HYDROGEOLOGICAL RISK ASSESSMENT

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1.0 INTRODUCTION

1.1 Report Context

White Rock Geo-Environmental Ltd were instructed by Mold Investments Limited the operators of Parrys Quarry to undertake a Hydrogeological Risk Assessment for the restoration of the site by way of inert landfilling to achieve a development platform for future residential or commercial development. This report provides the geological and hydrogeological setting of the site and considers the operational impacts of restoration by inert landfill in line with the Environmental Permit (England and Wales) Regulations 2016.

This report provides a summary to the geological and hydrogeological setting of the site, and the assessment demonstrates compliance the Environmental Permitting Regulations 2016 regarding the protection of groundwater which transposes the Groundwater Directive into law for England and Wales.

This report covers by way of assessment of Hazardous Substances and Non-Hazardous Polluting Substances, released into the groundwater.

The site is situated within the existing Parry's Quarry in Alltami, Flintshire and bounded by the A494 to the south, A55 to the north and Pinfold Road to the west. The National Grid Reference (NGR) for the entrance to the site is SJ 27478 66278, presented at Figure 1 below and is detailed at Drawing HRA 1.

Access to the site is directly off Pinfold Lane through lockable steel security gates.

As a core component of the EP, a Hydrogeological Risk Assessment is required for this installation to demonstrate compliance with the aforementioned regulations. These regulations require that there is no input of hazardous substances to groundwater and that any discharge of non-hazardous substances is limited so as to prevent pollution.

The site is currently operated as a brick clay quarry which covers an area of approximately 17 hectares. An area of the wider site holds an EP (Ref: EPR/TB3590HJ) for the transfer and reprocessing of inert waste. This EP application seeks to consolidate this activity within the overall landfill EP for the site. Extraction and landfill will therefore occur for at least 3 years with an inert waste importation rate of 950,000 tonnes per annum. The air space is therefore calculated at some 762,416m^3.

The site is to be infilled specifically with inert waste as listed by Natural Resources Wales and further complies with the Landfill Tax (Qualifying Material) Order or is to be WRAP compliant and therefore outside the scope of the permit. The quarry operates in accordance with the Planning Permissions issued by Flintshire County Council.

The Etruria Marl is designated as a Secondary B aquifer, is not regarded as a sensitive receptor.

The inert waste cells in Phase 1 will be constructed below the water table with a reworked basal and side wall geological barrier, and Phase 2 is to be developed using as basal geological barrier and side wall seal above the water table with an unsaturated zone, this HRA concentrates on the hydrogeological / geochemical properties of the geological barrier to be engineered at the site, to provide adequate protection to the aquifer. This groundwater body is recognised as the primary receptor. A substantial amount of geotechnical testing has been carried out at the quarry operated by MIL who had constructed a 1 metre thick liner in Phase 1 and has supporting permeability and particle size grading information

In accordance with 99/31/EC the following requirements do not generally apply to inert landfill sites given the nature of the materials to be deposited should fall outside the scope of the Groundwater Directive;

- Control systems to manage water from precipitation entering the landfill waste body
- Leachate head management
- Leachate collection and sealing system and hence no requirement for treatment prior to discharge of leachate
- Installation of an impermeable engineered cap

The underlying principle for inert landfill design is based on the presence of a geological barrier exhibiting a minimum thickness of 1.0m with a permeability of less than 1×10^{-7} m/s (or combination thereof).

The source is characterised as a leachate source term equivalent to maximum permissible Inert WAC thresholds, which is considered suitably conservative and a failure assessment is with a 10% breach of inert WAC.

This HRA has been prepared in accordance with international best practice to include;

- Description and understanding of the geological and hydrogeological setting
- Geo-environmental audit and proven ground conditions
- Conceptual site model based on a site specific *Source – Pathway – Receptor* model
- Tier I screening for potential contaminants of concern
- Development of a source term leaching model
- Hydraulic containment and Fate and Transport (F&T) modelling to assess potential contaminant flux across the geological liner
- LANDSIM Modelling of the unstated zone in Phase 2

- Sensitivity analysis
- Qualitative assessment of accidents and their consequences
- Requisite surveillance monitoring

A conceptual hydrogeological model is presented and potential contaminant migration pathways have been identified. The conceptual model has been developed on site specific data and local data obtained from the British Geological Survey. A probabilistic risk analysis for potential groundwater contamination at Parrys Quarry site has been undertaken based on the factual findings.

1.2 Conceptual Hydrogeological Site Model

1.2.1 Summary

The conceptual model for the site is based on the following context:

Source: is the potentially contaminating components of the leachate that will be generated and specifically Hazardous Substances and Non Hazardous Substances as defined in the Groundwater Framework Directive, though due to the nature of the waste proposed which is inert hazardous substances will not be present in any significant concentration within the waste within the site and at levels at or below those set out for inert landfill WAC criteria;

Pathway: includes the saturated zone within the bedrock geology of Phase 1 and flow through the unsaturated zone to the groundwater table in Phase 2 and the travel through the engineered geological barrier liner system on the base and sides, in which the degradation and attenuation process may occur;

Receptor: is the receiving groundwater directly around the site at the base and sides for Hazardous substances and the monitoring boreholes BHG, BHH, and BHI, down hydraulic gradient as shown on Drawing HRA 2 for Non Hazardous Substances.

1.2.2 Landfill Design

The conceptual site model is presented in Figure 1 with the proposed engineering design summarised in Table 1.

Table HRA1: Landfill Engineering Components

Inert Landfill Component	Description
Landfill Cap	Not Required
Leachate Drainage	Not Required
Artificial Sealing Liner	Not Required
Basal Mineral Liner	Minimum 1m thick with of $1x10^{-7}$ m/s
Sidewall Mineral Liner	Minimum 1m thick with of $1x10^{-7}$ m/s
Groundwater Control	Dewatering prior to mineral liner install in Phase 1
Construction Quality Assurance	All work subject to independent CQA

The landfill will be constructed as 2 No. Phases cells as shown in drawing ESSD 6 and detailed in Table 2.

All cell walls will be constructed from on-site re-worked Etruria Marl.

Cell walls will be lined with a 1.0m thick mineral liner using the available clay/marl materials located on site.

Cell wall stability has been assessed in the SRA.

Table HRA2: Cell construction volumes.

	Phase No.	Waste Cells Volume (m^3)	Purpose
Disposal	1	649,226	Inert Waste Disposal Cell
Disposal	2	113,190	Inert Waste Disposal Cell

Two disposal scenarios are considered for Parrys Quarry Landfill assuming filling operations commence during late 2020 following construction of the remainder of Phase 1 in 2020, and based on a total inert waste input of 762,416m^3.

Scenario 1 – Inert waste input of 633,000 m^3/yr with completion of landfilling operations by the mid of 2022.
Scenario 2 - Inert waste input of 300,000 m^3/yr with completion of landfilling operations by the end of 2023.

Table HRA3: Operational life of inert waste disposal cells

	Phase Life (yrs)		Phase Completion (year)	
Phase No.	**633,000 m³/yr**	**300,000 m³/yr**	**633,000 m³/yr**	**300,000 m³/yr**
1	1.02	2.16	2021	2022
2	0.18	0.38	2022	2023

1.2.3 Hydraulic Containment and the Unsaturated Zone

The construction and operation of sub-water table landfill cell within phase 1 is based on the principles of hydraulic containment. It is recognised that Landsim simulations are appropriate in Phase 2 where there is a larger unsaturated zone. The hydrogeological risk modes presented in subsequent sections of this document are based on EA spreadsheet model – Contaminant Fluxes from Hydraulic Containment Landfills for Phase 1. This specifically relates to early operational phases. Phase 2 uses the LANDSIM 2.17 models

Phase 1
The base of the landfill in Phase 1 will sit below the piezometric surface recorded at between 92 – 95 mAOD with the base at its lowest point at 91mAOD.

The base of the landfill will be 1m below the groundwater which is at 92m AOD and this is expected to rebound further once pumping ceases. The upper level of the groundwater in Phase 1 is at 95m AOD and the base is at 92m AOD.

The rate of advective groundwater flux into Phase 1 will be a function of the available driving head across the geological barrier.

The head of leachate generated within the phase is recognised as key parameter for sensitivity analysis, as active leachate management is not considered necessary for regulating leachate heads in inert waste bodies.

The development of the leachate head within the waste body is recognised to be a function of tipping rate, infiltration rate from rainfall and the water absorption capacity of the waste fill, prior to completion in the closure and post closure phases.

Modelling studies discussed below have assessed contaminant flux across the mineral liner under the following scenarios.

Scenario 1 – 1m leachate head (*early phase filling*)
Scenario 2 – 3m of leachate head representative of the poorest hydraulic containment conditions (*later phase filling*) and post groundwater pumping cessation
Scenario 3 – advective flux through the upper side wall mineral liner system for a completely saturated waste mass (*post closure*)

The maximum available leachate head under a hydraulic containment model for Parrys Quarry is circa. 3m. This is calculated from the average depth between the geological barrier (91.5 mAOD) and the observed maximum groundwater elevation (95.50 mAOD) at the up hydraulic gradient boreholes, (BHC).

It is considered unlikely, even in the absence of an active leachate management system, that leachate heads greater than 3m would develop within waste cells during the operational lifetime, and as stated above are likely to be 4 metres. Although no formal leachate collection system is required or will be installed, it is likely that the deployment of local surface water management within cells during construction will influence the development of leachate heads within the waste mass.

Notwithstanding the above, we consider it appropriate to establish a quarterly monitoring programme for surveillance of leachate head development within cells during operational phases.

Modelling has been undertaken in section 2 to assess the potential impact of groundwater flow.

The maximum possible head for a fully saturated waste fill is calculated to be 4m above the base. Based on a 1h in 1v slope, the driving head would be operating under a hydraulic gradient of 1.0 across 1.0 meters of mineral liner.

Calculations for hydraulic gradient where computed from the following equation, as derived by Giroud (1990) and implemented in Landsim and above.

$$i_{ave\infty} = 1 + 0.2\left(\frac{h_w}{t_s}\right)^{0.95}$$

Where $h_w$is the leachate head, t_s is the thickness of the mineral liner and $i_{ave\infty}$ is the average hydraulic gradient across the mineral liner.

