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Booth Ventures Waste (Midlands) Ltd

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Sandown Quarry Landfill

Environmental Permit Application – Hydrogeological Risk
Assessment (HRA)



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1 Introduction

1.1 Background and Risk Assessment Objectives

ByrneLooby (BL) has prepared this Hydrogeological Risk Assessment (HRA) for the Sandown Quarry Landfill site to support the application for an Environmental Permit.

This assessment utilises the conceptualisation of the site (provided in report 5430-BLP-R-003-02) and includes discussion on the source-pathway-receptor relationship and a qualitative assessment (Tier 1) and quantitative assessment (Tier 3) for completeness. This approach accords with the low sensitivity setting of the site and source – pathway – receptor relationships.

The infilling will comprise of non-hazardous wastes, those considered suitable are specified by Her Majesty's Revenue and Customs (HMRC) in The Landfill Tax (Qualifying Material) Order 2011 (as amended) (i.e. Qualifying Materials (QMs)).

1.2 Assessment Overview

Previous quantitative modelling undertaken at nearby sites has been on a “theoretical basis” to a hypothetical underlying target (in this case at Vigo Utopia Landfill a water bearing sandstone “Espley” that was sufficiently continuous to act as a Water Body under the Water Framework Directive classifications) or alternatively judged against an adjacent piezometric water level under the principle of hydraulic containment (Highfields South Landfill). It is noted however that these local sites contain “biodegradable / putrescible wastes” which are not proposed at Sandown.

As such however, theoretical assessment is not required at Sandown Quarry Landfill (as defined by the conceptualisation outlined herein). Porewaters are conceptually noted within the bedrock Etruria Formation strata (under confined conditions), and additionally perched / static waters are present within the significant thicknesses (vertical and lateral) of cast back interburden / overburden that approximate to adjacent ground levels.

Accordingly, a hydraulic containment assessment is provided for completeness however potential discharges at the edge of the engineered liner (or edge of cast back materials / contact with *in-situ* strata) are largely irrelevant as the leachate source term, at maximum concentrations are less than the significantly impacted waters currently monitored at the site periphery (impacted from historic and or ongoing land use effects).

2 Application of Aquifer Designation and Chemical Status at Sandown Quarry

2.1 Aquifer Classification and Regulatory Background

The ESID report (5430-BLP-R-003-02) that underpins the application has detailed the environmental setting of the site. The site is contained within a geological barrier (lower sidewalls and base, with a significant low permeability, i.e. evidenced by no groundwater inflow to the site) and with no associated connectivity to a receptor.

The upper sections of the sidewall (with associated significant lateral widths to the site boundary) are comprised of interburden / overburden materials surplus the brick manufacturing process. This material is not a receptor.

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

- The site proposal is for engineered containment where required (i.e. on lower sidewall faces where bedrock is exposed to mitigate against seepages to any sandstone or espleys). If present, they are contained / encapsulated overall within a geological barrier.
- There is no confirmed or documented pathway for the identified sandstone layers / Espley horizons at site;
- No justifiable receptor has been identified (that is linked by a pathway).

As part of this 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 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 parameterisation that underpins the regulatory framework regarding this matter.

2.2 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.

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 10m³ 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 100m³ 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.**

2.3 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.**

2.4 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 therefore quantifies an aquifer as a rock bearing a sustainable useable quantity of water in excess of 10m³/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 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 drift deposits with low permeability that have negligible significance for water supply or for river base flow.

In regard to Sandown Quarry, a Secondary A designation does not fit the site description of “a clay pit” that is primarily operated (and continues to be operated) “dry”. Collected water in the base of the void is periodically pumped to the on-site settlement pond prior to discharge in accordance with the sites discharge consent.

BGS available borehole logs at site and surrounding environs support the lack of water within the geological barrier (marl / mudrock), consistent with BGS / Environment Agency descriptions within the “Physical Properties of Minor Aquifer in England and Wales (2000)” R&D publication 68.

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 100m³/day as well as bodies of water used for the sustained abstraction of more than 10m³/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 10m³/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 for it to be sustained. 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 Formation (higher permeability layers or lenses) and baseflow fed surface water.

2.5 Site Specific Pumping Trials

In accordance with the criteria outlined above, hydraulic investigations were undertaken at site during September 2022 (further details are provided in Section 3.8.2 of report 5430-BLP-R-003-02) to document site specific conditions.

It was established through sustained pumping trials for the Etruria Formation bedrock strata at BH22-04D, that a potential “maximum” yield of **1.7m³/day** was recorded (incrementally falling to 0.8m³/day after 3hrs). The trial terminated due to insufficient recharge to sustain low-flow pumping, clogging and siltation in tandem with a continual drop in water level.

At the pre-existing site borehole BHP-03D located on the northern perimeter, a potential “maximum” yield of **1.5m³/day** was recorded (falling to a sustained yield equivalent to 0.6m³/day). Both determinations are an order of magnitude lower than the 10m³/day threshold to classify the strata as a “water body”.

Equivalent trials were undertaken on the cast back interburden / overburden materials at BH22-04S. The results indicated a potential “maximum” yield of **0.8m³/day** falling to a sustained yield equivalent of <0.01m³/day after 1 hour).

The very small volumes of water available for removal correspond to the low permeabilities noted from subsequent rising head tests (see Section 3.6 of report 5430-BLP-R-003-02) at 2.72×10^{-10} m/s to 9.04×10^{-10} m/s for the Etruria Formation bedrock and 4.7×10^{-10} m/s for the cast back interburden / overburden material.

3 Conceptual Site Model

3.1 Source

Any leachate generated from the non-hazardous QM’s will differ significantly from a typical Municipal Solid Waste (MSW) leachate as there is not a putrescible component to the waste stream. Consequently, the significant ammoniacal-N and dissolved organic matter (as represented by the COD) as well as other soluble salts will not be present as readily degradable organic matter and soluble salts are specifically excluded from the list of wastes described as QMs. Given that the proposed waste types are unlikely to contain a degradable organic content, elevated ammoniacal-N and BOD is not expected to be associated with site. Similarly, solvents, refined petroleum fuels or other chemical sources will be excluded. In simple terms, source characterisation will preclude any significantly contaminated soils.

