



February 2023
Report No 4915/R/004/4

RUABON LANDFILL

HYDROGEOLOGICAL RISK ASSESSMENT

Prepared for

WRG Midlands Ltd

(FCC Environment (UK) Ltd)

TerraConsult
A BYRNELOOBY COMPANY

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Prepared By:

TerraConsult Ltd
(a ByrneLooby Company)
Suite 104
Mere Grange Business Park
St Helens
WA9 5GG
Telephone: 01925 291111
Facsimile: 01925 29119
E-mail: sthelens@ByrneLooby.com

DOCUMENT INFORMATION AND CONTROL SHEET

Document Status and Approval Schedule

Report No	Title
4915/R/004/4	RUABON LANDFILL HYDROGEOLOGICAL RISK ASSESSMENT

Issue History

Issue	Status	Date		Signature	Date
1	Draft	August 2020	**Prepared By:** Phil Scotney		12/08/20
			Checked By: Phil Roberts	Phil Roberts	12/08/20
			Authorised By: John Baxter		13/08/20
1	Final	July 2021	**Authorised By:** John Baxter		13/07/21
2	Final	August 2022	**Authorised By:** John Baxter		16/08/22
3	Final	December 2022	**Authorised By:** John Baxter		05/12/22
4	Final	February 2023	**Authorised By:** John Baxter		01/02/23

RUABON LANDFILL

HYDROGEOLOGICAL RISK ASSESSMENT

CONTENTS

DRAWINGS

1. INTRODUCTION

1.1 Report Context

TerraConsult Ltd (TCL) has prepared this Hydrogeological Risk Assessment (HRA) for the Ruabon Landfill site on behalf of the Operator WRG Midland Limited.

The Site is covered by two adjoining Waste Disposal Licences (WDL's); the associated permit reference numbers are BP3494FC (WMBC L50) and HP3694FJ (WMBC L82). This report provides the supplementary Hydrogeological Risk Assessment that supports the current variation for both permits to:

- Consolidate the current WDL's (Permits) into a single "*modern style*" Environmental Permit (with one boundary);
- Modification or justification to amend certain compliance limits (e.g. leachate levels);
- Rationalise the groundwater / surface water monitoring schedule for the Site;

The Site's Permits do not require a periodic review of the hydrogeological status, this document has been prepared to support the above and primarily assess the likely impact from leachate on the environment with an increased leachate head. The current leachate level limit is *"2m above base of well".* This limit does not appear to be risk based (report 4915/R/002/2).

This assessment has also rationalised the conceptualisation of the site and includes detailed discussion on the source-pathway-receptor relationship and presents a risk based approach to deriving sustainable leachate level compliance limits during the sites aftercare period. Several published documents and data sources have been consulted in the preparation of this review, a fundamental understanding is the role of the surrounding hydrogeological systems as a receptor.

The first section of this report will rationalise this understanding. The second section will outline the source – pathway – receptor framework and finally provide a supporting risk assessment in line with current guidance. There are potentially "two" water bearing systems at site:

- A superficial "upper water bearing system" and;
- Etruria Formation ("lower system").

1.2 Aquifer Classification and Regulatory Background

Online sources inform that the site is contained within a geological barrier (with a significant low permeability) with no associated connectivity to a receptor. The Etruria Formation (formerly Ruabon Marl) is a clay / mudstone which in some areas of the UK may contain water bearing sandstone "Espley" layers or lenses. No such layers have been identified at Ruabon from the available information.

Notwithstanding the above, the following pertinent points are detailed for clarity:

- The site is engineered and contained within a geological barrier (clay pit);
- There is no confirmed or documented pathway;
- No justifiable receptor has been identified (that is linked by a pathway);
    - A 2m leachate head compliance limit has been applied within a ~40m deep clay excavation, this limit appears misplaced.

As such, as part of the review the role of a credible receptor has been undertaken.

A fundamental point is the applicability of the geological / hydrogeological system and its potential, and or fulfilment in the role as an "aquifer".

Clay pits, (in this case for tile and or brickmaking) are seldom located in areas defined as "aquifers", typically they are defined as non-productive strata as little (if any) water can be drawn from the formation even if pore-waters are recorded within environmental monitoring installations. As such, this review starts by introducing key parametrisation that underpins the regulatory framework regarding this matter.

- The upper water bearing system has the current aquifer classification of;
  - Secondary Undifferentiated (Glacial Till – Majority of Site periphery)
  - Secondary A (Fluvio-glacial deposits – partial contact with northeast site periphery)
- The lower water bearing system has the current aquifer classification of;
  - Secondary A (Etruria Formation Marl)

1.2.1 Classification of Water Resources

The classification of water resources is determined by the terminology and objectives of the Water Framework Directive. This directive was adopted with the specific purpose of establishing a framework for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater bodies. It will ensure that all aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands meet 'good status' by 2015.

With regards to groundwater, Article 7 (of 2000/60/EC) states that for *"Waters used for the abstraction of drinking water"*

1. Member States shall identify, within each river basin district:

- all bodies of water used for the abstraction of water intended for human consumption providing more than 10m^3 a day as an average or serving more than 50 persons, and
- those bodies of water intended for such future use.

Member states shall monitor, in accordance with Annex V, those bodies of water which according to Annex V, provide more than 100m^3 a day as an average.

Annex III (assessment of groundwater chemical status) of the Groundwater Daughter Directive (Directive 2006/118/EC) also states in Paragraph 4

4. For the purposes of investigating whether the conditions for good groundwater chemical status referred to in Article 4 (2)(c)(ii) and (iii) are met, Member States will, where relevant and necessary, and on the basis of relevant monitoring results and **of a suitable conceptual model of the body of groundwater, assess**:

   (a) the impact of the pollutants in the body of groundwater;

   (b) **the amounts and the concentrations of the pollutants being, or likely to be, transferred from the body of groundwater to the associated surface waters or directly dependent terrestrial ecosystems;**

(c) **the likely impact of the amounts and concentrations of the pollutants transferred to the associated surface waters and directly dependent terrestrial ecosystems;**

(d) the extent of any saline or other intrusions into the body of groundwater; and

(e) **the risk from pollutants in the body of groundwater to the quality of water abstracted, or intended to be abstracted, from the body of groundwater for human consumption.**

1.2.2 Chemical Status

Groundwater is considered to have a good chemical status when:

- measured or predicted nitrate levels do not exceed 50mg/l, while those of active pesticide ingredients, their metabolites and reaction products do not exceed 0.1µg/l (a total of 0.5µg/l for all pesticides measured);
- the levels of certain high-risk substances are below the threshold values set by Member States; at the very least, this must include ammonium, arsenic, cadmium, chloride, lead, mercury, sulphate, trichloroethylene and tetrachloroethylene;
- the concentration of any other pollutants conforms to the definition of good chemical status as set out in Annex V to the Water Framework Directive;
- if a value set as a quality standard or a threshold value is exceeded, **an investigation confirms, among other things, that this does not pose a significant environmental risk.**

1.2.3 Aquifer Classification

The Water Framework Directive (WFD) also defines an "aquifer" as

> "*a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater".*

and defines a "Body of groundwater" as

> "*a distinct volume of groundwater within an aquifer"*

The directive therefor quantifies an aquifer as a rock bearing a sustainable useable quantity of water in excess of 10m^3/d on average. The Environment Agency has further classified the status of an aquifer into Principal and Secondary Aquifers defined as:

Principal Aquifers: These are layers of rock or drift deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. In most cases, principal aquifers are aquifers previously designated as a major aquifer.

Secondary Aquifers include a wide range of rock layers or drift deposits with an equally wide range of water permeability and storage. Secondary aquifers are subdivided into two types:

- **Secondary A** - permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers;

- **Secondary B -** predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. **These are generally the water-bearing parts of the former non-aquifers.**

There is a third type of rock classification "Unproductive Strata". These are rock layers or superficial deposits with low permeability that have negligible significance for water supply or for river base flow.

In regard to Ruabon, a Secondary A bedrock designation does not fit the site description of "a clay pit" that was operated "dry".

The available Site borehole logs and surrounding literature records support the lack of water within the geological barrier (marl), consistent with BGS / Environment Agency descriptions within the "Physical Properties of Minor Aquifer in England and Wales (2000)" R&D publication 68[1].

The classification exercise undertaken for the purposes of the WFD was based on a simple assumption presented by the Environment Agency to the British Geological Survey (BGS) that rocks characterised as mudstones are unproductive strata and that all other strata (including potentially permeable bands and lenses) are classified as an aquifer, and hence considered as a high priority receptor within risk assessment irrespective of whether there is a viable sustainable recharge or not.

As a first stage high level screening exercise this is a useful starting point to focus on the key water resource strata and ensuring that important baseflow contributors to the surface water ecosystems are identified.

With regards to the aquifer status, the WFD defines two criteria, namely a requirement to monitor those bodies which provide more than 100m^3/day as well as bodies of water used for the sustained abstraction of more than 10m^3 a day as an average. These abstraction figures therefore provide a benchmark or threshold for assessing and classifying aquifers as either Principal or Secondary Aquifers.

Where there is the requirement for site specific clarification is associated with how a water body is assessed when sustainable recharge rates approach or are below 10m^3/day, but do not have a geological description as a mudstone. Under this condition, the groundwater resource value cannot be associated with abstraction, as there is clearly too little recharge to sustain abstraction. However, this does not prevent a need to assess such a geological strata as a pathway towards either a more permeable strata or its net base-flow contribution to surface water. With regards to the site there is no connectivity between the Etruria Marl and baseflow fed surface water system (Report 4915/R/002/2).

1.3 Site Location & Operation

The Site is located directly northwest of Ruabon and is approximately 7.5km southwest of Wrexham. The Site is a non-operational (Closed) non-hazardous landfill which ceased to accept wastes for disposal in 1997. Restoration of the surface profile was undertaken in 1999 and 2000. The capped area of Site is calculated at ~11.5 hectare.

[1] Physical Properties of Minor Aquifer in England and Wales (2000)" R&D publication 68. Jones, H K, Morris, B L, Cheney, C S, Brewerton, L J, Merrin, P D, Lewis, M A, MacDonald, A M, Coleby, L M, Talbot, J C, McKenzie, A A, Bird, M J, Cunningham, J, and Robinson, V K. 2000.

1.3.1 Historical Land Use & Topography

The landfill is in a former clay / marl quarry (BGS designated “mudstone”) located in area of extensive quarrying and mining which began locally in the late 1800’s.

Details available at http://industrialgwent.co.uk/g61-northwales/index.htm#ruabon indicate that the Site was the former “Tatham” Brickworks between 1874 and 1912, closing sometime in the 1940’s. The 1912 map extract indicates that the surface water pond to the north of the landfill and Monks Pool are both previously excavated voids associated with the works.

Borehole logs available at https://mapapps.bgs.ac.uk/geologyofbritain/home.html indicate that the Gardden Lodge Colliery was located to the northwest of the site, the current location of the Gardden Industrial Estate.

The topography of the area influences the drainage pattern and associated surface water systems, the closest river to Site, located to the south is the Eitha (flowing easterly / south-easterly). To the north east, and east of the A483 is the Black Brook (Clywedog).

Ground levels at Site are ~117mAOD in the northeast and 118mAOD in the north, 113 – 114mAOD on the east boundary near to a small surface water lagoon. At ~116mAOD at the south-eastern corner of Site, ground levels rise steadily to ~137mAOD in the south west. Levels on the western perimeter range between 137 – 134mAOD before falling to ~116mAOD at the Site access / gas compound (infrastructure is detailed on drawing 478M028A).

The monitoring drawing has been updated during the determination process to 478M035.

Surrounding Land use is presented in the accompanying ESID (4915/R/002/2).

2. SOURCE TERM

2.1 General Engineering

The Site has been developed within a "clay pit", key engineering details where available are summarised in Table 1.

Table 1 Engineering Design Summary & associated details

Installation Variable	**WMBC L50** BP3494FC	**WMBC L82 - Extension** HP3694FJ
Site Phasing	Specific Cell / Phase details unknown	Specific Cell / Phase details unknown, the 2019 Annual Monitoring Review states this area comprises of Cell 10 and 11
Liner Specification	Base: 1m engineered clay (1.0 x 10^{-9} m/s) + in-situ basal Ruabon Marl (Etruria Formation) Sidewall: 1m engineered clay (1.0 x 10^{-9} m/s) + in-situ basal Ruabon Marl (Etruria Formation)	
Base elevation	Range: 105 – 110mAOD Deepest: 105mAOD (dwg 478B002_4300/ 4) [central area southern boundary of area]	Range: 92 – 98mAOD Deepest: 92mAOD (dwg 478B002_4300/ 4) [southeast area southern boundary of area] – base of GWM10 currently at 97mAOD
Capping Specification	1m engineered clay (1.0 x 10^{-9} m/s) – minimum design and licence standard	
Waste thickness	Max ~ 25m (near GWM 6) (dwg 478B002_4300/4 and 478G009_6116 /2) See also drawing 428B026	Max ~ 34m (near GWM10) (dwg 478B002_4300/4 and 478G009_6116 /2) See also drawing 428B026
Wastes Types Received	Mines / quarry waste, construction, demolition, excavation wastes, household and commercial wastes and asbestos	
Leachate Management	Recirculation as required or disposal to sewer with vertical abstraction wells. No basal collection / drainage system known. The "GW M" series wells in the waste mass pump to a leachate tank. Leachate recirculation trenches (filled with non-calcareous stone) are connected to leachate dispersal array network trenches / pipes. Current management is "offsite" disposal.	

Basal elevations also shown on WRG drawing 428B026 (2011, Plan 12) & 478B002_4300/ 4 (2002)

Although referred to within previous working plans, it is understood that reference to "phasing" included areas of restoration, clay extraction and infilling operations. Phasing hence did not necessarily relate to "phased" areas or specific "Cell" areas. The referenced drawings GP – EDA series[2] are not available for review. Although the working plan indicates that both leachate and gas wells are to be progressively constructed as tipping proceeds.

The working plan for "Closed Site Operations" however details that Cell 11 was the largest at Site, and the only one with an engineered collection network[3] (spine drains only).

For conservatism, the Site will be considered as one, single hydraulic Cell (and judged against adjacent groundwater levels) as a hydraulically contained Site.

[2] Shanks & McEwan Northern Ltd (Section 12) Site Extension Working Plan
[3] Shanks Waste Services Ltd. Working Plan for Closed Site Operations ("Agreed" December 2001)

2.2 Leachate Infrastructure

As described in the associated ESID, the current environmental monitoring plan details the positions of the leachate infrastructure (see drawing 478M028A EMP). There is no longer any recirculation across this Site, leachate is pumped / removed and tankered to a treatment facility. The most recent Annual Monitoring Review[4] and Closed Site Working Plan[3] detail 10 monitoring points, namely:

- GW(M1), GW(M3), GW(M4), GW(M5), GW(M10), LMP(2), LMP(6), LMP(7), LMP(8), LMP(9)

Leachate levels are monitored monthly (Condition I.4 of the Closed Site Working Plan); leachate quality is monitored on a quarterly basis from 1 location – the leachate eductor tank.