These aforementioned scenarios have been investigated through the DQRA model presented in section 2.

Phase 2

The base of Phase 2 lies at 102m AOD and the groundwater table at rebound will be between 92.5m AOD and 90m AOD.

LANDSIM 2.5 was used to evaluate both magnitude and likelihood of leakage rate, the potential containment concentration at the critical receptor and breakthrough time to the critical receptor for the development in Phase 2 of the landfill site.

The model uses the statistical Monte Carlo methodology. The risk of leachate migration to the receptor was estimated by the range of concentrations of the selected chemical species in the groundwater at the receptor at an infinite time after the commencement of leachate leakage.

1.2.4 Source Term Leaching Model

Decomposition of inert waste is not considered highly complex like a non-hazardous waste landfill, with microbiological, physical and chemical processes acting simultaneously within each operational and closed landfill phase, and acting in a relatively consistent manner within an inert landfill site. Leachate is formed by the percolation of water through the inert waste mass coupled with the decay and release of contaminants from the waste itself.

In order for inert waste to be accepted at a landfill site, the holder or operator must be able to show that the waste meets the permit conditions and the waste acceptance criteria (WAC). To do this a set process to characterise and test the waste is required.

Waste acceptance criteria have been agreed by the European Council. They applied from 16 July 2005 under the Landfill (England and Wales) (Amendment) Regulations 2004 transposed under the Environmental Permitting Regulations 2010. These criteria are referred to as ‘full waste acceptance criteria’. For inert landfills, there is a limited list of wastes presented at Table HRA4 below that are deemed to meet the criteria for inert waste. These wastes are acceptable if:

- they are single stream waste of a single waste type (although different waste types from the list may be accepted together) and are from a single source; and
- they are not contaminated and do not contain other material or substances such as metals, asbestos, plastics, chemicals, etc to an extent which increases the risk associated with the waste sufficiently to justify their disposal in other classes of landfill.

Table HRA 4: Inert Wastes List

01 WASTES RESULTING FROM EXPLORATION, MINING, QUARRYING, AND PHYSICAL AND CHEMICAL TREATMENT OF MINERALS

01 04 wastes from physical and chemical processing of non-metalliferous minerals

01 04 08 waste gravel and crushed rocks other than those mentioned in 01 04 07
01 04 09 waste sand and clays

17 CONSTRUCTION AND DEMOLITION WASTES (INCLUDING EXCAVATED SOIL FROM CONTAMINATED SITES)

17 01 concrete, bricks, tiles and ceramics

17 01 01 concrete
17 01 02 bricks
17 01 03 tiles and ceramics
17 01 07 mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06

17 05 soil (including excavated soil from contaminated sites), stones and dredging spoil

17 05 04 soil and stones other than those mentioned in 17 05 03
17 05 06 dredging spoil other than those mentioned in 17 05 05
17 05 08 track ballast other than those containing dangerous substances

19 WASTES FROM WASTE MANAGEMENT FACILITIES, OFF-SITE WASTE WATER TREATMENT PLANTS AND THE PREPARATION OF WATER INTENDED FOR HUMAN CONSUMPTION AND WATER FOR INDUSTRIAL USE

19 12 wastes from the mechanical treatment of waste (for example sorting, crushing, compacting, pelletising) not otherwise specified

19 12 05 glass, (excluding residual fines from mechanical treatment of mixed wastes at transfer stations)

19 12 09 minerals (for example sand, stones)

19 13 wastes from soil and water groundwater remediation

20 MUNICIPAL WASTES (HOUSEHOLD WASTE AND SIMILAR COMMERCIAL, INDUSTRIAL AND INSTITUTIONAL WASTES) INCLUDING SEPARATELY COLLECTED FRACTIONS

20 02 garden and park wastes (including cemetery waste)

20 02 02 soil and stones

[a]*Selected construction and demolition waste (C & D waste): with low contents of other types of materials (like metals, plastic, organics, wood, rubber, etc). The origin of the waste must be known.*

No C & D waste from constructions, polluted with inorganic or organic dangerous substances, e.g. because of production processes in the *construction, soil pollution, storage and usage of pesticides or other dangerous substances, etc., unless it is made clear that the demolished construction was not significantly polluted.*

No C & D waste from constructions, treated, covered or painted with materials, containing dangerous substances in significant amounts.

The source term leaching model is based on the inert WAC suite as presented in Table HRA 5. Source terms are also considered for benzene, napthalene and ammonium. Reasonable worst case estimates of leaching source terms for benzene, napthalene and ammonium have been assumed to be 0.1 mg/l, 0.001 mg/l and 0.5 mg/l respectively.

Although it is common to use a declining source term leaching model for assessing the potential emissions to groundwater from landfills through the use of kappa values, we have assumed the conservative approach here of applying a constant leaching source term. The source term leaching model is set at inert WAC thresholds. This approach hence assumes that all waste accepted would generate leachate at threshold concentrations during the entire operational phase of the landfill, which we recognise as suitably conservative.

By comparison of inert WAC source terms with the relevant Water Quality Standards (WQS) and maximum observed background groundwater concentrations, proposed Environmental Assessment Limits (EALs) have been generated for the subject site.

The bedrock aquifer is unlikely to provide groundwater resources for potable water abstractions due to its low permeability and transmissivity values. It is considered a more important receptor for potentially providing base flows to local rivers such as the Alltami Brook and Wrepe Brook, hence preference is given to Environmental Quality Standards (EQS) over Drinking Water Standards (DWS).

The derivation of EAL's are based on the condition that, where groundwater concentrations already exceed the relevant WQS, the relevant EALs are set at 1.5 x background concentrations to account for the natural variability of groundwater quality.

Table HRA 5 also provides tier 1 risk screening to identify components that exceed the relevant EAL, hence would require sufficient attenuation capacity within the geological barrier to prevent the deterioration of groundwater quality. Where the Required Attenuation Factor (AF) is less than or equal to 1, there is predicted to be no impact on controlled waters.

Table HRA5: Inert WAC Screening & Recommended EALs.

Component	WAC Source Term	DWS	EQS	WHO	Mean Base Line GW	AF required by geological liner
As (µg/l)	50	10	50	10	0.25	1.00
Cd (µg/l)	4	5	0.15	3	0.25	**2.22**
Cr (µg/l)	50	50	50	50	5.3	1.00
Cu (µg/l)	200	2000	10	10	6.3	**4.30**
Hg (µg/l)	1	1	1	1	0.001	1.00
Ni (µg/l)	40	20	50	20	32	0.80
Pb (µg/l)	50	10	7.2	10	2	**5.56**
Zn (µg/l)	400	5000	75	3000	279	**3.38**
Cl (mg/l)	80	250	250	250	35-395	**0.17**
SO4 (mg/l)	100	250	400	250	203	**0.25**
Phenol (µg/l)	100	0.5	30	-	<0.05	**3.33**
Benzene (µg/l)	100	1	30	10	-	**100**
Napthalene (µg/l)	1	-	10	-	-	**100**
Ammonium (mg/l)	0.5	0.5	0.01 51	1.5	0.012-0.882	**0.39**

Sorption isotherms were generated at liquid:solid ratios (L/S) = 10 in a supporting background electrolyte of 0.1M NaCl. The electrolyte was chosen to provide counter-ion condensation for electrostatic surface charge development on the test clay mineral surfaces. Based on the conservative transport phenomena of Na and Cl, development of electrostatic surface charge within the mineral liner would be anticipated to precede the movement of potential contaminants across a mineral liner system.

12-point sorption isotherms were generated for all inorganic compounds and phenol, whereas napthalene and benzene sorption parameters were determined from 10 No. independent data-points. All isotherm datasets were produced at a target pH of 8.6, based on the observed native stable pH of the mineral barrier. Final equilibrium pH ranges are presented in Table HRA6 along with fitted linear and non-linear sorption isotherm parameters.

Table HRA6: Sorption isotherm parameters for selected compounds to describe geochemical retardation through the mineral liner.

		Linear			Freundlich			Langmuir		
	Kd	Log Kd	R^2	n	k	R^2	Qmax	k	R^2	Equilibrium pH Range
Ammonium	4.75	0.677	0.990	0.973	0.773	0.954	232.5	5.181E-04	0.873	8.238-8.466
Sulphate	0.962	-0.017	0.948	0.875	-0.418	0.919	3631.9	1.767E-04	0.858	8.244-8.428
Chloride	0.150	-0.823	0.179	0.584	-2.911	1.000	nd	nd	nd	8.313-8.675
Arsenate	49.4	1.694	0.950	1.128	1.525	0.981	61.0	3.167E-04	0.982	8.219-8.349
Zinc	7820	3.893	0.912	2.159	3.453	0.874	521.5	5.549E-08	0.852	8.213-8.733
Lead	13100	4.118	0.792	2.984	2.968	0.976	1300.3	3.199E-08	0.924	8.559-8.866
Cadmium	68.6	1.836	0.844	3.637	0.306	0.900	0.782	2.721E-02	0.996	8.496-8.626
Benzene	146	2.165	0.874	1.169	2.074	0.998	313.6	1.942E-05	0.672	8.309-8.325
Phenol	74.0	1.869	0.996	1.486	2.046	0.945	990.9	6.403E-06	0.450	8.367-8.384
Napthalene	8.94	0.951	0.910	0.941	0.590	0.920	nd	nd	nd	8.208-8.469

Sorption isotherm datasets are presented with parameterisation fits in Appendix 5, with associated certificates of analysis.

Tortuosity determinations were undertaken on a sample of the natural clay/marl mineral liner material spiked with 1 wt.% sodium chloride. This provided source term concentrations (Co) for Na of 3802 mg/kg. 8 fraction semi-dynamic tank testing was conducted over a 16 day period using a sampling methodology based on the square root of time.

Tortuosity was determined from the observed diffusive flux of sodium as a conservative tracer (i.e. low geochemical retardation). The experimentally derived, site specific effective diffusion coefficient (De) for sodium is 1.47 x 10^{-10} m^2/s, giving a tortuosity of 10.81.