For the purposes of this assessment, a source term has been derived for initial screening based on the leaching data that ByrneLooby (formerly TerraConsult) have compiled from 7 sites (including a hazardous soil landfill) over a 7-10 year period, as well as QMs data from identically proposed infill schemes (Table 1).

Table 1 Source Term Waste Leaching Data compared to Drinking Water Standards

Determinand	Soil Infill Site data			No. of Samples	% of samples < LOD	DWS mg/l	Comment
	25%ile	Median	95%ile				
Hazardous Metals							
Mercury	<0.00003	<0.00010	0.00025	331	87%	0.001	Below DWS at source
Lead	<0.001	<0.001	0.300	580	89%	0.01	Above DWS at source, actual presence of lead is considered negligible
Hazardous Metalloid							
Arsenic	0.003	0.005	0.021	593	4%	0.01	Above DWS at source
Non-hazardous Metals							
Cadmium	<0.00003	<0.00010	0.00060	593	66%	0.005	Below DWS at source
Nickel	0.007	0.011	0.052	579	3%	0.02	Above DWS at source
Chromium	0.001	0.002	0.015	586	61%	0.05	Below DWS at source
Copper	0.002	0.007	0.039	566	31%	2	Below DWS at source
Zinc	0.003	0.006	0.128	383	19%	5	
Matrix and Minor ions							
Chloride	69	133	637	768	0	250	Above DWS at source
Sulphate	607	912	1731	600	1%	250	
Ammoniacal-N	0.2	1.1	15.6	757	11%	0.39*	Above DWS at source
Herbicide and Hydrocarbons							
Mecoprop	0.006	0.013	0.034	61	77%	0.0001	Above DWS at source
Benzene	0.0013	0.0015	0.0020	50	96%	0.001 (MRV)	Above MRV at source
Toluene	0.0011	0.0012	0.0037	68	96%	0.004 (MRV)	≈ to MRV at source

DWS from 2016 No. 614, The Water Supply (Water Quality) Regulations 2016

https://www.legislation.gov.uk/uksi/2016/614/pdfs/uksi_20160614_en.pdf, Minimum Reporting Values, MRV concentrations (<https://www.gov.uk/government/publications/values-for-groundwater-risk-assessments/hazardous-substances-to-groundwater-minimum-reporting-values#:~:text=o%2Dxylene%20and%20m%2Fp,to%203%20micrograms%20per%20litre>)

*Ammonium (units of measurement as mg/NH₄/l) DWS 0.5mg/l guide value – (referenced standard for NH₄-N 0.39mg/l)

Mecoprop is not hazardous – as defined by JAGDAG 2017 (non-hazardous pollutant), DWS (DWS (organic herbicide “total” 0.0005mg/l, “other pesticides” 0.0001mg/l, EQS 0.018mg/l)

As evident (based on a significant dataset collected to date), the collated source term summary presented in Table 1 at similar sites contain a definitively different composition to the biochemically derived solutions typical of most non-hazardous landfill leachates which contain significant concentrations of ammoniacal-N and organic content. These are products of the breakdown of the types of bulk organic materials which are excluded prior to disposal.

As a dissolution derived liquor in this type of fill, the two primary constituents calcium and sulphate are limited by the solubility of gypsum under oxidising to anoxic conditions, ammoniacal-N is consistently low in these sites with median concentration of 1.1mg/l.

Chloride is typically <500mg/l in these sites, with median and average concentrations of 133mg/l and 214mg/l respectively. Infrequent or short term “outliers” can skew statistical appraisals, however, these are not reflective of the overall bulk infill chemistry. In this case a 95th %ile concentration of 637mg/l is reported.

It is recognised that this can occur for all substances analysed and in all likelihood the outlier data is representative of an analytical or sampling error (e.g. ammoniacal-N 95th %ile of 15.6mg/l compared to 85th %ile of 5.9mg/l).

Another significant factor for low organic and soil-based materials is that the primary vector which mobilises heavy metals, *i.e.* colloidal organo-metallic complexes are not present. Consequently, metals such as nickel and chromium which are also uniquely present within methanogenic and acetogenic leachates (as compared to other metals which can be present in UK groundwaters and geological strata) are in the case of nickel low within soil disposal sites whilst cadmium and chromium are invariably absent (>60% of all data reported at < LOD).

Copper and zinc data report occasional outliers, overall however these concentrations are insignificant compared to their 2mg/l and 5mg/l DWS.

Arsenic is also environmentally low, with only 19% of all concentrations above the 10µg/l DWS (593 samples), the hazardous metals mercury and lead are not considered present in the source term (87% and 89% of all samples reported at <LOD).

Specific organic substances are rarely reported in soil infill cells / schemes, *i.e.* the majority of substances are reported as “below detection level” or <LOD. Small quantities of mecoprop can be reported, with almost all data reported less than the 18µg/l EQS. However, this non-hazardous herbicide is not reported above 1µg/l for some of the sites evaluated and is <LOD for ~80% of the dataset.

All other organic substances reported are single occurrences at the individual locations sampled, which are not repeated on consecutive hazardous substance screens at those locations demonstrating that there is not a risk to groundwater.

The proposed source term is considered to be of a “low-pollution” potential compared to putrescible landfill leachates and those already consented, including historic sites located nearby.

Infill Permeability

Any hardcore, gravel or sand type materials that can be recovered at source are unlikely to be imported to site as this material has a commercial value and therefore it is likely to be diverted. Conversely however, if this material is imported, there is an intention for recyclable materials to be recovered through screening, hence this component will not form a large part of the infilled and deposited waste mass. Consequently, it is expected that the site will be restored primarily with clay and silt dominated soil forming materials. Hydraulic calculations (e.g. Hazen formula particle size / hydraulic conductivity relationships) demonstrate that as long as 10% of the infill material contains a medium silt or smaller grain size, a 1×10^{-8} m/s hydraulic conductivity criteria would be met.

This conclusion is also supported from permeability measurements of placed soils in five similar infill schemes undertaken by different operators. 16 laboratory measurements from a non-hazardous soils site reported a dry density range of between 1.48 and 1.93Mg/m³ and a hydraulic conductivity range of between 4.9×10^{-10} and 6.9×10^{-11} m/s (most likely conductivity of 2.05×10^{-10} m/s).

