



Supplementary Geo-Environmental Report.

Hydrogeology and potential Contaminant Transport.

Proposed Residential Development.

Former Sladen Mill,

Halifax Rd,

Littleborough.

Rochdale.

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Revision	Date	Reason
0	May 2024	Original modelling report using PFAS.

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1 Introduction.

T J Booth Associates have prepared a Geo-Environmental Phase 2-3 Report for the above Site, currently on revision 5, issued to the Environment Agency via the Rochdale MBC Planning Dept on the 23rd Feb 24.

A response letter was received from the EA via RMBC 28th Mar 24 which raised questions regarding:

Underlying stratigraphy:

We disagree with this position as the ground investigation logs confirm the absence of a lower permeability layer that is protective of the underlying sandstone bedrock deposits suggesting that there is indeed a likely pathway between the source and receptors. A good number of the reported logs show a likely direct linkage between the upper made ground deposits and the underlying natural deposits and therefore the underlying aquifer.

Hydrogeology:.

Based on the principles of LCRM, 2023 we strongly disagree with this evaluation as the presence of contaminants of concern in relevant receptors (i.e. the groundwater body identified beneath the site in the attached borehole and trial pit logs) is in itself at least a moderate to high risk as this is, in itself, a source, pathway and relevant receptor.

This report is to address the EA response; to clarify the Conclusions and Recommendations of the Phase 2-3 Report.

2 Regional Background.

2.1 Landform and process

OS 1:25 k Map.



The Site is outlined in red on the map above.

The regional landform is a plateau deeply dissected by river valleys, often with distinct 'steps' where rivers have cut down below the level of earlier broader valleys, and showing signs of over-deepening by glacial meltwater. Most of these valleys are narrow with some glacial till and moraine.

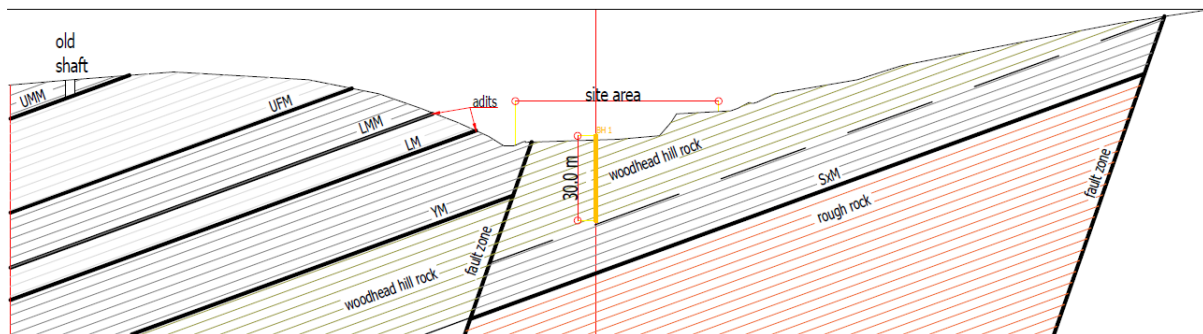
The rocks dip to the west, resulting in a series of escarpments, steep to the east and sloping away to the west, forming some prominent rocky edges.

Source: Countryside Character Area Description, Southern Pennines Natural Area Profile

2.2 Bedrock geology

The solid geology is dominated by Carboniferous rocks. The Millstone Grit group of Namurian age (Rough Rock series on the section) comprising gritstones, sandstones and coarse-grained sandstones formed by ancient river deltas. Between Todmorden and Bacup, Westphalian-age (lower) Coal Measures, a sequence of thin coals, shales and sandstones, (Woodhead Hill Rock series on the section) overlies the Millstone Grit.

The geology of the area is complex as these sedimentary rocks are of widely varying thickness and are cut by many faults.



Regional Section

Coal and ironstone have all been worked from the rocks in the past, as well as stone for building and shales for brick making. Currently the only commercial extraction is of stone for road construction and building.

A breakdown of the solid geology as a proportion of the total land area is:

- 52 per cent sandstones (including gritstones)
- 46 per cent mudstones and siltstones

Source: Countryside Character Area Description, Southern Pennines Natural Area Profile

2.3 Hydrogeology.

Coal measure rocks generally contain a series of high-permeability rocks (e.g., sandstone) of various thickness separated by low-permeability rocks (e.g., mudstones, shales), also of various thickness. These high-permeability rocks are generally termed aquifers, depending upon their capacity to yield useful volumes of water; the low-permeability rocks are generally termed aquitards, which limit or inhibit water and gas flow vertically across. The permeability of aquifer rocks ranges from about 1 to 100 md (millidarcy), and the permeability of aquitard rocks can be as low as 0.0001 md.

In general, depth from the ground surface to the groundwater table varies widely. Depending on the local topography, a groundwater system may contain local, perched groundwater (commonly fed by rainfall) and a sequence of deep regional groundwater (which is generally continuous over the entire basin). Depending on the thickness and permeability of aquitards separating individual groundwater systems, they may be connected hydraulically to varying degrees, described as loosely, moderately or well connected.

Groundwater flow in the Pennine Coal Measures is via fractures, with some intergranular flow within sandstone units. Aquifer properties are typically heterogeneous and anisotropic, and have been heavily modified by a legacy of coal mining. Increased fracturing following subsidence and new connections between once hydraulically isolated units via roadways and mines, has changed the natural behaviour of the Coal Measures (Banks, 1997; Jones et al., 2000). Regional flow is primarily from west to east, but also controlled by the folding and jointing/faulting across the region, alongside the historic mine workings, resulting in a complex 3D and potentially "karstic" like flow regime (Banks, 1997).