Certificates of analysis and interpretative calculations for determining tortuosity are presented in Appendix 6.

The calculated Kd values have also been used in the LANDSIM models. The LANDSIM modelling also has a half-life degradation values for specific compounds and justifications are set out in Table HRA 7.

Table HRA7: Half life decay rates for selected species

Determinant	Paramter	Value/Range	Justification
Ammonia	**Half Life(years)**	**6 years**	**Half life decay values for ammonia have been included with a value of six years based on the report entitled "Review of ammonium attenuation in soil and groundwater" produced by the NGWCL, published July 2003.Conservative as figures are quoted as 6-10 years.**
Benzene	**Half Life(years in parenthesis)** **Koc (l/kg)x FOC =Calculated**	**5 days-16days** **2.13**	**Range of values to take account for both aerobic and anaerobic environmental conditions based on Handbook of Environmental Degradation Rates Howard et al (1991)** **US EPA (1999) pH6-8, calculated from organic carbon test data from Eurofins**
Napthalene	**Half Life(years in parenthesis)** **Koc (l/kg)x FOC =Calculated**	**0.131-1.5** **487.7-1102-2309**	**Range of values to take account for both aerobic and anaerobic environmental conditions based on Handbook of Environmental Degradation Rates Howard et al (1991)** **US EPA (1999) pH6-8, calculated from organic carbon test data from Eurofins**
Phenol	**Half Life(years in parenthesis)**	**0.02-0.07**	**Range of values to take account for both aerobic and anaerobic environmental conditions based on Handbook of Environmental Degradation Rates Howard et al (1991)**

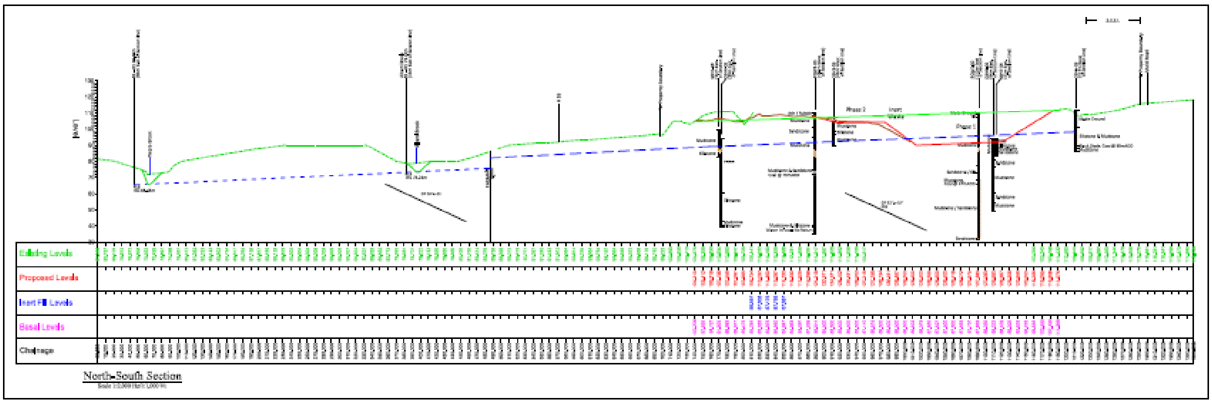
1.2.5 Receptors

The Environmental permitting Regulations, 2010 require that the entry of hazardous substances into groundwater must be prevented and that the entry of non-hazardous pollutants into groundwater must be minimised so as to prevent pollution. In compliance with these regulations the following compliance points are considered appropriate:

Hazardous Substances – pore water at the outer edge of the mineral liner prior to dilution for Phase 1 and the base of the unsaturated zone for Phase 2.
Non-hazardous Pollutants – groundwater within the aquifer following dilution but prior to interaction with surface water features. It is typical to set the compliance point at the down gradient installation boundary.

To provide the highest degree of conservatism in accordance with adopting the precautionary principles for environmental protection, this CSM assumes the compliance point for both hazardous and non-hazardous will be the pore water at the outer surface of the mineral liner. Under this approach, all components investigated in the following hydrogeological risk model are assumed to behave as hazardous substances.

Figure 1: Conceptual Site Model (CSM) showing the main lithological sequences at the subject site. For reference the compliance point (Cp) is located at the outer edge of the mineral liner (shown as orange side walls to inert waste body).



1.2.6 Geology and Hydrogeology

Geology

The site is situated within an outcrop of Carboniferous aged Coal Measures strata (predominately comprising mudstones with sub-ordinate sandstones, siltstones and coal beds). The geological succession is complicated by local structural controls; which has created a series of fault bounded blocks in the area and caused the various types of bedrock to locally become juxtaposed against each other.

The geological sequence at the site has previously been described as very complex (TerraConsult[1], 2015); which is considered to reflect the rapid lateral and vertical changes in lithology due to the depositional nature of the sequence and post-depositional structural controls (i.e. dipping, bedding and faulting). Attempts were made by TerraConsult to laterally correlate units observed at the site; evidently this was difficult due to the limitations of the available data (including that boreholes only provide a one-dimensional (vertical) record of the geological succession) and the complicated nature of the geology as outlined above. Nevertheless, based on published geological mapping, the following simplified geological sequence for local area has been identified:

- Etruria Formation[2] – comprising red, purple, brown, ochreous, green, grey and commonly mottled mudstone, with lenticular sandstones and conglomerates. The Etruria Formation includes the 'Buckley Blue' unit (a local and now obsolete name), which comprises a purple, black and grey mudstone, and was principally the clay that was excavated from the quarry void;

- Pennine Middle Coal Measures Formation – comprising inter-bedded grey mudstone, siltstone, pale grey sandstone and coal seams. The upper part of the Coal Measures includes a sandstone unit referred to as the 'Hollin Rock' which immediately underlies the Etruria Formation; and
- Pennie Lower Coal Measures Formation – comprising inter-bedded grey mudstone, siltstone and pale grey sandstone, commonly with mudstones containing marine fossils in the lower part, and more numerous and thicker coal seams in the upper part.

Available geological mapping (British Geological Survey (BGS) (2018), as shown on Drawing ESSD8, and at Figure 2 below indicates that sandstones of the Etruria Formation are present across the eastern two thirds of the Site (and extend to the area immediately to the east); mudstones, sandstones and conglomerates of the Etruria Formation are present across the western third of the Site. The Middle Coal Measures are then present further to the west. This includes the Hollin Rock Member which is identified beyond a north-south faulted boundary (with an apparent 50m downthrow) present along the western boundary of the Site.

The Lower Coal Measures Formation are present c. 50m to the east of the Site beyond another approximately north-south faulted boundary.

Mapping of the superficial geology, as shown on Drawing ESID10, also shows that glacial till is present above bedrock across much of the area surrounding the site. The TerraConsult report shows that it is c. 2m in thickness and comprises a sandy clay with sandstone fragments. Superficial deposits are absent along the route of Alltami Brook where it is closets to the site (i.e. 250m to the northeast). Elsewhere however, alluvium is present along the course of the brook to the south (i.e. up-stream); and alluvium and glacio-fluvial (sand and gravel) deposits are present on both Alltami and Wepre brooks to the north (i.e. down-stream).

The mapping shows that superficial deposits are absent from across much of the site; this is due to the development that has taken place (i.e. initially a brickworks, followed by quarry extraction). Furthermore, the southern quarter of the site; the areas immediately to the north and to the south of the site; and several other areas in the vicinity are identified as artificial ground. Again, this relates to the former uses of these areas.

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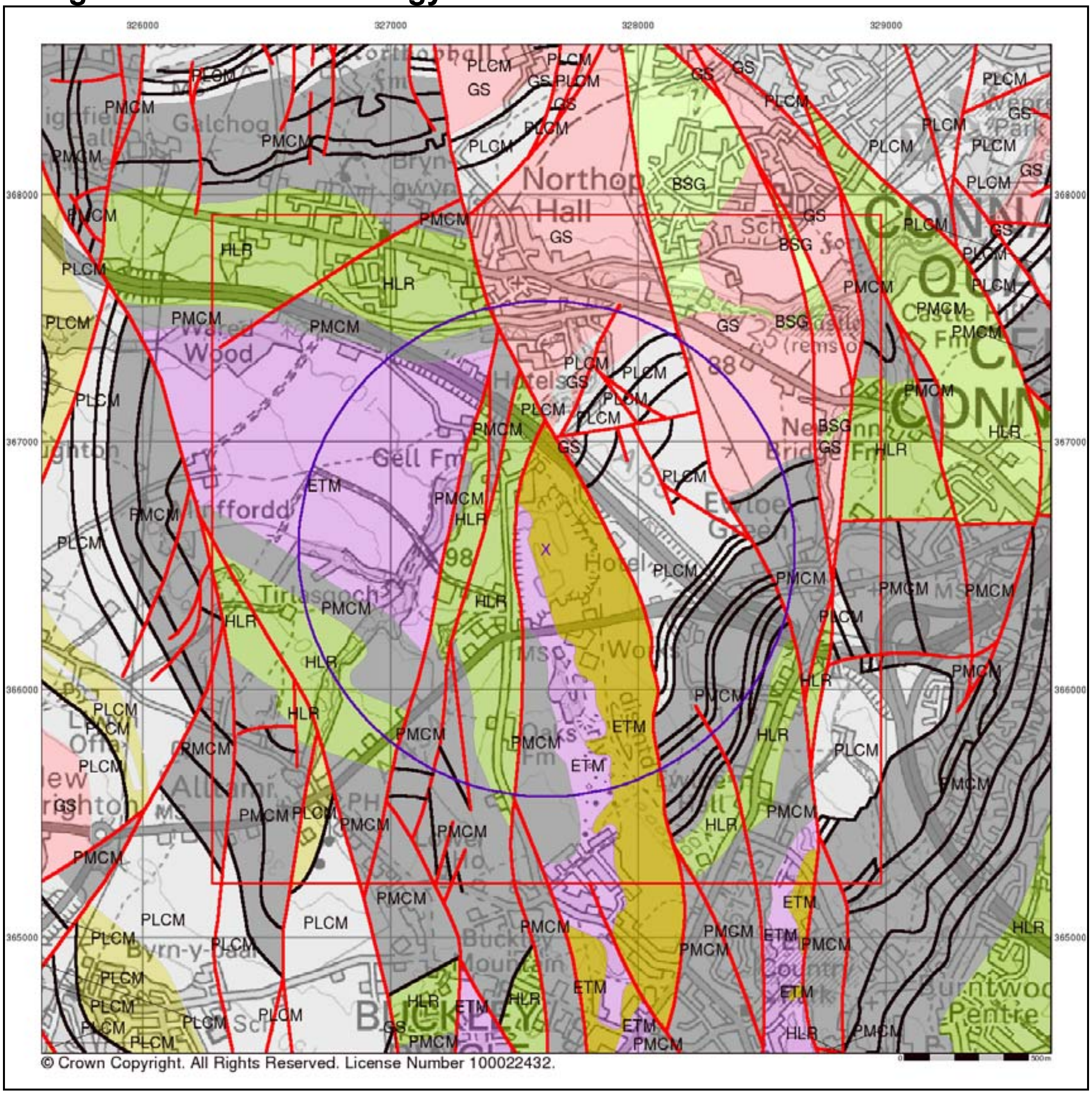
1 Terraconsult, 2015. Parrys Quarry Landfill Site. Hydrogeological Risk Assessment. December 2015. Report: 2434-R05

