity analysis (hydraulic conductivity, hydraulic gradient and FOC) influence the groundwater velocity and contaminant retarded flow rate.

These are used in the bulk attenuation rate (BAR) calculations that were in turn used to select degradation rates.

For example, a doubling in retarded flow rate would result in a halving of the BAR required to achieve the observed attenuation, and therefore indicate that faster half-lives should be selected.

This effect should reduce the impact of amending these parameters but varying them could still impact the assessed risk.

6.12 Potential Impact of Climate Change on Risk Assessment

The potential impact of climate change on assessed risks has been considered in line with the SoBRA report 'Guidance on Assessing Risk to Controlled Waters from UK Land Contamination Under Conditions of Future Climate Change', 2022. The site is not considered particularly vulnerable to effects of climate change, for example it is not within the likely flood zone of a river and the available data indicate that groundwater levels beneath the site are relatively stable. The presence of buildings and hardstanding on site and in the surrounding area that drain to combined sewer will reduce potential impacts of future changes in rainfall and infiltration rates and means that the site is not vulnerable to soil erosion during extreme rainfall. Increases in average air temperature are unlikely to affect soil and groundwater temperatures at the depths where

contamination has been identified, but any increased soil and groundwater temperatures should facilitate faster microbial degradation rates. Considering the timescales for climate change which are usually assessed over a 30-year period, and that the ongoing sources of CVOCs to soil and groundwater on site has been removed, there will be ongoing removal of CVOCs from soil and groundwater during that period that will reduce potential risks.

In conclusion, climate change is considered unlikely to impact the assessment of risks to controlled waters at this site and therefore has not been assessed further.

6.13 Controlled Waters Risk Evaluation

The updated controlled waters risk assessment indicates that risks from soil sources of CVOCs and the majority of groundwater CVOCs are acceptable.

The CVOC that is simulated to present greatest risk to controlled waters is TCE in groundwater, which is simulated to exceed the remedial target value protective of a default 50m compliance point by a factor of 2.2.

This assessment is based on a water target value of 5µg/litre which was set at half of the Drinking Water Standard (DWS) of 10µg/litre for combined TCE and PCE, to account for the presence of PCE at the site.

If the water target value was set to 10µg/litre then the exceedance would fall to a factor of 1.1.

The TCE source is located down-hydraulic gradient of the PCE source, and PCE concentrations are observed to decrease rapidly outside the source area, therefore TCE comprises the majority of the combined TCE and PCE impact at the compliance point.

The model indicates that the combined TCE and PCE concentrations would comply with the 10µg/litre standard between 55m and 60m from the TCE source, which would be a marginal exceedance of the default 50m compliance point for Hazardous substances (TCE), and well within the default 250m compliance point for Non-hazardous substances (PCE).

Groundwater concentrations of *cis*12DCE are greatest in monitoring well WS208 which is approximately 14m from the down-hydraulic gradient site boundary in the direction of groundwater flow. *cis*12DCE does not have a published UK DWS or EQS and is classified as a Non-hazardous substance, therefore a default compliance point of 250m applies to this compound and a precautionary water target value of 10µg/litre was applied.

The model indicates that *cis*12DCE concentrations would comply with this standard within 150m of the source area.

Vinyl chloride has not been detected on site in the current investigation. Since the background aquifer conditions are aerobic and suitable for vinyl chloride degradation then it is inferred that the rate of vinyl chloride degradation exceeds the rate of *cis*12DCE degradation which forms vinyl chloride.

The superficial deposits Secondary A aquifer and the Tarporley Siltstone Secondary B aquifer are not currently used for groundwater abstraction in the vicinity of the site, and the nearest surface water to which they could supply baseflow is approximately 485m from the site.

The future resource potential of the aquifers is considered to be low based on limited groundwater volumes available for abstraction, limited permeability, and the presence of mains water supply in the area down-hydraulic gradient of the site. An extended compliance point of 100m is therefore proposed for Hazardous substances.

The assessment indicates that risks to controlled waters receptors are potentially acceptable with potential localised off-site TCE and PCE impacts that are simulated to comply with their combined DWS/EQS less than 60m from the source.

Concentrations of *cis*-1,2-DCE may extend further but are simulated to comply within 250m of the site.

The assessment is based on a single round of groundwater concentrations from the current wells therefore potential variation in source concentrations over time is not defined.

Previous investigation in 2022 with wells at similar locations identified generally lower concentrations of CVOCs in groundwater.

Sensitivity analysis indicates that altering input parameters within their likely ranges could increase the likelihood of unacceptable risk to controlled waters or increase the confidence in the acceptable risk outcome.

6.14 Revised Groundwater Conceptual Model

6.14.1 Contaminant Sources

Based on the current and historical uses of the site and its surroundings, and the findings of the investigation, it is concluded that the following contaminant sources should be considered:

- **Historical Site Sources:** Surface source of dry-cleaning fluid (PCE), the volume lost, and date(s) of loss are not known. The site was last known to have operated as a dry cleaners in the year 2009. The car repair garages may also have used PCE as a de-greaser.
- **Groundwater:** The primary source zone is within the southern area of site at WS210. Based on soil observations and interface probe measurements, no source of DNAPL was identified from the site investigation which is considered to have been to sufficient depth to encounter DNAPL if present. The groundwater concentrations of PCE at WS210 (30.7 mg/l) are approximately 10% of the aqueous solubility limit for PCE (225 mg/l) which might indicate the presence of residual phase non-mobile NAPL in saturated soils at that location.

An infinite source term is assumed for the model.

6.14.2 Contaminant Pathways

Contaminants can reach potential receptors through various routes. The following are considered to be applicable to this site:

- **Ground Conditions:** The aquifer is heterogenous, comprising predominantly clayey sand and sandy clays with apparently discontinuous horizons or lenses of more permeable sands and gravels. When considered at the scale of tens to hundreds of metres over which transport could occur then the unit as a whole is likely to act as a low permeability system with transport by intergranular flow.

- Groundwater: Groundwater flow direction and gradient cannot be accurately determined from the groundwater contour plots due to the variable permeability making interpolation between different groundwater levels impractical. Local topography indicates that shallow groundwater is likely to flow approximately northwards towards the River Mersey or its tributaries. The topographic gradient of the area is relatively shallow (0.0124 m/m), indicating that groundwater gradients in superficial deposits are also unlikely to be steep. The hydraulic gradient measured on site is approximately 0.0377 m/m which is consistent with the low permeability geology but not the topographic gradient.
- Degradation: As described in sections 6.3 and 6.5, attenuation by microbial degradation is occurring at the site. The chemical results show reducing concentrations of parent compounds down hydraulic gradient of the source (30.7mg/litre PCE in WS210, <0.79mg/litre PCE in WS209), together with the presence of daughter products (TCE and *cis*-DCE) showing that degradation is occurring or has occurred on site.