Permeabilities for the Pennine Coal Measures are variable and typically greatest in the Upper Coal Measures (up to 3 orders of magnitude greater average permeability than the Lower and Middle Coal Measures). Permeability is greatest in the sandstone horizons, but the mudstones and siltstones can have low values, and function as leaky aquitards (Banks, 1997; Jones et al., 2000). Hydraulic conductivity ranges from 3.8×10^{-5} m/d to 9.4×10^{-4} m/d for the Pennine Lower Coal Measures, 4×10^{-4} m/d to 4×10^{-2} m/d for the Pennine Middle Coal Measures, and 6.4×10^{-6} m/d to 1.7×10^{-1} m/d for the Pennine Upper Coal Measures. Permeability is affected both by depth and structural features; with increasing overburden pressure permeability decreases. Jointing and faulting have juxtaposed much of the sandstone units against lower-permeability strata, which result in discontinuous horizons. Some units may even be hydraulically isolated from any incoming recharge (Jones et al., 2000).



Porosity across the Pennine Coal Measures ranges from an average of 11% to 17%, with greater storage typically associated with the sandstone units. Transmissivities range from 0.4 m²/d to 416 m²/d, with a median of 16 m²/d, as recorded in the BGS Aquifer Properties database (Jones et al., 2000). The Coal Measures have a distinct response curve during pumping tests, where drawdown "creeps" slowly downwards after initially high yields. This is attributed to the prominence of fracture flow and either the interaction with boundary conditions, or an excessive pumping rate (Jones et al., 2000). Historically, the Coal Measures were dewatered in order for mining to proceed at progressively greater depths. Following the closure of the coal-mining industry, water levels have rebounded across the region, and have been the subject of further study (Burke et al., 2005; Dumbleton et al., 2001; Gandy and Younger, 2007; Gee et al., 2020; Younger and Adams, 1997).

Baseline groundwater chemistry: the Pennine Coal Measures of the East Midlands and South Yorkshire, BGS 2021.

From the EA data; the regional aquifer ground water vulnerability is medium (east) and high (west), with poor polygon resolution noted. Its designation is **Secondary A** aquifer and the Superficial deposits are classed as **Unproductive**.

There aren't any potable water abstraction wells recorded in the area. United Utilities abstract surface water via reservoirs in the surrounding higher catchments.

3 Site Specific Properties.

The regional section above and detail section below indicate the stratigraphy of the underlying **bedrock** and the anthropogenic **made ground** local to the former buildings on the Site.

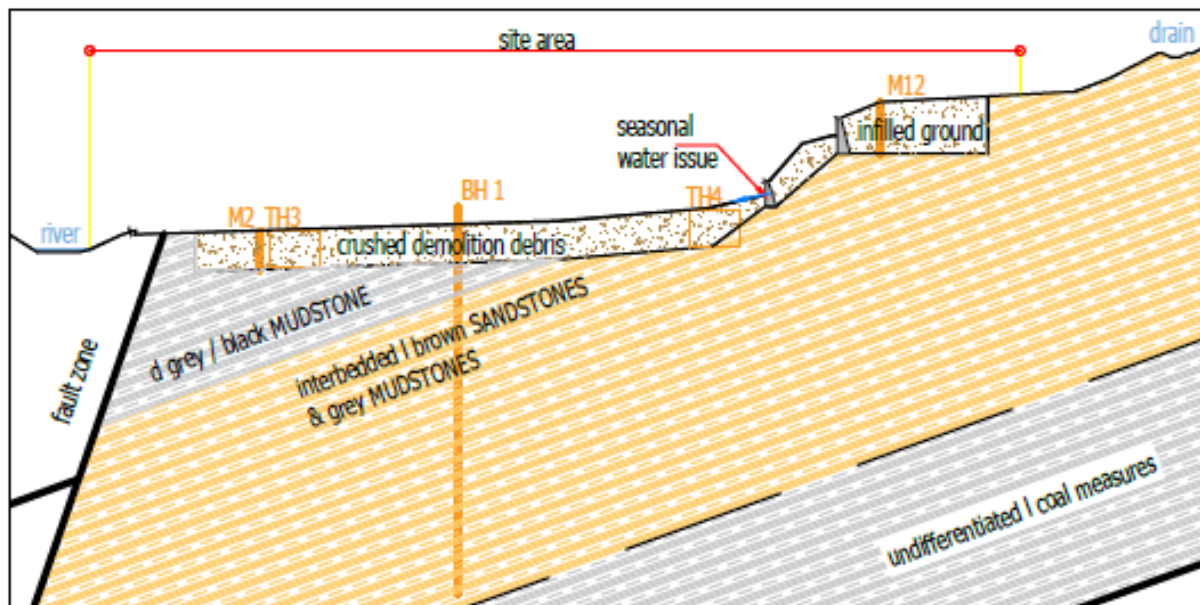
The Made Ground comprises crushed construction / demolition debris, described as slightly silty, very sandy GRAVEL with cobbles and occasional boulders, moderately graded in a med dense state. It varies in thickness over the Site from negligible up to 4.0 m deep in locations of former basements / pits. In some locations partial sub-structures still remain. During periods of steady rainfall water accumulates on the surface and runs off towards the adjacent watercourse. In drier periods the groundwater seats upon the underlying bedrock as a perched local water table and is occasionally absent altogether. Water springs were noted during the winter months at the junction of the MADE GROUND and embankment / wall structures.

The primary bedrock stratum below the Site is the Woodhead Hill Rock which comprises steeply dipping (c 20 degs) interbedded sedimentary sandstones and mudstones. The strata of this series are exposed in the steep slope bisecting the Site where the beds can be observed. In this exposure the Sandstones are thinly bedded weakly cemented pale brown with very weak grey laminated Mudstones. The former form approx. 25% of the strata depth.

A fault zone intersects the Site located generally along the stream alignment trending NW-SE with the W block downthrow cutting off the underlying Namurian grits on the W side.

The watercourse along the SW side of the Site is located directly onto the coal measures rock and in some parts the level of the former basements is deeper than the stream bed.

Local Site Stratigraphy Cross Section.



The interface between the Made Ground and bedrock is very variable with pockets of deeper deposits which would effectively function as sumps to water percolating downwards or arriving laterally (seasonal springs noted) from the higher areas into the Made Ground.