2 Note that the Etruria Formation is used here in preference to the term Etruria Marl as was adopted by TerraConsult (2015) since this is the current name for this unit given by the BGS (2018).

The Local bedrock geology is also presented at Figure 2 for reference below. The solid geological map is presented at Drawing ESSD 8 containerd within the ESSD.

Figure 2: Bedrock Geology



Hydrology

The site lies within the catchment area of the River Dee. The nearest water course to the site is Alltami Brook which is situated to the west of the site; flowing from southwest to northeast. At its closest point it is 250m to the northwest of the site; it flows onwards and converges with Wepre Brook 700m to the north of the site. Wepre Brook flows from west to the east and is a tributary to the River Dee c. 4km to the northeast of the site. New Inn Brook, another tributary to Wepre Brook, is present 900m to the east of the site.

Identified flood risk zones associated with Wepre Brook and Alltami Brook are confined to their respective river channels and, as such, at their closest they are approximately 250m to the northeast of the site.

The area immediately to the south of the site includes several ponds and is part of the Deeside and Buckley Newt Sites designated SSSI and SAC. This relates to the presence of four protected amphibian species which were identified on the site mid-1990s. The owner of the site at that time (Hanson Brick Ltd) relocated these species from an area of planned mineral extraction and established a dedicated conservation area (which were subsequently designated as part of the SSSI and SAC).

Discharge Consents

There is an active discharge consent for the site held by Mold. This allows trade discharges (e.g. surface water) from a point on the north-western boundary of the site to Alltami Brook. It is understood that the discharge is limited to a maximum of 14 l/s. There is a similar discharge consent for trade discharges from the adjacent quarry between Pinfold Lane and Alltami Brook.

There are two discharge consents for treated sewage effluent into a tributary of the Alltami Brook, c. 350 m southwest (and upstream) of the Site associated with the FCC depot. There are also a group of discharge consents for treated sewage effluent from domestic properties to the same tributary immediately upstream of this point. There is another group of discharge consents, primarily relating to sewage discharges from a water company to Wepre Brook c. 700 m to the north of the Site.

Hydrogeology

Aquifer Characteristics

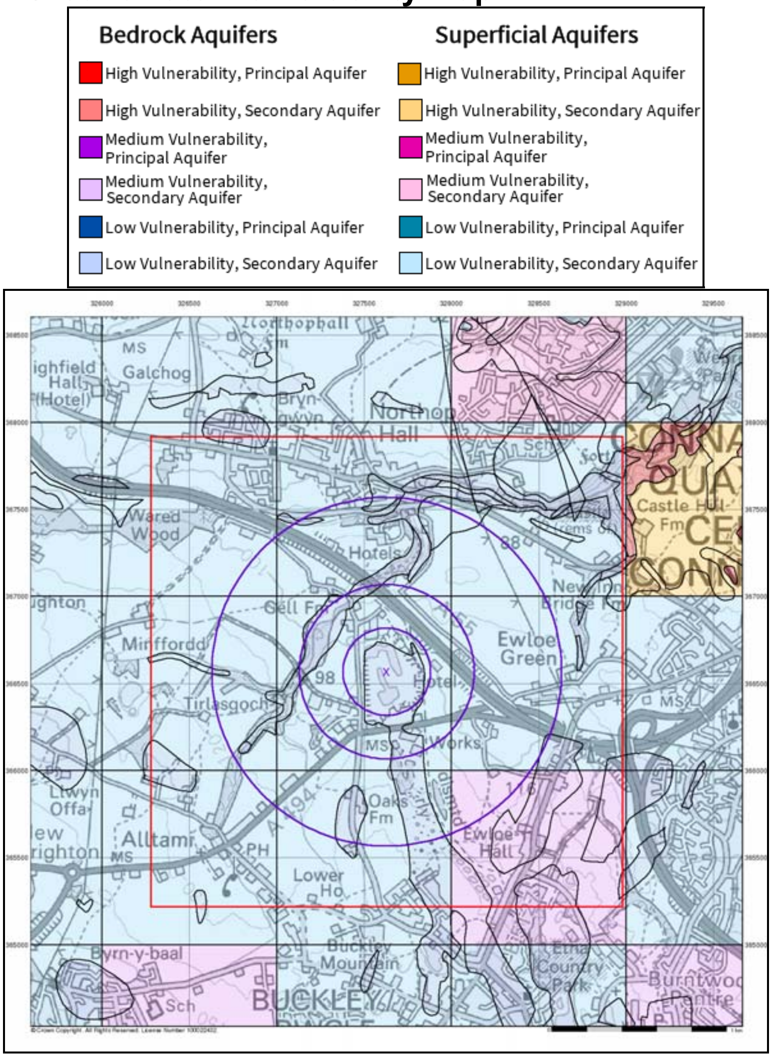
From 1st April 2010 new aquifer designations replace the old system of classifying aquifers as Major, Minor and Non-Aquifer. This new system is in line with our Groundwater Protection Policy (GP3) and the Water Framework Directive (WFD) and is based on British Geological Survey mapping.

The Coal Measures and surrounding bedrock are classified as a Secondary A Aquifer. Jones *et al.* (2000) describe how these strata are expected to behave as a multi-layered aquifer system in which lower permeability mudstones act as aquicludes between sandstone aquifer horizons. Both the mudstones and sandstones (which are well cemented) possess minimal primary porosity. Groundwater flows predominately occur within joints and fractures within the sandstone strata to depths of up to 250m; transmission of groundwater will depend on how locally well connected these hydrogeological units are. Lateral recharge is considered likely to be limited as the hydraulic continuity of the aquifer is disrupted by the faulting which effectively splits the aquifer units into isolated blocks. Locally, the hydrogeology can be modified by the presence of mine shafts and inter-connecting mine workings.

The superficial deposits (alluvium and glacio-fluvial) locally present along Alltami Brook and Wepre Brook are classified as Secondary A Aquifer. The Glacial Till is classified as unproductive strata.

Figure 3 shows the groundwater vulnerability mapping which is designated as low for and around the site.

Figure 3: Groundwater vulnerability map



The site is not within a Source Protection Zone.

3.5.2 Groundwater Flow

In general, the groundwater flow direction within the Coal Measures is expected to follow the overall topography towards the north; however local variations in flow directions (and hence piezometric head differences between separate or poorly connected hydrogeological units present within the Coal Measures) are also likely to be apparent.

TerraConsult (2015) previously undertook a detailed review of available groundwater level data at the site. However, limitations were recognised with the available data set including borehole records were not available for all monitoring points (i.e. so there was no knowledge of which hydrogeological units were being monitored); and rather than targeting discrete water bearing units, the groundwater monitoring points tended to have been installed with long response zones that intersect multiple, higher and lower, permeability units. As a result, the water levels may provide an 'average' water level for all the units; including some at higher elevations where groundwater flows may actually be negligible. Other limitations included the frequency and duration of available groundwater level monitoring data; and identifying the influence of groundwater dewatering that had been undertaken historically at the Site and in a neighbouring quarry.

For these reasons, it was decided that a new network of groundwater monitoring points was required at the site. This resulted in borehole drilling and the installation of 14 dedicated groundwater monitoring locations around the perimeter of the site in early 2017 (TerraConsult, 2017).

A programme of a groundwater level monitoring has been undertaken since these new groundwater monitoring points have been installed. The results are discussed in further detail in the HRA and are summarised below:

- The groundwater level monitoring that has been undertaken between January 2017 and June 2020 suggests that a relatively consistent piezometric surface is present which falls from c. 98 to 100mAOD in the south-east to c. 87 to 90mAOD in the west and north-west of the site.
- With the exception of one monitoring location (2016-C) the variation in groundwater levels that has been observed over this period is on average c. 2m but variations of up to a maximum of c. 4m have been identified.
- The recent groundwater monitoring data suggests that despite the identified small scale geological complexity, individual water bearing units appear to be relatively well connected at the scale of the site and so appear to combine to act as a single aquifer unit with a broadly consistent and identifiable piezometric surface across the site.

As described above, Alltami Brook, is located c. 250m to the north-west of the site. It is down topography from the site (where it is situated in a valley at an elevation of between c. 80 and 90mAOD; compared to the elevation of the site at around 110mAOD). Given that groundwater levels within the Coal Measures are typically between 87 and 90mAOD on the north-western boundary of the Site it is considered likely that there is hydraulic connection between groundwater and the brook down hydraulic gradient of the site (TerraConsult, 2015).