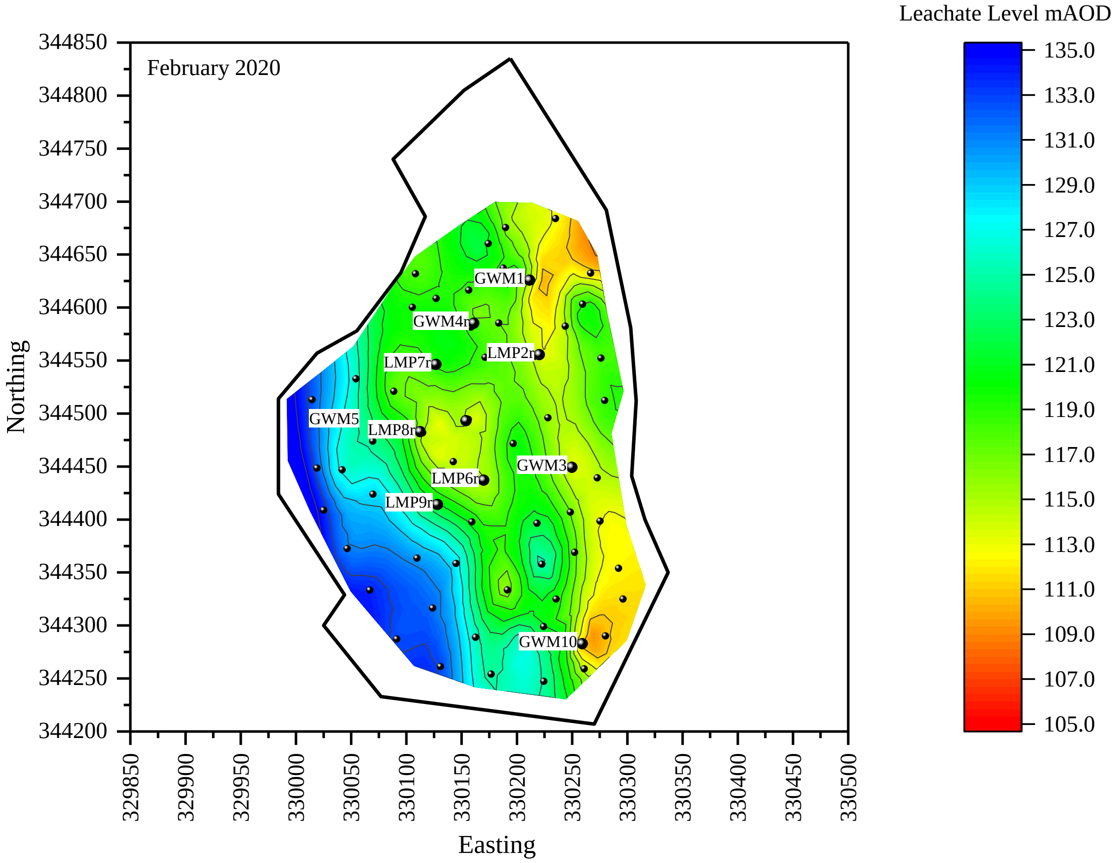
2.3 Leachate Distribution

The distribution of leachate within the Site has been characterised by analysis of the recording dip to leachate monitoring data from installed monitoring points and also gas infrastructure.

Highest levels are apparent on the western perimeter ~ 133 – 135mAD which are coincident with the increase in ground surface / topography compared to the east. Overall, a large proportion of the Site has a saturated waste leachate level of ~117mAOD or above (see the ESID for further details and Figure 1).

There are no reported occurrences of leachate outbreaks or seepages.

Figure 1 Leachate Elevation Contour Plot (Feb 2020)



[4] Annual Monitoring Review, FCC Environment 2019

2.4 Leachate Volume

The cap area of 11.5ha will generate 14m^3/day (based on 44mm/yr infiltration, a 1.5m clay cap compacted to a hydraulic conductivity of at least 1x10^{-9}m/s and 0.6m permanent saturated head). A cap placed at a thickness of 1.5m on average is however expected to limit infiltration further, an order of magnitude reduction in permeability reduces seepage rate by an order of magnitude which would reduce the leachate volume generated to 1.4m^3/day.

Groundwater influx cannot be ruled out however it is understood that where excavation pre landfilling required groundwater management, this engineering precaution was accounted for by the installation of cut-off drains around the site perimeter.

2.5 Leachate Levels

Leachate levels are monitored at 10 locations within the waste, the permits state measurements should be taken prior to any pumping / purging. Leachate levels were typically compliant with the 2m head limit between June 2013 and August 2019, recent levels are presented in Table 2 (represented as meters above base of well).

Table 2 Leachate level recent average (m)

Monitoring point	West				Central			North	East	Extension
	GWM4r	GWM7r	GWM8r	GWM9r	LMP2r	GWM5	LMP6r	GWM1	GWM3	GWM10
09/19 – 06/20	5.20	6.71	5.84	10.14	*3.42	4.64	*2.62	*1.58	*1.47	9.48
12/18 – 08/19	1.35	1.41	<1	1.73	1.06	1.41	1.56	1.10	1.46	<1

Borehole locations identified on the monitoring plan (drawing 478M028A)
Data for GWM8r and GWM10 <1m under recirculation
*GWM1, GWM3, LMP2r, LMP6r– not monitored since April 2020

2.6 Leachate Management

Leachate has primarily been managed by recirculation; current management is direct disposal via off-site tankering.

2.7 Leachate Quality

The leachate chemistry is monitored from the educator tank only (LT01). The leachate is consistent with that expected for a municipal non-hazardous landfill receiving domestic, industrial and commercial wastes *i.e.* the leachate is a sodium-bicarbonate-chloride solution containing elevated ammoniacal-N, chloride and potassium compared with terrestrial waters.

The composition can be categorised into a series of sub-groups, namely:

- Matrix salts including sodium (Na), Potassium (K), Calcium (Ca), magnesium (Mg), Chloride (Cl), Sulphate (SO_4) and alkalinity which are non-toxic, but could potentially increase salinity levels above typical terrestrial water concentrations and exceed drinking water standards (DWS) or Environmental Quality Standards (EQS);
- Secondary organic degradation products, including ammonium, and dissolved organic matter (as represented by BOD, COD and TOC). Of these, ammoniacal-N (NH_4-N) is toxic at high concentrations, whereas elevated BOD can cause oxygen depletion and eutrophication in surface water bodies;
- The redox sensitive metals iron (Fe) and manganese (Mn) are common metals that are insoluble under oxidising and strongly anaerobic conditions but soluble under anoxic (iron and manganese reducing) conditions. In leachates these are usually in a colloidal form that can be physically filtered by the liner;

- Priority metals including chromium (Cr), copper (Cu), nickel (Ni), zinc (Zn) and lead (Pb) form the largest potential component of persistent pollutants within wastes and any resulting leachate;
- The hazardous metal mercury (Hg) and non-hazardous metal cadmium are rarely present and where identified, approximate to the detection limit;
- Specific biodegradation and hydrolysis products formed during site stabilisation such as the phenols and substituted BTEX compounds; and
- Small to negligible quantities of hazardous and non-hazardous organic compounds, which are primary components of the deposited materials.

The available data however does not include information to assess the recalcitrant organic matter (i.e. dissolved organics/fatty acids, inorganics and aromatics).

It is noted however that up until early 2019, all leachate at site was recirculated which is reflected in the marginal decrease in source term concentrations over the past 15 years and potentially accounts for limited infiltration. Chloride concentrations have reduced from ~4000 – 3000mg/l to 3000 – 2000 mg/l; ammoniacal-N from ~1500mg/l to ~1000mg/l and potassium from ~900 to 700mg/l (Figure 2).

Table 3 presents statistical maximum and average concentrations for the period 2014 – 2020. Calcium, magnesium and sulphate are low compared to potassium and sodium ions.

In regard to the priority metals typically present in landfill leachate, Cd, Cr, Cu, Ni, Zn and Pb concentrations are presented in Figure 3. Outlier concentrations can skew statistical interpretations, however where obvious outliers are evident they have been omitted from the interpretations.

Figure 2 Leachate NH4-N, chloride and potassium time series (mg/l)

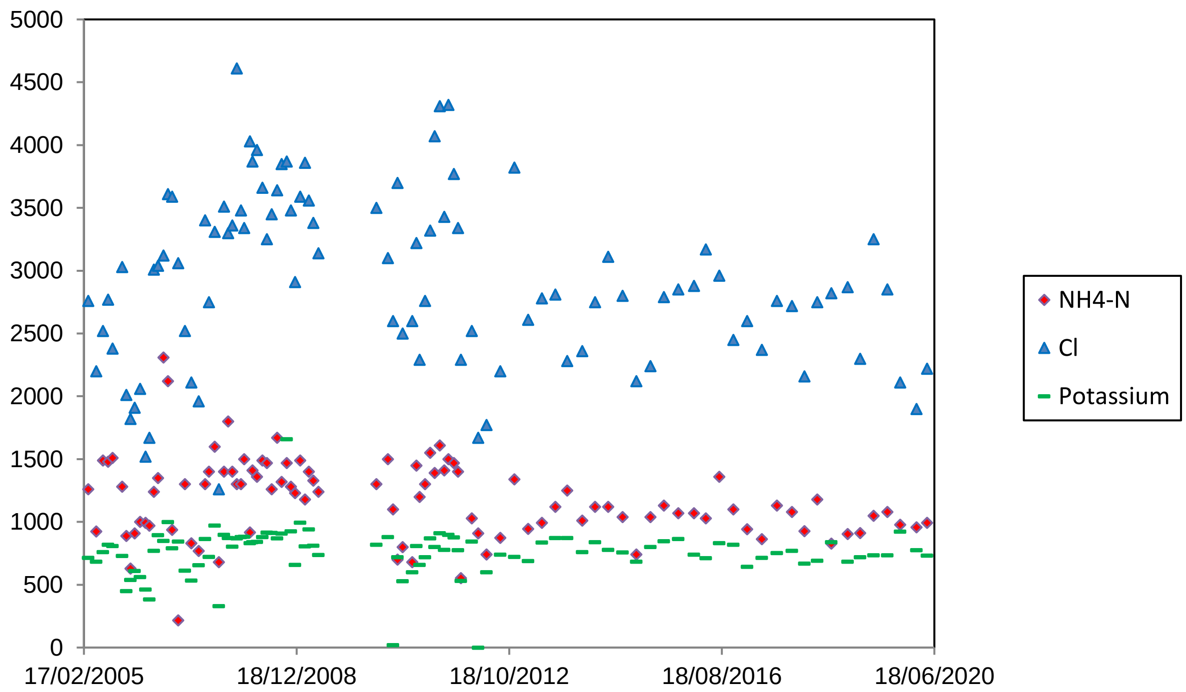


Table 3 Leachate matrix ions LT01, max and average, 2014-2020

Monitoring point	EC µS/cm	NH_4-N mg/l	Cl mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	TOC mg/l	SO_4 mg/l	Alk mg/l
Max	23,500	1,360	3,250	110	123	2,690	925	970	132	9,000
Average	18,864	1,025	2,632	88	107	2,230	763	673	99	6,698

A clear observation within the data is that the Cd and Pb data plot at the recent detection limits of <0.001 and <0.01mg/l respectively. A statistical summary of metal concentrations are provided in Table 4.

Figure 3 Priority Metals Present within the Leachate (mg/l)

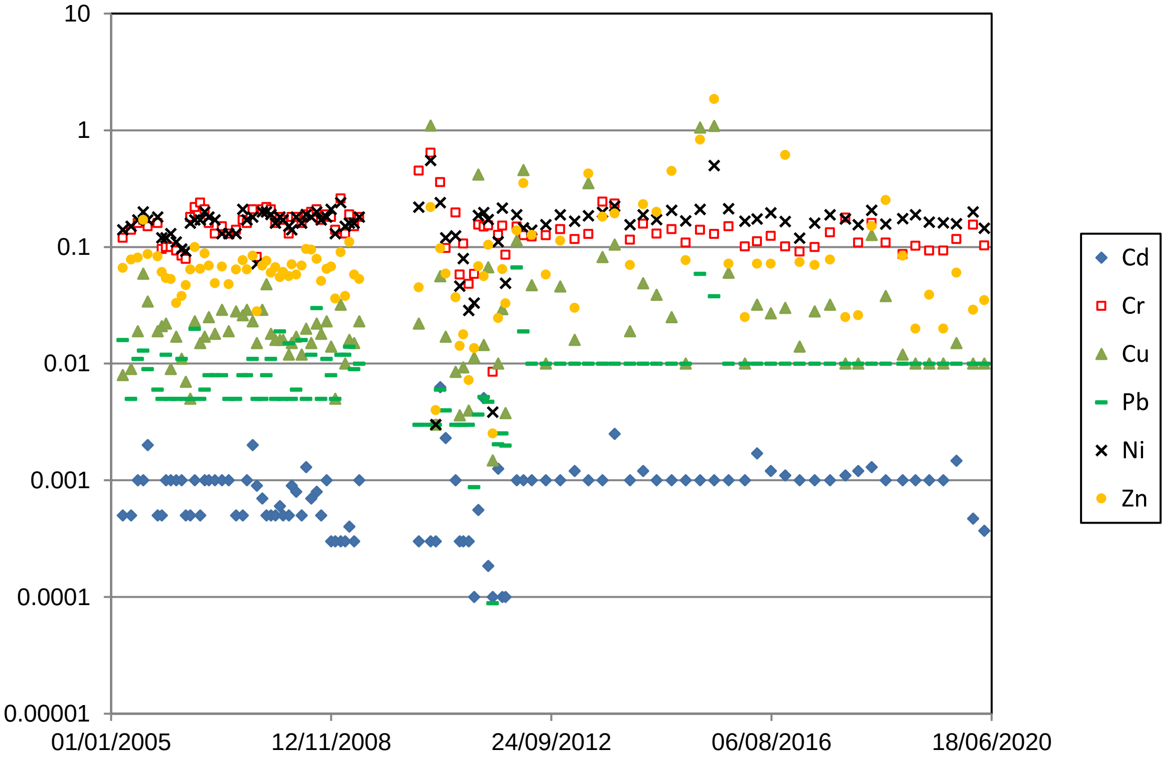


Table 4 Leachate Metals max, min and average, 2014-2020 (mg/l)

	Cd	Cr	Cu	Pb	Ni	Zn	Fe	Mn
Max	0.0017	0.178	1.09	0.059	0.498	1.847	8.70	0.27
Average	0.0011	0.121	0.15	0.049	0.188	0.235	7.06	0.21
Min	<0.0001	0.087	<0.01	<0.01	0.119	<0.02	4.46	0.16
Count	*11*	*25*	*18*	*2*	*25*	*23*	*25*	*16*
DWS	**0.005**	**0.05**	**2**	**0.01**	**0.02**	**5**	**0.2**	**0.05**

Only 2 positive detections for Pb, Green shaded cells exceed the DWS
from -http://www.legislation.gov.uk/uksi/2016/614/pdfs/uksi_20160614_en.pdf page 38; Fe & Mn "at consumer's taps"

The metals Cr (non-hazardous) and Pb (hazardous) are recorded at average concentrations of 0.12 and 0.05mg/l respectively (2014-2020 data) albeit 88% of the Pb data (2012-2020) is reported at detection limit of <0.01mg/l. The average concentration of Cr and Pb are greater than their respective DWS concentrations however Pb is not apparently persistent in the source term.