Site Investigation Plan.

On the plan (see Appendix) the location of the site investigation trial and boreholes have been indicated. Also indicated is the boundary between continuous mudstone strata to the SW and the interbedded sandstone strata. The boundary is also indicated on the Local Section above.

The site investigation exploratory holes encountered groundwater of negligible depth at the interface with the base of the Made Ground and bedrock. The monitoring boreholes were sunk to a shallow depth into the underlying bedrock to allow sampling to take place. The immediate water table below

the Site is a rainwater fed perched feature and only present seasonally depending upon rainfall amounts in the region.

The deeper borehole (BH1) transited through the MG into MUDSTONE and then interbedded yellow & grey SANDSTONES. Water was struck in the top of the MUDSTONE (perched), but the remainder of the hole was dry to a depth of 30.0m.

3.1 Contaminants of Concern.

The source contaminant (µg/l) with receptor EQS and Drinking Water limits is tabulated below from the groundwater test results.

Client / Site:		Mere Group - Sladen Mill, Littleborough.									
Sample Type:		Groundwater Samples									
Sampling Date:		20.07.2023, 22.08.2023, 07.09.2023, 19.10.2023, 20.10.2023, 07.11.2023 & 09.11.2023									
CONTAMINANT		No	Max (µg/l)	Mean (µg/l)	t 95 (µg/l)	EQS FRESHWATER AA		EQS FRESHWATER MAX		UK DWI WATER SUPPLY REGULATIONS 2016	
						(µg/l)	Pass/Fail	(µg/l)	Pass/Fail	(µg/l)	Pass/Fail
METALS											
	Chromium VI	17	10.0	6.3	10.0	3.4	FURTHER ACTION	0	NO REGS	50	PASS
	Copper	20	15.0	3.6	12.2	1	FURTHER ACTION	0	NO REGS	2000	PASS
	Nickel	20	39.0	5.4	12.4	4	FURTHER ACTION	34	PASS	20	PASS
	Selenium	20	19.0	3.5	18.1	0	NO REGS	0	NO REGS	10	FURTHER ACTION
	Zinc	20	85.0	38.9	84.1	10.9	FURTHER ACTION	0	NO REGS	0	NO REGS
INORGANIC											
	Cyanide (Total)	14	40.0	32.5	40.0	1	FURTHER	5	FURTHER	50	PASS
	Sulphate	14	473000	124779	434650	400000	PASS	0	NO REGS	250000	FURTHER ACTION
ORGANIC											
	PAH benzo[a]pyrene	14	0.09	0.01929	0.051	0.00017	FURTHER ACTION	0.27	PASS	0.01	FURTHER ACTION
	PAH fluoranthene	14	0.16	0.04	0.11	0.0063	FURTHER ACTION	0.12	PASS	0	NO REGS
	SVOC phenol	14	100.0	87.1	100.0	7.7	FURTHER	46	FURTHER	0	NO REGS
POPS											
	perfluorooctane sulfonate (PFOS) total	17	0.0405	0.01343	0.0384	0.00065	FURTHER ACTION	36	PASS	0.1	PASS
	Per/polyfluoroalkyl substances (PFAS) total	17	0.6479	0.1701	0.3996	0.00065	FURTHER ACTION	36	PASS	0.1	FURTHER ACTION

It's to be noted that the Annual Average EQS for freshwater bodies is the dominant measure giving rise to seven contaminants of concern, if the UK drinking water levels were used it would reduce to four contaminants; Selenium, Sulphate, PAH benzo(a)pyrene and Per/polyfluoroalkyl substances (PFAS).

4 Numerical Source / Pathway / Receptor Model.

The final paragraphs of the EA response letter suggests that a Numerical Model of the Pathway from Source to potential Receptor be undertaken, specifically using the Remedial Targets Methodology Worksheet. It goes further to suggest that Site Specific parameters are adopted in the model in the absence of real-world alternatives.

When we previously recommended that further assessment was undertaken, we anticipated that the principles of LCRM, 2023 would be applied and that a suitable (numeric) detailed quantitative risk assessment would be undertaken especially as some of the contaminants of concern are considered hazardous and assessment of their risk to relevant receptors undertaken. We feel that this is additionally supported by the Groundwater (Daughter) directive 2006/118/EC.

This version does not undertake that work therefore we are unable to agree that no remediation is required.

In undertaking this work we advise that you consider and follow the Remedial Targets Methodology guidance document (Remedial Targets Methodology: Hydrogeological Risk Assessment for Land Contamination (RTM P20) ref. LIT 6627, EA, 2006) which can be found at this website address [Land contamination: remedial targets methodology \(RTM\) - GOV.UK \(www.gov.uk\)](http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/281242/RTM_P20.pdf).

Further, we recommend that where possible site specific input parameters are used to populate your chosen model so that the risk assessment reflects ground conditions as closely as possible and only used academic or generic values in the absence of real-world alternatives.

4.1 Remedial Targets Worksheet (RTW v3.2).

The EA RTW v 3.2 requires substantial input data in order to determine contaminant risk at a remote groundwater receptor. It allows a number of potential contaminants to be modelled, subject to knowing their behavioural properties during groundwater transport.

It presumes knowledge of a wide range of soil properties, such as porosity (air & water filled), Henry's coefficient, infiltration properties, saturated aquifer thickness, hydraulic gradient, mixing zone thickness, soil water partition coefficients...etc.

Further, the Worksheet clearly states that the geo-hydraulic properties of the soils should be ideally derived from direct testing of the strata (boreholes, soil lab samples, hydraulic permeability tests such as pumped packer / falling head tests). Only failing this adopting the use of global parameters based upon published literature.

However the stratigraphy and nature of the bedrock is such that direct testing as per the first option above would only provide local properties and could not account for the effect of faulting, folding, variability in seam thicknesses and overburden pressures. Thus it is not practicable to try and model the geo-hydraulic behaviour from direct insitu / lab testing unless extensive enough to characterise the regional stratigraphy. Similarly the made ground has variable properties depending upon the source, crushing & sorting process and compaction.