6.14.3 Contaminant Receptors

The following potential receptors are considered to be applicable to this site:

- Surface Water: No specific surface water receptors have been identified within 250m of the site, however EQS as well as DWS have been set as target values to be protective of baseflow to the River Mersey located approximately 485m north of the site.
- Underlying Aquifer: In the absence of any groundwater abstractions from the superficial deposits Secondary A aquifer or the Secondary B Tarporley Siltstone bedrock, Drinking Water Standards have been applied where available to be protective of the future resource quality of the aquifer, or EQS where a DWS not available.
- All Receptors: The Environment Agency's default compliance points of 50m for Hazardous substances and 250m for Non-hazardous substances were initially applied, which are protective of baseflow to the River Mersey located approximately 485m north of the site and future quality of the aquifer. Following DQRA an extended compliance point of 100m is proposed for Hazardous substances, including combined TCE and PCE, due to the low future resource potential of the aquifers down-hydraulic gradient of the site. Using an extended compliance point then risks to controlled waters receptors are potentially acceptable. There are, however, potentially significant uncertainties in the data that should be addressed to increase confidence in the assessment.

7.0 HUMAN HEALTH RISK ASSESSMENT

7.1 Tier II Human Health Soil Risk Assessment – Future Site Users

The following section provides a Human Health Soil Assessment for future site users. Based on the proposed development type, the following section compares the results of contamination analyses to residential types of end development as specified by DEFRA/LQM/CIEH/ CL:AIRE. As part of the contamination assessment, the chemical results obtained by EEG have been screened against accepted compliance criteria, namely:

- DEFRA Category 4 Screening Levels ⁽²⁰²¹⁾ (C4SL), where available.
- Tier 1 Assessment Values - based on LQM/CIEH Sutable 4 Use Levels ⁽²⁰¹⁵⁾ (S4ULs).
- EIC/AGS/CL: AIRE Soil Generic Assessment Criteria for Human Health Risk Assessment ⁽²⁰¹⁰⁾.

Generic assumptions have been made for each land use and for soil type. The GAC for sand soils with 1% SOM are considered appropriate for this site.

The soil chemical testing results for CVOCs, which were identified as contaminants of concern at this site, are summarised in Table 15 overleaf.

Potential contaminants of concern have been found in exceedance of long-term human health screening criteria for a Residential End Use (with plant uptake in gardens).

The soil contaminant exceedances include:

- **Tetrachloroethene (PCE)** in 12no. samples: WS201 to WS204, WS208 to WS210 (all sample depths)
- **Trichloroethene (TCE)** in 11no. samples: WS201 to WS204, WS209 to WS210 (all sample depths), and WS208 at 1.25m.

The maximum recorded PCE concentration was found in WS203 at 1.10m (15.79mg/kg) and the maximum recorded TCE concentration was found at WS202 at 0.90m (0.103mg/kg).

No other chlorinated solvents tested exceeded the assessment criteria, including vinyl chloride.

Plots showing the distribution of soil contaminants across the site are included in Figure 7, above.

The plots show the concentrations of PCE, TCE and *cis*12DCE in the soils at 0-1m depth and 1-2m depth.

The concentration of volatile organic compounds in the headspace of soil samples was also measured using the photo ionisation detector (10.6eV lamp).

The peak concentrations recorded ranged from 2.86ppm (W203 at 4.50m) and 247.60ppm (WS204b at 0.50m). It should be noted that 0ppm was recorded at locations WS207, WS206, WS206b, WS205, WS205b and WS203 at some sampling depths.

Due to the contamination encountered in the soils, a cover system is proposed within garden areas, and installation of vapour resistant membranes within the houses to break the pollutant linkages.

The details of the remedial work are included within the Remediation Strategy.

7.2 Tier II Human Health Vapour Risk from Groundwater

The risk to human health for a residential end use scenario has been assessed by reference to Society of Brownfield Risk Assessment (SOBRA) Generic Assessment Criteria for Assessing Vapour Risks to Human Health from Volatile Contaminants in Groundwater, February 2017.

The SOBRA groundwater vapour GAC (GAC_{gwvap}) is intended as a conservative screening tool that assessors may choose to use to help assess the long-term (chronic) risks to human health from inhalation of vapours arising from groundwater. They are intended for comparison with measured groundwater concentrations and represent the estimated concentration in groundwater below which the long-term risks to human health from vapour migration and inhalation can be considered low/tolerable, i.e., unlikely to be of concern (for the land use scenarios considered). When used as part of a Generic Quantitative Risk Assessment (GQRA) (which includes consideration of uncertainties – see Defra and Environment Agency, 2004) comparison of the GAC_{gwvap} with measured concentrations in groundwater can be used to screen out contaminants as being unlikely to represent an unacceptable risk to humans living or working above the groundwater plume.

The GAC_{gwvap} have been developed in line with UK risk assessment guidance (e.g., Defra and Environment Agency, 2004; Environment Agency, 2009a) and are intended to be used for sites in the UK.

The GAC have been derived for two land use scenarios for which the vapour intrusion pathway is likely to require assessment: residential and commercial. Generic assumptions have been made for each land use. These include assumptions about the depth to groundwater (default depth of 0.65m), soil type in the unsaturated zone (default of sand), building dimension (default small, terraced house) and foundation type, and receptor behaviour. These are generally considered appropriate for this site although the minimum depth to groundwater in three monthly rounds between October to December 2023 was 1.0m bgl (WS209), and in the majority of wells was between 1.5 and 2.2m bgl, thus the GAC_{gwvap} are conservative regarding this parameter. Solubility limits have not been exceeded at any location, indicating that NAPL is not present.

As described in CLEA SR3 report (Environment Agency, 2009a) the parameter values have been chosen to ensure that the GAC are precautionary for the vast majority of commercial and residential properties in the UK. Since the SoBRA GAC_{GWVAP} were released, C4SL reports have been released for PCE, TCE and VC, with a *cis*-12DCE report scheduled for release imminently. Following the C4SLs reviews the target health criteria values (HCVs) for PCE and VC were reduced, thus their GAC_{GWVAP} are conservative compared to the soil C4SLs. The HCV for TCE was reduced following the C4SL review, therefore the GAC_{GWVAP} for TCE is less conservative than the soil C4SLs. The changes to HCVs were by less than an order of magnitude, therefore they are considered appropriate for screening risks at this site where the majority of detected concentrations exceed the GAC_{GWVAP} by more than an order of magnitude.

The VOC concentrations encountered in locations WS201 to WS204, WS206 to WS210 are included in the Vapor Risk Assessment Table 16, overleaf.

A potential risk to human health from volatile compounds in shallow groundwater have been found at 6no. locations (WS201 to WS203 and WS208 to WS210). However, as noted in the SoBRA GAC_{GWVAP} report soil vapour samples should be used where possible to estimate risks rather than

groundwater data.