Where Cd is observed (non-hazardous), concentrations are at or below the 0.005mg/l DWS, with average concentrations of 0.001mg/l. However, most of the recent data (2012-2020, 60%) plots at the reported detection limit of <0.001mg/l. Cd is not persistent in the source term and average concentrations are < than DWS.

The priority metals, (non-hazardous pollutants) Cu, Ni and Zn are present typically between 0.01-0.12mg/l; 0.11-0.23mg/l and 0.02-0.25mg/l (2014-2020). Average concentrations for Cu and Zn are 0.15g/l, and 0.24mg/l respectively which are less than respective DWS concentrations of 2mg/l and 5mg/l. Cu and Zn are not at environmentally significant concentrations within the source term. The average Ni concentration of 0.18mg/l is greater than the DWS of 0.02mg/l.

There are also two redox sensitive metals present within the leachate, namely Fe and Mn. Although iron concentrations are apparently elevated into the 4-9mg/l range, Fe in this concentration range in methanogenic leachates is primarily present as a colloidal form and not a dissolved form. Consequently, this non-dissolved phase will be physically filtered by the clay / marl mineral containment barriers and it would not be available for seepage through the base of the site. There is no requirement to undertake a hazardous organic screen as per the requirement of the permits (typically undertaken for a combination of hazardous and non-hazardous substances) hence no further information is available to characterise the source term.

2.8 Source Term Summary

The leachate is a sodium-bicarbonate-chloride solution which contains elevated ammoniacal-N and potassium compared to most terrestrial waters. The composition across the site is consistent with expectations for a non-hazardous landfill site which previously accepted household, commercial and industrial waste streams.

Substances considered appropriate in regard to quantitative modelling (based on the source term data available) include NH4-N, chloride and Ni.

3. PATHWAYS

3.1 Geology and Hydrogeology – Overview and Ground Condition

The site is a former clay quarry, which was operated dry and exploited the Etruria Formation Marl. This marl was present below glacial sediments. It is understood that groundwater management was required around the periphery of the Site to exclude groundwater ingress into the void from the upper water bearing system. Details are limited however it is understood that a perimeter drain was installed around the southern and south-eastern perimeter (to a depth of 10m).

Prior to landfilling there was some disturbance of the ground, particularly around the periphery associated with mineral extraction and railway line development. Made Ground is locally reported as present within a number of investigation borehole logs (e.g. GBH4) reported as "*dark reddish brown, firm stiff silty clay + clast, brick frag and sandy patches*" consistent with overburden from the historical quarry operations.

A detailed description of the site geology is provided within the ESID report, key aspects are presented below and discussed in terms of the hydrogeological setting implications.

The surrounding geological sequence comprises:
Superficial Glacial Till, glacial sand and gravel, river terrace deposits and river alluvium:

1. Glacial Till – clay dominated (at site)
2. Glacial sand and gravel (south and east of site)
3. River terrace deposits – sand and gravel (west of site)
4. Alluvium – follows Eitha river and Black Brook (west and northeast)

The underlying geological sequence comprises:

Bedrock Strata:

1. Warwickshire Group – (Halesowen Formation) Mudstone, Siltstone, Sandstone (east 1km from site)
2. Etruria Formation – Marl (at site)
3. Pennine Lower Coal Measures and Pennine Middle Coal Measure undifferentiated – Mudstone, Siltstone and Sandstone (west)
4. Cefn Rock – Sandstone member within the coal measures (west and southwest)
5. Millstone Grit Group (west)

3.2 Superficial Geology

Made ground is present in most of the perimeter boreholes as the topmost superficial material. The made ground varies from 0-2.6m in thickness, and typically consists of dark red/brown/black sand and clay with brick fragments.

The borehole logs for the perimeter boreholes indicate a thickness for the glacial till of up to 10m, with an average of between 6-8m. There appears to be a large variance in grain size and distribution within the glacial till, indicating it is highly heterogeneous. There are no horizons within the glacial till that can be correlated between boreholes, indicating that any lenses are of limited areal extent and potentially unconnected to other lenses.

3.3 Bedrock Geology

The site is located within "marine / alluvial plain facies clay" bedrock known as the Etruria Formation formerly referred to as the Etruria Group or Etruria Marl[5]. This is a geological barrier.

The BGS description is a "*red, purple, brown, ochreous, green, grey and commonly mottled mudstone, with lenticular sandstones and conglomerates referred to as 'espleys'.*" The sandstones (if present) are discontinuous and form "wedges" within the marl.

None of the perimeter borehole extend through the Etruria Formation marl, therefore the thickness directly beneath the site cannot be ascertained from these boreholes. The deepest perimeter borehole is WB17 (location unknown), which indicates there is a minimum thickness of 14m of Etruria Formation marl adjacent to the Site boundary, drawing 478B002_4300-4 indicates however that the excavation extended to depths of ~92mAOD.

BGS borehole log SJ34SW8 is located approximately 100m to the northwest of the site, extends to a depth of ~225m, and indicates the Etruria Formation marl basal contact is ~43m below ground level at ~79mAOD.

The adjacent BGS borehole log SJ34SW9 indicates base of Etruria Formation at ~65mAOD. The disparity may be attributed to fault offset near the contact between with the Coal Measures strata. Conservatively there is ~13m of Etruria Formation beneath the Site as a minimum (deepest part of excavation at ~92mAOD).

With the majority of leachate wells base levels at ~110mAOD on average, it indicates that the majority of the site is underlain by a Etruria Formation thickness of ~31m.

The boundary between the top of the Etruria Formation marl and the overlying glacial till is described here as the rockhead level. The rockhead surface is ~125mAOD on the west falling to ~110mAOD on the east, consistent with borehole log information. The rockhead is not expected to be strictly planar however the fall in elevation to the east is also consistent with overall topography.

3.4 Hydrogeology

Groundwater monitoring is undertaken within the Etruria Formation (within deeper monitoring installations) around the site's periphery, monitoring water level and chemistry within a geological barrier appears misplaced. Monitoring is also undertaken in the shallower superficial (glacial) deposits.

As a result of the faulted geological relationships juxtaposing mudstones / coal seam against the marl (to the west) and Halesowen Formation (to the east, ~1km) it is conceptualised that the site is hydrogeologically separate from the surrounding strata.

It is the dominance of the mudstone/marl units that led to the BGS describing the Etruria Marl in The Physical Properties of Minor Aquifers in England and Wales[6] as being "poorly productive".

[5] Origin of red beds in a moist tropical climate (Etruria Formation, Upper Carboniferous, UK) B. M. Besly and P. Turner Geological Society, London, Special Publications, 11, 131-147, 1 January 1983
[6] Jones, H K, Morris, B L, Cheney, C S, Brewerton, L J, Merrin, P D, Lewis, M A, MacDonald, A M, Coleby, L M, Talbot, J C, McKenzie, A A, Bird, M J, Cunningham, J, and Robinson, V K. 2000. The physical properties of minor aquifers in England and Wales. British Geological Survey Technical Report, WD/00/4. 234pp. Environment Agency R&D Publication 68.

This BGS review, described the Etruria Marl as being composed predominantly of impermeable argillaceous rocks and "yields little or no water". Fractures in the 'espley' rocks, however, can yield moderate quantities of water suitable for small-scale agricultural or industrial requirements (Downing et al., 1970; Barrow et al., 1919). Although the 'espley' rocks are generally well cemented, in south Staffordshire they often have a more sandy and porous matrix and may yield a good supply[1].

The BGS report goes on to state *"Many sandstones and some limestones, particularly those of Westphalian age, are local developments and not laterally persistent. In some cases thick localised sandstones have an extensive outcrop area through which recharge can occur but thin rapidly down dip and yield little or no groundwater at depth. Where the aquifer horizon has an outcrop area of limited extent, recharge may be insufficient to sustain initially high yields, which decline with time as storage is depleted".*

At Site, there is no evidence of sandstone units outcropping at the surface (or espley lenses at depth throughout the profile), and any surface outcrop is limited in extent due to the faulted offsets to the west and east. Therefore any higher permeable unit within the Etruria sequence (if present) would fall under the characterisation of "*insufficient to sustain initially high yields".*

Groundwater flow within the Etruria Formation is conceptualised as being limited to the non-mudstone units (reported in some literature accounts elsewhere in the UK) and therefore when present the hydraulic flux is likely to be limited.

However, the evidence provided from Site borehole logs indicates that no groundwater strikes were recorded in either of the two site boreholes (WB17 and GBH4) drilled throughout the "silty clay" referenced sequence.

Geological sequences with the capability of water transmission will yield on penetration, hence the Site detail is consistent with BGS accounts for the majority of the Etruria Formation in that the marl is not water bearing. Additionally, the drilling logs do not record any "layers" or "lenses" that could be attributed to Espleys. It is therefore considered highly unlikely that a laterally persistent water bearing layer (or water bearing lenses) is present at Site.

The monitoring data however indicates that there is a general hydraulic gradient (pore-water) from west to east, this piezometric surface falls with topography. The lack of clear seasonality indicates no induced variance through surficial or lateral recharge mechanisms and confirms BGS stratigraphic descriptions. Local mapping indicates a moderate dip of ~20º to the east, hence if any permeable layers were present they would be juxtaposed against the first associated fault to the east of the site (beyond the A483) and hence lateral linkages in an easterly direction would by offset further.

The "upper" water bearing system are glacial superficial deposits are variable nature, and also variable in thickness hence hydraulic characteristics will be variable. The ESID has also established that the water table flows from the west to the east / northeast. As the excavated Site extends below the base of the Glacial strata, all water flow within this upper system is around the periphery of the Site whereby water levels also reduce from ~130mAOD at BH3A to ~111mAOD at BH2A.

Variance is likely and based on the differentiation between glacial till and fluvio-glacial deposits, the latter of which is only tentatively linked to the Site periphery (see further detail at Section 4.1).

3.5 Potential Linkages & Pathway Properties

The BGS available data (in addition to Site information detailed in the supporting ESID) provides the following key detail:

Southern boundary

- Etruria Formation Marl at depth, rockhead profile reduces from west to east (~125mAOD to 110mAOD);
- No espleys or water bearing layers / lenses present;
- Glacial materials are entirely comprised of "Till"
- Glacial till thickness up to 5.7m

Western boundary

- Etruria Formation Marl at depth, rockhead profile at ~125mAOD;
- No espleys or water bearing layers / lenses present;
- Glacial materials are entirely comprised of "Till"
- Glacial till thickness between 2.8 to 7.8m

Northern boundary

- Etruria Formation Marl at depth, rockhead profile reduces from west to east (~125mAOD to 110mAOD);
- No espleys or water bearing layers / lenses present;
- Glacial materials are entirely comprised of "Till"
- Glacial till thickness up to 10m (BGS data)

Eastern boundary

- Etruria Formation Marl at depth, rockhead profile at ~110mAOD;
- No espleys or water bearing layers / lenses present;
- Glacial materials are entirely comprised of "Till" (north east area opposite Newell Drive and south of the Railway intersection with the B5605);
- Limited, if any contact with Fluvio-glacial material in the central area of the eastern boundary opposite Garrden View;
- Fluvio-Glacial thickness up to 8.1m
- Glacial till thickness up to 8.4m
    - *See figure 4 for named locations*

Basal Linkages

There are no confirmed basal linkages or underlying water bearing sequences. Below the Site, the geological barrier extends (as a minimum) to a thickness of 13m prior to the presence of the Coal Measures Strata at depth.

Sidewall Linkages

The detail described above assists in the understanding of potential relationships across the sidewall liner, according to the Sites permits the sidewalls were shaped at no greater than 60º with 1m of marl at $1x10^{-9}$m/s. There are no confirmed water bearing layers / lenses or espleys within the geological barrier that provide a link to any lateral water bearing geological formations.

There are no confirmed lateral linkages to any surface water features, or potential for base-flow contributions to surface water features.

The uppermost section of sidewall (~10m to surface) is adjacent to glacial till around the majority of the Site perimeter. Glacial Till is predominantly clay dominated and typically low in bulk permeability.

A 65m lateral section of fluvio-glacial strata is recorded on the superficial aquifer map (https://maps.cyfoethnaturiolcymru.gov.uk/) in the vicinity between monitoring boreholes BH3A/3B and BH4A/4B (drawing 478M028A). This small, arcuate section of glacial strata extends to the southeast (see also Figure 27 in the supporting ESID) whereby it increases in spatial distribution to the east (see Figure 4) and potentially links to mapped "alluvial deposits".

Seepages may link to the drain which in turn may link to Afon Goch prior to merging with Black Brook in the area of the A483 (Section 4.1). The length of the drain linkage to the Afon Goch is ~670m.

Properties

The Etruria Formation Marl is effectively a dual property unit, that can provide a range of hydraulic properties.

However, with no "permeable" layers present at site, the in-situ mudstone / marl is expected to be characterised by a low hydraulic conductivity. Waine *et al*.,[7] state that the Etruria Formation (lower section of the sidewall liner) is composed of firm to very stiff clayey material for the undisturbed bedrock. Equally, they describe the weathered Etruria Formation marl as having weathered to a stiff to very stiff silty, calcareous clay. This indicates that the *in-situ* Etruria Formation marl is likely to have very low permeability.

The Etruria Formation is a natural geological barrier.

Waine *et al*.,[7] also state that the glacial till is heterogeneous and therefore poorly sorted, with fragment sizes ranging from clay to boulders. The borehole logs indicate that around the perimeter of the site there is an average of between 6-8m of glacial till, which will provide a low permeability barrier around the Site. Any sand and gravel lenses within the glacial till are expected to be discontinuous and therefore will not provide pathways for flow towards or away from the site. There are no Site permeability or hydraulic test results available.

The drilling log for BH2C is in the area mapped are by BGS as being representative of fluvio-glacial material, the 6.2m of strata however are variable in nature (heterogeneous) with a 0.9m thick sandier lens between 5.4 and 6.5mbgl.

There is less variability noted in the log for the nearby GBH1 (also in this sequence) and the sand lens is absent. Moving to the south the thickness of glacial material reduces (from ~6 - 7m) to ~3 – 4.5m at GBH3 with a greater degree of sand and less clasts. The adjacent GBH4 however indicates greater variability (and increased proportion of clasts) and a large boulder at rockhead, glacial strata at GBH5 and GBH6 towards the south eastern site boundary are ~6m in thickness and 1.4m of made ground is noted on the drilling log for GBH6 which is located south of the south eastern corner. Borehole logs on the western boundary (GBH7, 9 and 10) are just as variable as those described on the east.

The available information supports literature accounts noted above.

[7] Waine et al., 1990, Engineering Geology of the Wrexham Area. BGS report number WN/90/10

4. RECEPTORS

4.1 Groundwater and associated Levels

There are “potentially” two water bearing systems at Site.