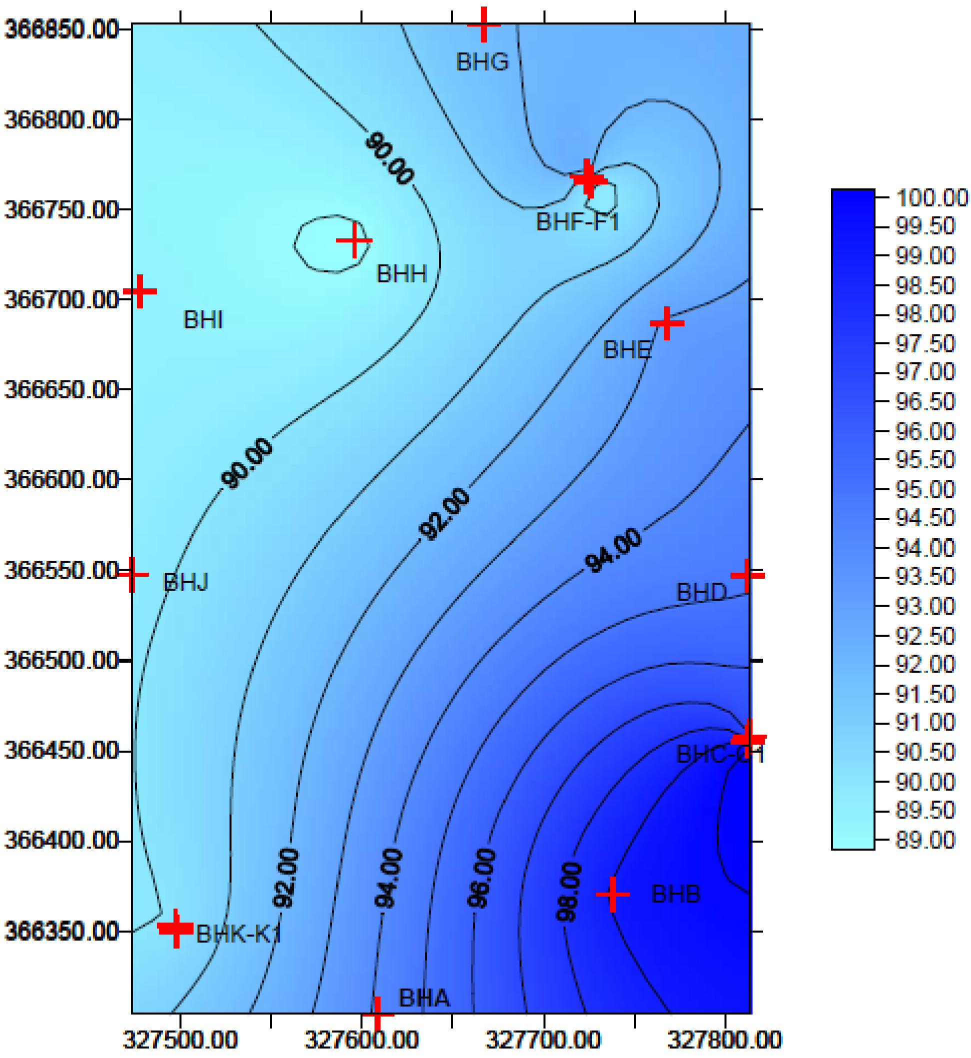
Assuming connection between the Alltami Brook and the groundwater flow from the quarry and the depth of the Barren and Productive measures at well over 100 metres a 10 metre mixing zone within the aquifer is assumed as a reasonable figure.

Groundwater Flow

Groundwater levels have been monitored on site since the initial installation of the boreholes and the results are presented in the HRA and are summarised as a hydrograph at Appendix HRA 3.

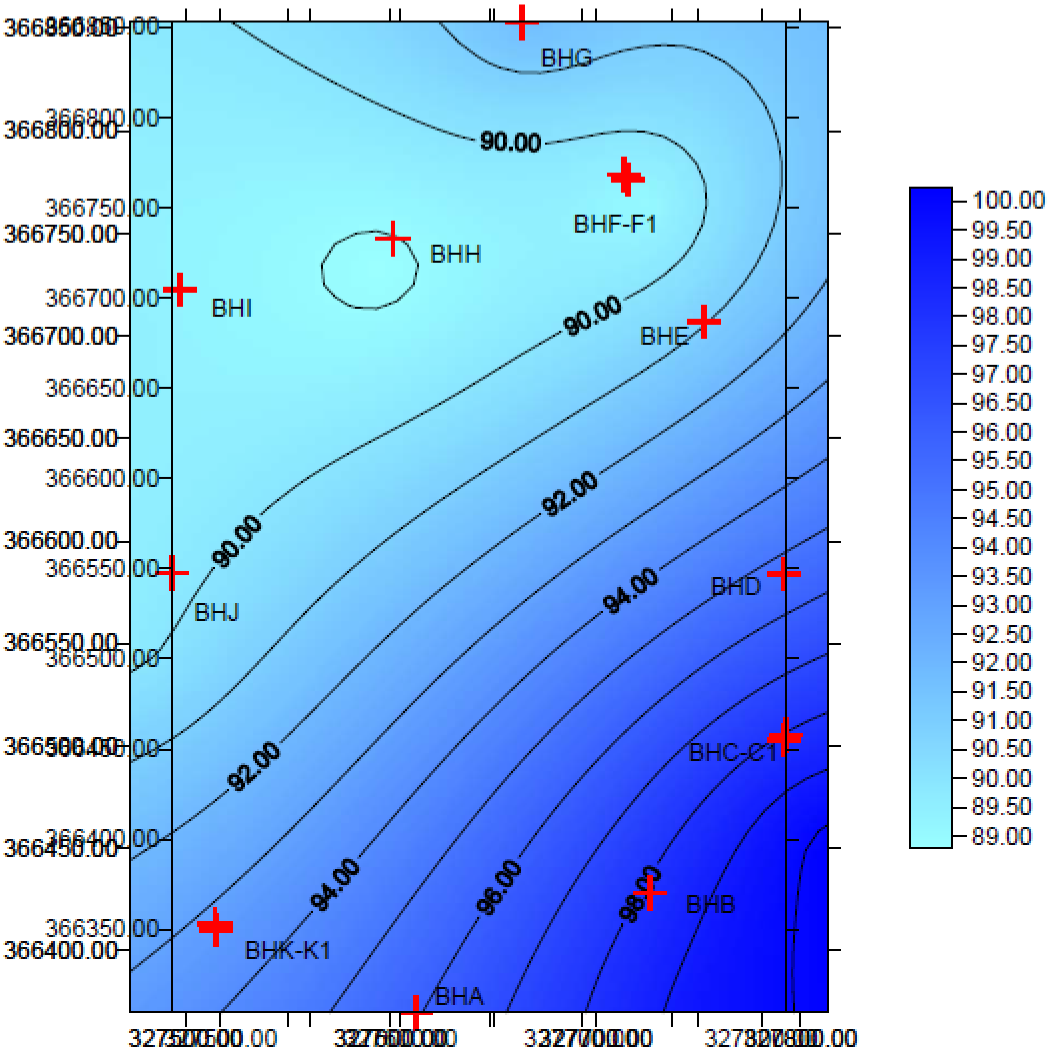
The groundwater flow is northwards and is presented at Figure 4 showing the maximum recorded levels to date and are influenced by on site pumping

Figure 4: Maximum groundwater contour model



It is assumed that the groundwater levels at the northern end of the site, principally BH G,H, and I are not influenced by pumping and that boreholes B,C and C1 are also not influenced by dewatering in the quarry and have been used to develop the rebound groundwater model which is presented as Figure 5.

Figure 5: Groundwater rebound contour model



The distance from Borehole B to Borehole H is 390 metres and the head loss is 10 metres falling from 99m AOD to 89m AOD giving a hydraulic gradient of 0.0254

Two distinct ranges of hydraulic conductivity values have been identified from aquifer testing that has been performed at the Site (TerraConsult, 2015). Values of $<10^{-6}$ m/s were deemed to be consistent with primary (rock matrix) permeability; and values in the order of 6×10^{-5} m/s were considered to represent the secondary permeability of the Coal Measures rock types (i.e. bulk flow via the fracture network). This is consistent with the original site investigations carried out by Hafren Water that reported permeability valuers on site to range from 0.5(5.78×10^{-6}m/s) to 3m/d (3.472×10^{-5}m/s) and the Hafren site values have been used in the LANDSIM models with an average value of 2.025×10^{-5}m/s.

2.0 DETAILED QUANTITATIVE HYDROGEOLOGICAL ASSESSMENT

2.1 Introduction

By reference to Table HRA5, it is apparent that the adoption of inert WAC will limit the potential risk to groundwater at Parrys Quarry. The determinands identified in Table HRA6 have been used to quantitatively predict the potential risk to the shallow aquifer. The approach here is considered to be protective to any down gradient receptors, such as brooks, streams, rivers or surface water features as the compliance point is taken as groundwater immediately adjacent to the inert waste landfill cell mineral liner (i.e. no dilution).

Operation of an inert landfill at the site is regarded as low risk with respect to controlled waters. As model parameterisation is predominantly based on observed values from testing of geological materials to be used for constructing the mineral liner, we suggest that the relative confidence is high and hence does not necessitate a requirement for a stochastic modelling approach. Furthermore, it is considered that the level of risk associated with the construction of an inert landfill at Parrys Quarry landfill is not commensurate with the level of complexity introduced by numerical modelling approaches such as Landsim.

The quantitative risk model for the subject site have been developed using a Source – Pathway – Receptor model based on the following spreadsheet models developed by the Environment Agency

- Contaminant Fluxes from Hydraulic Containment Landfills version 1.0 for Phase 1
- Remedial Targets Worksheet release 3.2.for Phase 1
- LANDSIM 2.17 for Phase 2

This approach has been developed to provide a full lifecycle analysis for the inert landfill installation by assessing hydraulic containment during early phase operations and advective contaminant flux through the mineral liner during latter stages of waste filling operations and the post-closure scenario in Phase 1 and the leachate release from the base of Phase 2 through the unsaturated zone into the rebounded groundwater table.

The source is identified as a progressively filled inert waste body, predominantly comprising waste soils. The total source area created by the placement of inert waste fill will be 762,416m^3.