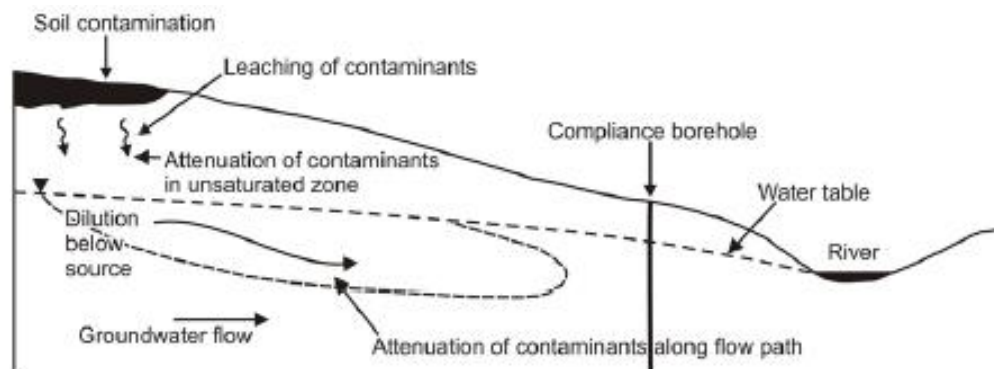
The Model is simplistic, it cannot deal with anisotropy and or faulted soils, so at best only indicative output can be expected for the Sladen Mill Site and its environs.

Considering the above it is only logical to undertake the modelling based upon published parameters and basic assumptions regarding the local / regional groundwater regime, using mean input values to identify receptor outcomes.

Should the modelling indicate **high contaminative risks** to receptors further soil characterisation may be advised.

4.2 The Model.

The input requirements to the model are based upon a simple flow regime, source, partial saturated zone, regional water table connected to receptor water body.



Potential receptors were identified on the OS 1:25k map and are;

Watercourse adjacent to the Site.

River Roch, 650 m W at 150 m aOD (*direct pathway*).

Pond fed by a leat from the Lydgate Brook 300 m NW at 160 m aOD is likely to be above the regional water table so is discounted.

Rochdale canal located 600 m W is not considered a receptor due to its raised level above the valley and use of clay linings to seal the cuttings / embankments.

Boreholes undertaken by the EA in the Roch valley approx. 0.65 km west (*Littleborough & Rochdale FRMS phase1-gale storage reservoir-jun19*) have identified the local water table (150 m aOD) and stratigraphy (BH/GSR/15). A review of all the boreholes for the above showed the local Roch Valley water table to be at or close to the river level.

Pathways to the receptor are into the vadose zone in the underlying soil / rock towards the local/ regional water table and hence onwards to the receptor water course.

For the local **watercourse** receptor the pathway is in the vadose zone within the Made Ground into the perched water table which is modelled as 50 mm deep (conservative) located upon the mudstone Bedrock and hence down gradient to the watercourse.

Regarding the river **Roch** receptor the depth to the regional water table directly beneath the Site is unknown, but from the results of BH1 is in excess of 30 m placing it at not greater than 140.00 m aOD. This implies that the water table at the Site doesn't interact directly with the river Roch where it is closest to the Site (unless artesian conditions exist). So in order to facilitate the Model there were two options; presume a higher regional water table level beneath the Site (conservative), or select a receptor at a level less than 140 m aOD (approx. 1.5 km SW in Littleborough). For the purposes of the Model the former option was used, the depth to the Site water table has been assumed to be 19 m bGL (i.e. 151 maOD). This will provide a minimal hydraulic gradient to the receptor. The depth of the partially saturated zone will be taken as 20 m and the underlying aquifer depth at 70 m.

The Model outputs three levels of assessment, but only the groundwater level three is used:

Level 3, (Soil & Ground water attenuation in the aquifer).

A steady state analysis is selected with vertical & lateral dispersion.

The **parameters** used in the Model are tabulated in the Appendix:

4.3 Modelling Input.

For the purpose of modelling because the distribution of local 'hotspots' and their precise extent aren't known accurately, the mean contaminant concentration has been applied over the full area of the Site.

The **Dominico Steady State** option is selected for remedial target calculation.

4.3.1 PFAS (total).

Source groundwater concentration (total PFAS mean)		1.70x10 ⁻⁴ mg/l	170 ng/l.
	(total PFAS t95)	0.399x10 ⁻⁴ mg/l	400 ng/l.
	(PFOA mean)	1.57x10 ⁻⁴ mg/l	157 ng/l.
	(PFOS mean)	1.34x10 ⁻⁵ mg/l	13 ng/l.
Source soil concentration (mean)	n/a	-----mg/kg.	
Target concentration (total PFAS)	see para below	2.4x10 ⁻⁴ mg/l	240 ng/l.

Remarks on the EQS (ref: *Environmental Fate of PFAS, Rep 8/16, Concawe 2016*)

The AA-EQS for PFOS in surface water 0.00065 µg/l (**0.65** ng/l) is considerably lower than the UK drinking water standards 0.1 µg/l (**100** ng/l).

The low level of the AA-EQS is driven by the starting point for the calculation being the consumption of fish. Wilson (2015) demonstrated that with alternative (also defensible) values for: TDI (0.3 vs. 0.15 µg/kg day), contribution of fish to dietary uptake (73% vs. 10%), average fish consumption rate (0.028 kg/day vs. 0.115 kg/day), bioconcentration and biomagnification factors (1.124 vs 2.800 and 2 vs 5), the AA-EQS could have been derived 370 times higher at 0.24 µg/l (**240** ng/l).

The **PFOA's** have the lower sorption properties, thus most mobile in ground water and these properties will be used in the Model.

The following **physiochemical** properties are used in the Model (*Concawe 2016; Table in Appendix*).

PFOA.