3.1 Pathway

The site is fully contained within a natural geological barrier (lower sidewall and basal succession) in addition to higher sidewalls at the site periphery behind extensive thicknesses of cast back interburden / overburden material. Sandstone layers where reported are typically less than 1m in thickness and based on visual observation are cemented, with minor, near vertical joints and discontinuities.

These observations are consistent with the Etruria Marl being described effectively a dual property unit, a distinction that is not readily apparent from bulk permeability testing of the unit which returns an *in-situ* permeability of the formation to between $1.5 \times 10^{-11} \text{m/s}$ and $2 \times 10^{-5} \text{m/s}^1$. However, this upper range was considered to be due to the more permeable intermittent sandstone espleys where hydraulic conductivity ranges from $1.6 \times 10^{-8} \text{m/s}$ to $1.7 \times 10^{-5} \text{m/s}$ with an average hydraulic conductivity of $4 \times 10^{-6} \text{m/s}$, with the mudstone units at the lower (10^{-11}m/s) end of the range.

Around the site periphery, interburden / overburden material is present at variable depths / thicknesses. This material provides a significant lateral thickness to the *in-situ* strata at the site boundary.

To the east (borehole log reference BH22-01), 24m of interburden / overburden is recorded, to the north 15m (borehole log reference BH22-02D), to the south / southwest 25.5m (borehole log reference BH22-04D) with 10.6m on the west perimeter location (geotechnical test position, borehole log reference BH22-03 (see report 5430-BLP-R-003-02). 6.9m was recorded in the base of pit (borehole log reference BH22-05). Additionally, the lateral thickness of this material is significant with even greater distances from the infill scheme to the associated monitoring points at the edge of the site. Based on the site investigation it is apparent that lateral thickness (as a minimum to the monitoring locations) is between 15m and 135m at BH22-01; 12m and 55m at BH22-02S / 2D; 20m and 110m at BH22-04S / 4D.

3.2 Receptor

Geology

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 Wales² as being “poorly productive”.

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

¹ SLR Consulting (2002) Vigo Hydrogeological Risk Assessment

² 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.

'espley' rocks are generally well cemented, in south Staffordshire they often have a more sandy and porous matrix and may yield a good supply.

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 Sandown, (like at the nearby Vigo Utopia Landfill), the sandstone units do not outcrop at the surface, and therefore falls under the characterisation of *insufficient to sustain initially high yields*. This is further supported by the recent site-specific pumping trials.

There are no confirmed lateral relationships or down dip linkages between the sandstone sequences identified during the site investigations. Encapsulated water bearing horizons are not receptors as they are contained within a geological barrier. As such, water contained within this material is not a receptor, and where present contains insufficient volumes to be referenced as a "water body" under the criteria of the Water Framework Directive. However, based on good environmental practice, the water quality will be monitored (if present).

There are no superficial deposits reported at site, as such these deposits (although reported locally) are not a receptor. As such, there is no monitoring of superficial strata.

Interburden / overburden material is present around the site perimeter (section 3.1 contained herein and detail provided in report 5430-BLP-R-003-02). This material is not a receptor and hence does not require protective enhancement through the placement of an artificial geological barrier however if more granular materials are encountered during final void preparation, they will be removed, processed and replaced with suitable materials relocated from elsewhere on the site.

Hydrology

There are no surface water receptors on the site, the surface water pond forms part of the site's surface water management system. The adjacent Swan Pool is topographically equivalent to the current surface water settlement pond. As such, this pond is above the infill and hence is not at risk from the scheme. As the site surface water (water collected during operations, and conversely post restoration) is to be collected, managed, and diverted to the enlarged "on site" pond (or secondary pond during infilling) there can be no influence on the adjacent Swan Pool. Off-site flows when discharged, bypass Swan Pool in accordance with the current discharge consent.

The adjacent Daw End Canal is topographically above the site, hence there are no risks from the proposed infill on this receptor, the upper profile (restoration surface) of the site falls towards the west / northwest as such all potential flows are away from the canal.

4 Requirement for Risk Assessment

4.1 CSM Overview

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

Source → Pathway → Receptor

This relationship at Sandown Quarry is:

- The Source is leachate / porewater within the soils waste landfill;
- The Pathway is the sidewall engineering, underlying basal *in-situ* barrier and the geological pathway (groundwater / porewater within the Etruria Formation) towards a water resource; and
- The Receptor under normal circumstances is **a useable water resource** or **baseflow contribution** to a surface water feature. These are not present at Sandown Quarry.

Pathway linkages are purely theoretical – there is no established lateral connectivity between sandstone layers within the reviewed borehole logs. The geological strata dips to the north / northwest hence any “water bearing” or permeable formations (if present) become progressively deeper with distance from the site. In the absence of a receptor, and to fulfil the Hydrogeological Risk Assessment On-line Guidance³ (for completeness only), the following assessment locations are defined as:

- 1) For Hazardous Substances – groundwater / porewater at the down-gradient boundary of the landfill, (including dilution)^{4,5}
- 2) For Non-Hazardous Substances – groundwater / porewater at the down-gradient boundary of the landfill (pragmatically positioned peripheral monitoring boreholes)

A schematic representation of the assessment scenario is provided in Figure 1 to provide context.

4.2 Groundwater Level

Groundwater / porewater levels on the northern perimeter (down-dip direction) for the Etruria Formation at BH22-02D are ~126mAOD, porewater in the cast back interburden / overburden at BH22-02S are ~134mAOD compared to a ground level of 135mAOD.