The Conceptual Site Model (CSM) presented in section 1 is based on the conservative assumption that there will be no dilution of potential contaminants within the shallow sand and gravel aquifer for any of the modelled components. This is equivalent to treating all components as hazardous substances in accordance with the Groundwater Directive, as implement by the Environmental Permitting Regulations.

From the interpretation of existing intrusive ground investigation data, published borehole logs, and geological and hydrogeological reports discussed in section 1, a single hydrogeological pathway has been identified. This relates to the migration of contaminants through the low permeability clay/marl mineral liner, with contaminant flux into the aquifer.

This HRA specifically considers risks to the groundwater within the Etruria Marl as the main receptor. Given the flow rates and baseline quality within the aquifer it is considered unlikely it would be regarded as a future water resource for potable water abstractions.

The environmental compliance point is modelled as the outer surface of the mineral liner (most onerous assumption) for Phase 1 and the base of the unsaturated zone for Hazardous Substance release in Phase 2 and the outer boreholes around the perimeter for non-hazardous polluting substances and the release point into the wider environment as the Alltami Brook located c. 250m to the north-west of the site. .

2.2 Contaminant Transport Modelling Phase 1

Contaminant flux through the natural geological clay barrier has been modelled for two scenarios for Phase 1;

Hydraulic containment within inert waste cells where the leachate head is below groundwater elevations – **Early Operational Phase of Waste Cells**

Contaminant flux through the mineral liner for waste cells where leachate heads exceed groundwater elevations – **Late Operational Phase & Post Closure of Waste Cells**

Hydraulic containment

Worst case assumptions were used for hydraulic containment modelling;

All components treated as hazardous hence the compliance point is the immediate outer surface of the mineral barrier, with no dilution within the receptor

No degradation of organic compounds in the sorbed phase

This approach has the advantage that the model becomes insensitive to waste cell dimensions, hence a single model construct is applicable to all proposed waste cells.

Hydraulic containment has been modelled for the two previously described scenarios;

Scenario 1 – 2.0m leachate head (92.0 mAOD) which is considered representative of a normally operating inert waste cell filled predominantly with inert soils

Scenario 2 - 4m leachate (94.0 mAOD), which presents a worst case hydraulic containment risk model based on rebound with pumps turned off.

The model is based on the following input parameters;

1.0m mineral liner exhibiting an average hydraulic conductivity of 1.08E-10m/s, based on site investigation values and all permeability determinations for the geological barrier at the nearby Meriden landfill site, see Appendix HRA 4.

Site specific Kd parameters derived from sorption isotherms.

Site specific tortuosity of 10.81, as determined by semi-dynamic tank testing.

Co values based on the maximum inert WAC thresholds, or estimated from maximum permissible solid phase concentrations for benzene and naphthalene, ammonia and phenols.

Default values were used for effective porosity (0.162) and average pore radius (1×10^{-5}m).

Free water diffusion coefficients were taken from literature values as referenced within model spreadsheets.

Average groundwater elevations (92.0mAOD) are taken from groundwater monitoring datasets

The base of the landfill (90.0 mAOD) is taken as floor of quarry with 1 metre clay geological barrier placed across entire area.

Contaminant flux through the mineral liner

The time variant option of the Dominco equation has been used to assess the retarded travel of contaminants through the mineral liner. Break-through concentrations (if observed) are based on the maximum possible leachate head that could develop within waste cells.

Analytical contaminant transport calculations were undertaken using the EA's Remedial Targets Worksheet by applying the following conditions;

Vertical flux adopting a hydraulic gradient of 0.0126 where the leachate head is situated above groundwater elevations.

No degradation for organic components in the sorbed phase

Contaminant transport modelled through a 1.0m mineral liner, based on the vertical distance across slopes at a 1v in 1h gradient, exhibiting a permeability of 1.08 x 10^{-10}m/s

Site specific Kd parameters derived from sorption isotherms.

Source term leachate concentrations (Co) based on inert WAC thresholds, consistent with the approach used for the hydraulic containment scenario.

The assessment is based on modelling pore water concentrations across the mineral liner, taking the compliance point as the outer edge, hence no dilution within the superficial aquifer.

Hydrodynamic dispersion is based on a 10%, 1%, 0.1% dispersivity model. Sensitivity analysis showed that when modelled as plug-flow system (no dispersivity), there is a significant reduction in all contaminant migration velocities.

Modelling is based on a 10,000 year simulation timeframe.

2.3 Early phase waste cell operation

All waste cells will initially operate on the principle of hydraulic containment after the initial rebound of groundwater following the cessation of dewatering. We anticipate, based on the high permeability observed for the shallow superficial aquifer, that groundwater rebound will be relatively rapid at the site.

Hydraulic containment will function for a minimum of half the operational lifetime of each cell based on a worst-case assumption that inert fills would be completely saturated. It is considered likely that hydraulic containment will be the main process dictating contaminant flux rates throughout the entire filling operation within Phase 1 and pumps for groundwater pumping will be switched off as soon as there is over three metres of soils across the base.

Two scenarios were modelled, as presented in Table HRA7. Scenario 1 is based on a leachate head of 1.0m, whereas Scenario 2 is based on a maximum leachate head of 4m, taken as the greatest extent of leachate development still allowing hydraulic containment to function.

The hydraulic containment models under the normal operating scenario are presented at Appendix HRA 7.

Table HRA7: Modelled concentrations (mg/l) at the compliance point after 10,000 years.

Modelled Maximum Concentration (mg/l) over 10,000 years at Compliance Point under either 1.0m or 4.0m of Leachate Head					
	EAL/MRV	No Biodegradation		Biodegradation	
Determinand		1.0m	4.0m	1.0m	4.0m
As	0.01	3.77E-8	1.74E-19		
Cd	0.0001	2.11E-10	9.79E-21		
Pb	0.01	0	0		
Zn	5	0	0		
NH_4	0.5	9.04E-6	2.31E-10		
SO_4	250	8.31E-5	2.27E-13		
Cl	250	2.42E-6	3.19E-19		
Benzene	0.001	4.65E-42	3.72E-49	0	0
Napthalene	0.00001	1.09E-13	1.08E-20	3.27E-87	2.43E-92
Phenol	0.05	2.38E-35	1.21E-41	0	0

None of the modelled compounds exceeded their respective EAL at the compliance point taken as the outer edge of the mineral liner.

The simulated biodegradation rates remain conservative as degradation in the sorbed phase was not applied and the maximum available half-lives were modelled.

As would be anticipated, all compounds demonstrate higher breakthrough concentrations when hydraulic containment is simulated with the maximum available head of 4m. There is little or no influence on Pb and Zn due to their high geochemical retardation arising from the observed high sorption affinity for the mineral barrier (high Kd).

The modelled groundwater influx rates are notably low and for the intents and purposes of this assessment regarded as negligible. Under a 1.0m leachate head, influx from groundwater would constitute less than 1cm of additional head over the entire operational life of any of the proposed inert waste disposal cell, assuming the lowest filling rate of 300,000 m^3/year.

It is anticipated that there will be continuing development of leachate heads throughout the latter phase filling operations and during post-closure. This will predominantly be driven by infiltration rates. We consider that the modelling results for a 4m leachate head, presented in Table HRA 7 are also relevant to late phase waste cell operation and the post-closure scenario.

If or when leachate heads extend above surrounding equilibrium groundwater elevations (unmanaged leachate head), the dominant mechanism controlling contaminant flux rates will be retarded travel through the mineral liner.

Models are based on premise of a fully saturated waste body, with a maximum driving leachate head of 7m above groundwater. The mineral liner has been modelled as a 1.0m thick saturated pathway acting under a hydraulic gradient of 1.0 as previously described. This approach provides worst case contaminant retarded travel times across the mineral line. No dilution in the shallow aquifer is assumed.

As previously observed in section 2.3, none of the modelled substances exceed their relevant EAL When a first order degradation rate is applied using a half-life values, breakthrough at the compliance point after 10,000 years is substantially below the EAL for all organic compounds.

2.4 Review of Technical Precautions

In the context of a hydrogeological risk assessment, the necessary essential and technical precautions required by the Groundwater Regulations and Environmental Permitting Regulations are likely to include limitations on the rates of input and concentrations of permitted waste types. The waste types to be accepted the site are strictly inert wastes as detailed in Table HRA 4 for the landfill and pre-treated waste from the treatment facility.

All waste will be accepted in accordance with the Waste Acceptance Criteria Protocol for the site WAC/Cornets End.

A failure model assumes that there will be some breach of the WAC due to rogue loads and this has been considered as 10% increase on contamination and is detailed in the sensitivity analysis set out in Section 2.5.

The acceptance procedures will have detailed Waste Inquiry, Non-Conformance, Load Rejection and Quality Assurance procedures that integrate with the Environmental Management System for the site.

The liner system will be constructed in accordance with the Construction Quality Assurance Plan contained within the Environmental Site Setting and Design Report and is based on experience at the nearby landfill site at Meriden Quarry likely to have a side wall seal that exceeds 1 metre in thickness .

Figure 9: Side wall seal construction at Parrys Quarry Landfill site

2.5 Sensitivity Analysis

The 10% increase above WAC models are presented at Appendix HRA8 and have been run with the 4 metre head as this typically gives the worst case scenario with a 1 metre head around the outside. Taking account of global warming it is likely that rebound and groundwater levels around the outside of the site are likely to be higher than current and thus have a constant positive gradient into the site. The waste mass and profile will encourage long term runoff into the water bodies which will drain into the Alltami Brook.

Table HRA8: Modelled concentrations (mg/l) at the compliance point after 10,000 years with groundwater levels with 10% increase in WAC.

Modelled Maximum Concentration (mg/l) over 10,000 years at Compliance			
Determinand	**EAL/MRV**	**No Biodegradation**	**Biodegradation**
As	0.01	4.41E-8	
Cd	0.0001	2.90E-9	
Pb	0.01	0	
Zn	5	0	
NH4	0.5	9.48E-6	

SO4	250	9.14E-5	
Cl	250	2.66E-6	
Benzene	0.001	3.57E-42	0
Napthalene	0.00001	1.21E-12	3.59E-86
Phenol	0.05	0	0

The model has also been run using Hazardous Waste WAC input values and the results are presented at Table HRA9. The models are presented at Appendix HRA 9. These also do not exceed EAL values or Drinking Water Standards. Ammonia was run at up to 1000mg/l and produced a value of 0.018, and Napthalene, Benzene have each been run up with a total BTEX input value of 6mg/l and Phenol at 5mg/l and all are reported below the EAL.