Henrys Coefficient (Pa.m ³ /mol)		0.04 - 0.09	0.065.
Octanol water partition coeff (log Kow)	5.30	Kow =	0.403.
Organic carbon partition coeff (log Koc)	1.31 – 2.35	Koc =	0.117 – 0.371 0.244.
Soil-water partition coeff (K _d @pH 7.0)		0.0 – 3.4	1.80.
Dissociation constant (pKa)		-0.16 – 3.8	3.2.

PFOS.

Henrys Coefficient (Pa.m ³ /mol)		<2e-6 – 3e-4	0.0002.
Octanol water partition coeff (log Kow)	6.43	Kow =	0.808.
Organic carbon partition coeff (log Koc)	2.5 – 3.1	Koc =	0.398 – 0.491 0.445.
Soil-water partition coeff (K _d @pH 7.0)		0.1 – 97	1.80.
Dissociation constant (pKa)		-0.6 – -2.6	-1.6.



4.4 Modelling Output.

4.4.1 PFAS.

River Roch receptor.

PFOA's Level 3 (groundwater).

Remedial target	179 ng/l	>157 ng/l	PASS.
Concentration at Compliance Point	88 ng/l	<100 ng/l	PASS.

Stream receptor.

PFOA's Level 3 (groundwater).

Remedial target	264 ng/l	>157 ng/l	PASS.
Concentration at Compliance Point	64 ng/l	<100 ng/l	PASS.

4.4.2 Summary.

The model output achieved the remedial target concentrations at the source and compliance point concentrations.

Contaminant transport times were in the order of 10^3 years.

5 Discussion & Recommendations.

5.1 Discussion.

The Site development for residential dwellings and the risks to site operatives and future residents is addressed in the Phase 2+3 Geo-Environmental Report rev 5 (Feb 24). It identified the need to provide a clean cover system to the garden & landscape areas over the made ground on the site and provision of ground gas protection to the buildings.

In the above report the fate of potentially mobile contaminants within the made ground and their risk to groundwater receptors was not addressed directly. In particular PFAS were identified by the EA to be of particular concern and further surface and groundwater sampling regimes were undertaken to characterise the extent of this contaminant.

The modelling in this report has been undertaken to investigate the specific contamination from PFAS within the groundwater regime beneath the Site (170 ng/l mean) and the effects on potential receptors linked (pathway) to the groundwater; i.e. local rivers & streams.

PFAS are moderately mobile in a groundwater environment, by their very nature they are hydrophobic repelling water molecules and PFOA's in particular are the most persistent. In the Model the properties for PFOA's are used providing conservative results.

The target level for PFAS within the water environment differ, whether for potable purposes or for aquatic species, the former is set at 100 ng/l (UK DW Standard) and the latter 0.65 ng/l (EQS AA). However it is reasoned elsewhere (*Wilson 2015*) that a more practicable level would be 240 ng/l for aquatic environments. For the purposes of this report and modelling a remedial compliance level for Drinking Water at the receptor of 100 ng/l was be used.

The variability of the subsoils, geology and the limitations of the Remedial Targets Worksheet will mean that the results of the modelling will be indicative only and should be used only to gain a level of confidence in the fate of potential contaminants within the groundwater regime.

Also the PFAS contaminant was noted to be present with the watercourse upstream of the Site at 30 ng/l reducing downstream to <25 ng/l, so appears to be already widely present even in this primarily rural catchment.

The proposed cover system to be employed will further reduce the pathway potential by reducing the surface permeability into the underlying made ground, however the Model cannot deal with this level of detail (i.e. introduction of soil layers). If the final recommended cover system was to be utilised in the model it would have to be modelled using a modified overall permeability value for the vadose layer.

The result of the modelling suggests even with some conservative assumptions (using parameters for PFOA's, mean contaminant concentrations and soil properties) that a Site-specific remediation is not necessary in order to protect the groundwater receptors.

The simple hydro-geological calculations sections indicate magnitudes of 10^3 years for contaminants to reach the receptors.

However, in the light of the above conservatisms / assumptions, it would be prudent to introduce an additional level of protection to the Site by providing two zones of low permeability; firstly a 50 mm compacted MOT1 'no dig' layer overlain by 200 mm of clayey subsoil as part of the overall 600 mm of clean inert cover soil. This would give an increased level of confidence in the security of off-site receptors.

5.2 Recommendations.

In order to have reasonable confidence to manage and mitigate the effects of ground water contamination within the Site subsoils it is recommended that the finished Site is protected with a low permeability cover system. This shall comprise provision of a two-layer barrier; 50 mm of well compacted MOT1 crushed limestone overlain by 200 mm of clayey subsoil carefully placed and



compacted. Onto this can be a sandy subsoil and topsoil finish upto the 600 mm overall thickness of cover soil.

To paved areas a minimum of 200 mm of well compacted MOT1 shall be adopted as a foundation.

On steep slopes and landscaped areas 200 mm of clayey subsoil shall be utilised as part of the 450 overall cover soil requirements.

The requirement for SUDS shall not permit the use of soakaways into the underlying made ground, only the use of sealed storage tanks / ponds / basins is to be permitted.

Signed.....

A handwritten signature in black ink, appearing to be 'TJ Booth', written over a dotted line.

T J Booth BSc (Hons), C. Eng. C. Env. MICE.

T J Booth Associates.



6 Appendix.

6.1 Site Investigation Plan.



6.2 Model Parameters.

Physical Parameters.

Site level	168.00 m aOD.
Site rockhead level	166.00 m aOD.
Site local (perched) water table	166.05 m aOD.
Site regional water table	140.00 m aOD.
Roch Valley level	152.00 m aOD.
Roch Valley upper water table level	150.00 m aOD.
Roch Valley rockhead level	130.00 m aOD.
Distance to local watercourse (average of Site width)	35.00 m.
Distance to Roch Valley (direct)	0.65 km
Site length (<i>approx. perp to gw flow dirn</i>)	200.00 m.
Site width (<i>approx. parallel to gw flow dirn</i>)	70.00 m.
Site total area	14000 sqm.

