

Parry's Quarry Landfill Environmental Permit Application – Hydrogeological Risk Assessment



22 July 2019

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Prepared for

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Report reference:

66388R1

Report status:

Final

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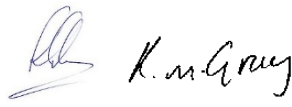


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Revision record:

Issue	Date	Status	Comment	Author	Checker	Reviewer
1	22/07/2019	Final	-	RAG KMG	AJS JWG	AJS

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1 INTRODUCTION

1.1 Report context

SLR Consulting Ltd (SLR) has been commissioned by Mold Investments Ltd (Mold) to prepare an Environmental Permit application for the proposed Parry's Quarry landfill and associated Waste Transfer Station (the Site) in Mold, Flintshire. Stantec UK Ltd (Stantec) has been commissioned by White Rock Geo-Environmental Ltd, on behalf of Mold Investments Ltd, to provide hydrogeological support to the permit application. For the purposes of the application 'the Site' refers to the area defined by a proposed Environment Permit boundary as shown on Drawings ESID1 and ESID2.

The proposed landfill will accept inert, non-hazardous non-biodegradable and biodegradable waste types which are likely to produce leachate that contains potentially polluting substances. Environment Agency guidance (UK Government, 2019a) on the information that is expected to be provided as part of an environmental permit application for a landfill that accept such wastes, includes the requirement for a complex Hydrogeological Risk Assessment (HRA) using site-specific data, including what hazardous substances and non-hazardous pollutants may be present in the leachate.

The HRA detailed in this report has been prepared by Stantec in support of the Environmental Permit application. The HRA is based on the data and information contained within the Environmental Setting and Design (ESID) report prepared by SLR (2019a).

The HRA corresponds to Question 2, Appendix 2 of Part B3 of the Environmental Permit application forms.

2 SITE INFORMATION

2.1 Site setting

The Site is situated within the existing Parry's Quarry in Alltami, Flintshire and is bordered by the A494 to the south, the 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.

The Site is situated at an elevation of approximately 115 m AOD. The prevailing topography generally slopes from the higher ground present to the south-west (i.e., the land rises to 160 m AOD at Buckley, c. 2 km to the south) towards the River Dee which is situated approximately 4 km to the north-east of the Site. The land immediately to the north of the Site (beyond the A55) is broadly level and has an elevation of approximately 90 m AOD; and a steep sided valley containing Wepre Brook is incised into this area with a base of approximately 55 m AOD. Another steep sided valley containing Alltami Brook is situated 250 m to the north-west of the Site (the valley falls in elevation over a distance of around 1 km from approximately 100 m AOD to the west of the Site to 70 m AOD to the north of the Site).

The immediately surrounding area is predominantly agricultural and largely undeveloped, however, the settlements of Northop Hall (1 km to the north), Buckley and Ewloe (2 km to the west) are present in the local area. Various commercial / light industrial premises are situated immediately to the north, south and south-west of the Site. A service station including fuel filling station, food retail premises and a hotel are located immediately to the east of the Site.

2.2 Geology

Published mapping of the superficial geology (BGS (2019); as shown on Drawing ESID11) indicates that glacial till is present above bedrock across much of the area surrounding the Site. However, superficial deposits are absent along the route of Alltami Brook where it is closest to the Site (i.e. 250 m to the northeast). Elsewhere alluvium is present along the course of the brook to the south; and alluvium and glacio-fluvial (sand and gravel) deposits are present on both Alltami and Wepre brooks to the north. The mapping also shows that superficial deposits are absent from across much of the Site; this is due to the development that has taken place

Published mapping of the bedrock geology (BGS (2019); as shown on Drawing ESID10) shows that 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 bedrock succession is complicated by local structural controls, which have created a series of fault bounded blocks in the area, resulting in various lithologies to locally become juxtaposed against each other.

The local geological sequence at the Site is summarised in Table 2.1.

Table 2.1 Generalised local stratigraphy

Group	Formation	Member	Rock types
Warwickshire Group	Etruria Formation	-	Mudstones with subordinate sandstones (generally lacking coal)
Pennine Coal Measures Group	Pennie Middle Coal Measures Formation	Hollin Rock Member (sandstone)	Mudstones with subordinate sandstones, siltstones and coal seams
	Pennie Lower Coal Measures Formation	-	

Published geological mapping (BGS (2019); as shown on Drawing ESID10) 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); and mudstones, sandstones and conglomerates of the Etruria Formation are present across the western third of the Site. The Middle Coal Measures are present at outcrop further to the west, including the Hollin Rock Member which is identified beyond a north-south faulted boundary (with an apparent 50 m downthrow) present close to the western boundary of the Site. The Lower Coal Measures Formation is present ~50 m to the east of the Site beyond another approximately north-south trending fault line.