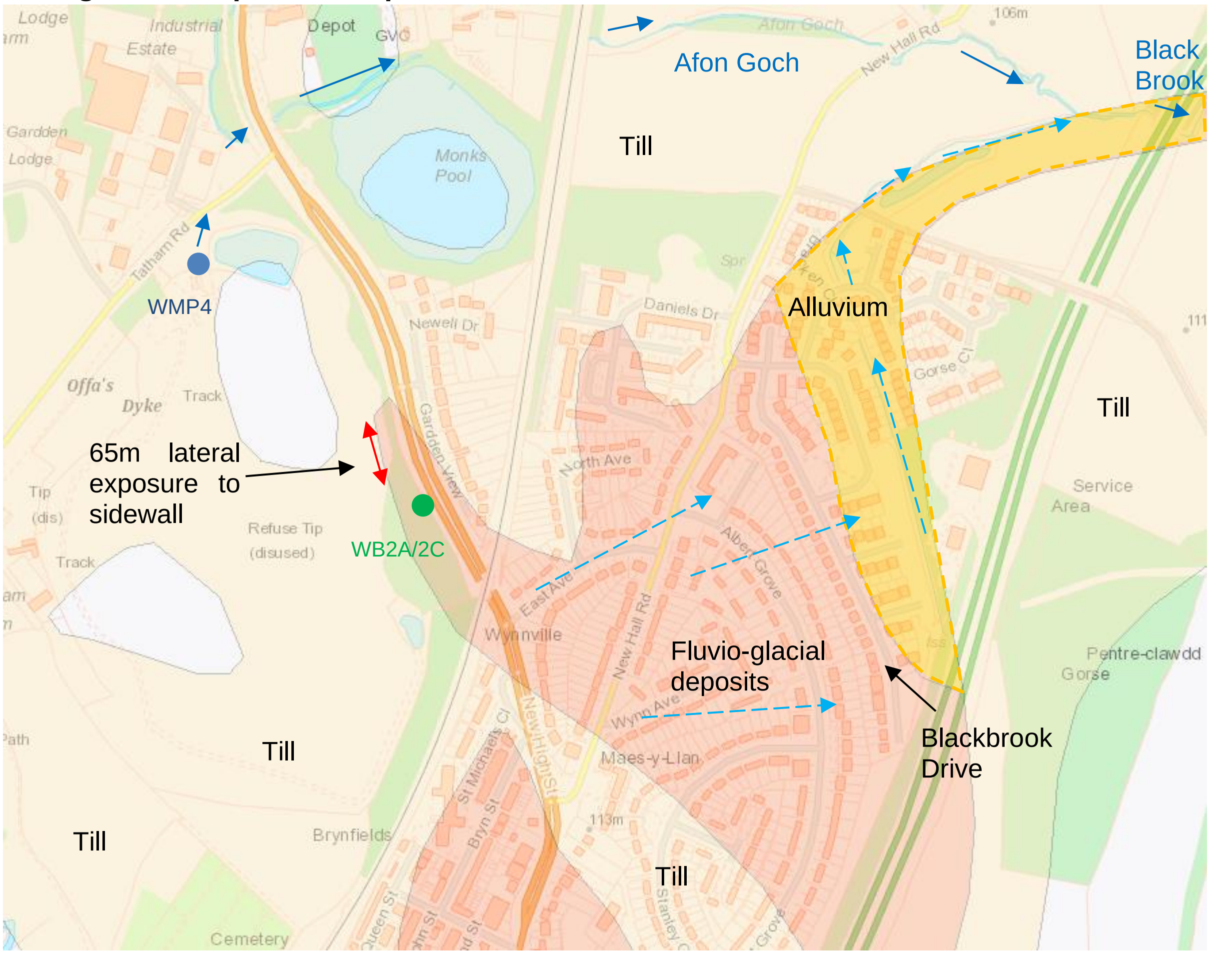
- A superficial “upper water bearing system” and;
- Etruria Formation (“lower system”).

Locally the Glacial Till superficial deposits have a Secondary undifferentiated aquifer designation, and the glacio-fluvial deposits, river terrace deposits and alluvium (where present) are Secondary A aquifers (Figure 4). These superficial deposits are the “upper water bearing system”.

The underlying Etruria Formation (“lower system”) is designated as a Secondary A aquifer.

Figure 4 depicts the potential groundwater / surface water interconnectivity in close proximity to the east of the Site boundary.

Figure 4 Superficial Aquifer Site Detail & Local Surface Water Courses



https://maps.cyfoethnaturiolcymru.gov.uk/, WMP4 is a surface water monitoring point – Section 4.3

The Site is not located in a groundwater Source Protection Zone (SPZ), the closest (SPZ Zone 3) is located 8.3km to the North East in the Abenbury area to the east of Wrexham.

Groundwater level monitoring is undertaken at 9 locations around the Site, as per the requirements of the permits and associated working plan.

Borehole locations are depicted on drawing 478M028A. Groundwater levels are recorded at:

- WB2A, 2B, 2C, 2D, 3A, 4A, 5A, 5B, BH13.

Based on interpretation of borehole depth (see supporting ESID) the following are interpreted to monitor the glacial strata:

- WB3A, WB5B, WB2A, WB2C

Based on interpretation of borehole depth the following are interpreted to monitor the Marl:

- BH13, WB4A, WB5A, WB2D, WB2B

The Etruria Marl is not considered a receptor. Groundwater levels have been discussed in the associated ESID, recorded water levels fall with topography from west to east.

The fluvio-glacial deposits (of a higher aquifer designation category than the Till) are only potentially monitored by WB2A / WB2C, as a result of the limited / minimal exposure of these deposits within the site boundary (i.e. they are not present elsewhere at the site periphery).

Associated groundwater levels for the glacial strata also fall (overall) from west to the east, as the excavated Site extends below the base of these deposits, all water flow within this upper system is around the periphery of the Site and engineered containment. The presence of a backwall drain around the southern and south eastern perimeter may modify water flow locally around the landfill void, conversely, so could the presence of extensive railway sidings / ballast foundations on the Site periphery. However, these anthropogenic pathways are not expected to materially alter water levels reported at monitoring installations and overall flow is expected to continue to the east / northeast with the concomitant fall in topography.

If groundwater seepages from the glacial strata to the alluvium are possible (east of Blackbrook Drive), there is also likely to be a contribution and association with surface water run-off in this valley feature which will include associated run-off from hardstanding areas. The drainage within the ditch flows northerly, diverts north-easterly before joining Afon Goch which then joins Black Brook at the A483 (Figure 4). This drainage route is ~700m in length.

A spring is noted on some OS maps to the south beyond the Afon Eitha close to the position where the river meets the B5097, located up-gradient / cross gradient in regard to groundwater flow the river is not linked to the Site via a groundwater baseflow connection. It is conceptualised that the spring (in addition to the one located to the northeast) emanate from superficial seepages from the glacial strata.

4.2 Groundwater Quality

The groundwater monitoring programme at the site has been designed previously to monitor the groundwater within the Etruria Formation and glacial strata.

Average groundwater matrix chemistry for both Glacial strata and Etruria Formation monitored boreholes are presented in Table 5 Table 6 respectively.

Table 5 Glacial Groundwater Matrix Constituents Av. Concentration (2014 - 2020)

Borehole	EC µS/cm	NH4-N mg/l	Cl mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	TOC mg/l	SO4 mg/l	Alk mg/l
Up-gradient										
BH13	708	0.21	10	134	11	25	4	4	55	328*
Cross-Gradient										
WB5B	780	0.93	109	81	16	55	12	3	56	174
Down-gradient										
WB2A	830	0.63	103	79	16	82	11	2	7	288
WB2C	2,433	2.20	324	179	20	383	18	8	36	897

* outliers removed. Shaded cells exceed the DWS. Limits: EC (2500µS/cm); Cl & SO4 (250mg/l); Na (200mg/l); NH4-N (0.39mg/l) from http://www.legislation.gov.uk/uksi/2016/614/pdfs/uksi_20160614_en.pdf page 38

Table 6 Etruria Formation Groundwater Matrix Constituents Av. Concentration (2014 - 2020)

Borehole	EC µS/cm	NH4-N mg/l	Cl mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	TOC mg/l	SO4 mg/l	Alk mg/l
Up-gradient										
WB4A	1,009	0.40	22	5	10	260	8	2	18	507
WB3A	694	1.03	22	8	13	138	15	2	20	355
Cross-Gradient										
WB5A	1,066	0.83	45	12	14	246	5	1	197*	341
Down-gradient										
WB2D	768	0.29	29	12	3	175	8	2	34	341
WB2B	1,760	1.84	472	77	43	195	27	4	27	127

* outliers removed. Shaded cells exceed the DWS. Limits: EC (2500µS/cm); Cl & SO4 (250mg/l); Na (200mg/l); NH4-N (0.39mg/l) from http://www.legislation.gov.uk/uksi/2016/614/pdfs/uksi_20160614_en.pdf page 38

Groundwater quality is variable in both strata, and typically poorer downgradient of the Site (based on statistical summaries detailed above for the previous 6 years). However, periodic increase in ammoniacal-N have occurred historically, the recent increase at WB2C coincides with a reduction in chloride and sodium concentration (time series plot in Appendix A of the ESID). There are no increases in potassium (during this ammoniacal-N oscillation noted between 2014 and 2020) hence the Site is not considered to be attributable to these variations.

Typically the groundwater ammoniacal-N concentrations fluctuate between 0.1 and 2.5mg/l.

Most evident in the long-term data series is the increase in chloride on the eastern boundary at WB2B (Etruria Formation) and WB2C / WB2A (Glacial strata).

Concentrations of ~200mg/l at WB2A have reduced post 2012, concentrations of ~350mg/l have reduced in WB2C post May 2019 however increases have continued at WB2B. In accordance with the conceptualisation summarised in the supporting ESID, a visual cross-section is presented in Figure 7 to illustrate the associated chemical relationships.

If the sidewall liner was reprofiled at an angle of no greater than 60º (Site permit condition) then the upper part of the slotted section of borehole WB2D (depth of 9m) would be at a lateral distance (minimum) from the sidewall of 5m. Lateral migration through a 1m reworked liner and in-situ Etruria Formation Marl, (taking into account the distance of WB2B from the edge of the site) would increase the pathway length to some 40m.

Figure 5 Groundwater ammoniacal-N (mg/l)

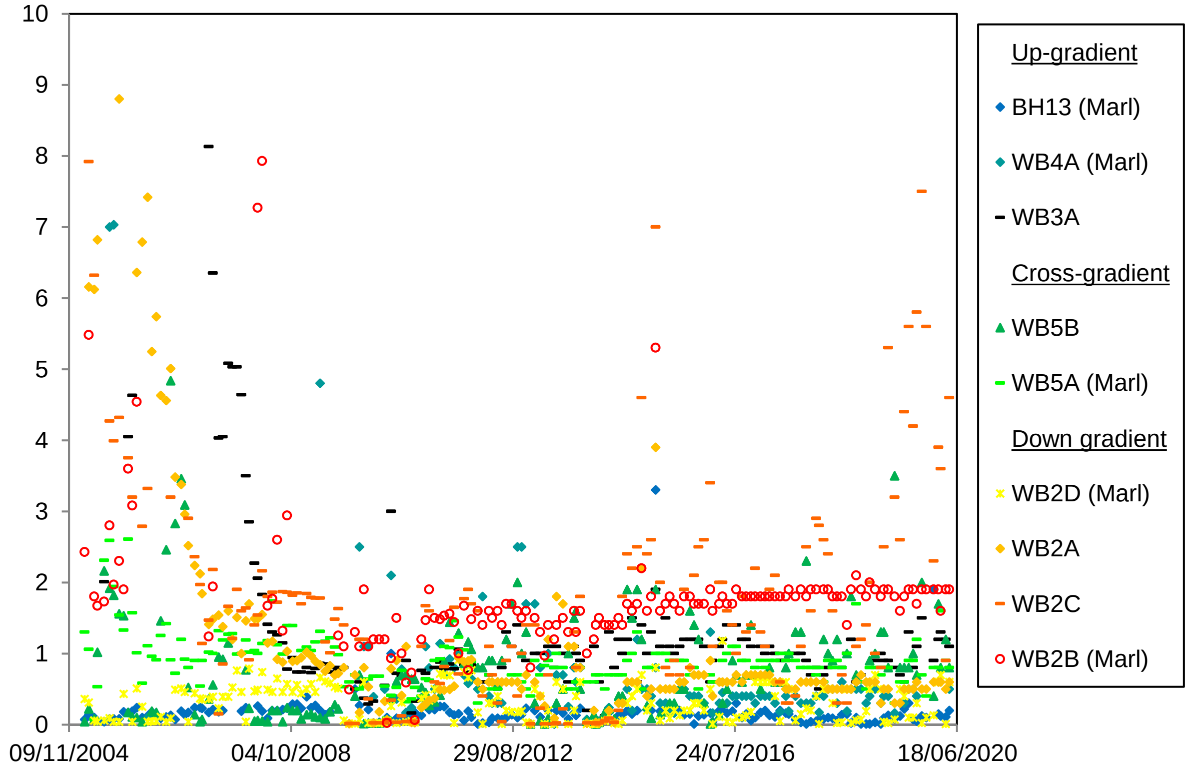


Figure 6 Groundwater chloride (mg/l)