Table HRA9: Modelled concentrations (mg/l) at the compliance point after 10,000 years with groundwater levels with Hazardous Waste Limit Rogue Loads.

Modelled Maximum Concentration (mg/l) over 10,000 years at Compliance			
Determinand	**EAL/MRV**	**No Biodegradation**	**Biodegradation**
As	0.01	1.84E-6	
Cd	0.0001	2.64E-8	
Pb	0.01	0	
Zn	5	0	
NH4	0.5	0.018	
SO4	250	0.004	
Cl	250	6.05E-6	
Benzene	0.001	1.94E-40	0
Napthalene	0.00001	6.58E-10	1.96E-83
Phenol	0.05	1.12E-33	0

We conclude that the proposed inert landfill operations in Phase 1 presents low/negligible risks to controlled waters. Hydraulic containment will initially function during early phase operation to prevent advective flux across the mineral liner. Diffusive contaminant flux against the hydraulic gradient during hydraulic containment is demonstrably low. Latter phase operation and post closure may experience advective flux across the side walls of waste cells, however, due to the high geochemical retardation and low permeability of the mineral liner, retarded travel times are significantly long to prevent a risk to shallow groundwater over 10,000 years. These observations are based on conservative modelling assumptions, in particular; constant leaching source terms and no dilution at the receptor, both of which are considered probable.

2.6 Contaminant Transport Modelling Phase 2

In the case of the LANDSIM 2.5, the results are the range of possible leachate leakage from the site and contaminant concentration levels and breakthrough times at a receptor beneath the site at a given time after the commencement of leachate leakage. Using these results, it is possible to quantify the likelihood of a certain leakage rate or concentration occurring from the extension cells that lie on clay within the Salop Formation above the water table.

The concepts and usage of probabilistic analysis in the assessment of landfill sites is described more fully in the LANDSIM 2.5 manual (EA, R&D Publication 120, 2001), and has further been developed by the Environment Agency during 2003 and 2004 with the introduction and development of LANDSIM 2.5 and further revisions up to 2012 and this assessment has used Version 17.

The process of probabilistic assessment of landfill sites has been validated by others (LANDSIM Manual, EA, 2001 and 2003) and has been shown to be a conservative approach to the assessment of environmental impact.

LANDSIM 2.5 was used to evaluate both the magnitude and likelihood of leakage rate, the potential containment concentration at the critical receptor and breakthrough time to the critical receptor for the operational and development at the Parrys Quarry landfill Phase 2.

The risk of leachate migration to the receptor was estimated by the range of concentrations of the selected chemical species in the groundwater at the receptor at an infinite time after the commencement of leachate leakage. In order to determine this value, the concentration of chemicals within the landfill was assumed to decline over time after waste placement; the source, and the results are based on actual data from the leachate data from WAC test data and leachate analyses.

The calculated concentration at the receptor at infinite time thus represents a conservatively high estimate of the concentration that could develop at the receptor given the scenario assessed. In reality any reduction in the leachate source concentration in time will reduce the ultimate concentration that could reach and impact on the receptor.

Uncertainty in the natural processes of leachate migration through composite liner and contamination transportation in groundwater were incorporated in the modelling process by the inclusion of stochastic values to represent certain controlling parameters (e.g. permeability of the liner material and underlying strata). The stochastic values were defined by probability density functions based on the findings of the field investigations carried out at the site and appropriate supporting published information. Uniform (represented by a minimum and maximum value) and triangular distributions (represented by a minimum, most-likely and maximum value) have been used to incorporate judgements on parameter values into the modelling. Triangular distributions are appropriate for representing judgements on values for risk analysis (Megill, 1984). Logarithmic triangular distributions have been used where the uncertainty relates to order of magnitude.

Fixed values were used for some parameters where uncertainty in value is known to have limited effect or in scenarios where certain conditions were assumed.

The results of the models are presented probabilistically to facilitate the application of confidence levels to the results. The 95th percentile results are presented at Tables HRA 10 to HRA 11. The 50th percentile represents the most likely occurrence as there is a 50% chance of it happening. The 95th percentile represents the worst case scenario as there is only a 5% chance of occurrence.

The completion criteria for the landfill have been assessed using the declining source term as set out in LANDSIM 2.5 for metals, anions and some organic substances. The completion criteria are reached when the concentrations of determinands in the landfill leachate have reduced to a level where without active controls there will be no risk of discernible discharge of hazardous substances to groundwater or no risk of pollution of groundwater by non-hazardous pollutants at the respective receptors. For a landfill this is when the concentrations of contamination have reduced to the EALs as a worst case scenario.

Operational and environmental monitoring will continue at the site to inform modifications to the conceptual model, risk assessments, engineering design and control measures at the site as part of the routine continual review process carried out at the site.

Hazardous Substance Release in Phase 2

The predicted concentrations of Hazardous Substances at the point that they enter the groundwater at the base of the unsaturated zone modelling presented at Appendix HRA 11 are summarised in Table HRA 10 are compared to the Minimum Reporting Values set out in the Environment Agency Guidance on Hydrogeological Risk Assessment and the concentrations are indiscernible and the site has no Hazardous Substance release predicted from the site under the normal operating mode or when there is an exceedance of 10% of WAC limits.

Table HRA10. Hazardous Substances Maximum concentrations

Determinant	Model Concentration Normal	Model Concentration Failure	Minimum Reporting Value
Cadmium	1.12E-5	8.03E-8	1E-4
Benzene	0	0	1E-3
Lead	0	0	0.1
Napthalene	0	0	1E-3

- is presented at from the modelling presented at Appendix HRA 3 are summarised in Table HRA 9 are compared to the Minimum Reporting

The site design even with a breach of the WAC protocol shows the site to remain in compliance with the MRV values for Hazardous Substances and the values shown for the hazardous substances in the groundwater directly below the liner and the contact point with the water table.

Non-Hazardous Polluting Substances in Phase 2

The predicted concentrations of Non-Hazardous Pollutants are not likely to exceed relevant Drinking Water Standards at the monitoring boreholes and are summarised below in Table HRA 11 and the model outputs are presented at Appendix HRA 11 and Appendix HRA 12. The Drinking Water Standards have been used as the Environmental Acceptable Levels (EAL) at the edge of the site.

Table HRA 11. Non-Hazardous Pollutant Maximum Concentrations at the edge of the site

Determinant	Model Concentration at the monitoring point Normal	Model Concentration at the monitoring point Failure	Drinking Water Standard
Ammonia	0.0	0	0.5
Chloride	70.77	74.15	250
Sulphate	18.32	20.09	250
Arsenic	9.42E-12	1.42E-11	0.01
Zinc	0	0	5.0
Phenol	0	0	0.05

The total impact of Phase 2 has been assessed at the point of breakout of groundwater as baseflow to the Alltami Brook and the off-site compliance modelling is presented at Appendix HRA 11 and 12 and summarised below at Table HRA 12.

Table HRA 12. Non-Hazardous Pollutant Maximum Concentrations at the Alltami Brook

Determinant	Model Concentration at the monitoring point Normal	Model Concentration at the monitoring point Failure	Drinking Water Standard
Ammonia	0.0	0	0.5
Chloride	71.09	74.94	250
Sulphate	24.66	26.93	250
Arsenic	0	2.29E-11	0.01
Zinc	0	0	5.0
Phenol	0	0	0.05

Hazardous substances are not predicted at the Alltami Brook from the Phase 2 operation.

2.7 Accidents and their Consequences

A qualitative risk assessment of the potential impacts of accidents and resulting damage to engineered barrier systems is presented in Table HRA13. This approach considers the likelihood of the accidents occurring and the magnitude of the consequences of such accidents and failures.

This assessment indicates that:

- it has been determined to be "unlikely" that the consequence of any potential accident would create a non-compliance with the requirements of the Environmental Permitting Regulations, 2016. Only under extremely unlikely events would the potential exist for increased discharge of hazardous substances and non- hazardous pollutants into the environment; and

- the prevention of the accidents from occurring is key to the management of Parrys Quarry Landfill. Consequently, this places the emphasis on having robust and workable procedures and actions in place in order to prevent them from occurring and by ensuring a comprehensive CQA system is in place during construction.

Given that the likelihood of an accident resulting in non-compliance is "unlikely" additional quantitative assessment of the potential events is not considered necessary.

It should be noted that accidents creating the most severe consequences, relating to damage to the mineral liner, are considered extremely unlikely. Waste materials to be deposited will be predominately inert soils, which greatly limits the potential risks posed by fires, subterranean combustion or explosion.

Quantifiable changes from normal operating conditions have been identified to include the loss of hydraulic containment or increased groundwater levels with reduced unsaturated zone.

Fluctuations in Groundwater Elevations

It is not considered likely that groundwater levels will fall at the site as the pumping levels for use on site have been used for the hydraulic containment and it is noted that where quarrying operations have ceased groundwater rebound has been relatively quick.

Groundwater rebound is relatively quick based on historic operational experience.

Provision for continual leachate and groundwater level monitoring has been made.

Differential Settlement

Differential settlement across the landfill is considered unlikely due to the inert nature of the waste. No lining systems using composite materials are to be used and no landfill cap is required. The geological barrier will be constructed using clays and silts. The inert nature of the waste means that movement will be minimal to structures within the waste mass (such as gas monitoring points which are also to be retro fitted), and is therefore not considered further as part of this assessment. Pre and post settlement contours are presented within the landscape and visual concept models and are considered as one and the same with no surcharging allowed.

The risk of differential settlement cannot be completely eliminated from a site design. However, monitoring for the effects of differential settlement would be undertaken through:

- Regular site surveys of completed and restored areas of the site;
- Completion of walk over surveys across restored areas;

Remedial measures to repair and reinstate the restoration profile where differential settlement occurs would be undertaken by the NRS as part of the aftercare management of the restored site.