4.3 Groundwater Quality

Determination of EAL's

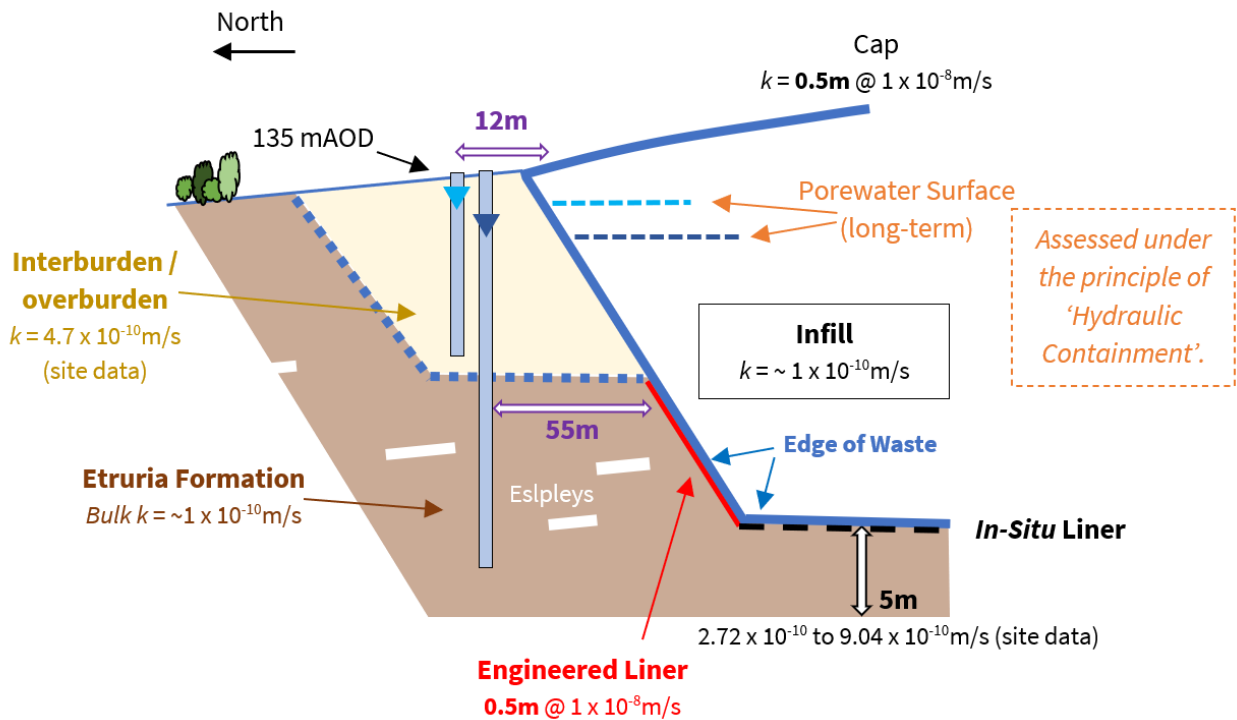
Under normal circumstances a contaminant “risk factor” is usually calculated simply by dividing the maximum leachate concentration by the most stringent EAL.

³<https://www.gov.uk/guidance/landfill-operators-environmental-permits/what-to-include-in-your-hydrogeological-risk-assessment>

⁴https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/602593/Groundwater-discernibility.pdf

⁵<https://www.gov.uk/government/publications/groundwater-protection-technical-guidance/groundwater-protection-technical-guidance#discernibility>

Figure 1 Hydrogeological CSM



For example, a risk factor of 1 would denote that the site did not represent a hazard to groundwater for that particular contaminant as the maximum leachate concentration is identical to the EAL. It provides a very simple indication of the potential hazard presented by a contaminant to the water environment.

However, with a soil infill scheme as proposed which excludes putrescible wastes and their associated biodegradation by-products as well as the exclusion of industrial chemical wastes there is a limited number of potential contaminants compared to conventional waste landfill sites.

Of the potential contaminants screened in Table 1, the EAL's appropriate are either defined as a water quality standard or local groundwater concentration. The EAL's appropriate to Sandown Landfill are presented in Table 2.

Table 2 additionally provides a cross referencing of the proposed source term with local groundwater / porewater data.

Through a review of the site-specific water quality data collected during the baselining activities, it has been established that the water locally has been significantly impacted via off-site sources (ESID, report 5430/BLP/R/006/02, Section 3.8.6). As such, it is apparent that the anticipated source term is not capable of deteriorating local water quality within the interburden / overburden or underlying Etruria Formation bedrock.

Table 2 Source Term Waste Leaching Data (substances above DWS) compared to Local Water Quality (mg/l)

	Soil Infill data Sandown – Source Term			Site Perimeter Maximum (Interburden / overburden)	Site Perimeter Maximum (Etruria Formation)	DWS mg/l	Site EAL mg/l	Comment
	25 th %ile	Median	85 th %ile					
	mg/l							
Non-hazardous Metal								
Nickel	0.007	0.011	0.030	0.31	0.16	0.02	0.31	Adjacent to Butterly Hole site (North)
Hazardous Metalloid								
Arsenic	0.003	0.005	0.013	0.16	0.02	0.01	0.16	Adjacent to Butterly Hole site (North)
Matrix and Minor ions								
Chloride	69	133	370	14,500	3,420	250	14,500	Adjacent to Butterly Hole site (North)
Sulphate	607	912	1,410	1,050	1,350	250	1,350	Adjacent to southwest boundary
Ammoniacal-N	0.2	1.1	5.9	190	13	0.39*	190	Adjacent to Butterly Hole site (North)

Shaded cells denote water quality exceedance of regulatory standards. Site data includes data available from all site monitoring locations. 85th percentile concentration used for assessment purposes due to statistical skew of data due to outliers. Ammonium (units of measurement as mg/NH₄/l) DWS 0.5mg/l guide value – (referenced standard for NH₄-N 0.39mg/l).

4.4 Site Sensitivity

As outlined above and detailed within the supporting ESID, the location of the Site is not considered to fall within a sensitive hydrogeological / hydrological area. There are no public water supply abstractions nearby, no springs no known baseflow contributions to surface water ecosystems.

It is clear from the conceptual model and the very limited (if any) pollution potential of the proposed infill Qualifying Materials that the hazards are low and the environmental setting is sufficiently insensitive to negate the possibility of significant impacts. Notwithstanding the above, in accordance with good environmental practices and due consideration of the water quality in the receiving Etruria Formation strata, a “quantitative” assessment is provided for completeness.

4.5 Assessment Scenarios

Hydrogeological risk assessment for landfill type operations must assess the proposed development’s compliance with the requirements of the relevant Regulations throughout the lifecycle of the landfill *i.e.* from the start of the operational phases until the point at which the landfill is no longer capable of posing an unacceptable environmental risk.

These lifecycle phases are summarised as a conceptualisation framework as:

1. Quarry excavated to full depth, lined with an AGB at 0.5m, 1x10⁻⁸m/s on areas of exposed in-situ strata on lower sidewalls and infilled – Years 1-19.
 - a. Waste infill, placed and compacted through depositional process (recoverable aggregates and large stones / boulders are to be removed at source or screened

prior to waste placement) such that machine and natural compaction achieves a bulk hydraulic conductivity in the order of $1 \times 10^{-10} \text{m/s}$.