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Table 15: Soil Results Comparison with C4SL/S4UL Values

Parameter	C4SL/S4UL Levels Residential End Use (mg/kg)	WS201 1.30m	WS201 1.90m	WS202 0.90m	WS202 1.25m	WS203 1.10m	WS203 1.50m	WS204 0.80m	WS204 1.80m	WS205 0.70m	WS206 1.70m	WS207 0.20m	WS208 0.80m	WS208 1.25m	WS209 1.50m	WS210 0.60m	No. of Exceedances
CVOCs																	
1,2-Dichloroethane	0.11	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0
Trans 1,2-Dichloroethene (<i>trans</i> -DCE)*	0.19	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0
Cis 1,2 Dichloroethene (<i>cis</i> -DCE)*	0.11	< 0.005	0.007	0.011	< 0.005	0.013	0.02	< 0.005	0.009	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.036	0.012	0
Tetrachloroethene (PCE)	0.31	0.495	1.242	5.724	10.17	15.78	8.867	0.561	3.693	0.223	0.023	0.132	0.346	0.431	0.331	0.908	12
Trichloroethene (TCE)	0.0093	0.012	0.028	0.103	0.059	0.078	0.035	0.025	0.035	< 0.005	< 0.005	< 0.005	< 0.005	0.047	0.042	0.028	11
Vinyl Chloride	0.0064	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0
Concentrations in red are above the assessment criteria based on Residential End Use with Plant Uptake (SOM content of 1%).																	
*Based on The EIC/AGS/CL:AIRE Soil Generic Assessment Criteria for Human Health Risk Assessment																	

Table 16: Vapour Risk from Volatile Compounds in Groundwater (µg/l)

Determinand	SOBRA GAC µg/l	Aqueous Solubility µg/l	WS201	WS202	WS203	WS206	WS207	WS208	WS209	WS210	No. of GAC Exceedances
<i>cis</i> 1,2 Dichloroethene (<i>cis</i> -DCE)	130	7,550,000	9	49	85	< 5	< 5	926	997	19	2
Tetrachloroethene (PCE)	34	225,000	194	3824	2727	< 5	6	794	688	30,740	6
Trichloroethene (TCE)	5.7	1,370,000	23	171	220	< 5	< 5	279	403	104	6
Vinyl Chloride	0.62	2,760,000	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	0

7.3 Tier II Human Health Vapour Risk from Soil Vapour

7.3.1 Vapor Conceptual Model

Contaminants of Concern

Soil vapour GAC have been derived for nineteen contaminants detected in soil vapour samples, and also for vinyl chloride which was not detected but GAC are presented to demonstrate that the detection limit is appropriate. The following contaminants were detected in soil vapour, but GAC have not been derived for them as set out below:

- Ethanol and propanol – these are low toxicity alcohols detected at $<1.0 \text{ mg/m}^3$ in soil vapour. No plausible pollutant linkage.
- Pentane and iso-butene – these are low toxicity gases detected at $<0.1 \text{ mg/m}^3$ in soil vapour and unlikely to be associated with contamination on site. No plausible pollutant linkage.
- Cyclohexane – no suitable toxicological data were reported in previous reviews by EIC/CL:AIRE or LQM/CIEH. This contaminant has therefore been assessed using the GAC for TPH Aliphatic C5-C6 fraction.
- Acetone & propanal, 2-butanone, and pentanal – ketones detected at $<0.1 \text{ mg/m}^3$ in soil gas. No suitable toxicological data were reported in reviews by EIC/CL:AIRE or LQM/CIEH. All are considered to have relatively low toxicity compared to other contaminants for which GAC have been derived, therefore ketones are unlikely to be risk drivers at this site.

Sources

Soil. The primary soil source is in the southern area of site. Vapours formed within the soils can migrate vertically and laterally from the soil source.

Groundwater. Dissolved phase volatile compounds that have been transported in groundwater can volatilise and migrate vertically upwards from the groundwater. Based on the previously calculated groundwater flow direction and current distribution of PCE degradation products in groundwater then groundwater impacted by volatile contaminants could be present near or beneath the houses north or north-east of the site, which could form vapours that then migrate vertically up into the houses.

NAPL. No measurable thickness of NAPL has been observed on site, and measurable NAPL is considered unlikely to be present on site given the absence of any identified in three phases of investigation. If dense NAPL was present below groundwater then it would not present a direct vapour source because vapours will not form below groundwater, rather it would be assessed from the dissolved phase concentrations formed from the NAPL. Potential residual NAPL trapped in the pore spaces of shallow unsaturated soils is considered to be part of the soil source.

Soil vapour. This is formed from soil, groundwater, or potential residual phase NAPL contamination as noted above and has been measured directly with vapour wells at selected locations that were targeted on maximum soil/groundwater concentrations and on proximity to receptors.

Pathways

Vapours can migrate through unsaturated permeable soils, with greatest migration rates through the more permeable granular strata. Shallow layers of gravelly sand are present across the site, at similar depths to the substructures of on-site and off-site houses. Sub-structures include ventilated sub-floor voids and basements. Some shallow soils are described as clayey sand or sandy clay however their distribution and thickness are not sufficient to infer that they are continuously present beneath the on-site or off-site receptor properties.

Where there are unsaturated soil vapour sources or groundwater vapour sources beneath buildings then vapours can migrate vertically through the soils into the building.

For vapours to migrate significant distances laterally through soil then a low permeability confining layer such as hardstanding or clay is required to prevent them being lost to atmosphere. These are discussed further below.

Below ground features such as gravel-filled trenches for services, or drainage pipes and sewers, can act as preferential pathways for vapour migration.

Receptors

On-site. The partially constructed houses on-site have beam and block floors with ventilated sub-floor voids. The Remediation Method Statement for the site requires that these should be fitted with 0.4 mm thick membranes impervious to VOCs, in accordance with CIRIA C748. At the time of reporting the floors were not completed, the beams and blocks have been installed but no membrane or screed has been fitted. Membranes have been installed across the cavity wall with an overlap for a floor membrane to join on to, the site manager has advised that the membrane is Visqueen Ultimate HC Blok', which is intended to be resistant to CVOCs and other organic compounds.

North (Kingsley Road). The house adjacent north of site appears to have been extended with an extension that abuts the site boundary. The extension appears to comprise a garage on the ground floor with living space above. The garage is assumed to have a ground bearing concrete floor. The main part of the house does not appear to have a basement, but ventilation bricks indicate that it has a ventilated sub-floor void and therefore is likely to have a suspended timber floor which would be consistent with the age of the house (between 1910 and 1934 as shown on historical maps provided in the REC Phase 1 report for the site).