Site impermeable area (houses, roads pathways) 6000 sqm.

Site permeable area (gardens, landscaped areas) 8000 sqm.

Geo-Hydraulic Parameters.

Lower Coal Measures, (refer to section 2.3).

Permeability (hydraulic conductivity)	lower	3.8x10 ⁻⁵ m/day.
	Upper	9.4x10 ⁻⁴ m/day.
	Mean	5.0x10 ⁻⁴ m/day.
bulk density	25 kN/cu m	2.5 g/cu cm.
Porosity		14 % (<i>computed in worksheet</i>).

Made Ground.

Permeability (hydraulic conductivity)	Mean	0.010 m/day (<i>Appendix 1.16x10⁻⁷ m/s</i>).
bulk density	20 kN/cu m	2.0 g/cu cm.
Porosity		39 % (<i>computed in worksheet</i>).
Soil pH		7.7.
TOC (SOM/1.72)		3.6% / 1.72 = 2.1%

Effective Rainfall 0.5 m/y 1.37 mm/d (*chart in Appendix*).

6.2.1 Soil Properties.

Table C.1 Typical mass densities of basic soil types

Type of Soil	Mass density ρ (Mg/m ³)*			
	Poorly graded soil		Well-graded soil	
	Range	Typical value	Range	Typical value
Loose sand	1.70–1.90	1.75	1.75–2.00	1.85
Dense sand	1.90–2.10	2.07	2.00–2.20	2.10
Soft clay	1.60–1.90	1.75	1.60–1.90	1.75
Stiff clay	1.90–2.25	2.00	1.90–2.25	2.07
Silty soils	1.60–2.00	1.75	1.60–2.00	1.75
Gravelly soils	1.90–2.25	2.07	2.00–2.30	2.15

*Values are representative of moist sand, gravel, saturated silt, and clay.



Porosity

Gravel	30-40%	
Sand	20-35 %	
Silt	35-50 %	
Clay	33-60 %	
Sand and gravel, mixed	20-35 %	
Glacial till	10-20 %	
Sandstone	5-30%	
Limestone	5-30%	
Shale	10-30 %	
Fractured igneous rock	10-40%	
Granite	0.5-1.5 %	--- (Unfractured) ---
Diabase	0.1-0.5 %	
Gabbro	0.1-0.2 %	
Basalt	0.1-1.0 %	
Gneiss	0.5-1.5 %	
Marble	0.5-2 %	
Slate	0.1-0.5 %	
Quartzite	0.1-0.5 %	

Permeability

Well-sorted gravel	10^{-2} to 1 cm/sec
Well-sorted sands, glacial outwash	10^{-3} to 10^{-1} cm/sec
Silty sands, fine sands	10^{-5} to 10^{-3} cm/sec
Silt, sandy silts, clayey sands, till	10^{-6} to 10^{-4} cm/sec
Clay	10^{-9} to 10^{-6} cm/sec

6.3 Littleborough FRMS Phase 1; BH/GSR/15.

BOREHOLE LOG

Borehole No:
BH/GSR/15
Sheet 1 of 4

Project Name:	Littleborough & Rochdale FRMS Phase 1	Survey Grid System:	OSGB	Hole Type:	CP+RC
Project No:	314C	Co-ordinates:	394567.40 mE 417419.85 mN	Checked By:	HA
Client:	Environment Agency	Ground Level:	152.33 mOD	Approved By:	PMOG
Engineer:	Jacobs	Orientation:	-- deg.	Scale:	1:50
Date Started:	08/11/2018	Inclination:	90 deg.	Log Status:	FINAL
Date Completed:	12/12/2018			Print Date:	18/06/2019
				Final Depth:	32.50m

Stratum Description	Legend	Depth (Thickness) (m)	Level (m)	Sampling, Coring and In Situ Testing							TCR SCR (RQD) %	If min. if max. (mm)	Water	Well/ Backfill
				Depth (m)	Type	Dia (mm)	Rec %	Blows (min)	Test	Test Result				
Grass and peaty TOPSOIL.		0.00 - 0.30	152.03	0.25	ES									
Very soft to soft dark brown mottled dark grey slightly gravelly slightly sandy silty CLAY. Sand is fine to coarse. Gravel is subrounded to subangular fine to coarse of sandstone, mudstone and various other lithologies.		0.30 - 1.10		0.50	ES									
				0.70	D									
				0.50 - 1.00	B									
				1.00	ES									
Medium dense dark greyish brown very sandy silty subrounded to subangular fine to coarse GRAVEL of sandstone, siltstone and various other lithologies with occasional subrounded cobbles of sandstone. Sand is fine to coarse.		1.40 - 2.60	150.03	1.20 - 1.65	UT	100	75	66						
				1.65 - 1.70	D									
				2.00 - 2.45	B									
				2.00 - 2.45					C	N=15				
				2.70	D									
				3.00 - 3.45	B									
Soft dark brownish grey slightly gravelly sandy silty CLAY. Sand is fine to coarse. Gravel is subrounded to subangular fine to coarse of sandstone, siltstone and various other lithologies.		3.00 - 3.45		3.00 - 3.45					C	N=24				
				3.70	D									
		4.00 - 4.20	148.33	4.00 - 4.45	B									
				4.00 - 4.45					C	N=11				
Medium dense dark greyish brown and dark grey sandy slightly clayey subangular and angular fine to coarse GRAVEL of various lithologies. Sand is fine to coarse.		4.20 - 5.20	147.13	4.70	D									
				5.00 - 5.45	B									
				5.00 - 5.45	D									
				5.00 - 5.45					S	N=16				
				5.70	D									
				6.00 - 6.45	B									
				6.00 - 6.45					C	N=15				
				6.70	D									
				7.00 - 7.45	B									
				7.00 - 7.45					C	N=16				
Firm dark grey slightly gravelly slightly sandy CLAY. Sand is fine to coarse. Gravel is subrounded to subangular fine to coarse of various lithologies.				7.70	D									
				8.00 - 8.45	B									
				8.00 - 8.45					C	N=16				
				8.70	D									
		9.00 - 9.40	142.83	9.00 - 9.45	B									
				9.00 - 9.45					C	N=19				
		9.40 - 9.90	142.43	9.70	D									