Should monitoring points be damaged through excessive or differential settlement within the waste mass, retrospectively installed wells will be constructed adjacent to the damaged monitoring point using conventional drilling techniques for drilling into inert waste (i.e. open hole air flush). Given the type of the waste in the site and that it will all be compacted, the retrospective installation of such wells is not considered to be problematic.

A line of weakness in the mineral liner/geological barrier

A mineral liner is proposed for Parrys Quarry Landfill to form the geological barrier required for inert landfill sites. To achieve a line of weakness thorough the full 1.0 metre of mineral liner/ soil base would require a minimum of four consecutive weak points to occur directly above each other. This in itself is extremely unlikely and with a CQA program in place for all phases, this is not considered to be a likely scenario.

The liner on the base shows a substantial thickness of Mercia Mudstone and the side wall seal is likely to be in excess in 3 metres to support earth moving plant used in the construction.

The ground beneath the base of the quarry has not been mined and so differential settlement is not considered a failure scenario at Parrys Quarry landfill site.

Diesel Fuel Storage Tank Qualitative Assessment

The location of the diesel fuel tank will be in the maintenance building on a concrete slab floor. Result of leakage or failure of the tank would result in diesel infiltrating the glaciofluvial sand and gravel strata on the floor. The groundwater is not a protection source area. To assess the impact of any failure of the diesel storage tank on groundwater, assumptions and design have been reviewed, where there is a catastrophic failure of the tank whilst it is at full capacity.

The tank capacity at Parrys Quarry is $32m^3$. Degradation rates in the aerobic phase range from 1.9 to 9.5 years. Dilution would also play an important role.

The mitigation measures are that the diesel tank currently used is steel, double skinned, and manufactured to high engineering standards and is bunded to Environment Agency guidelines. The tank will be located above ground, and bunding would be on a concrete base, with a capacity of 110% of the tank capacity. The spillage procedure has been reviewed as part of the NRS EMS system. Procedures and practices are regularly inspected and audited. The protection measures therefore provide adequate protection to significantly reduce risk to the groundwater locally.

Mining Subsidence

Subsidence of mine workings has been considered due to the possibility of collapse and catastrophic damage to the geological barrier. The primary consideration for subsidence is the depth to the coal workings. The shallowest coals seen are at approximately 60 beneath the base of the site and were worked down to a depth of 340 metres, see Appendix HRA 13.

Based on Design Manual for Roads and Bridges, Part 14 BD/10/97 Section 3, states "*in relatively level strata, if a working exists at more than 30 metres (or 10 times the thickness of extraction) below rockhead, designers may assume that subsidence is unlikely".*

Furthermore, the surface subsidence is less than the thickness of the extracted seam and Piggott *et al* suggest the maximum height of collapse is 5 – 10 times the seam thickness. Both of these statements suggest maximum settlement would have been between 6 – 7 metres.

Subsidence in mines start within 24 hours of extraction, but its full effects are transmitted slowly upwards and it may be as long as 12 years before the ground is completely stable. The colliery closed in 1932.

Therefore, the seam thickness and time limits would suggest mining subsidence is complete. In addition, the groundwater rebound within the workings would further reduce collapse. Therefore, mining subsidence is not considered a hazard at the Oak Farm Quarry.

Table HRA13: Risks and consequences

Potential Accident	Likelihood	Implication	Consequence	Likelihood of Non-compliance
Flooding	Unlikely	Inundation of waste cell	Negligible/marginal	Unlikely
Subsidence	Unlikely	Breach of engineered mineral barrier	Marginal / significant	Unlikely
Fires / subterranean combustion	Extremely Unlikely	Damage to mineral liner / desiccation & increased permeability	Significant	Fairly Probable
Explosions	Extremely Unlikely	Loss of structural integrity of cell walls and breach of mineral liner	Significant	Probable

3.0 REQUISITE SURVEILLANCE

3.1 The Risk Based Monitoring Scheme

Under the Environmental Permitting Regulations, the NRW must ensure that "*requisite surveillance*" is undertaken, which takes the form of leachate, groundwater and surface water monitoring. In addition, environmental monitoring plays a central role in environmental risk assessment and management.

The hydrogeological risk assessment has been used to develop a risk-based monitoring plan containing both objectives and a sampling plan. This section must provide the technical rationalisation for the design of a monitoring programme, to focus monitoring effort on actual risks.

Appropriate assessment and compliance criteria, as well as control and trigger levels for groundwater quality, must be specified within each of the appropriate sections. Full justification and a clear audit trail must be provided for each proposed criterion/level.

3.1.1 Leachate Monitoring

Leachate monitoring is not required at inert landfill sites.

3.1.2 Groundwater monitoring

It is essential to monitor groundwater adjacent to the site for quality to assess the integrity of the performance of the site and to ensure that there is no impact on groundwater.

Proposed borehole locations are presented at Drawing ESSD 10.

It is recommended that the compliance levels are reviewed on an annual basis or as appropriate. If, for example, the compliance levels are exceeded on three consecutive times, then this should be highlighted and discussed within any annual review of monitoring data. Such an occurrence may be the result of contaminant breakthrough or a change in the up hydraulic gradient groundwater quality.

3.1.3 Quality assurance of groundwater quality monitoring and sampling

Samples will be collected using dedicated groundwater inertial pumps, or balers in individual boreholes, to avoid cross contamination with groundwater samples.

Appropriate protective equipment will be worn when handling groundwater. Samples will, where possible, be despatched to the laboratory on the same day, and in any event no later than the following day. Samples which are stored overnight will either be stored in a refrigerator or cool box. All samples will be analysed at a laboratory under UKAS accreditation. The laboratory shall operate externally verified quality control procedures and checks on analytical work. These include spiked samples, blanks etc. On account of the large batches of samples that are processed by the laboratory, the QA/QC checks implemented are efficient in identifying any quality control failures. Accordingly, it is not proposed to submit additional QC samples (sampling duplicates, field standards or field blanks) from the site, as this will only duplicate the controls already being implemented.

Sampling will be undertaken by staff appropriately trained in environmental monitoring procedures, and who are familiar with the equipment and its limitations. The Company warrants that the personnel engaged in monitoring activities are trained to undertake the task. These will comprise the companies own technical personnel, the site manager or nominated deputy, following appropriate training by technical personnel. All monitoring staff undergo a period of job training and in addition external courses are used to supplement internal training. Results will be validated by the sampling personnel detailed above.

Making and submission of records

Records will be kept on site of determinands analysed, date of sampling, sampler, results, units and any repeat analysis or laboratory comment, or internal assessment, on the validity of the results.

A copy of the results of sampling and analysis will be forwarded to the Agency as per the Schedule set out in the Permit.

A proposed action plan for groundwater the site is detailed below. In Table HRA 14.

Table HRA 14: Proposed Action Plan in the Event of a Breached Compliance Level Concentration in Groundwater Monitoring Boreholes

1. The original sample will be re-tested for the determinand by the analytical laboratory within 10 days.
2. In the event that the determinand remains elevated in the original sample, the borehole will be re-sampled within two weeks of receipt of the results and the sampling suite will be repeated. Results of the second analysis will be obtained as soon as possible and in any case within three weeks. The results of the re-sampling will be forwarded to the Agency.
3. If the result of the second analysis also exceeds the trigger concentration, then the boreholes adjacent to the borehole in which the breach was recorded will be re-sampled weekly for a further two months. Analysis will be the same as for the monthly monitoring suite.
4. Data from the boreholes will be reviewed by use of statistics and graphical presentation to establish the presence of any trends or patterns.
5. Groundwater levels will be reviewed to establish flow direction in

	order to determine whether the site is the most likely cause of any change in groundwater quality.
6.	An inspection will be carried out to determine whether there has been any unusual activity or occurrence on the site that could account for the increase in the parameter exceeding the trigger concentration.
7.	If the laboratory results from the monthly monitoring show no indications of decline over the two month period, and the evidence indicates that the site is the most likely cause of the increase in levels, then a review of the hydrogeological risk assessment will be submitted to the Agency within one month of receipt of final monitoring data.

3.1.4 Compliance Limits

The compliance levels have been set at geometric mean plus three times the standard deviation, based on all of the groundwater monitoring carried out from the installed boreholes. Compliance levels are set for Boreholes BHG, BHH and BHI down hydraulic gradient.

Spreadsheet calculations are presented at Appendix HRA 14.

Table HRA15: Compliance Limits

Determinand	Unit			
		BHG	BHH	BH1
Ammoniacal Nitrogen	mg/l	0.39	2.8	0.55
Chloride	mg/l	250	433.2	555.5
Zinc	mg/l	0.5	0.5	0.5
Phenol	mg/l	0.5	0.5	0.5

4.0 CONCLUSIONS

4.1 Compliance with the Environmental Permitting Regulations 2016

The current and proposed extension to the Parrys Quarry inert landfill site to be operated at Mold Investments Limited complies with the following requirements of the Landfill Regulations 2002 and the Environmental Permitting Regulations 2016.

- The geological barrier complies with the requirements constructed under CQA will achieve an overall minimum permeability of 1 x 10^{-7}m/s
- The compliance of the installation with the specified engineering standards
- The compliance levels for groundwater quality have been set and the modelling and current sampling has shown no release of Hazardous substances and predicts no release of Hazardous substances in the short or long term.
- Non-Hazardous Pollutants releases are in accordance with the Drinking Water Standards.
- Monitoring strategies are in place and recommended in line with the Environmental Permitting Regulations 2016 for inert landfill sites.

4.2 Compliance with the Groundwater Framework Directive and Environmental Permitting Regulations 2016

The Parrys Quarry landfill development complies with the requirements of the Groundwater Framework Directive transposed through the Environmental Permitting Regulations 2016 as the modelling and the groundwater monitoring and leachability testing following detailed site investigation has shown compliance that.

- The site design prevents the Hazardous Substances from entering the groundwater.
- The site design limits the introduction of Non-Hazardous Pollutants into groundwater so as to avoid pollution down hydraulic gradient of the cells.
- Essential and technical precautions have been considered including an engineered basal and side wall seal.
- Requisite surveillance for groundwater and leachate is detailed in the report.