South (Beech Avenue). The house adjacent south of site has a ground floor extension that abuts the site boundary, the extension could be either living space or a garage. The extension is assumed to have a ground bearing concrete floor slab.

The main house is approximately 3m from the site boundary and has a basement (evidenced by windows at floor level). Floor details are not known, however if the basement forms part of the living space, then is likely to have been 'tanked' to prevent damp ingress. The height of the window indicates that the basement floor is likely to be approximately 1.5m – 2.0 m bgl.

East (Kingsley Road). The nearest houses to the east lie beyond Kingsley Road and are approximately 18m – 19m east of the site boundary. They appear to have been built in late twentieth century and no floor ventilation bricks are visible, indicating that they likely have ground-bearing concrete floor slabs which would be consistent with their age. The houses opposite the

southern part of the site have lawns between the road and the house and therefore there is no continuous confining layer to support lateral migration of vapours from the site. Houses opposite the northern part of the site are mainly paved between the houses and the road with some narrow-gravelled areas therefore a lateral migration pathway to these houses is plausible. Considering the similarities in floor type to the residential extensions adjacent north and south of the site, risk assessment that is protective of those extensions will also provide conservative assessment for these houses.

West (Chapel Road). These houses are typically between 15m and 8m from the site boundary at the southern and central areas of the site, respectively. They are separated from the site by lawns and therefore there is unlikely to be a continuous confining layer along the whole pathway length to support lateral vapour migration from the site to the houses. The houses have basements (evidenced by ground level windows). The height of the windows indicates that the basement floor is likely to be approximately 1.5m – 2.0 m bgl.

North-west (Chapel Road). One house to the north-west is nearer to the site than those described above and has different floor construction. The nearest part is approximately 6m from the north-west site boundary, while the main building is 8m from the boundary. It is smaller than the houses described above and does not appear to have a basement. Aerial photography shows a probable paved area between the site boundary and the house which could act as a confining layer to support lateral vapour migration. Based on its age (early nineteenth century), the house is expected to have a suspended timber floor over a ventilated void.

7.3.2 Vapour GAC Modelling Approach

As noted in the Pathways section above, parts of the nearest off-site properties appear to have ground-bearing floor slabs and therefore the Environment Agency CLEA model considered suitable for initially assessing risks to those properties. This assessment is also intended to be representative of tanked basements.

The CLEA model does not have an option to assess vapour intrusion risks to a property with a ventilated sub-floor void. The assumption of a ground-bearing slab is likely to be conservative for the on-site houses since there would be dilution of vapours within the void but is appropriate for initial screening. However, the model may under-predict risks to properties with un-tanked basements, or with suspended timber floors.

Soil vapour concentrations have been measured at wells targeted on greatest soil or groundwater concentrations, and at locations nearest to off-site receptors. It has been assumed that the vapour concentrations measured within the vapour wells could extend to the nearest site boundary.

Different lateral pathway lengths have been assessed by altering the 'Depth to Top of Source (beneath building)' in the model, thus a 3m lateral distance between a basement wall and a potential below ground source has modelled as a 3m deep source. The 'living space height below ground' option has not been applied because that reduces the distance between the floor and a source measured directly beneath the floor, which is not applicable to this setting because the vapour wells are laterally off set from the buildings which have basements.

Soil vapour remedial targets are not included in the default CLEA results outputs, these have been extracted from the 'media concentrations' sheet, which is the same approach as used by SoBRA to extract soil water remedial targets when generating groundwater generic assessment criteria (SoBRA, 2017).

7.3.3 Model Settings

All model settings other than Source Depth are the defaults in CLEA for 'residential without produce – C4SL' for a 'sand' soil type, but with only the vapour inhalation pathways active and the 'use default soil gas ingress rate' option switched off so that ingress from the Sand soil type is modelled. Contaminant toxicological and physicochemical data have been taken from the Environment Agency, C4SL reports, EIC/ CL:AIRE and SoBRA Groundwater GAC reports.

The source depths applied are based on the pathlengths presented below.

Table 17: Assessed Vapour Pathlengths

Receptor	Pathlength (m)	Justification	Vapour Wells Applicable to GAC
On-site houses	0.5	Depth to top of response zone in vapour monitoring wells adjacent to the houses	All – WS202b, WS206b, WS208b and WS209b
Residential extensions (above ground) adjacent north and south	0.5*	Nearest vapour well. Site boundary to extension wall.	WS202b (near southern boundary) WS208b (near northern boundary)
Residential basement, south. Residential house, north.	3*	Southern site boundary to basement wall. Northern site boundary to main part of house adjacent north.	WS202b (near southern boundary)
Residential house (no basement)	6*	North-western site boundary to nearest part of house.	WS206b (adjacent to north-western boundary)

Notes

*Assumes concentrations measures in vapour wells could extend to the site boundary

7.3.4 Model Results and Data Screen

The derived GAC are presented in the Table 18, overleaf, together with the measured vapour concentrations screened against the GAC. The maximum hazard index (HI) for each GAC has been calculated by dividing the maximum detected vapour concentration by each GAC. An HI >1.0 means that the vapour concentration exceeds the GAC and therefor indicates potentially unacceptable risk.

The majority of contaminants report maximum HI <0.01, indicating acceptable risks to all receptors from the majority of contaminants. The maximum *cis*1,2-DCE HI is 0.12, which is also considered to be acceptable risk. The only contaminants detected in soil vapour that exceed the vapour GAC are TCE and PCE.

When considering different vapour migration pathlengths, no contaminants exceed the GAC for a 6.0m pathlength. Concentrations of TCE and PCE both exceed the GAC for 3.0m pathlength at borehole WS202b only, with HI of 1.80 and 1.65, respectively. Concentrations of TCE and PCE exceed the 0.5m pathlength GAC at two locations, WS202b and WS208b. The HI for TCE

and PCE with 0.5m pathlength at WS208b are between 3.13 and 3.53, while the TCE and PCE HI at WS202b are 7.56 and 7.88.

The CLEA results and Outputs are collated in Appendix 6.

7.3.5 Risk Evaluation

On-site Houses

The assessment indicates potentially unacceptable risks to future occupants of the partially constructed on-site houses from TCE and PCE. The maximum HI is less than ten, indicating that if vapour ingress to the houses can be reduced by a factor of at least ten compared to the modelled scenario then risks to future occupants should be acceptable.

The houses have ventilated sub-floor voids which will provide dilution of migrating vapours that is not assessed by the model. The model also assumes a 2mm wide gap around the entire floor perimeter which should not occur in a house constructed to current good practice and fitted with vapour membranes. Construction of the beam and block floors has not been completed therefore an assessment of the finished floor permeability cannot be made at this stage.