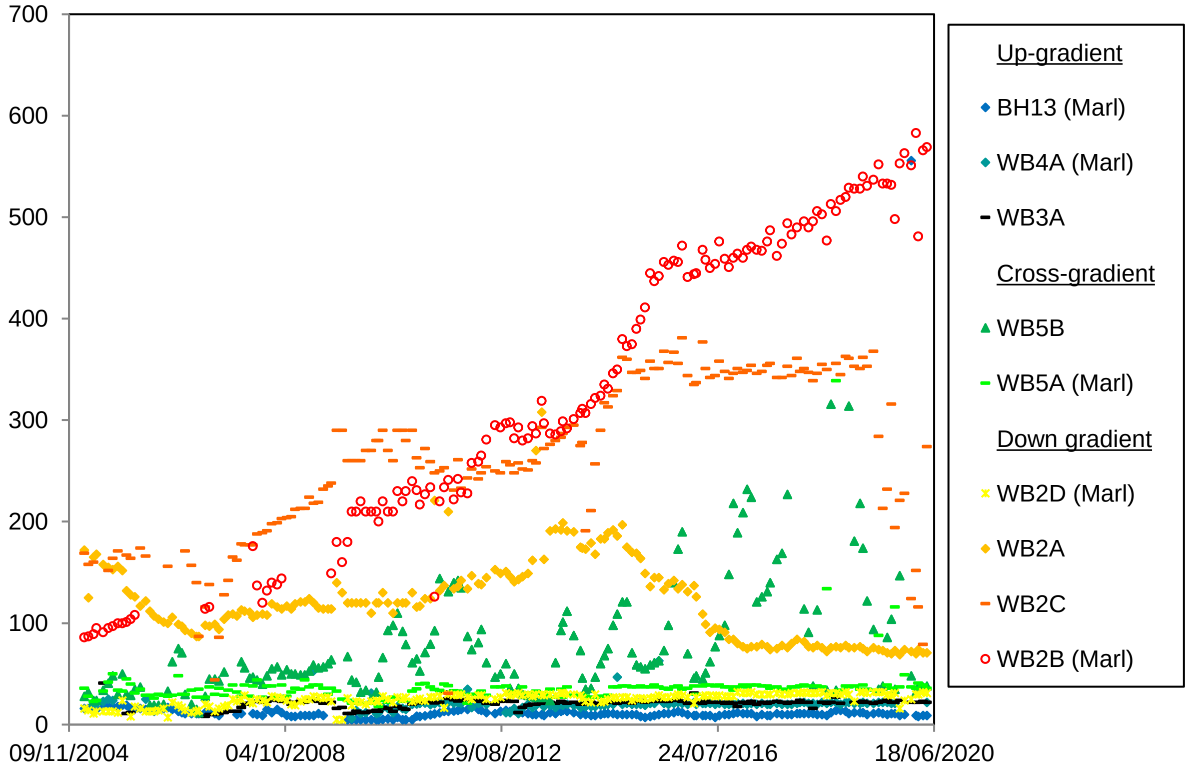
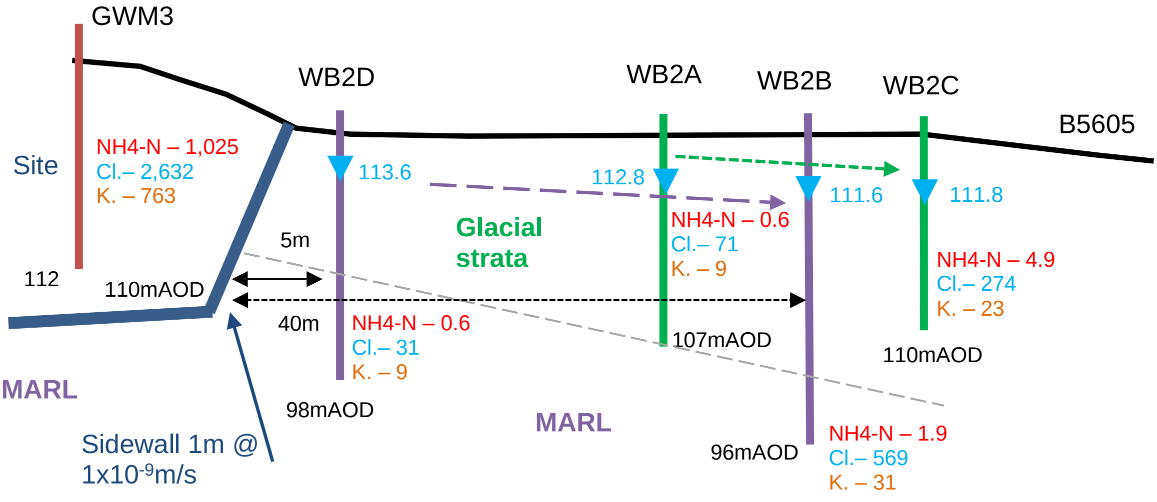


Figure 7 WB2D – WB2C Groundwater Quality Conceptualisation (W-E)



Schematic representation only for visual purposes only

Although current concentrations at WB2B are ~560mg/l, borehole WB2D which is located at the Site periphery (i.e. 35m closer to the source term that WB2B) does not record the same increase in chloride concentration indicating the Site is unlikely to be the source. The source term has typical average ammoniacal-N, chloride and potassium concentrations of ~1,000mg/l, ~2600mg/l and ~750mg/l respectively.

A downgradient relationship is not evident between:

- Source → WB2D → WB2B, or
- Source → WB2A → WB2C

Greater ammoniacal-N concentrations are noted currently (May 2020 data) adjacent to the B5605 for the glacial strata monitored boreholes (e.g. 4.9mg/l at WB2C versus 0.6mg/l at WB2A) and Etruria Formation borehole (e.g. 1.9mg/l at WB2B verses 0.6mg/l at the site boundary at WB2D). The Site is not considered the source for the increasing chloride concentrations at WB2B particularly on account of no associated increase in NH4-N, associated hydraulic location (i.e. upgradient) and extensive pathway length. Neither is it considered the source for ammoniacal-N in WB2C based on the information available.

A chloride versus sodium cross-plot for WB2B indicates a concomitant increase between these two ions, an R^2 correlation coefficient of 0.61 indicates a “good” correlation (n=297, data range 2005 - 2020), the R^2 correlation coefficient increases slightly to 0.64 for WB2C. The correlation is poor at WB2D (0.24) hence the effects noted above are considered “off-site” in derivation and whatever the cause, they do not appear to represent natural baseline fluctuation or association with winter salt application on the adjacent road. With no apparent groundwater flow conceptualised in the Etruria Formation (only static pore-water within the borehole anulus of WB2B) there is no assumed subsequent dilution.

It is noted that the cluster of 3 boreholes are located in close proximity, however the variability in water quality is evident between WB2A and WB2C (with similar base depths and assumed similar borehole construction) hence water quality within the glacial deposits is variable over a distance of “*meters*”.

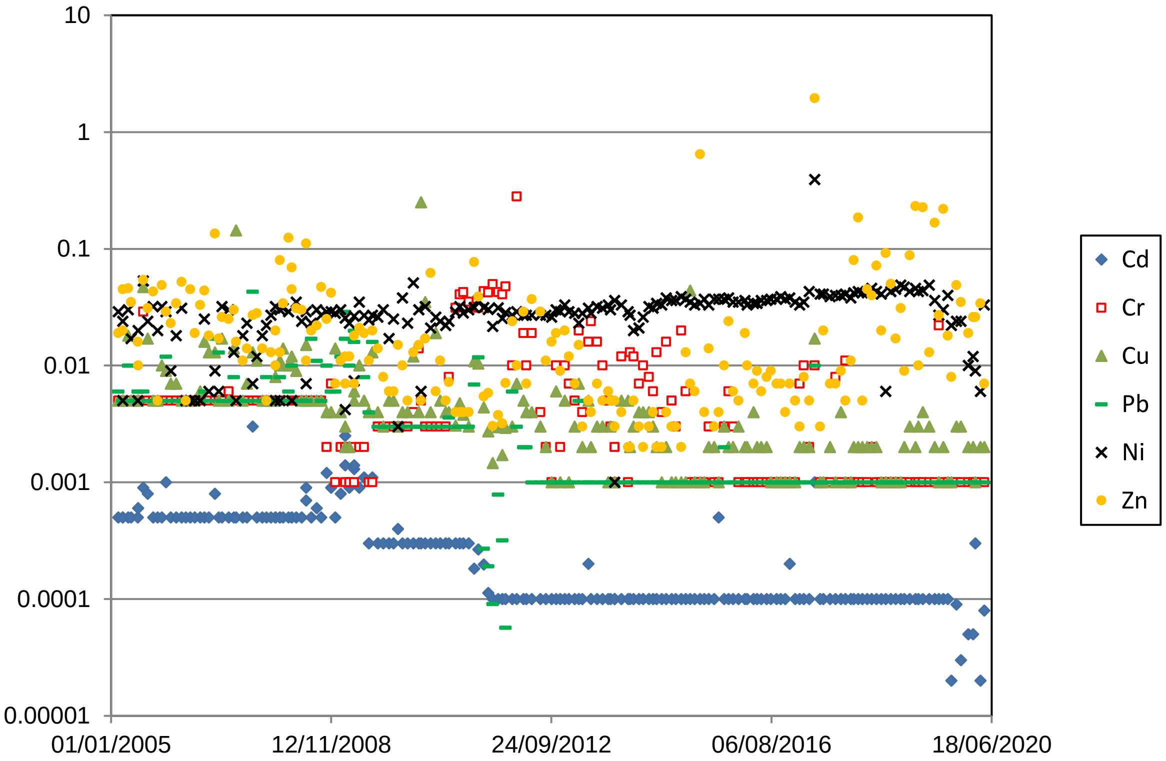
WB5B (monitoring glacial deposit strata) is located in an upgradient / cross gradient position and appears to indicate some seasonality in chloride variance (Figure 6).

Sulphate average concentrations are highest at the cross-gradient boreholes WB5A and WB5B (ESID report Appendix A), indicating a localised source of sulphate. At all other locations, typical sulphate concentrations are below 100mg/l.

Metals

Time-series data (all groundwater) is presented below in Figure 8 with recent statistical summary provided in Table 7 and Table 8.

Figure 8 Groundwater Metals (mg/l)



Cd and Cr (non-hazardous) and Pb (hazardous metals)[8,9] are almost exclusively reported at detection limit. The only notable variance in the time series data is the variability in zinc within the range of 0.002mgl – 0.23mg/l (some outliers are evident). Notwithstanding this variance, there are no exceedances of the DWS and no evidence of increasing trends.

Zn (prior to 2019) remained consistently in the range 0.02 – 0.04mg/l, post 2019 concentrations have reduced.

All metal concentrations appear reflective in baseline conditions, Mn and Fe associations (redox sensitive) are attributed to the host marl and glacial geological sequences. The maximum values compared to averages denote outlier concentrations, the variance however in both glacial

[8]https://www.gov.uk/government/publications/values-for-groundwater-risk-assessments/hazardous-substances-to-groundwater-minimum-reporting-values
[9]http://wfduk.org/sites/default/files/Media/JAGDAG/2018%2001%2031%20Confirmed%20hazardous%20substances%20list_0.pdf

groundwater and Etruria Pore-waters are apparent at all locations around the periphery of the Site.

Table 7 Glacial Groundwater Metal Concentration (2014 - 2020)

Borehole		Cd mg/l	Cr mg/l	Cu mg/l	Pb mg/l	Ni mg/l	Zn mg/l	Mn mg/l	Fe mg/l
Up-gradient									
BH13	Max	0.0004	0.022	0.017	<0.01	0.011	0.027	3.8	1.1
	Ave	0.0001	0.004	0.002	-	0.002	0.006	0.3	0.2
Cross-Gradient									
WB5B	Max	0.0005	0.004	0.002	<0.01	0.008	0.646	1.6	49.7
	Ave	0.0003	0.002	-	-	0.002	0.049	0.2	0.9
Down-gradient									
WB2A	Max	0.0003	0.006	<0.01	<0.01	0.024	0.020	3.7	1.2
	Ave	0.0002	0.003	-	-	0.006	0.006	0.2	0.2
WB2C	Max	0.0005	0.020	0.011	0.002	0.391	1.942	12.2	46.7
	Ave	0.0002	0.007	0.002	-	0.041	0.059	2.7	1.9
DWS		0.005	0.05	2	0.01	0.02	5	0.05	0.2

No average denotes < value; shaded cells denote exceedance of DWS - from http://www.legislation.gov.uk/uksi/2016/614/pdfs/uksi_20160614_en.pdf page 38; Fe & Mn "at consumer's taps"

Table 8 Etruria Formation Groundwater Metal Concentration (2014 - 2020)

Borehole		Cd mg/l	Cr mg/l	Cu mg/l	Pb mg/l	Ni mg/l	Zn mg/l	Mn mg/l	Fe mg/l
Up-gradient									
BH4A	Max	0.0005	0.009	0.002	<0.01	0.005	0.010	0.8	1.5
	Ave	-	0.004	0.001	-	0.002	0.005	0.02	0.4
BH3A	Max	0.0003	0.007	0.001	<0.01	0.003	0.013	0.9	0.8
	Ave	-	0.003	0.001	-	0.001	0.005	0.1	0.1
Cross-Gradient									
WB5A	Max	0.0003	0.005	0.002	<0.01	0.010	0.092	1.5	18.4
	Ave	-	0.003	0.002	-	0.003	0.017	0.1	0.7
Down-gradient									
WB2D	Max	0.0003	0.006	0.003	<0.01	0.003	0.088	0.3	1.3
	Ave	0.0002	0.003	0.002	-	0.002	0.012	0.03	0.1
WB2B	Max	0.0003	0.005	0.044	<0.01	0.046	0.054	1.4	1.9
	Ave	0.0001	0.003	-	-	0.005	0.010	0.2	0.3
DWS		0.005	0.05	2	0.01	0.02	5	0.05	0.2

No average denotes < value; shaded cells denote exceedance of DWS - from http://www.legislation.gov.uk/uksi/2016/614/pdfs/uksi_20160614_en.pdf page 38; Fe & Mn "at consumer's taps"

Other Substances

There are no additional monitored substances for review.

Comparison with Permit Limits

There are no compliance limits applied to boreholes at the Site.

4.3 Surface Water

The river Eitha located to the south and southwest is upgradient / cross gradient to the Site and respect to potential groundwater baseflow connections (see also Section 5).

The potential connectivity with Black Brook / Afon Goch has been described above (Section 4.1) and is a considerable distance from Site (additional detail at Section 5).

Surface water is monitoring is undertaken at one location (WP4A) according to the recent annual monitoring review however the working Plan for close site operations states monitoring is undertaken at WMP1, WMP4A, WMP5 and WMP7 on a monthly basis.

The location of monitoring point WMP4A is to the west of the settling lagoon on the environmental monitoring plan (478M028A), a recent statistical summary is provided in Table 9 below.

Table 9 Surface Water Quality at WP4A (2014-2020)

Parameter	EC	NH4-N	Cl	SO4	Alk	BOD	COD	DO	pH	Suspended solids
	µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l		mg/l
Min	8	0	21	109	272	0	0	0.5	7	0
Max	1,250	7.6	70	109	272	10	45	10.6	9.4	402
Average	723	1.2	46	109	272	3.3	28	7.3	7.7	36
Count	74	74	74	1	1	44	73	72	74	66
Discharge limit	**-**	**1.3**	**250**	**-**	**-**	**-**	**-**	**-**	**6 to 9**	**50**
Exceedances	-	17	0	-	-	-	-	-	2	9

The ammoniacal-N concentrations in the surface water are below the discharge limit for the majority of the review period however there is a slight increase in ammoniacal nitrogen concentrations in the last 12 months. There are no increases in any of the other substances monitored. Chloride is consistently below the discharge limit of 250mg/l, with no rising or falling trends evident. Time Series plots are provided in the supporting ESID (4915/R/002/2)

Suspended solids within the surface water have also remained steady throughout the monitoring period, with minor exceedances of the discharge limit in the last 12 months. The same applies for the pH of the surface water, with the previous two exceedances being over 5 years ago. The annual monitoring review stated that the occasionally higher volumes of suspended solids have occurred when a sample is bailed from the bottom of the sampling point (rather than in the free-flowing liquid) and excess solids are collected.

Discharge Consents

Two consents are associated with surface water discharges, consent CM0180301 conveys Site drainage to the Afon Goch to the northwest, monitoring in accordance with the consent is at the surface water lagoon “sampling point”, the discharge point is on the far side of Tatham Road at the Industrial Estate. It is noted that discharge volume shall not exceed 5184m^3/d at 60l/sec. Discharge limits are note in Table 9 above. Sampling is currently undertaken at the sampling point.

Consent CG0387001 relates to the south, adjacent to the cemetery and utilises a local authority drainage system via a railway culvert. The imposed limits are chemically consistent with CM0180301 however volumes are 432m^3/d at 5l/sec.