2.3 Hydrology

The Site lies within the catchment area of the River Dee. As shown on Drawing ESID12, the nearest water course to the Site is Alltami Brook which is situated to the west of the Site; flowing from south-west to north-east. At its closest point, the brook is c. 250 m to the north-west of the Site; it converges with Wepre Brook c. 700 m to the north of the Site.

Wepre Brook flows from west to the east and is a tributary to the River Dee which is located c. 4 km to the north-east of the Site. New Inn Brook, another tributary to Wepre Brook, is present c. 900 m to the east of the Site.

It is understood that any surface water run-off that accumulates in the base of the existing quarry void is managed via ad hoc pumping via a permitted discharge activity to Alltami Brook via a point on the north-western boundary of the Site.

2.4 Hydrogeology

2.4.1 Aquifer characteristics

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

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sandstone strata to depths of up to 250 m bgl; transmission of groundwater will depend on how locally well connected these hydrogeological units are. Groundwater movement 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. No groundwater abstractions have been identified within 1 km of the Site.

Historical coal mining within the Coal Measures occurred in the local area and mine workings are known to be present beneath the Site. However, the depth of the seams that were worked (>150 m) suggest that they are unlikely to affect groundwater pathways at the Site.

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

2.4.2 Aquifer properties

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).

2.4.3 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 direction (driven by piezometric head differences between separate or poorly connected hydrogeological units) are also likely to occur.

As detailed in the ESID report (SLR, 2019a), groundwater level monitoring that has been undertaken at the Site between January 2017 and March 2018 suggests that a relatively consistent piezometric surface is present which falls from c. 98 to 100 m AOD in the south-east to c. 87 to 90 m AOD in the west and north-west.

The monitoring data suggest that despite the identified geological complexity, the lithologies present beneath the Site appear to be hydraulically connected and seem to act as a single aquifer unit with a broadly consistent and identifiable piezometric surface.

Given that groundwater levels within the Coal Measures are typically between 87 and 90 m AOD on the north-western boundary of the Site; and Alltami Brook is at an elevation of between 80 and 90 m AOD to the north-west of the Site it is considered likely that there is hydraulic connection between local groundwater and surface water down hydraulic gradient of the Site.

2.4.4 Groundwater quality

As detailed in the ESID report (SLR, 2019a), groundwater quality monitoring has been undertaken on 10 occasions (i.e. approximately monthly) at fourteen monitoring points on the Site between January 2017 and March 2018. This monitoring has confirmed earlier work (TerraConsult, 2015) that suggests that the local groundwater chemistry is locally influenced by chloride, sulphate and sodium which likely originate from road salt stored in a nearby Flintshire County Council (FCC) depot. Concentrations of these non-hazardous pollutants

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have been observed in excess of current UK Drinking Water Standards (DWS) in parts of the Site; in particular along the western boundary (the FCC depot is located immediately to the south-west of the Site).

Concentrations of ammoniacal nitrogen largely remained below the UK DWS during the monitoring period. The exception was in one monitoring point located on the northern boundary of the Site where a peak concentration of 2 mg/l was observed in May 2017; concentrations since then have reduced appreciably and have remained below the UK DWS since October 2018. The source of the ammoniacal nitrogen is unknown.

In general, concentrations of metals and minor ions are below relevant UK DWS. However, elevated concentrations of iron and manganese are commonly observed although it is believed that these originate from natural mineralogy within the Coal Measures and Etruria formations.

Phenols (and phenolic compounds) have largely remained undetected in the groundwater monitoring that has been undertaken to date. The exceptions are two isolated occurrences where phenols were detected separately in two groundwater monitoring points located on the southern (i.e. up-hydraulic gradient) boundary of the Site.

As identified in Section 3.5.4 of the ESID report (SLR, 2019a) it is suspected that local groundwater quality may also be affected by several historical landfills that are present near the Site (see Drawing ESID3); including two c. 200 m and c. 500 m to the south (i.e. up-hydraulic gradient) which received various waste types (including received household, commercial and industrial) in the 1980s and 1990s.