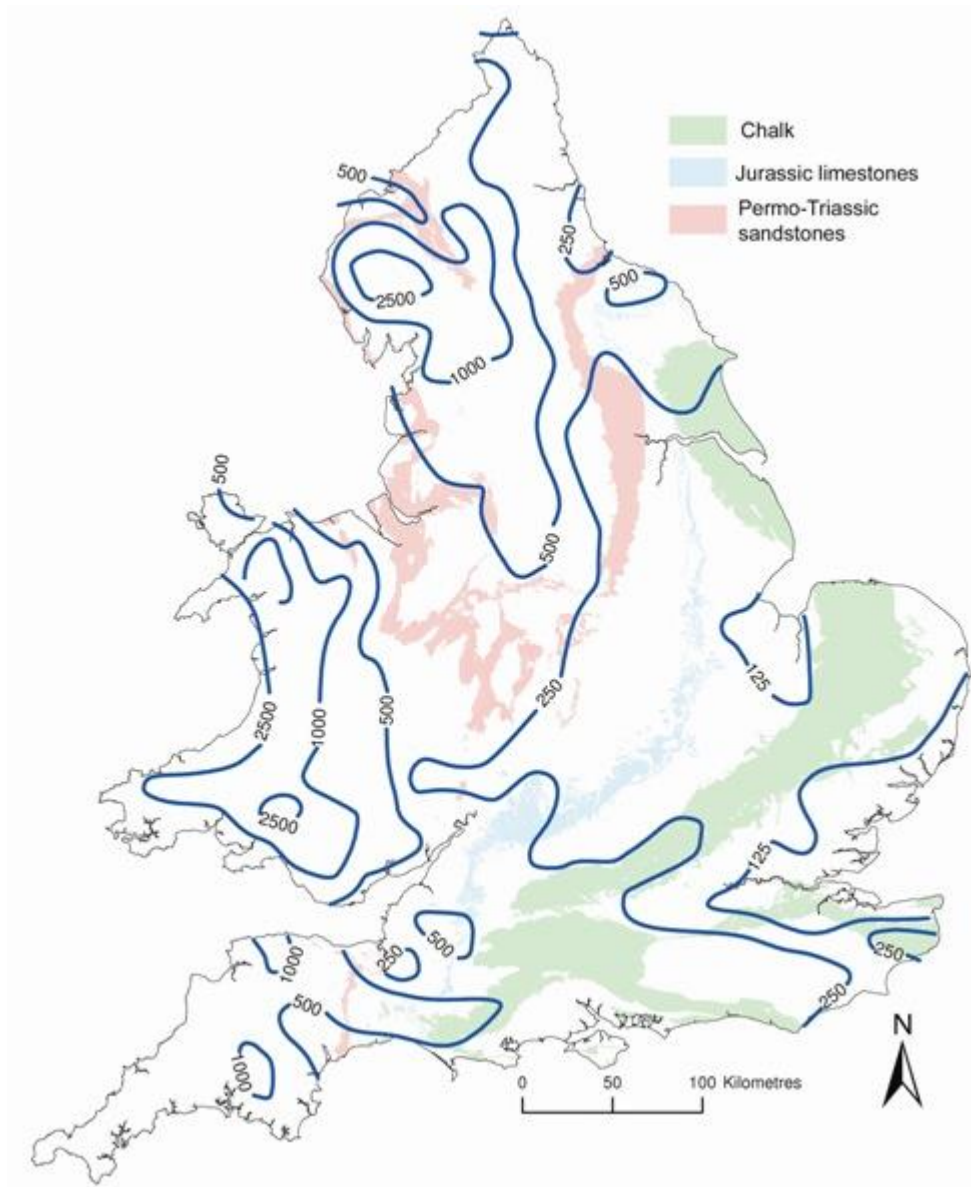
Stratum depths measured along borehole axis.
Groundwater levels may be subject to seasonal, tidal and other fluctuations and should not be taken as constant.
Explanation of symbols and abbreviations given in 'Key to Exploratory Holes'
Further details given on appended 'Borehole Information Sheet'.