5. CONCEPTUAL SITE MODEL

A simple conceptual model can be constructed for the site, based on the relationship:

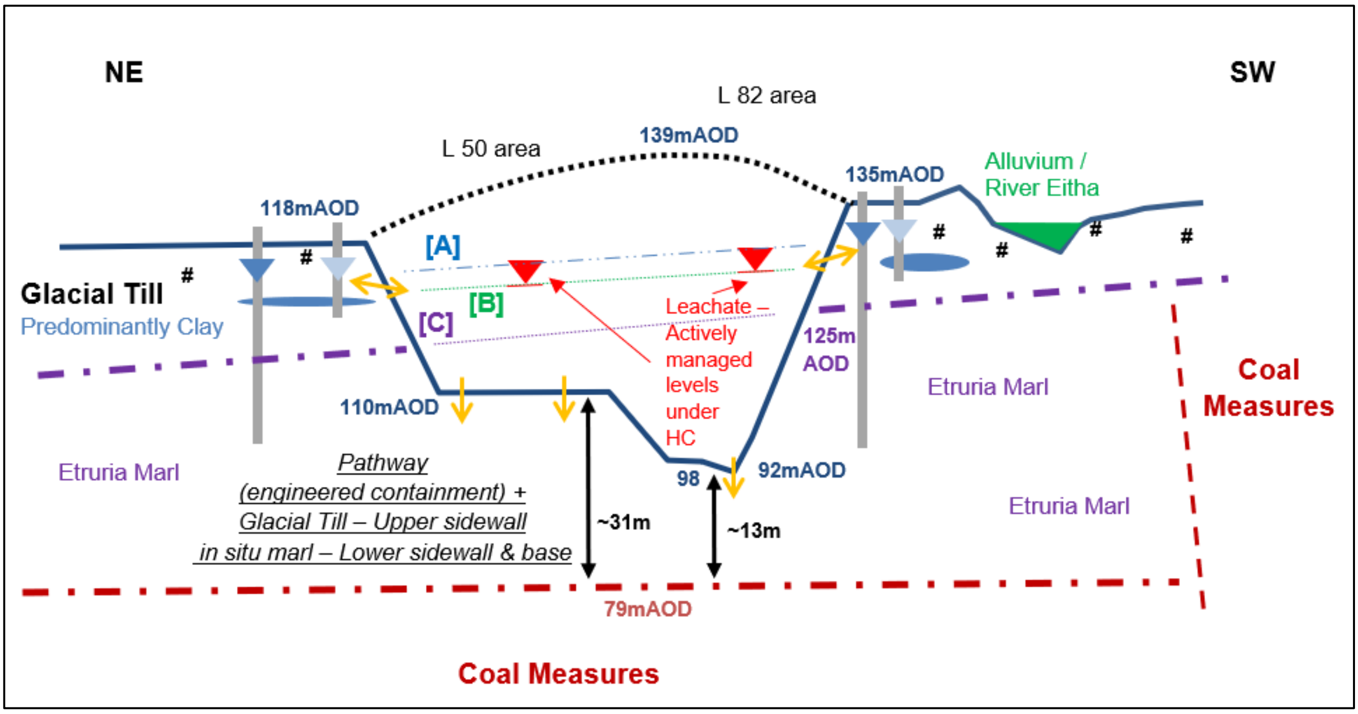
Source → Pathway → Receptor

This relationship is shown schematically (Figure 9) in which:

- The Source is leachate within the landfill;
- The Pathway is the engineered lining system; and in-situ Etruria Formation Marl / Glacial Till;
- The Receptor is the groundwater within the Glacial Strata

There are no established (or identified) permeable, or water bearing layers within the Etruria Formation, the Water Framework threshold characteristics outlined in Section 1 therefore cannot be met hence the Marl is not a receptor, or a pathway to a receptor.

Figure 9 Schematic Conceptual Site Model



[A] – groundwater table; [B] – management of leachate in accordance with principles of hydraulic containment; [C] – Geological containment

The base of the site has been constructed upon a significant thickness of Etruria Formation strata which will act as a natural geological barrier in regard to basal seepages.

There are two possible mechanisms that leachate constituents could migrate through the containment liners, the first is under a hydraulic diffusive flux driven by a hydraulic gradient from the difference between the leachate head acting on the sidewall liner and the adjacent groundwater system. A second mechanism is from advective flux whereby leachate levels are above adjacent groundwater levels.

The Afon Goch is the only surface water receptor down gradient of the site that is in potential continuity with groundwater within the Glacial strata. Section 4.1 has outlined this possible transport route through the alluvial deposits and drainage systems.

The Afon Eitha surface water course to the southwest is unlikely to be at risk from "overtopping containment" or "above cap" outbreaks, as the topography rises steeply beyond the southwestern site perimeter to a "dome" at 140mAOD (Brynfields) that lies in between Tatham Farm and the cemetery. The Afon Eitha is at an elevation of ~130mAOD beyond this topographical divide at a distance of ~210m from the site boundary. The on-site lagoon is only on-site feature at risk from leachate "above cap" outbreaks. This is a management issue not related to risk assessment.

The site is managed as an engineered containment landfill. The current permit condition for leachate levels limits was set for the period when engineering containment was being developed. Since this time, the sidewall engineering has been completed and capping works finalised.

The long-term management philosophy proposed is that the Site should be managed under the principle of "hydraulic containment" [B] in Figure 9, the current philosophy of leachate level minimisation within a site that is contained within a significant lateral (and basal) thickness of geological barrier appears misplaced.

There is no requirement for "geological containment" and levels maintained at an elevation below [C] in Figure 9. The thickness of glacial till is greatest on the eastern side of the Site sidewall.

The Role of Hydraulic Containment

The landfill is considered as a "hydraulically contained landfill", in which there is a hydraulic gradient exerted by the groundwater in the Glacial strata (predominantly Till) into the landfill, proportional to the groundwater elevation above the managed leachate head (proposed).

The Environment Agency has developed a spreadsheet model the "Hydraulic Containment Model" (HCM) to assess contaminant fluxes from hydraulically contained landfills[10], which is supported by a technical review[11]. This model was produced because mass transport models, including programmes such as LandSim which are based on substance migration which is proportional to the hydraulic gradient. Under hydraulic containment this flux is into the landfill site and the hydraulic models would return a zero value.

However, chemicals can diffuse across a concentration gradient even when against the hydraulic flux, albeit at a significantly lower rate than occurs under a hydraulic gradient when there is the physical movement of dissolved chemicals with the hydraulic flow. The hydraulic containment model has been produced to assess the chemical diffusion flux through the sides and / or base of a landfill in the context of how diffusion is affected by the inwards hydraulic gradient and landfill liner properties.

The model presents three hydraulic containment scenarios dependent on the relative location of an aquitard and a groundwater system, Scenario 3 is appropriate for the Site whereby contaminant fluxes only occur across the sidewall liner (c.f. with CSM in Figure 9).

[10] Environment Agency (2004) Contaminant fluxes from hydraulic containment landfills spreadsheet v1.0 User Manual. Science Report SC0310/SR
[11] Environment Agency (2004) Contaminant fluxes from hydraulic containment landfills spreadsheet - a review. Science Report SC0310/SR

In accordance with the site conceptualisation, hydraulic containment is proposed to be based on groundwater levels as referenced by monitoring within the Glacial Strata. Additional infrastructure that may be utilised for this purpose are detailed below in Table 10.

Table 10 Glacial Strata Monitoring Infrastructure

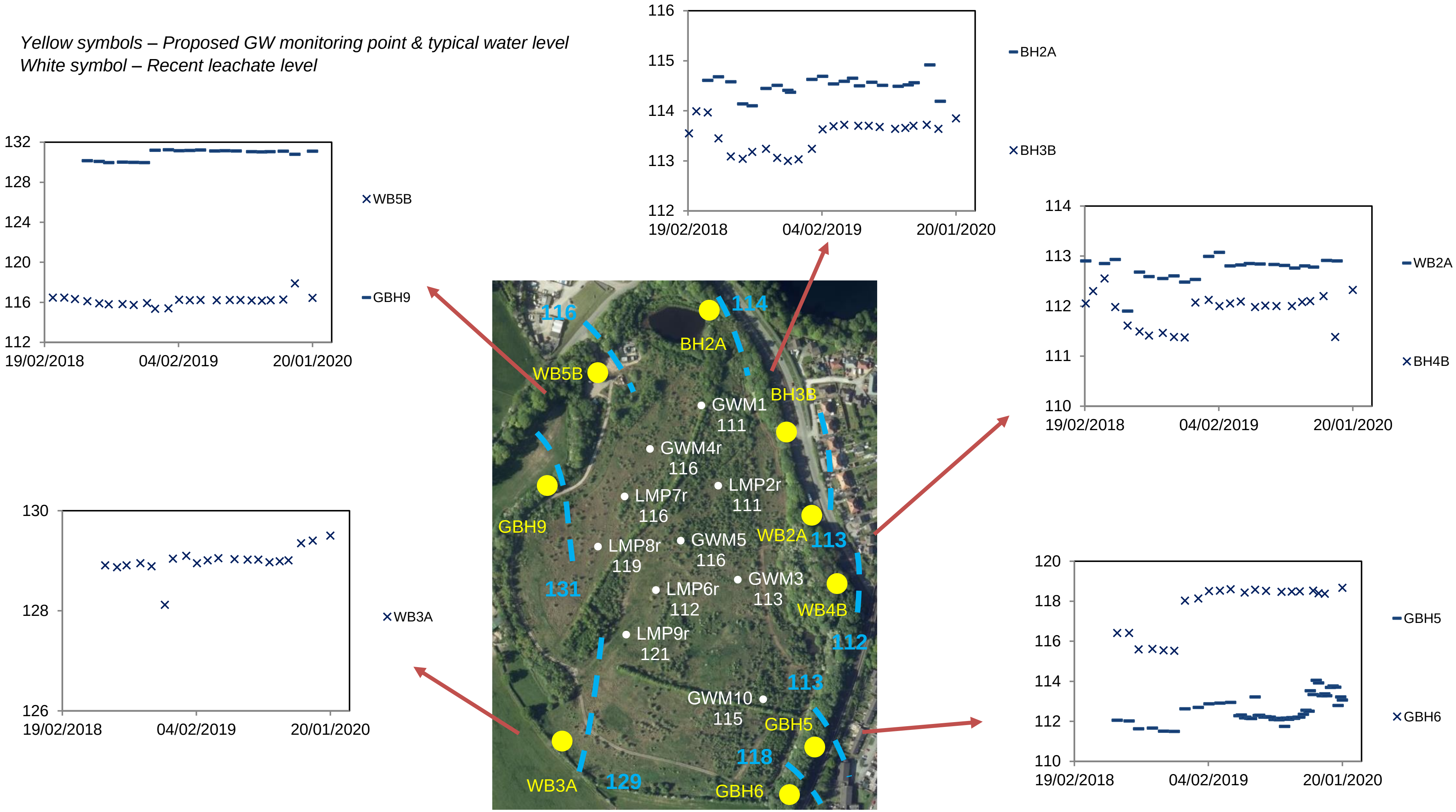
Monitoring Point	Datum (mAOD)	Depth (m)	Base (mAOD)	2019 Average GW level (mAOD)	Assumed or confirmed Monitored Interval
Southwest					
GBH7	136.7	3.3	133.5	135.8	Glacial Till
GBH8	136.3	6.4	129.8	135.0	Glacial Till
WB3A*	138.0	10.8	127.2	129.1	Glacial Till
South					
BH12A	135.8	5.5	130.3	134.4	Glacial Till
West					
GBH9	132.2	8.3	123.8	131.1	Glacial Till
GBH10	128.5	4.3	124.2	127.6	Glacial Till
Northwest					
WB5B*	119.1	8.5	110.7	114.3	Glacial Till
BH1A	120.2	13.1	107.1	115.4	
BH1B	120.2	7.0	113.1	115.1	Glacial Till
BH2A	119.6	6.5	113.1	114.6	Glacial Till
BH2B	119.6	11.8	107.8	114.4	
Northeast					
BH3A	118.8	13.2	105.6	113.1	
BH3B	118.9	6.4	112.5	113.6	Fluvio-Glacial
East					
WB2A	117.4	10.4	107.0	112.8	Fluvio-Glacial
WB2C	117.8	8.1	109.7	111.7	Fluvio-Glacial
BH4A	117.5	11.2	106.3	111.9	
BH4B	117.5	6.5	111.0	112.0	Fluvio-Glacial
Southeast					
GBH6	119.4	7.2	112.3	118.5	Glacial Till
GBH2A	114.1	1.4	112.7	112.9	Glacial Till
GBH2	114.7	7.1	107.7	112.3	Glacial Till
GBH5	115.7	6.3	109.4	112.6	Glacial Till
GBH3	114.8	4.9	109.9	112.0	Glacial Till
BH6	114.2	12.0	102.2	111.7	

* WB3A, WB5B, WB2A, WB2C already monitor this upper water bearing system (Working Plan requirement)

Utilising existing infrastructure (where possible) and appropriate boreholes from above, a monitoring network is proposed in section 8 and 9 (also in report 4915/R/006/2). A selection of boreholes are provided to understand the current hydraulic containment status (Figure 10) which are augmented further, with a far greater dataset as detailed in Section 8.

For visual purposes, current leachate levels are presented in accordance with adjacent groundwater levels (last 2 years). It is apparent that some leachate management is required in the south-eastern corner of Site to re-establish hydraulic containment conditions.

Figure 10 Hydraulic Containment Review (Current Leachate level versus recent Groundwater Levels mAOD)



6. RISK ASSESSMENT

6.1 Previous Assessments

There are no known prior hydrogeological risk assessments for the Site.

6.2 Previous Emissions to Groundwater

Not assessed.

6.3 Current Assessment

Ongoing leachate data collection has indicated that the source term has peaked (Figure 2) and is now in decline, this benchmarks upper limits on the source term for the hydrogeological modelling. The modelling will justify appropriate "risk base" leachate level limits for the sites closure and aftercare period, a leachate limit of "2m above the base of the site at that point" in a clay pit appears misplaced.

A full appreciation of the hydrogeological system has been undertaken within this review:

- The Etruria Formation Marl is not a receptor, it is a geological barrier;
- There are no established linkages of permeable sandstone "espleys" to a receptor;
- Espleys are not present at Site based on the information reviewed;
- If Espelys are present, they are encapsulated within a geological barrier;
- Hence the marl sequence at Ruabon cannot be regarded as an aquifer in regards to groundwater, Water Framework Directive Article 7 (of 2000/60/EC) which states that for "Waters used for the abstraction of drinking water"
    - all bodies of water used for the abstraction of water intended for human consumption providing more than $10m^3$ a day as an average or serving more than 50 persons, and
    - those bodies of water intended for such future use.
- The Water Framework Directive (WFD) also defines an "aquifer" as

"a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater".

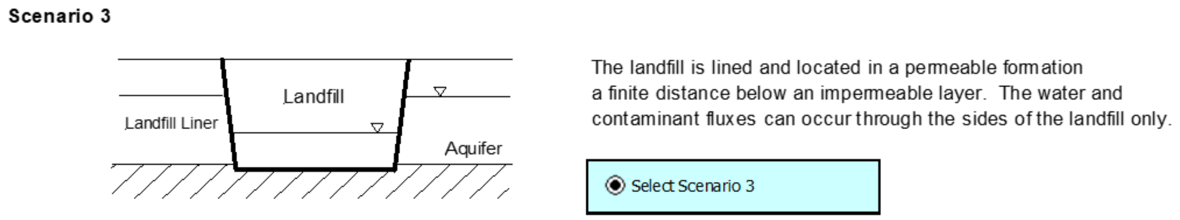
and defines a "Body of groundwater" as

- *"a distinct volume of groundwater within an aquifer"*
- The directive therefor quantifies an aquifer as a rock bearing a sustainable useable quantity of water in excess of $10m^3/d$ on average.