Table 18: Soil Vapour GAC Screening Table

Contaminant	Units	LOD	Vapour GAC, Depths m bgl			WS202B	WS206B	WS208B	WS209B	Maximum	HI Max, each GAC Depth		
			0.5m	3.0m	6.0m						0.5	3.0	6.0
Vinyl Chloride	µg/m3	<2.6	7.60E+03	2.88E+04	5.43E+04	<2.6	<2.6	<2.6	<2.6	<2.6	<3.42E-04	<9.03E-05	<4.79E-05
Chloromethane	µg/m3	<2.1	3.25E+03	1.16E+04	2.15E+04	4	<2.1	<2.1	<2.1	4	1.26E-03	3.55E-04	1.90E-04
1,1-Dichloroethene (1,1 DCE)	µg/m3	<4.0	8.21E+04	3.38E+05	6.45E+05	8	<4.0	<4.0	<4.0	8	9.63E-05	2.34E-05	1.23E-05
cis-1,2-Dichloroethene	µg/m3	<4.0	7.85E+03	3.26E+04	6.22E+04	975	<4.0	32	24	975	1.24E-01	2.99E-02	1.57E-02
Trichloroethene (TCE)	µg/m3	<5.4	4.98E+02	2.18E+03	4.20E+03	3,923	22	1,757	242	3,923	7.88E+00	1.80E+00	9.34E-01
Tetrachloroethene (PCE)	µg/m3	<6.8	8.94E+03	4.09E+04	7.92E+04	67,592	360	27,993	1,906	67,592	7.56E+00	1.65E+00	8.53E-01
Chloroform	µg/m3	<4.9	5.03E+04	2.13E+05	4.08E+05	10	10	10	<4.9	10	1.95E-04	4.60E-05	2.40E-05
1,1,1-Trichloroethane	µg/m3	<5.5	9.03E+05	3.99E+06	7.69E+06	<5.5	<5.5	<5.5	<5.5	6	6.09E-06	1.38E-06	7.15E-07
1,2-Dichloropropane	µg/m3	<4.6	1.28E+03	5.67E+03	1.09E+04	14	<4.6	<4.6	<4.6	14	1.08E-02	2.45E-03	1.27E-03
Benzene	µg/m3	<3.2	4.85E+04	2.04E+05	3.89E+05	54	<3.2	6	16	54	1.12E-03	2.67E-04	1.39E-04
Toluene	µg/m3	<3.8	2.13E+07	9.37E+07	1.81E+08	38	19	26	11	38	1.77E-06	4.02E-07	2.09E-07
Ethylbenzene	µg/m3	<4.3	3.46E+06	1.59E+07	3.07E+07	43	4	4	<4.3	43	1.25E-05	2.73E-06	1.41E-06
m/p-Xylene	µg/m3	<8.7	8.41E+05	3.86E+06	7.47E+06	130	22	17	13	130	1.55E-04	3.38E-05	1.74E-05
o-Xylene	µg/m3	<4.3	8.42E+05	3.87E+06	7.49E+06	213	9	9	4	213	2.53E-04	5.50E-05	2.84E-05
Xylenes - Total	µg/m3	<4.3	8.40E+05	3.85E+06	7.46E+06	387	35	30	17	387	4.60E-04	1.00E-04	5.18E-05
Hexane	µg/m3	<5.3	2.76E+06	1.10E+07	2.08E+07	151	<5.3	<5.3	9	151	5.47E-05	1.38E-05	7.26E-06
Styrene	µg/m3	<6.4	3.87E+05	1.76E+06	3.41E+06	9	72	7	<6.4	72	1.85E-04	4.07E-05	2.10E-05
Cyclohexane (as TPH Aliphatic C5-C6)	µg/m3	<7	3.47E+07	1.38E+08	2.61E+08	24	<7	<7	<7	24	6.92E-07	1.74E-07	9.18E-08
TPH Aromatic >EC8-EC10 (sum of E, X, Styrene)	µg/m3	<4.3	4.17E+05	1.65E+06	3.13E+06	396	106	38	17	396	9.50E-04	2.40E-04	1.26E-04
Carbon Disulfide	µg/m3	<4.7	1.95E+04	7.62E+04	1.44E+05	89	34	68	23	89	4.54E-03	1.16E-03	6.15E-04

Notes

bold values exceed 0.5m GAC

italic values exceed 3.0m GAC

yellow highlight exceeds 6.0m GAC

HI Max - Maximum Hazard Index

Off-site House to North

Exceedances of both the 0.5m and 3.0m pathlength GAC in borehole WS208b 14m the northern boundary indicate potentially unacceptable risks from TCE and PCE to occupants of the house if the observed vapour concentrations extend to the northern boundary. The GAC may be conservative for this building because they assume that the entire building is underlain by vapours at the reported concentrations whereas WS208b is off set from the site boundary by approximately 14m.

The part of the building nearest the site boundary appears to be a garage on the ground floor with living space above, with the main house beyond. There should be dilution of vapours within the garage before entering the living space above or adjacent to the garage. The main house appears to have a suspended timber floor with ventilated sub-floor void. The void should dilute migrating vapours; however, a timber floor would allow greater ingress of air from the void than the concrete floor slab assessed in the model.

Elevated concentrations of PCE and TCE were reported in soil and groundwater at WS208b, therefore the vapour concentrations in the well detected are likely to be from a combination of both sources. The 2022 groundwater monitoring data indicate that groundwater at the northern boundary is at a depth of 2.3m bgl and that the flow direction is towards the north. Therefore, groundwater impacted by PCE or TCE could be present beneath the house and act as a secondary source to the vapours detected at WS208b.

Risks to the house from PCE and TCE vapours are considered potentially unacceptable based on current information.

Off-site House to South

Exceedances of both the 0.5m and 3.0m pathlength GAC in borehole WS202b near the southern boundary indicate potentially unacceptable risks from TCE and PCE to occupants of the house. The GAC may be conservative for this building because they assume that the entire building is underlain by vapours at the reported concentrations whereas WS202b is off set from the site boundary by approximately 10m, furthermore it is unclear whether the nearest part of the house is living space or a vehicle garage.

The main part of the house has a basement and is approximately 12m from WS202b. Vapour concentrations at WS202b do not exceed the 6m pathlength GAC. Therefore, if the basement is tanked and there is no additional vapour source between WS202b and the house, then risks to the basement could be acceptable. However, details of the basement construction are not known, and previous investigation reported elevated PCE and TCE in groundwater at WS109 which is nearer to the house than WS202b.

Risks to the house are therefore considered to be potentially unacceptable.

Off-site House to North-west

The absence of detected vapour concentrations above any of the GAC at WS206b, which is located approximately 6m from the house, indicates that risks to the house from vapour concentrations on site are potentially acceptable. However, the house is likely to have a suspended timber floor and it is not confirmed whether the sub-floor void is ventilated. A timber floor may allow significantly greater rates of soil vapour intrusion than a ground bearing concrete slab.