Also, as described in Section 3.4.2 of the ESID report (SLR, 2019a), various pollution incidents are known to have occurred in the local area which may also have had some influence on local water quality (including within Alltami Brook). The majority of incidents relate to incidents associated with sewage and farming / agricultural activities.

2.5 Site history

Historical mapping shows that the Site had originally been developed by the late 18th Century as a clay pit (quarry) for two brickworks; one located in the south-east of the Site and the other located immediately to the north. The pit had expanded and occupied the eastern half of the Site by the mid-1960s but the brickwork in the south-east was, by then, described as disused. By the 1980s the clay pit was also described as disused and the brickworks to the north of the Site had been demolished and replaced by buildings described as a workshop. The 1980s mapping also shows that the quarry void in the eastern part of the Site had become largely flooded.

An aerial photograph from 2001 shows that little change had occurred since the 1980s with the western half of the Site being used for agriculture at this time. However, an aerial photograph from 2006 shows that operations had re-started at the Site and the western half of the Site was being worked for mineral (brick clay) extraction. Various aerial photographs are available since 2006 which show that the western part of the Site and latterly also the eastern part of the Site continued to be worked.

2.6 Proposed landfill

The proposed development is for the restoration of the quarry void through landfilling with non-hazardous waste. The landfill will be above water table and operated on the principle of engineered containment with active management.

2.6.1 Engineering

Details of the proposed landfill engineering are provided by SLR (2019b). In summary, the engineered containment will comprise engineered basal and sidewall lining system with an engineered capping system.

The above water table design of the landfill necessitates positioning the engineered containment system above the piezometric groundwater surface that has been identified at the Site. As described in Section 2.4.3, the piezometric surface falls from c. 98 to 100 m AOD in the south-east to c. 87 to 90 m AOD in the west and north-west of the Site. Since the base of the existing quarry void is below these levels it will be necessary to place an engineered backfill with a thickness of between 5 m and 11 m to create a suitable formation level for the containment system.

The formation level for the containment system has been designed to be at an elevation of 91.5 m AOD in the west and north-west of the Site rising to 99.5 m AOD in the south-east. This design has been selected by SLR (2019b) so that the base of the engineered liner will be above the observed maximum groundwater levels that have been measured at the Site. This is to allow for potential longer-term rising trends in groundwater levels that may occur.

The basal lining system will be on the established formation level and will comprise:

- Geological barrier a minimum of 0.5 m thick constructed of clay with a permeability of 5×10^{-10} m/s;
- Geosynthetic Clay Liner (GCL);
- Artificial sealing liner (HDPE);
- Protective geotextile (non-woven); and,
- Leachate drainage layer.

The side slope lining system will be engineered from the same material as the basal lining system.

The landfill will be operated as a sequence of eight engineered cells; with waste materials being placed into each cell to pre-settlement levels before they are completed with the engineering capping system.

The engineered capping system will comprise a minimum of 1 m of restoration soils overlying an artificial sealing liner (LLDPE) and underlying regulation layer. Due to operational requirements it will be necessary to initially complete some areas with temporary capping prior to placement of the permeant capping system.

2.6.2 Leachate management

Each engineered cell will contain a leachate management system which will comprise a basal leachate drainage blanket with abstraction points. Abstracted leachate will be pumped to holding tanks prior to be tankered to an off-Site treatment facility.

2.6.3 Groundwater management

The engineered containment system will be above the water table and there will be no requirement for groundwater management during the operational or post closure phases of the landfill.

3 HYDROGEOLOGICAL CONCEPTUAL SITE MODEL

A summary of the hydrogeological conceptual site model is provided in the following sub-sections and illustrated schematically in Figure 3.1. The model has been developed based upon the proposed landfill engineering and environmental setting described in the ESID report (SLR, 2019a), as summarised in Section 2.

Details of the leachate source (i.e. the inert, non-hazardous non-biodegradable and biodegradable waste types) relevant hydrogeological pathways (i.e. via groundwater transport); and identified receptors (i.e. local groundwater and surface waters) that will be considered in the risk assessment are provided below. A summary of the Site water balance, which describes the various fluxes into and out of the landfill and how they are represented in the risk assessment model, is also presented.

3.1 Landfill design

The proposed installation is an above water table engineered landfill benefitting from composite engineered basal and side slope liners and an engineered cap. The landfill will include a leachate management system within each cell enabling the active management of leachate generated within the landfill during the operational and post closure with aftercare (i.e. managed) phases.

Following completion of the Site the engineered liners and cap are assumed to degrade with time which will alter their performance. The changes in engineering performance and resultant changes to the predicted fluxes into and out of the landfill are represented by a staged water balance in the risk assessment.