- b. Waste infill is to be placed dry.
 - c. Minimum basal elevation of cell at 75mAOD, with an infill depth of ~60m.
 - d. Across an area of ~130x50m at the base, widening at the upper surface.
 - e. Infill mass is considered analogous as a low permeability “plug” equivalent in entirety to the placement of a geological barrier.
 - f. Process of diffusion may occur theoretically if the soil / infill mass becomes saturated (expectation is more likely that all water will be shed laterally from the restored surface).
2. Restoration – Year 19-21.
 - a. Placement of 0.5m layer, $1 \times 10^{-8} \text{m/s}$ and 1m of soils to complete the proposed landform.
 - b. Completion of surface water scheme, inclusion of attenuation pond.
 - c. Theoretical seepage at cap / sidewall interface (to be collected with the surface water management system and discharged to surface water through agreed discharge consent).
 3. Aftercare period – Post year 21 (expectation based on waste types).
 - a. Continued stabilisation of the infilled materials.
 - b. Monitoring and periodic review to be undertaken as per Environmental Permit requirements.

The lifecycle phases therefore include an “operational phase” (Stages 1 above), “post closure phase” (Stage 2 above) and “long-term closure phase” (Stage 3 above).

Additionally, the potential source, pathway and receptor terms can all be defined with sufficient certainty so as to be confidently represented by conservative inputs, models and assumptions, e.g. a single homogenous source of non-hazardous soils / construction / demolition wastes with conceptually understood flow characteristics and directions (in the long term flow expectations are northerly consistent with geological dip and fall in topographic elevation).

4.6 Accidents and Consequences

In regard to accidents, they are considered to be unintentional incidents that could reasonably occur, which are unforeseeable in terms of their time of occurrence. The process of evaluating environmental risks should therefore include the consideration of the potential impact of accidents as well as the resulting harm.

Based on the site setting and associated design and proposed infilling / restoration, potential accidents such as flooding, subsidence, landslides, fires and explosions are all considered to be unlikely / very unlikely. As such, further assessment is not considered necessary.

5 Risk Assessment

5.1 Priority Contaminants to be modelled

After a review of the potential source term (Table 1), and under normal circumstances it would be considered appropriate to assess the following contaminants:

Hazardous Substances:

- Arsenic – Present in the source term as concentrations above DWS

Non-Hazardous Pollutants:

- Nickel – Non-hazardous metal present in the source term at concentrations above DWS
- Chloride, sulphate and ammoniacal-N – Matrix and minor ions present in the source term at concentrations above DWS (ammoniacal-N is however only included based on “perceived water impact sensitivity”)

This would constitute a qualitative screening, Tier 1 assessment approach.

However, as observed in Table 2 and with reference to the local groundwater / porewater quality (and assigned EAL’s), only sulphate within the infill source term (85th percentile concentration of 1,410mg/l) is greater than the cross gradient (up dip) groundwater quality at BH22-04S with a maximum concentration of 1,350mg/l.

As such, only sulphate and arsenic are considered further however it is recognised that the most likely “median” sulphate value for the proposed infill approximates to only 2/3 of the current groundwater concentration.

5.2 The Nature of the Hydrogeological Risk Assessment

In regard to available Environment Agency technical guidance, it is apparent that Sandown Landfill (although close to surface water bodies) falls within a category of simple risk assessment:

“It is clear from the conceptual model and the risk screening that the hazards are relatively low and the environmental setting is sufficiently insensitive to negate the possibility of significant impacts (e.g. sites on low permeability strata remote from abstractions and surface waters)”

In accordance with the conceptualisation of “Hydraulic Containment” as depicted in Figure 1, the following observations are noted:

Etruria Formation

- Consider the site as a hydraulically contained landfill, in which the water levels (pore-water) within the site / infill are below the external groundwater level of the Etruria Formation. It has been established through environmental baselining that water levels within the Etruria Formation are individual “to each specific monitoring location” with no overall lateral connectivity. If there was a coherent and linked water system (with permeability and thickness) to allow the fulfilment of a “water body” classification under the requirements of the Water Framework Directive, then the site would be full of water or conversely would require groundwater management.

This is not the case.

- Secondly, if pore-water within the site was to exceed the external groundwater level in the Etruria Formation, then basal seepages could be considered to an underlying receptor or established pathway to a receptor.

This has not been established or verified at site, with at least 5.5m of *in-situ* clay / mudstone beneath the base of the site (report reference 5430-BLP-R-003-02). Basal seepages are not considered further.

Interburden / overburden

There is water present within this material which is significantly impacted, water levels are reported at almost ground level, hence the infill could be considered as being “fully hydraulically contained” in this regard. Currently there is a local hydraulic gradient towards the site (as an open void).

Permeability derived from BH22-04S at 4.7×10^{-10} m/s exceeds the minimum directive requirements for a geological barrier between the infill and the natural strata (Etruria Formation) at the site boundary. Lateral thicknesses are in the range between 15m and 135m to the monitoring locations at the periphery of the infill, hence the distances to the natural strata and site boundary are far greater. This material is not considered a receptor, as such there is no requirement for modelling or lining with an AGB for the benefit of environmental protection, particularly in reference to the already impacted water quality observed through baseline data collection (Table 2).

5.3 Hydrogeological Containment Assessment

For completeness, this section and associated modelling constitutes a “Tier 3 assessment” in accordance with current on-line guidance.

The hydraulic containment model is a spreadsheet model published by the Environment Agency and default values proposed in the accompanying review document have been utilised where material or site-specific properties cannot be sourced. The hydraulic containment model is based on the assumption that leachate levels are below the external piezometric level. The model itself is insensitive to the absolute levels used, but is dependent on the relative difference in water levels and the barrier properties. A leachate height set 1m below the external groundwater level has been assessed to demonstrate the diffusion potential for a substance from the site, subsequent sensitivity assessment considered a head differential of 0.1m.

For sensitivity purposes the model has been run in “List I” mode for both substances (the edge of the barrier / liner), *i.e.* prior to entering the Etruria Formation strata so that a direct comparison can be made with the underlying / adjacent groundwater quality. The model assessment has utilised scenario 3 (sidewall contaminant fluxes only), model parameters are shown in Table 3, substance specific parameters for arsenic and sulphate are derived from supporting documentation^{6,7,8}, liner properties considered are 0.5m thickness at a hydraulic conductivity of 1×10^{-8} m/s.