The concentrations of TCE and PCE in vapour at WS206b are over an order of magnitude below their respective GAC, therefore if vapour intrusion through the timber floor is within an order of

magnitude greater than the rate through a concrete slab then risks from soil vapour on site migrating to the house could be acceptable. Conversely, if vapour migration rates through a timber floor are over an order of magnitude greater than those modelled through a concrete slab then risks could be unacceptable.

Concentrations of PCE and TCE in groundwater at WS206b were below detection limits in October 2023 monitoring, while soil concentrations of TCE at WS206 were also below detection limits and the soil PCE concentration was relatively low at 0.22 mg/kg. It therefore appears likely that the TCE, and a proportion of the PCE, detected in vapour at WS206b has migrated to the well from elsewhere on site.

Risks from vapour on-site migrating to the house may be acceptable, subject to assessment of potential vapour migration rates through the suspended timber floor.

Off-site Houses to West

As noted in the Vapour Conceptual Site Model, these houses are over 8m from the site and there is not likely to be an impermeable confining surface layer covering the permeable soils between the site and the houses to support lateral vapour migration over this distance. Therefore, risks from vapours migrating laterally from on-site sources to the houses west of site are considered likely to be acceptable.

Groundwater flow direction is inferred to be northwards, therefore there is not expected to be a groundwater source beneath the houses west of site. Borehole WS204 near the south-west boundary was not monitored for soil vapours but reports groundwater concentrations of TCE and PCE at the same order of magnitude as at WS202 therefore may have similar soil vapour concentrations. Since W204 is located approximately 20m from the nearest off-site house to the west then risk from lateral migration is considered acceptable, and based on current groundwater flow direction then risks from vapours formed from dissolved phase contamination are also considered acceptable.

Off-site Houses to East

The absence of exceedances of the 6.0m pathlength GAC at all locations, together with the low likelihood of a groundwater source beneath or near to these houses and floor types that are expected to be similar to that modelled, indicates that vapour risks to these houses from the site are acceptable.

7.3.6 Vapour Migration Risk Summary

Risks to on-site properties are potentially unacceptable but are expected to be of limited magnitude and therefore it should be possible to mitigate risks by installation of passive mitigation such as the proposed vapour membranes.

Risks to off-site houses to the east are considered acceptable. Risks to houses to the west are also likely to be acceptable, subject to confirmation that groundwater impacted by PCE or TCE does not migrate westwards from the site towards the houses.

Risks to the house adjacent south of the site are potentially unacceptable, primarily due to potential vapour ingress into the basement. This assessment is based on a number of conservative assumptions and there is limited confidence in the assessment with the current data.

Risks to the house adjacent north of the site are considered to be potentially unacceptable, primarily due to combination of the expected floor construction (suspended timber floor) and potential for groundwater impacted by PCE or TCE to be present beneath or near to the house.

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8.0 REVISED GROUND GAS CONTAMINATION RISK ASSESSMENT

8.1 Revised Ground Gas Conceptual Model

Ground Gas Sources

Mine Gas: The site is not located in a coal mining area as defined by the Coal Authority. Therefore, there is a very low risk of mine gas present below the site.

Landfill Gas: The nearest historical landfill site is located approximately 807m to the north of the site which accepted inert, industrial, commercial, household, and liquid sludge between 1950 and 1965. Given the significant distance, the likelihood of ground gas vapours migrating from the landfill and affecting the site is unlikely and the overall risk is low.

Made Ground: The only known source of ground gas on site is made ground which was proven to a maximum depth of 1.30m bgl. Organic material in the made ground can degrade to produce carbon dioxide and/or methane. However, the carbon dioxide is usually generated so slowly that it will not be emitted from the ground surface in quantities or at a rate that is sufficient to pose a risk to overlying development.

8.2 Radon Gas

The site is not located within a Radon Affected Area as defined by the Health Protection Agency, as less than 1% of properties are above the Action Level of exposure. Therefore, radon protection measures are not necessary.

8.3 Bulk Ground Gases (Methane, Carbon Dioxide and Oxygen)

The potential risk associated with gases being generated in the ground (whether from natural or man-made sources) depends on the concentrations of gas and its flow rate to the surface. These factors are assessed by monitoring of the gas installations in the boreholes. The variable nature of gas generation and the effect of barometric pressure on gas flow, means that the volume of gas potentially reaching the ground surface is normally inconsistent over time.

During the original Site Investigation, a total of four gas monitoring visits were completed by Earth Environmental & Geotechnical Ltd between the 9th and 29th April 2021. The monitoring was conducted in boreholes WS01 to WS08.

The results recorded methane (CH₄) levels of 0.0% (v/v) and carbon dioxide (CO₂) levels of 0.1% to 6.3% v/v. Oxygen concentrations of between 14.1% to 20.6% v/v were also recorded. Atmospheric pressure was recorded to be 1009 and 1031mb.

A further two gas monitoring visits have been completed by Environmental & Geotechnical Ltd on the 31st October and the 9th November 2023. The monitoring was conducted in boreholes WS201 to WS204, WS206 to WS210 (response zones in the superficial deposits), and the shallow 1m boreholes WS201b to WS210b (response zones in the Made Ground).

The results recorded methane (CH₄) levels of between 0.0% to 0.8% v/v and carbon dioxide (CO₂) levels of between 0.0% to 10.4% v/v. Oxygen concentrations of between 0.1% and 21.5% v/v were also recorded. Atmospheric pressure was recorded to be 989 and 995mb.

PID testing was also conducted and revealed concentrations of volatile organic compounds between 0.0ppm and 498.6ppm in the headspace of the monitoring wells.

With regard to flow rates, for the purposes of the ground gas risk assessment BS8485 2015+A1 2019 states that *'steady state flow rates, rather than brief peak values on opening, should be used in screening risk assessment if these are representative of the conceptual site model'*.

An absence of flow rates was locally recorded at the site. For our initial assessment purposes, we have adopted a steady flow rate of 0.1litres/hour (i.e., the limit of detection of the monitoring device).

Full results of the monitoring are presented in Appendix 2.

Table 19 overleaf, adapted from CIRIA C665 "Assessing risks posed by hazardous ground gases to buildings", shows a summary of the current UK practice with respect to appropriate gas protection measures based upon a Gas Screening Value (GSV).

Hazardous gas flow rates for the site have been obtained by multiplying the maximum concentration of gas by the steady flow rate of 0.1l/h adopted for assessment purposes.

- Carbon dioxide: steady flow rate = 0.1l/hr, max concentration = 10.4%
- Methane: steady flow rate = 0.1l/hr, max concentration = 0.8%.