The Etruria Formation Marl cannot fulfil the role as useable resource, irrespective of water quality as any associated exploitable storage volume (considered pore-water in this case) cannot be sustained through extraction.

This assessment considers the only receptor is the "upper", water bearing glacial superficial strata and will utilise the hydraulic containment (HC) spreadsheet, Scenario 3 (Figure 11). It is noted that Glacial Till seldom provides homogenous, laterally connected groundwater flow.

Figure 11 Hydraulic Containment Modelled Scenario



The modelled area (relative levels) are taken from the south eastern corner of Site

6.4 Preliminary Screening and Model Parameterisation

In light of the holistic review of the sites source term (all available data) and assessment of groundwater quality there are a limited number of substances that should be considered further within this review:

- the primary leachate constituents ammoniacal-N and chloride;
  - present in the source term above background groundwater concentrations and DWS
- the non-hazardous metal nickel;
  - present in the source term above background groundwater concentration and DWS

Substance specific parameterisation is detailed in Table 11, the hydraulic containment model requires two further substance properties, namely an attenuation coefficient (K_d) and a diffusion coefficient for each substance. Attenuation coefficients are based on attenuation studies undertaken on landfill leachate constituents to geological materials[12], the LandSim & HC manual, USEPA studies[13] and professional experience. All other model parameters are summarised in Table 12, Table 13 and Table 14.

A leachate / groundwater head differential of 1m is considered appropriate for model based assessment. The Site is considered as a single hydraulic unit.

Table 11 Substance Specific Parameters

Substance	Conc^n	Attenuation	Free Water Diffusion	JAGDAG Classification
	mg/l	ml/g	m^2/s	
Ammoniacal-N	1,360	2	1.96×10^{-9}	Primary non-hazardous substance
Chloride	3,250	0	2.03×10^{-9}	Conservative non-hazardous constituent
Nickel	0.5	19	0.594×10^{-9}	Persistent non-hazardous pollutant

[12] Fannin (2006) An evaluation of the chemical attenuation capacity of UK mineral liner and geological barrier materials for landfill leachate components, Q. J Eng. Geol. & Hydrol. **39** 267 - 281
[13] USEPA (2005) Partition coefficients for metals in surface water, soil and waste. EPA/600/R-05/074, July 2005

Table 12 Hydraulic Containment Landfill and Liner Parameters

Ruabon Landfill			
CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION			
Conceptual model of landfill construction	CM	3	-
Is a geomembrane present?	GM_opt	No	-
Basal width perpendicular to groundwater flow	Width_LF	150	m
Basal length parallel to groundwater flow	Length_LF	280	m
Basal area	Base_Area	42000	m^2
Elevation of base of landfill	LFbase_elev	90	maOD
Elevation of base of aquifer	Aqbound_elev	110	maOD
Leachate head inside landfill	Head_inLF	112	maOD
Groundwater head outside landfill	Head_outLF	113	maOD
Area of liner below the water table	Area_contact	1720	m2
CONTAMINANT PARAMETERS			
Contaminant name	Cont_Nme	Ammoniacal-N	-
Contaminant type	Cont_Type	Inorganic	-
Contaminant classification	Cont_Class	List II	-
Concentration in landfill leachate	Conc_LF	1360	mg/l
Free water diffusion coefficient	Dw_cl	1.96E-09	m^2/s
Partition coefficient in clay	Kd_cl	2	l/kg
Retardation factor in clay	R_cl	9.75	-
Half life in clay (0 for no decay)	thalf_cl	0	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	0	1/s
MINERAL BARRIER / LINER			
Thickness of mineral liner	thick_clbr	1	m
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	1.00E-05	m
Effective porosity	n	0.4	-
Dry bulk density	rho	1750	kg/m^3
Tortuosity	tau_cl	10	-

Table 13 Hydraulic Containment Aquifer Parameters

STEADY STATE DILUTION			
Hydraulic gradient in the aquifer	aq_I	0.06	-
Hydraulic conductivity of the aquifer	k_aq	1.00E-05	m/s
Downgradient distance of compliance point from landfill	dist_cp	10	m
Mixing width	Mix_W	150	m
Mixing depth	Mix_D	3	m
Dilution flow in aquifer downstream to the landfill	aq_Q	0.00027	m^3/s
CONTAMINANT AND WATER FLUXES			
Groundwater flux into landfill		0.00000344	m^3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	2.5E-0.5	mg/l
CHART PARAMETERS			
Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+04	years

Table 14 Hydraulic Containment Aquifer Parameters

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION			Justification / Reference / Notes
Scenario	3		Conceptual model to adjacent glacial till
Is a geomembrane present?	No		Clay barrier
Basal width perpendicular to groundwater flow	150	m	Estimated Landfill design
Basal length parallel to groundwater flow	280	m	Estimated Landfill design
Elevation of base of landfill	90	maOD	Drawing 478B002_4300-4
Elevation of base of aquifer	110	maOD	Lower estimation for top of Etruria Fmt
Leachate head inside landfill	112	maOD	Monitoring data
Groundwater head outside landfill	113	maOD	Monitoring data
CONTAMINANT PARAMETERS			
Contaminant name	Ammoniacal-N	-	
Contaminant type	Inorganic	-	
Contaminant classification	List II	-	Non-hazardous pollutant
Concentration in landfill leachate	1360	mg/l	Monitoring data – Table 3
Free water diffusion coefficient	1.96E-09	m^2/s	NC/03/10/TR p45
Partition coefficient in clay	2	l/kg	None expected
Half life in clay (0 for no decay)	0	days	Inorganic
Decay in sorbed phase?	No	-	N/A
Thickness of mineral liner	1	m	Sensitivity analysis (assumed design)
Hydraulic conductivity	1E-09	m/s	Sensitivity analysis (assumed design)
Average pore radius	0.00001	m	
Effective porosity	0.4	-	Mid-range from Tellam & Lloyd (1981)
Dry bulk density	1750	kg/m^3	Typical value
Tortuosity	5	-	Mid-range from Freeze & Cherry (1979)

6.5 Emissions to Groundwater

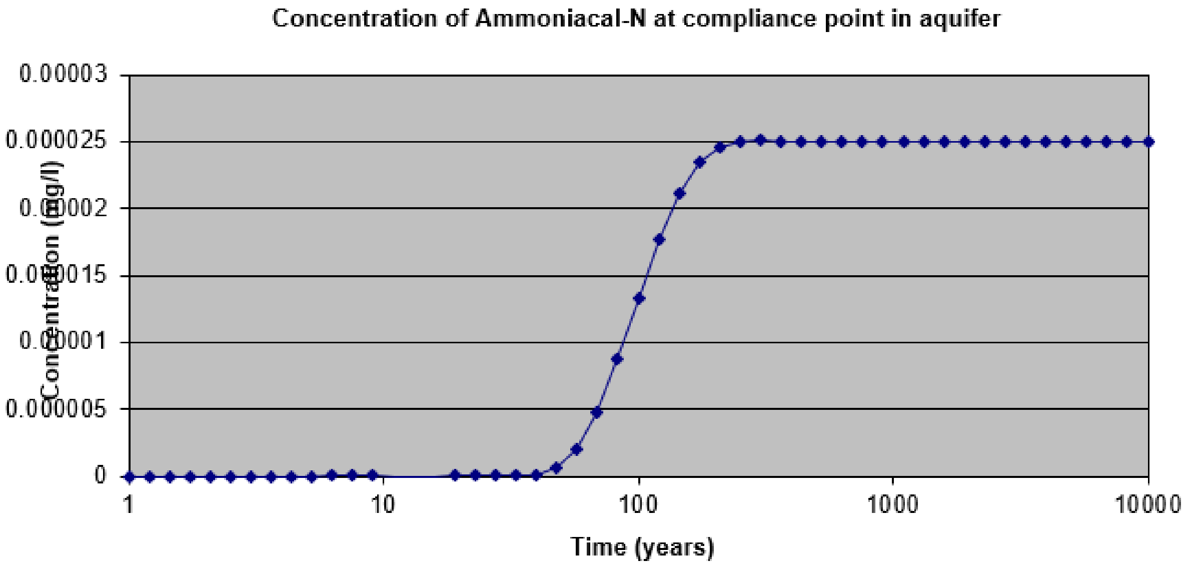
The hydraulic containment model demonstrates that chemical diffusion to the edge of a 1m barrier and then mixing within the glacial strata groundwater to a hypothetical monitoring point (10m downgradient of the site) is negligible and not environmentally significant.

The hydraulic containment model predicts that ammoniacal-N (the greatest concentration within the source term with reference to DWS concentrations) will reduce to a concentration of <2.5×10^{-5}mg/l within 10m of the edge of the sidewall liner (Figure 12).

This will occur as a progressive increase in ammoniacal-N over a 200 year period, during which the source term will decline considerably. Notwithstanding this, a groundwater concentration of less than the Good Water Quality EQS (*i.e*. <0.6mg/l) at the edge of the site is environmentally insignificant, modelling assessment at the edge of the liner peaks at 0.004mg/l at ~300 years.

Chloride and nickel concentrations are not expected to exceed 0.00009mg/l and 0.00005mg/l respectively at the edge of liner (at 10,000 years) prior to mixing with groundwater in the glacial strata (assumes a steady-state source concentration).

Figure 12 Hydraulic Containment Model Predicted Ammoniacal-N Concentration in Glacial Strata



6.6 Sensitivity Analysis

The above conclusion is also applicable to a negligible hydraulic gradient when leachate levels are almost at parity with groundwater (i.e. 0.2m below external groundwater level). Ammoniacal-N concentrations do not exceed 0.2mg/l, chloride 0.5mg/l and nickel 0.0007mg/l.

If liner hydraulic conductivities are an order of magnitude lower than the specified design standard / criteria, ammoniacal-N concentrations peak at 0.35mg/l at 912 years. All results are conservative as no source term decline is included within the simulation.

6.7 Model Conclusions

There are no adverse environmental effects modelled when the Site is operated under the principle of hydraulic containment.

7. REVIEW OF TECHNICAL PRECAUTIONS

The Ruabon Landfill site is in the aftercare phase of its lifecycle. The site was developed as an engineered containment landfill with the capability for active leachate management.

Controlled water pollution is prevented by two mechanisms namely the engineered containment in combination with a theoretically induced inwards hydraulic flux by managing leachate to below the adjacent groundwater surface.

The technical precautions undertaken can be summarised as:

- A sloped surface designed to shed incidental rainfall;
- A vegetated and soil restored surface designed to protect the underlying cap;
- An engineered cap designed to minimise infiltration;
- Original and retro-fitted vertical abstraction chambers
- An artificial mineral sealing liner, compacted to a hydraulic conductivity of no more than $<1x10^{-9}$m/s;
- An *in-situ* geological barrier provided by the mudstone of the Etruria Formation.

It is therefore considered that the active and passive technical precautions should be based on the risk to water resources, however, the underlying / adjacent Marl strata is not considered as a pathway towards a designated water resource under the Water Framework Directive.

The Etruria Marl cannot in any way be considered as a water resource, but does have a hydraulic conductivity in discrete layers which are capable of transmitting water in some areas of the UK, there is no evidence for such layers however at Site.

It is also noted that the Site was operated “dry” and available borehole logs do not record water strikes or influx of water during installation (in regard to the Etruria Formation Bedrock). It is conceptualised that pore-water from the Marl itself infills the monitoring boreholes with time, a water surface is recorded at monitoring points that appear topographically controlled.

It is noted that groundwater management was required to limit / control “high level” water seepages from entering the void around the periphery contained within the glacial strata. Exact details however are unknown on the position and design of any backwall drains. This knowledge gap however does not affect the modelling simulations.

Although hydraulic containment is considered in this review as the primary management control, a leachate limit was not set according on this premise during the operational phase of the Site life.

8. RECOMMENDATIONS

Given that the site does not pose a risk to the underlying / adjacent pore-water system or adjacent water features via a sub-surface pathway (i.e through the significant lateral thickness of the geological barrier / *in-situ* marl), it is therefore recommended that active leachate level management control levels are based on the prevention of over-topping the sidewalls of the site, and are managed at 1m below adjacent glacial (superficial strata) groundwater levels.

The operating philosophy for ongoing leachate management into and throughout the aftercare period is therefore based on:

1) Maintaining a leachate level surface below the cap-sidewall interface
2) Progressively reducing leachate levels (where applicable) to ensure a minimum 1m freeboard below the adjacent glacial strata groundwater levels
3) The management of 1 and 2 above are considered relevant to optimise the remaining / residual landfill gas - for the optimal utilisation of the gas for energy generation and to limit off site emissions

Cap / sidewall interface levels (ground level) range between the following (based on borehole datum levels and contours depicted on drawing 478B002_4300/ 4):

- ~119 - 114mAOD on the southeast boundary
- ~119 - 118mAOD on the northeast boundary
- ~138 - 127mAOD on the southwest boundary
- ~133 - 120mAOD on the northwest boundary

Permitted leachate elevation limits should therefore be increased based on reference to the following primary superficial groundwater monitoring points (see also Figure 10):

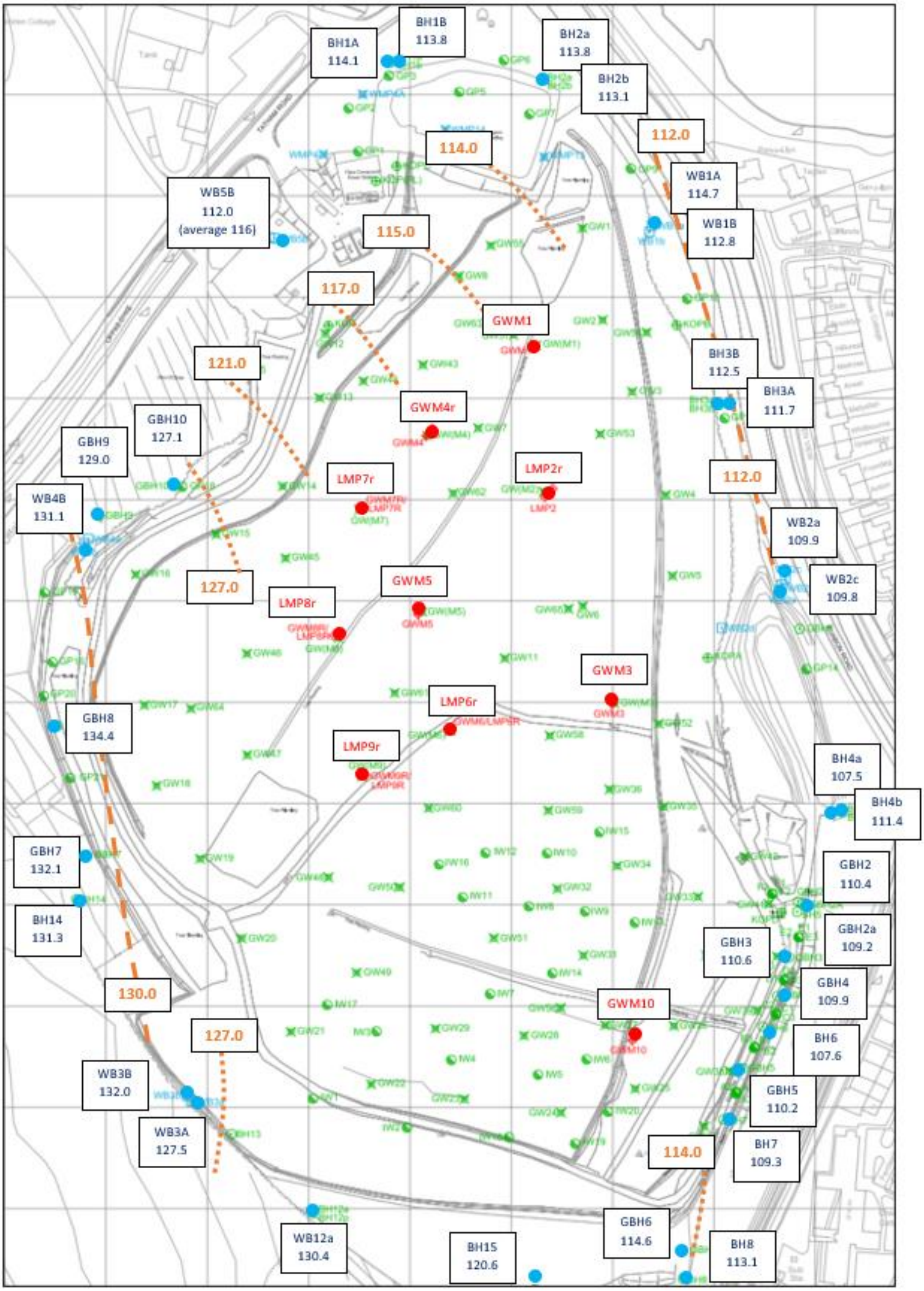
Glacial Strata only at:

- Upgradient (west perimeter)
  - WB5B (north), GBH9 (central) and WB3A (south)
- Cross gradient (north perimeter)
  - BH2A
- Cross gradient (south perimeter)
  - GBH6
- Down gradient (east perimeter)
  - WB2A & BH4B (central), BH3B (north), GBH5 (south)

In accordance with the Schedule 5 issued by NRW in July 2022 (dated 08/07/2022) further clarification was requested on the pairing of perimeter groundwater monitoring points with leachate infrastructure and further confirmation on the setting of hydraulic containment limits. Further leachate compliance level confirmation was requested in the "re-issue" of the Schedule 5 notice (email issued 23/11/2022) subsequent to a meeting held between NRW and TerraConsult on the 18th November 2022.

Figure 13 provides a visual representation and presents the superficial groundwater "*lowest levels*" for the years 2007 to 2020 to assist in further defining groundwater contours (over those previously presented in Figure 10). The setting of leachate limits on this basis is additionally conservative in regard to the previous judgment against "recent levels" (2018 - 2020) as presented in Figure 10.

Figure 13 Hydraulic Containment and Assignment of Limits (Superficial Strata)



Groundwater levels presented are "lowest" levels (2007 to 2020) for conservatism, recent available data for WB3A, WB5B, WB2A, WB2C (up to July 2022) also included.

It is evident that **ALL** groundwater levels are near the surface and hence the flow pattern is defined by the topography with water flowing from the high ground in the west to the low ground in the east. It can be seen that the lowest level at WB5B of 112mAOD is marginally low compared to the wider dataset, however the average level of 116mAOD is consistent with the overall flow around the north-westerly facing site perimeter and is intermediate in water level when referenced against GBH10 (lowest elevation of 127.1mAOD) and BH1A (lowest level of 114.1mAOD). This flow pattern is consistent with the 2020 data in isolation as presented in the ESID (Figure 29).

It should be recognised that, although the contours are presented across the site (west and east for overall context, as presented by the long-dashed orange marker) the actual flow is only around the periphery of the site (as the site itself acts as a barrier to flow), i.e. the superficial strata does not extend to the full depth of the site, c.f. with Figure 9. The inferred superficial strata groundwater contours (lowest levels) are defined on Figure 13 by the short-dashed orange contours.

Flow on the downgradient side of site (particularly in the south-easterly facing boundary) may potentially be modified by historic activities at site (discussed in the ESID) and installation of historic engineering measures.

A steeper fall in ground elevation in between GBH9 and BH1a is reflected by the steeper water table gradient along the perimeter of the site. It can be recognised that all of the leachate (at the leachate extraction and monitoring points) are hydraulically contained between groundwater levels of 126mAOD and 114mAOD (cross referenced with groundwater levels of 127.1mAOD at GBH10 and 115mAOD as a projected contour along the north-westerly facing boundary). Leachate monitoring and proposed compliance limits are proposed at 1m below the inferred contours “as projected” from the nearest site boundary in accordance with the overall defined flow direction (Figure 13).

It can also be recognised that it is not possible to assign individual pairs of infrastructure, i.e. a specific leachate well against a specific groundwater monitoring point for the purpose of “hydraulic containment tracking” as a result of the spatial relationships. For example, 5 of the leachate wells (LMP7r, GWM5, LMP6r, LMP8r and LMP9r) fall in between the monitoring points of GBH9 and WB5B.

Subsequent to the submission of the application and HRA (report version dated July 2021) additional works have been undertaken by the applicant / operator. This has included additional leachate removal in the south-eastern extension area (through GWM10) and pumping from the Groundwater Sump (location depicted on drawing 478M028A).

It is understood that through correspondence between the operator and NRW it has been established that leachate extraction to current levels of below 99mAOD at GWM10 (post Oct 2020) and water removal from the groundwater sump at a level of 5.5mbgl (sump depth of 8.46mbgl) that gas control has now been established in this area of the site.

Although, through the risk-based assessment it is proposed to manage leachate at 1m below hydraulic containment levels, the above recognition has been made in setting leachate level limits at GWM10 for the benefit of gas control and compliance. There remains no technical or environmental justification for monitoring pore-water in the Etruria Formation, or management leachate in accordance with hydraulic containment of pore-water in this formation.

However, based on the outcome of a meeting dated 18th November 2022, it is noted that NRW will not accept proposals for leachate level limits that are higher than “hydraulic containment levels" within monitoring locations that are centrally located within the waste mass, (wells that are at significant distances from the site perimeter). At these locations however there is no "flux" across the sidewall liner, however this recognition of NRW's request has also been accounted for in the revised leachate compliance limits as presented in Table 15.

Table 15 Proposed Leachate Limits

Monitoring point	Location	Datum (mAOD)	Base (mAOD)	Current Limit $ (mAOD)	Proposed Limit (mAOD)
GWM4r	West	127.79	110.08	112.08	116.0
LMP7r	West	129.22	110.80	112.80	119.0
LMP8r	West	132.45	110.00	112.00	125.0
LMP9r	West	132.68	110.30	112.30	125.0
LMP2r	Central	126.09	110.00	112.00	114.0
GWM5	Central	131.82	110.50	112.50	119.0
LMP6r	Central	130.74	111.40	113.40	119.0
GWM1	North	124.69	110.45	112.45	114.0
GWM3	East	125.41	112.25	114.25	114.25
GWM10 #	Extension	123.15	96.00	98.00#	106.60 *

$ based on current base datum levels.
# GWM10 compliance limit of 106.6mAOD but controlled to 98mAOD for gas control purposes (see text above)
* based on 1m below the lowest groundwater level at BH6 (107.6mAOD) however it is recognised that pumping form the "sump" in this areas may have influences locally that are beyond the limitations of recognition available in the dataset. It is additionally recognised that an outlier is skewing this "lowest level", the removal of this data point defines the lowest level of 109.6mAOD. Limit however defined based on gas control at 98mAOD.

Where there is no immediate adjacent peripheral groundwater monitoring location, leachate limits have been set against the projection of contours from the site boundary (inferred groundwater level) into the waste mass / monitoring well, with the subtraction of 1m to define the appropriate limit.

As such, it can be readily seen that LMP8r and LMP9r fall upon a projected groundwater contour of 126mAOD, proposed limits are therefore 125mAOD. Moving in an easterly direction across the site, it is evident that LMP7r, GWM5 and LMP6r all fall upon a projected contour of 120mAOD, proposed limits are therefore 119mAOD.

GWM4r is close to a projected groundwater contour of 117mAOD, a limit of 116mAOD is proposed. GWM3 would project upon a contour at 116mAOD (marginally downgradient of GWM4r as referenced against the water levels on the site boundary), the current limit of 115.5mAOD is retained. LMP2r would project upon a contour at 116mAOD, a limit of 115mAOD is proposed.

GMW1 is close to the projection of the 115mAOD contour and hence a limit of 114mAOD is proposed.

All levels are lower than the cap/sidewall interface inferred from available plans (drawing 478B002_4300/ 4) as referenced above and are additionally lower than the "appropriate" groundwater levels in the near surface superficial deposits. It is only these strata that are regarded as a receptor, or conversely, can provide a pathway to a surface water receptor.

9. REQUISITE SURVEILLANCE

The above recommendations therefore have an influence on the Requisite Surveillance section of the site's Permit, this is expected to be reflected within modern style permit tables when the site is issued with a consolidated permit.

The relevant (anticipated) Schedule 3 Permit Tables with respect to leachate and water are:

- Table S3.1 Leachate level and monitoring requirements
- Table S3.2 Point source emissions to water (other than sewer) – emission limits and monitoring requirements
- Table S3.4 Groundwater – emission limits and monitoring requirements
- Table S3.6 Point source emissions to sewer
- Table S3.8 Groundwater – other monitoring requirements
- Table S3.10 Leachate – other monitoring requirements
- Table S3.11 Surface water – other monitoring requirements

The leachate monitoring requirements are as set out in Table 16 and Table 17 of this report, which are likely to represent the Permit Tables S3.1 and S3.10.

The permit will specific that all monitoring points are in non-operational cells (Permit Table S3.1), therefore leachate elevation monitoring is a quarterly requirement and quality sampling a quarterly requirement (as per Permit Table S3.10).

Proposed leachate level limits are detailed in Table 16, associated monitoring is detailed in Table 17.

Table 16 Permit Table S3.1 Leachate Height Limits

Table S3.1 Leachate level limits and monitoring requirements		
Monitoring Point reference /Description	**Limit mAOD**	**Monitoring Frequency**
Operational Cells or Phases		
-	-	Monthly
Non Operational Cells or Phases		
Leachate compliance and monitoring points; North - GWM1 West - GWM4r / GWM7r / GWM8r Southwest - GWM9r Central - LMP2r / GWM5 / LMP6r East - GWM3 Extension (southeast) - GWM10	 114 116 / 119 / 125 125 114 / 119 / 119 114.25 106.6 (control level of 98)	Monthly

Table 17 Permit Table S3.10 Leachate Other Monitoring Requirements

Permit Table S3.10 Leachate – other monitoring requirements		
Non Operational Cells or Phases		
Monitoring Point	**Parameter**	**Frequency**
MEPP At leachate tank LT01	pH, EC, TON, TOC COD, BOD Ammoniacal-N Chloride Calcium, magnesium Sodium, potassium Sulphate, alkalinity Arsenic, cadmium Chromium, copper Nickel, zinc, lead, Iron, manganese	Quarterly
	Hazardous substances	N/A
	Depth to base (mAOD)	Annually

Note all monitoring points are classified as non-operational as per Table S3.1

The groundwater monitoring programme is based on a rationalised monitoring network based on monitoring the "upper" water bearing system – the glacial strata. Primary monitoring locations proposed are listed in Table 18, other monitoring requirement are detailed in Table 19, the monitoring plan (MEPP) should be updated in line with the retained monitoring locations detailed in report 4915/R/006/03.

Table 18 Permit Table S3.4 Groundwater Emission Limits

Permit Table S3.4 Groundwater – emission limits and monitoring requirements				
Monitoring Point	**Parameter**	**Limit**	**Period**	**Frequency**
Superficial Strata Upgradient WB5B (north), GBH9 (central) and WB3A (south) Cross-gradient BH2A (north), GBH6 (south) Down-gradient WB2A & BH4B (central), BH3B (north), GBH5 (south) Etruria Formation Upgradient WB4A Downgradient WB2B & WB2D	As per Table S3.8	N/A	Spot Sample	

Table 19 Permit Table S3.8 Groundwater Other Monitoring Requirements

Permit Table S3.8 Groundwater – other monitoring requirements		
Monitoring Point	**Parameter**	**Frequency**
MEPP Upgradient / Cross-gradient /	Water level	Monthly
	pH, EC, TOC, TON Ammoniacal-N	Quarterly

Down-gradient (as per Table S3.4)	Chloride Calcium, Magnesium Sodium, Potassium Sulphate, Alkalinity Chromium, cadmium Copper, nickel, zinc, lead Iron, manganese	
	Hazardous substances	N/A
MEPP	Base of monitoring point	Annually
Sump	Water level Base level	Monthly

It is proposed that water level is additionally collected on a quarterly basis at the following superficial monitoring locations to confirm overall flow direction as depicted in Figure 13:

North Perimeter – WB4B, GBH9, GBH10, BH1B

South Perimeter – WB3B, WB12A, BH15, GBH6

The surface water discharge limits as set out within discharge consent CM0180301, these limits are reproduced in Table 20. No other changes are proposed, the associated monitoring schedule is provided in Table 21.

Table 20 Surface Water Discharge Limits

Permit Table S3.3 Point source emissions to water (other than sewer) – emission limits and monitoring requirements					
Monitoring Point	**Parameter**	**Source**	**Limit**	**Reference Period**	**Frequency**
Sampling point WMP4A	Volume	Surface water lagoon	5184m^3/day, 60l/sec	Spot Sample	Quarterly
	Oils and grease		No visible discharge		
	Ammoniacal-N		1.3		
	Chloride		250		
	pH		>6 and <9		
	Suspended solids		50mg/l		

Discharge consent CG0387001 retained as per FCC requirements. Additional review of Surface water schedules, monitoring locations, analytical requirements and limits to be reviewed under an improvement condition.

Table 21 Surface Water Monitoring Schedule

Permit Table S3.11 Surface water – other monitoring requirements			
Monitoring Point	**Parameter**	**Frequency**	**Method**
WMP4A	Ammoniacal-N	Quarterly	Spot Sample
	Chloride		
	EC		
	pH		
	Suspended Solids		
	Visual oil and grease		

10. CONCLUSION

There is no observed impact on the superficial groundwater from the Ruabon landfill. There is no surface water at risk from sub-surface leachate migration.

The landfill is in Definitive Closure and monitoring schedules have been rationalised within a Source-Pathway-Receptor framework.

Any conceptualisation of the Etruria Marl as a receptor is considered to be flawed, because a “high-level” aquifer classification, this review (based on available data) indicates the bedrock is essentially dry ground with minimal free water.

It is considered that the espley / sandstone layers form a transitory position between formally classified unproductive strata (*i.e.* mudstones) and secondary aquifers, however at Ruabon they are not demonstrated to be present.

The hydrogeological risk assessment has demonstrated that operation under the principle of hydraulic containment (based on a upper water bearing Glacial system) the Site will not cause environmental harm, revised leachate level limits are based on this premise.

Therefore the primary potential risk to the environment from leachate is in the event that leachate overtops the sides of the site; hence the future leachate management strategy should be based on this risk pathway and hydraulic containment.

Drawings