⁶ Environment Agency (2004) Contaminant fluxes from hydraulic containment landfills spreadsheet v1.0 User Manual. Science Report SC0310/SR

⁷ Environment Agency (2004) Contaminant fluxes from hydraulic containment landfills spreadsheet - a review. Science Report SC0310/SR

⁸ Science Report SC050021 / Arsenic SGV, Science Report SC050021 / Arsenic supplementary report

Table 3 Hydraulic Containment Parameterisation

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION			
	Parameter	Units	Justification / Reference / Notes
Scenario	3		Landfill constructed into Etruria Clay pit (sidewall & base assessment flux) to 'Espleys' through engineered liner
Basal width perpendicular to groundwater flow	130	m	Void dimensions
Basal length parallel to groundwater flow	50	m	Void dimensions
Elevation of base of landfill	75	mAOD	Design
Elevation of base of aquifer	75.01	mAOD	Assume permeable horizons on sidewall (equivalent to or above base level of site)
Maximum thickness of underlying aquifer	-	m	Not used in Scenario 3
Leachate head inside landfill	125.9	mAOD	Assumed at 1m below groundwater / porewater, sensitivity analysis – 0.1m below groundwater level
Groundwater head outside landfill	126.0	mAOD	Site monitoring data
CONTAMINANT PARAMETERS			
Contaminant name	Arsenic	-	Priority Metal
Contaminant type	Inorganic	-	
Contaminant classification	List I	-	Modelled to edge of liner for conservatism (including SO ₄)
Concentration in landfill leachate	0.013	mg/l	85 th ile concentration expected – sensitivity analysis 95 th ile +20%
Free water diffusion coefficient	0.717 E-09	m ² /s	HCM Table 3.1 (<i>assumed as per cadmium</i>)
Partition coefficient in clay	500	l/kg	Science Report SC050021/ arsenic SGV
Half-life in clay (0 for no decay)	0	days	
Decay in sorbed phase?	No	-	
MINERAL BARRIER / LINER			
Thickness of mineral barrier is calculated as 1.5m	0.5	m	minimum thickness likely to be constructed (0.5m 1x10 ⁻⁸) + in-situ barrier (1m, 1x10 ⁻¹¹) – combined appraisal
Hydraulic conductivity	1E-8	m/s	Engineered Liner
Average pore radius	1E-5	m	Adapted from Burke et al (1988)
Effective porosity	0.15	-	Assumed continuity through ancient clay
Dry bulk density	2100	kg/m ³	
Tortuosity	10	-	HCM Table 3.3, De Marsily (1986)

No readily available diffusion coefficient for arsenic, cadmium standard used at 0.717x10⁻⁹m²/s⁻¹. Attenuation coefficient 500cm³ g⁻¹ (Science Report SC050021/ arsenic SGV). Sulphate diffusion coefficient 1.07x10⁻⁹m²/s⁻¹ (HC manual, Table 3.1), attenuation coefficient (partition coefficient) in clay 0 (Conservatively a Kd of zero is used for sulphate even though sulphate frequently undergoes chemical reactions during migration in the subsurface).

5.4 Emissions to Groundwater

The priority metal arsenic and matrix ion sulphate are not predicted to impact the Etruria Formation groundwater / porewater at 85thile source term concentrations when leachate levels (qualifying material pore-water) are 1m below adjacent groundwater. The hydraulic containment model predicts that arsenic concentrations would be <1x10⁻⁹mg/l prior to mixing with groundwater through the engineered liner.

As part of a series of sensitivity analysis, there is no breakthrough of the modelled substances at a reduced head differential of 0.1m (almost parity between soil infill porewater and Etruria Formation Groundwater) or when modelling 95thile source term concentrations (Table 1) plus 20%.

If the *in-situ* properties of the Etruria Formation strata are considered as the liner i.e. bulk permeability of $1 \times 10^{-9} \text{m/s}$ (to account for a combination of host mudrock with more permeable Espley horizons) at a thickness of 0.5m, sulphate concentrations would attain a concentration of 0.12mg/l at the edge of the liner after 31,000 years.

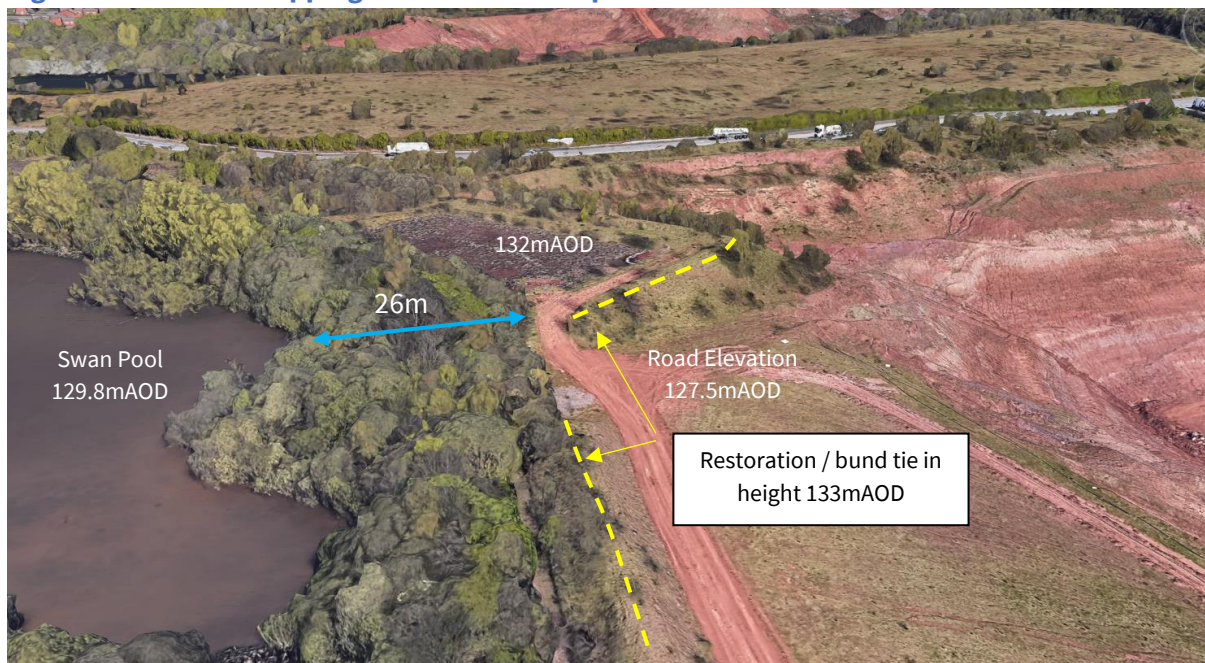
If no permeable horizons are present (bulk permeability of $\sim 1 \times 10^{-10} \text{m/s}$), and diffusion occurs only through *in-situ* Etruria Formation mudrock to porewater, the DWS concentration of 250mg/l would be realised after 79,500 years. In reality the liner thickness would not be 0.5m, as the minimum distance to the monitoring location is 12m at which point no breakthrough of sulphate is observed.