Based on the above figures, the hazardous gas flow rate is calculated as:

- **Carbon dioxide:** $0.1 \times 10.4 / 100 = 0.0104$ litres/hr
- **Methane :** $0.1 \times 0.8 / 100 = 0.0008$ litres/hr

The calculated hazardous gas flow rates have been compared against the GSVs. The CIRIA guidance document notes that '...the GSV is a guideline value and not an absolute threshold'.

The above hazardous gas flow rates fall within a Characteristic Situation (CS) 1, i.e., 'very low risk' in accordance with the GSVs presented in Table 19 overleaf.

Typically, for a CS1 classification, the methane concentration is usually < 1% and the carbon dioxide concentration is < 5%. However, the carbon dioxide was above 5% on several visits.

The previous site investigations have not identified any elevated hydrocarbons that could degrade to form ground gases. As mentioned above, the only known ground gas source is made ground which is a low-risk source.

The low hazardous gas flow rates are consistent with the ground gas conceptual model for the site. However, additional protection against the ingress of ground gas will be provided with the vapour membrane which is proposed to mitigate the vapour risks from the chlorinated solvents present.

Protection Measures

Due to the presence of chlorinated solvents in the perched groundwater which can produce vapours that are harmful to human health, it is recommended that all the proposed townhouses are fitted with vapour protection measures.

The vapour protection measures should comprise a membrane which complies with CIRIA C748:2014 industry standard for VOC protection which will also comply with BS 8485:2015 + A1:2019 industry standard for methane and carbon dioxide protection. The gas protection measures should comply with NHBC Foundation's NF94 guidance for use in Type A and Type B membrane locations.

The membrane should be installed to effectively prevent vapours and ground gases from entering the footprint of the proposed buildings. The membrane should be extended across wall cavities and any joints sealed (typically heat-welded) with appropriate overlapping. Any service penetrations should be appropriately sealed to the membrane.

These protection measures could consist of the following:

Subfloor

- Pre-cast suspended segmental floor i.e., beam and block (**Score – 0**);

Visqueen Ultimate HC BLOCK Membrane

- 0.5mm thick chemically resistant co-extruded VOC barrier and gas barrier meeting all the following criteria (**Score – 2**):
 - Sufficiently impervious to gases with a methane gas transmission rate <40.0ml/day/m²/atm (average) tested in accordance with BS ISO 15105-1, for sheet and joints;
 - Sufficiently impervious to VOC vapours and hydrocarbon immersions in accordance with CIRIA C748:2014;
 - Sufficiently durable to last for the anticipated life of the building and duration of gas emissions;
 - Sufficiently strong to withstand in-service stresses and installation process together with ongoing construction until covered.
 - All penetrations and joints sealed (welded not glued) to achieve complete integrity across entire building footprint.

After installation, the membrane should be capable of providing a complete barrier to gas and vapour entry.

Service entry locations and physical penetrations through the subfloor pose a potentially high risk to the continuity and integrity of any waterproofing and/or gas protection system. The reduction of service penetrations through a slab by relocation through the outer wall above ground level will reduce the detailing required if laying a membrane and therefore reduce the risk of failure.

The gas membrane should be installed correctly by a competent contractor. Appropriate

specification, supervision and control will be needed during design and construction, including validation and verification of the construction accordance with CIRIA C735.

The performance of membranes is heavily dependent on the quality and design of the installation, resistance to damage after installation and integrity of joints.

If a membrane is installed that does not meet all the criteria opposite, then the “score” is zero.

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Table 19: Characteristic Situation (Wilson et al 2006/2007 modified from Wilson and Card, 1999)

<i>Characteristic Situation</i>	<i>Risk Classification</i>	<i>Gas Screening Value CH₄ or CO₂ (l/hr)</i>	<i>Additional Factors</i>	<i>Typical source of generation</i>
1	Very Low	<0.07	Typically, < 1% methane Typically, < 5% carbon dioxide	Typical made ground
2	Low	<0.7	Borehole air flow rate to not exceed 70l/hr otherwise consider increase to Characteristic Situation 3	Typical made ground
3	Moderate	<3.5		Old landfill, inert waste, flooded mineworkings
4	Moderate to High	<15	Quantitative risk assessment	Mineworkings susceptible to flooding, completed landfill
5	High Risk	<70		Mineworking unflooded inactive with shallow workings near surface
6	Very High Risk	>70		Recent landfill site

9.0 CONCLUSIONS & RECOMMENDATIONS

9.1 Local Geology

The site investigation has proved a thin mantle of Made Ground underlain by variable sand and clay horizons. Gravel was also encountered in boreholes WS204, WS207 and WS209.

9.2 Hydrology and Hydrogeology

The site is not located within 1km of a surface water or a surface/groundwater abstraction borehole.

The sand and gravel that underlies the site is classified by the Environment Agency as a Secondary A aquifer.

9.3 Controlled Waters Risk Assessment

The updated controlled waters risk assessment indicates that risks from soil sources of CVOCs and the majority of groundwater CVOCs are acceptable.

The CVOC that is simulated to present greatest risk to controlled waters is TCE in groundwater, which is simulated to exceed the remedial target value protective of a default 50m compliance point by a factor of 2.2.

This assessment is based on a water target value of 5µg/litre which was set at half of the Drinking Water Standard (DWS) of 10µg/litre for combined TCE and PCE, to account for the presence of PCE at the site.

If the water target value was set to 10µg/litre then the exceedance would fall to a factor of 1.1.

The TCE source is located down-hydraulic gradient of the PCE source, and PCE concentrations are observed to decrease rapidly outside the source area, therefore TCE comprises the majority of the combined TCE and PCE impact at the compliance point.

The model indicates that the combined TCE and PCE concentrations would comply with the 10µg/litre standard between 55m and 60m from the TCE source, which would be a marginal exceedance of the default 50m compliance point for Hazardous substances (TCE), and well within the default 250m compliance point for Non-hazardous substances (PCE).

9.4 Human Health Risk Assessment

Risks to on-site properties are potentially unacceptable but are expected to be of limited magnitude and therefore it should be possible to mitigate risks by installation of passive mitigation such as the proposed vapour membranes.

Risks to off-site houses to the east are considered acceptable. Risks to houses to the west are also likely to be acceptable, subject to confirmation that groundwater impacted by PCE or TCE does not migrate westwards from the site towards the houses.

Risks to the house adjacent south of the site are potentially unacceptable, primarily due to potential vapour ingress into the basement. This assessment is based on a number of conservative assumptions and there is limited confidence in the assessment with the current data.

9.5 Ground Gas Risk Assessment

Due to the presence of chlorinated solvents in the perched groundwater which can produce vapours that are harmful to human health, it is recommended that all the proposed townhouses are fitted with vapour protection measures.

The vapour protection measures should comprise a membrane which complies with CIRIA C748:2014 industry standard for VOC protection which will also comply with BS 8485:2015 + A1:2019 industry standard for methane and carbon dioxide protection. The gas protection measures should comply with NHBC Foundation's NF94 guidance for use in Type A and Type B membrane locations.