Office: BAM Ritchies, Glasgow Road, Killyth, Glasgow G65 9BL

BAM R Borehole Log 17/10/2017



6.4 Effective Rainfall (UK).



6.5 PFAS; physiochemical properties table (CONCAWE 2016).

Name	Acronym	CAS Registry Number	Molecular Formula	Molecular Weight [g/mol]	Density ^a (20 - 25 °C) [g/mL]	Water Solubility ^b (20 - 25 °C) [g/L]	Melting Point ^a [°C]	Boiling Point ^a [°C]	Vapor Pressure ^b [Pa]	Henry-Coefficient [Pa·m ³ ·mol ⁻¹]	log K _{ow} ^c [-]	log K _{oc} [L/kg]	K _d (pH 7)	Dissociation Constant (pK _a)
Perfluoroalkyl Carboxylates / Perfluoroalkyl Carboxylic Acids	PFCAs													
Perfluorobutanoic Acid	PFBA	375-22-4	F(CF ₂) ₃ COOH	214.04	1.65	Miscible	-17.5	121	1307	--	2.82	1.88	--	-0.2 to 0.7
Perfluoropentanoic Acid	PFPeA	2708-60-3	F(CF ₂) ₄ COOH	284.05	1.70	112.6	--	124.4	1057	--	3.43	1.37	--	-0.08
Perfluorohexanoic Acid	PFHxA	307-24-4	F(CF ₂) ₅ COOH	314.05	1.72	21.7	14	143	457	--	4.08	1.91	--	-0.13
Perfluoroheptanoic Acid	PFHpA	375-85-9	F(CF ₂) ₆ COOH	384.08	1.79	4.2	30	175	158	--	4.67	2.19	0.4 - 1.1	-0.15
Perfluorooctanoic Acid	PFOA	335-87-1	F(CF ₂) ₇ COOH	414.07	1.80	3.4 - 9.5	37 - 60	188 - 192	4 - 1300	0.04 - 0.09	5.30	1.31 - 2.35	0 - 3.4	-0.18 to 3.8
Perfluorononanoic Acid	PFNA	375-85-1	F(CF ₂) ₈ COOH	484.08	1.75	9.50	59 - 66	218	1.3	--	5.62	2.38	2.6 - 5.9	-0.17
Perfluorodecanoic Acid	PFDA	335-76-2	F(CF ₂) ₉ COOH	514.09	1.78	9.50	77 - 88	218	0.2	--	6.50	2.76	2.0 - 3.1	-0.17
Perfluoroundecanoic Acid	PFUnA	2058-94-8	F(CF ₂) ₁₀ COOH	584.09	1.78	0.004	83 - 101	180 - 230	0.1	--	7.15	3.30	12 - 103	-0.17
Perfluorododecanoic Acid	PFDoA	307-55-1	F(CF ₂) ₁₁ COOH	614.10	1.77	0.0007	107 - 109	245	0.01	--	7.77	--	24 - 269	-0.17 to 0.8
Perfluorotridecanoic Acid	PFTriA	72626-94-8	F(CF ₂) ₁₂ COOH	684.11	1.77	0.0002	--	--	0.3	--	8.25	--	--	--
Perfluorotetradecanoic Acid	PFTeA	378-06-7	F(CF ₂) ₁₃ COOH	714.12	1.78	0.00003	--	276	0.1	--	8.90	--	--	--
Perfluoropentadecanoic Acid	PFPeDA	14107-43-7	F(CF ₂) ₁₄ COOH	784.12	--	--	--	--	--	--	--	--	--	--
Perfluorohexadecanoic Acid	PFHxDA	3825-26-1	C8 H4 NF16 NO2	445.11	--	14.2	157 - 165	--	0.01	--	--	--	--	2.5
Pentadecafluorooctanoic Acid Ammonium Salt (Ammonium Pentadecafluorooctanoate)	APFO													
Perfluoroalkyl Sulfonates / Perfluoroalkyl Sulfonic Acids	PFSAs													
Perfluorobutane Sulfonate	PFBS	375-73-5	F(CF ₂) ₃ SO ₃ H	300.10	1.81	46.2 - 88.8	78 - 84	211	631	--	3.90	1.00	--	-8.0 to -5.0
Perfluorohexane Sulfonate	PFHxS	432-50-8	F(CF ₂) ₅ SO ₃ H	400.11	--	2.3	--	--	58.9	--	5.17	1.78	0.8 - 3.2	-6.0 to -5.0
Perfluoroheptane Sulfonate	PFHpS	367-92-8	F(CF ₂) ₆ SO ₃ H	450.12	--	--	--	--	--	--	--	--	--	--
Perfluorooctane Sulfonate	PFOs	1783-23-1	F(CF ₂) ₇ SO ₃ H	500.13	H	0.62 - 0.57	54	>400	6.7	<2e-8 to 3e-4	6.43	2.5 - 3.1	0.1 - 97	-6.0 to -2.6
Perfluorodecane Sulfonate	PFDS	333-77-3	F(CF ₂) ₉ SO ₃ H	600.14	--	0.002	--	--	0.71	--	7.68	3.53	--	--
Perfluoroalkyl Phosphonic Acids	PFPA													
Perfluorobutyl Phosphonic Acid	PFBP	52298-24-8	F(CF ₂) ₃ PO(OH) ₂	360.02	--	14256.1	--	--	0.18	--	2.19	--	--	--
Perfluorohexyl Phosphonic Acid	PFHxPA	40143-70-8	F(CF ₂) ₅ PO(OH) ₂	400.03	--	515.3	--	--	0.04	--	3.48	--	--	--
Perfluoroheptyl Phosphonic Acid	PFOPA	40143-78-0	F(CF ₂) ₆ PO(OH) ₂	500.05	--	24.5	--	--	0.01	--	4.73	--	--	--
Perfluorooctyl Phosphonic Acid	PFOPA	52298-28-0	F(CF ₂) ₇ PO(OH) ₂	600.06	--	0.5	--	--	0.0002	--	5.98	--	--	--
Perfluorooctane Sulfonamide and Derivatives														
Perfluorooctane Sulfonamide	PFOSA	754-91-6	F(CF ₂) ₇ SO ₂ NH ₂	488.14	--	--	154 - 155	--	--	--	--	2.5 - 2.82	36 - 50	--
Perfluorooctane Sulfonamidethanol	FOSE	10118-92-4	F(CF ₂) ₇ SO ₂ NH(CH ₂) ₂ OH	543.19	--	0.0009	--	--	0.00	--	5.78	--	--	--
N-Methyl-Perfluorooctane Sulfonamide	N-MeFOSA	31506-32-8	F(CF ₂) ₇ SO ₂ NHCH ₃	513.17	--	0.0002	--	--	0.30	--	6.07	3.14	--	--
N-Ethyl-Perfluorooctane Sulfonamide	N-EFOSA	4151-50-2	F(CF ₂) ₇ SO ₂ NHCH ₂ CH ₃	527.20	--	0.0001	--	--	0.12	--	6.71	3.23	--	--
N-Methyl-Perfluorooctane Sulfonamidethanol	N-MeFOSE	24448-09-7	F(CF ₂) ₇ SO ₂ NH(CH ₂) ₂ OH	557.22	--	0.0003	--	--	0.0004	--	6.00	--	--	--
N-Ethyl-Perfluorooctane Sulfonamidethanol	N-EFOSE	1681-89-2	F(CF ₂) ₇ SO ₂ NHCH ₂ CH ₂ (CH ₂) ₂ OH	571.25	--	0.0001	55 - 60	--	0.002	--	6.52	--	--	--