5.5 Lateral Migration to Surface Waters

Leachate / Porewater Seepages

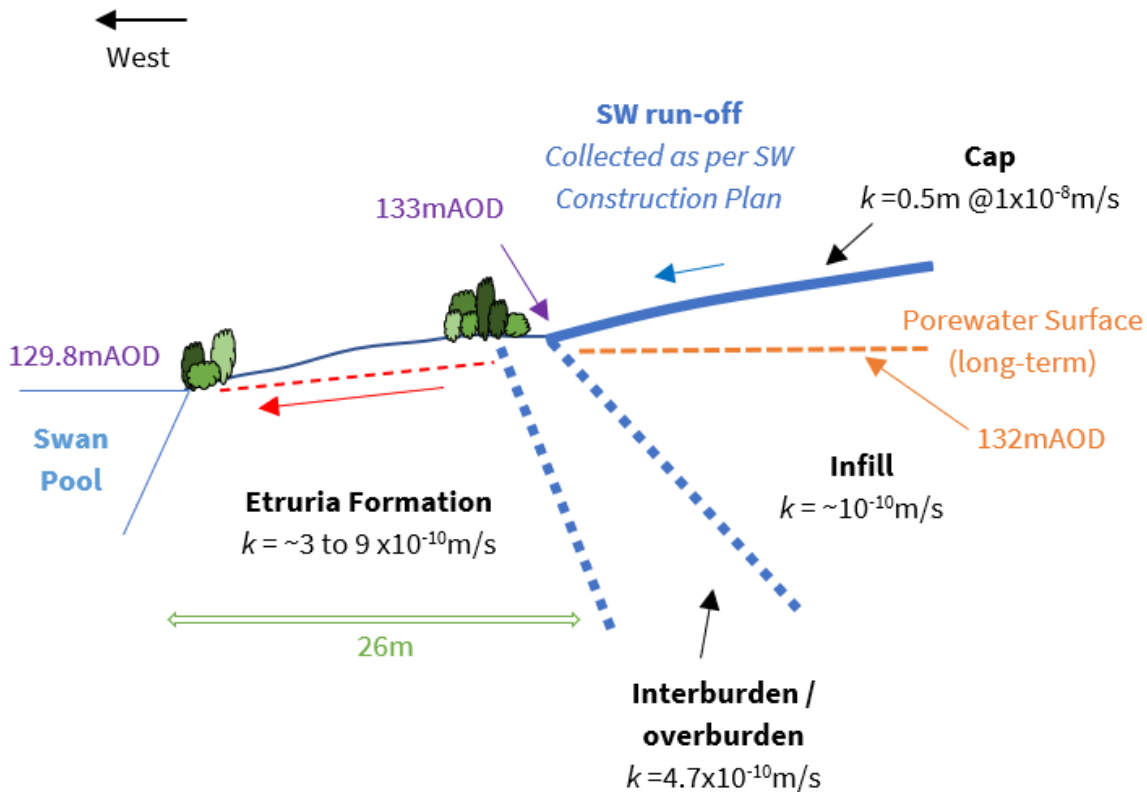
On the eastern boundary of the site, the elevation of the Daw End Canal is above the restoration / infill and hence there are no potential linkages from the site. On the western boundary there is a significant lateral width of land (with extensive tree / shrub cover) between the infill scheme / restoration toe slope and site perimeter. A measured distance of 26m separates the infill from the adjacent Swan Pool. A visual and schematic representation is provided on Figure 2 and Figure 3 respectively.

Figure 2 Overtopping Surface Water Impact Overview



Any potential seepages from the soil / infill are expected to be of a “low volume” (expected waste mass permeability of 10^{-10}m/s) and with a restoration surface low point at 133m AOD porewater will be contained by the 0.5m engineered cap/interburden tie-in ($1 \times 10^{-8} \text{m/s}$) prior to any transit through the adjacent geological strata towards the receptor.

Figure 3 Overtopping Surface Water Impact Schematic Representation



A direct linkage to Swan Pool is considered to be contained by a lateral pathway of *in-situ* geological barrier with a lateral width of ~26m. The surface level of Swan Pool is 129.8 mAOD.

Irrespective of the sidewall liner and capping surface interface ($0.5\text{m} @ 1 \times 10^{-8} \text{ m/s}$ in addition to restoration soils) un-retarded travel time for porewater seepage from the soil infill at 132mAOD (a maximum possible level, equivalent to containment overtopping) migrating laterally through the *in-situ* geological barrier towards Swan Pool (head differential of 2.2m, porosity of 17%, Etruria Formation conservative hydraulic conductivity k of $1 \times 10^{-9} \text{ m/s}$) is ~1,656 years.

This calculation is also conservative, excluding effective porosity of the clay / marl would increase travel times to the receptor to 9,744 years.

Such extended travel times through a significant attenuation barrier (i.e. Etruria Formation Clay / marl) would prevent the potential for pollution to occur, hence there is not considered a risk to the environment from lateral leachate porewater migration through the sides of the site and *in-situ* geological barrier.

Notwithstanding the above, the surface area of Swan Pool is 0.92hectares (9,200 m^2). With a conservative depth estimate of 3m, the volume of water in the pond would equate to 26,600 m^3 hence there would be considerable dilution potential in the event of direct seepage transport.