The membrane should be installed to effectively prevent vapours and ground gases from entering the footprint of the proposed buildings. The membrane should be extended across wall cavities and any joints sealed (typically heat-welded) with appropriate overlapping. Any service penetrations should be appropriately sealed to the membrane.

9.6 Risk to Buried (Water) Services

It is considered that, due to the presence of significant VOC contamination, non-standard materials will be required for new water pipes. Further advice should be sought from the local water company.

Previous guidance on buried water pipes was contained in Water Regulations Advisory Scheme (WRAS) Guidance Note No. 9-04-03⁽²⁰⁰²⁾, however this has been superseded by the UK Water Industry Research Report 'Guidance for the Selection of Water Supply Pipes to be used in Brownfield Sites' Ref 10/WM/03/21 (January 2011).

9.7 Site Personnel

As with all construction sites, personnel working on the site during the construction period should be encouraged to maintain a high standard of personal hygiene and on-site washing facilities should be available.

9.8 Other Matters

Due diligence is required during the construction period, and should any further evidence of contamination be found, appropriate investigation and / or action should be taken. The significance of any contamination not discovered by this investigation is outside the scope of this report.

APPENDIX 1
EXPLORATORY HOLE LOGS

APPENDIX 2
ENVIRONMENTAL MONITORING DATA

APPENDIX 3
CHEMICAL TESTING RESULTS

APPENDIX 4
FENCE DIAGRAMS

APPENDIX 5
REMEDIAL TARGET WORKSHEETS

APPENDIX 6
CLEA RESULTS AND OUTPUTS

APPENDIX 7
REPORT LIMITATIONS

REPORT LIMITATIONS

This contract was completed by Earth Environmental & Geotechnical Ltd on the basis of a defined programme and scope of works and terms and conditions agreed with the client. This report was compiled with all reasonable skill, and care, bearing in mind the project objectives, the agreed scope of works, the prevailing site conditions, the budget, and staff resources allocated to the project.

Other than that, expressly contained in the above paragraph, Earth Environmental & Geotechnical Ltd provides no other representation or warranty whether express or implied, is made in relation to the services. Unless otherwise agreed this report has been prepared exclusively for the use and reliance of the client in accordance with generally accepted consulting practices and for the intended purposes as stated in the agreement under which this work was completed. This report may not be relied upon, or transferred to, by any other party without the written agreement of a Director of Earth Environmental & Geotechnical Ltd.

If a third party relies on this report, it does so wholly at its own and sole risk and Earth Environmental & Geotechnical Ltd disclaims any liability to such parties.

It is Earth Environmental & Geotechnical Ltd understanding that this report is to be used for the purpose described in the introduction to the report. That purpose was an important factor in determining the scope and level of the services. Should the purpose for which the report is used, or the proposed use of the site change, this report will no longer be valid and any further use of, or reliance upon the report in those circumstances by the client without Earth Environmental & Geotechnical Ltd review and advice shall be at the client's sole and own risk.

The report was written in 2024 and should be read in light of any subsequent changes in legislation, statutory requirements, and industry best practices. Ground conditions can also change over time and further investigations, or assessment should be made if there is any significant delay in acting on the findings of this report. The passage of time may result in changes in site conditions, regulatory or other legal provisions, technology or economic conditions which could render the report inaccurate or unreliable. The information and conclusions contained in this report should not be relied upon in the future without the written advice of Earth Environmental & Geotechnical Ltd. In the absence of such written advice of Earth Environmental & Geotechnical Ltd, reliance on the report in the future shall be at the client's own and sole risk. Should Earth Environmental & Geotechnical Ltd be requested to review the report in the future, Earth Environmental & Geotechnical Ltd shall be entitled to additional payment at the then existing rate or such other terms as may be agreed between Earth Environmental & Geotechnical Ltd and the client.

The observations and conclusions described in this report are based solely upon the services that were provided pursuant to the agreement between the client and Earth Environmental & Geotechnical Ltd. Earth Environmental & Geotechnical Ltd has not performed any observations, investigations, studies or testing not specifically set out or mentioned within this report.

Earth Environmental & Geotechnical Ltd is not liable for the existence of any condition, the discovery of which would require performance of services not otherwise contained in the services. For the avoidance of doubt, unless otherwise expressly referred to in the introduction to this report, Earth Environmental & Geotechnical Ltd did not seek to evaluate the presence on or off the site of electromagnetic fields, lead paint, radon gas or other radioactive materials.

The services are based upon Earth Environmental & Geotechnical Ltd observations of existing physical conditions at the site gained from a walkover survey of the site together with Earth Environmental & Geotechnical Ltd interpretation of information including documentation, obtained from third parties and from the client on the history and usage of the site. The findings and recommendations contained in this report are based in part upon information provided by third parties, and whilst Earth Environmental & Geotechnical Ltd have no reason to doubt the accuracy and that it has been provided in full from those it was requested from, the items relied on have not been verified.

No responsibility can be accepted for errors within third party items presented in this report. Further Earth Environmental & Geotechnical Ltd was not authorised and did not attempt to independently verify the accuracy or completeness of information, documentation or materials received from the client or third parties, including laboratories and information services, during the performance of the services. Earth Environmental & Geotechnical Ltd is not liable for any inaccurate information, misrepresentation of data or conclusions, the discovery of which inaccuracies required the doing of any act including the gathering of any information which was not reasonably available to Earth Environmental & Geotechnical Ltd and including the doing of any independent investigation of the information provided to Earth Environmental & Geotechnical Ltd save as otherwise provided in the terms of the contract between the client and Earth Environmental & Geotechnical Ltd.

Where field investigations have been carried out these have been restricted to a level of detail required to achieve the stated objectives of the work. Ground conditions can also be variable and as investigation excavations only allow examination of the ground at discrete locations. The potential exists for ground conditions to be encountered which are different to those considered in this report. The extent of the limited area depends on the soil and groundwater conditions, together with the position of any current structures and underground facilities and natural and other activities on site. In addition, chemical analysis was carried out for a limited number of parameters [as stipulated in the contract between the client and Earth Environmental & Geotechnical Ltd] based on an understanding of the available operational and historical information, and it should not be inferred that other chemical species are not present.

The groundwater conditions entered on the exploratory hole records are those observed at the time of investigation. The normal speed of investigation usually does not permit the recording of an equilibrium water level for any one water strike. Moreover, groundwater levels are subject to seasonal variation or changes in local drainage conditions and higher groundwater levels may occur at other times of the year than were recorded during this investigation.

Any site drawing(s) provided in this report is (are) not meant to be an accurate base plan but is (are) used to present the general relative locations of features on, and surrounding, the site.