If in the event that cap / leachate seepages remain of environmental concern, and if, through the collection of the pore-water / leachate source term data there is any significant deviation from the assumed source term is noted then a collection drain could be considered. The drain would be installed progressively as restoration phasing is completed and would drain to a temporary sump and ultimately a permanent chamber all of which can be dewatered using a suitable pump. The drain would collect porewater from the highest level of waste fill during the operational period allowing collected water to be tested prior to pumping (if pumping proves necessary) to ascertain the most appropriate disposal/re-use route in accordance with the surface water management scheme. The drain would continue to function following the installation of the engineered cap, however there is no expectation that any pumping will be required at this point.

Seepage flux, assessment of environmental risk, application of any associated compliance limits could all be included within an appropriately worded improvement condition based on the collection of site data during the operational period. This would be integrated into the production of a CQA plan for the design of the sub-cap drain (not required until years 18-20).

Cap Run-off

The site surface water run-off once restored (~16 Ha) will runoff in a westerly and north-westerly direction towards the enlarged surface water pond (Surface Water Management Plan (07200/SWMP/R02 – 7 Engineering Consultancy, Appendix D of report 5430BLP-003-02). Any potential seepages noted above if collected (at the infill / cap interface) would be significantly diluted in comparison to the surface water volume conveyed to the surface water management system (containing an available attenuation storage volume of 5,900m³). If there is a requirement for sub-cap seepage collection, then the scenario outlined in Figure 3 becomes redundant.

6 Review of Technical Precautions

The primary technical precaution implemented for the void restoration scheme is through restricting the restoration materials to the QMs. These materials have negligible organic content and a resulting negligible leachate generating potential. This qualitative hydrogeological risk assessment has demonstrated that technical precautions are not required for the restoration of Sandown Quarry Landfill using QMs.

Protection is provided for by the properties of a significant thickness of *in-situ* Etruria Formation strata, which acts as a natural geological barrier beneath and to the side of the landfill, albeit off-site contaminant effects on water contained in the interburden / overburden material are recognised locally (primarily to the north).

The report has demonstrated (in conjunction with the ESID) that leachate level (pore-water) control is not necessary and that any substances exiting the site either under a concentration gradient (*i.e.* chemical diffusion) or a mass flux under a hydraulic gradient would not lead to a change in groundwater quality.

It is however, considered possible that a proportion of the incidental rainfall will not infiltrate into the deposited materials and will run-off as surface water. Therefore, some surface water

management will be required during the first phase of operations when the quarry floor has been partially infilled / restored.

7 Requisite Surveillance

A monitoring schedule is based on the risk assessment which has demonstrated that provided that the robust waste acceptance control procedures are implemented, monitoring of the leachate and groundwater is unlikely to be necessary.

However, as per previously determined permit applications for equivalent schemes, a monitoring network for off-waste and in-waste monitoring will be proposed (monitoring schedule are proposed in report 5430-BLP-009-02). Spine drains beneath the infill will convey some porewater collection to the monitoring chamber. Monitoring the quality will allow cross-referencing with the assumed source term contained herein.

8 Conclusions

The site is located within a low-risk area, namely a clay / marl pit within Etruria Formation. A natural geological barrier.

It is considered that given the current groundwater / Etruria Formation porewater quality and the attenuation capacity of the geological barrier that it is highly unlikely that the proposed restoration scheme could discernibly impact on groundwater quality. Consequently, the requirements of the Groundwater Directive (1998) have been met. The nature of the proposed materials and the associated hydrogeological risk is consistent with that for an inert site.

Such sites do not require active management controls and there is not a sensitive underlying water resource. There is not a risk-based justification for implementing active management controls for leachate within the site. However, a monitoring schedule has been proposed in the permit application which will enable the design assumptions to be validated. This monitoring schedule will however include infrastructure capable of being utilised for leachate abstraction should a condition arise where active leachate management is required.

It is considered that the espley / sandstone layers form a transitory position between formally classified unproductive strata (*i.e.* mudstones) and secondary aquifers. It is considered appropriate that given the permeable layers do contain a pore-water, under this scenario they will not fulfil a role as a useable water resource or water body as defined by the Water Framework Directive.

With limited lateral extent and variable thicknesses of these sandstone espley units (many <1m in thickness) which are separated by marls and mudstone; offsets through minor faulting; juxtaposition against lower bulk permeability sequences then water framework directive yield targets cannot be met as the sandstone layers are not linked to the surface to allow any recharge, conversely they do not link with any receptors (in any direction). Disconnected layers (irrespective of hydraulic properties) only have a "limited" exploitable storage.

The local porewater within the interburden / overburden (particularly to the north), whereby long-term infilling will promote overall flow direction to the north / northwest i.e. consistent with topography indicates that the source term is not capable of worsening the downgradient (down-dip) water quality.

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. This can be mitigated by the incorporation of a sub cap collection ditch and monitoring sump however this is not required for at least 18 years from the onset of infilling and its requirement should be assessed appropriately at that time.

8.1 Compliance with Schedule 10 (Landfill) of the Environmental Permitting (England and Wales) Regulations 2016

The Landfill Regulations have been superseded by the Environmental Permitting (England and Wales) Regulations 2016 (as amended). These regulations implement the underlying Landfill Directive.

The conclusions of this report are that:

- The development does not pose a hazard to groundwater and surface water quality, subject to the technical precautions identified with regards to passive controls (i.e. waste acceptance criteria to be followed as per agreed Site Management Systems / EMS and adherence to waste acceptance criteria).

The site therefore complies with the Schedule 10 of the Regulations.

8.2 Compliance with Schedule 22 (Groundwater Activities) of the Environmental Permitting (England and Wales) Regulations 2016

This Schedule implements the Water Framework Directive, which requires that hazardous (formerly List I) substances are prevented from entering groundwater and that non-hazardous pollutants (formerly List II) substances are controlled so as to prevent pollution.

The risk assessment has demonstrated that the technical precautions identified and implemented at the site are sufficient to:

- prevent a direct discharge of hazardous substances
- prevent hazardous substances entering groundwater at discernible concentrations; and
- prevent pollution by non-hazardous substances.

The risk assessments in association with the monitoring data demonstrate that the site is highly unlikely to have a discernible impact on groundwater quality given the background trends that have already been observed.

The site therefore complies with the relevant requirements of the Regulations and the Water Framework Directive.



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