3.2 Source

The source term is taken to be the final volume of waste in the Site after completion of landfilling. The leachate inventory is defined by assuming that the leachate is present in the waste at the field capacity of the waste form for the full volume of the waste-filled void space.

Infiltration entering the landfill dilutes this leachate, and for a steady state water balance this diluted leachate is pumped out through the leachate management system during the operational and post closure with aftercare phases. This leads to a decline in the source term.

Since the landfill is yet to be constructed no existing leachate quality data are available to describe the source term. However, leachate quality data from existing landfills that taken similar waste streams to those proposed for the Site have been reviewed and are assumed to be analogous to the quality of leachate that will be present in the landfill (SLR, 2019c).

As described in the ESID (SLR, 2019a), it is intended that Cell 6 will accept different waste streams from the other cells, which, it is anticipated, will result in concentrations of ammoniacal nitrogen, benzene, naphthalene and arsenic in leachate than are higher than concentrations in leachate generated in the remainder of the Site. Due to the expected differences, the source term for Cell 6 will be modelled separately from the remainder of the Site (see Section 4.3).

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It is conservatively assumed that leachate will be immediately available for migration from the landfill. Furthermore, no allowance is made for leachate that may have been removed from the landfill during the operational and post closure with aftercare phases.

The priority contaminants included in the model are ammoniacal nitrogen, chloride, benzene, phenol, naphthalene, nickel and arsenic. The justification for their inclusion is described in Section 4.3.

3.3 Pathways

During the operational phase of the landfill, infiltrating rainfall will pass through the temporary capping and enter the waste, thus generating leachate. As outlined above, during the operational and post closure with aftercare phases leachate heads will be actively controlled. Excess leachate will be pumped from the landfill to holding tanks prior to off-site treatment and disposal.

After the landfill is closed, there will no longer be any active leachate management and leachate heads will be allowed to rise until equilibrium is established between inflows through the engineered cap and outflows through the engineered basal and side slope liners. Inflows through the cap and outflows through the basal and side slope liners after the landfill is closed will be controlled by the long-term performance of the landfill engineering.

The basal and side slope pathways will involve migration of leachate through the composite geomembrane and engineered clay liners, where the processes of dispersion, attenuation and retardation will occur. The properties of the composite basal and side slope liners and natural attenuation properties of the contaminant species used for the risk assessment are described in Section 4.6.4.

Similar processes occur during vertical migration through the basal backfill, underlying the basal liner and the unsaturated zone beneath the side slope engineered lining system.

The flux through the basal backfill will migrate both horizontally and vertically to the Coal Measures driven by the leachate head within the backfill material. However, as a conservative measure, the vertical thickness rather than the horizontal distance from the centre of the landfill to the edge of the backfill has been used for the travel distance in the base case model. In addition, the hydraulic gradient in the aquifer was used to obtain a conservative estimate of the velocity through the backfill.

The impact of decreasing the thickness of the unsaturated zone is investigated in the sensitivity analysis as this could be reduced at times of elevated groundwater levels.

For the purposes of the risk assessment model, the basal flux and the side slope flux from the landfill are summed and conceptualised to migrate laterally through the Coal Measures onwards towards Alltami Brook. Processes of dispersion, retardation, degradation and dilution occur within the Coal Measures. The properties of the basal backfill and the Coal Measures used in the risk assessment are described in Section 4.6.4.

3.4 Receptors

The following receptors have been identified:

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- *For hazardous substances:* groundwater at the water table beneath / at the edge of the landfill; and
- *For non-hazardous pollutants:* groundwater at a hypothetical borehole located in the Coal Measures Secondary A Aquifer located on the down hydraulic gradient boundary of the Site; and in Alltami Brook (which is assumed to receive baseflow from groundwater from the Coal Measures and is the closest surface water course to the Site).

Appropriate Environmentally Acceptance Levels (EALs) of the modelled contaminants are based on Minimum Reporting Values (MRV) (UK Government, 2019b) or UK Drinking Water Quality Standards (UK DWS) to be protective of the groundwater receptor; and where these are not available Environmental Quality Standards to be protective of the surface water receptor.

3.5 Water balance for the landfill

The various fluxes into and out of the landfill are estimated in the model using a water balance approach, as described below. For the purposes of the model; separate steady state water balances have been developed to represent the anticipated changes that will occur during the four lifecycle phases of the landfill (operational; post closure with aftercare; site completion and post site-completion).

Engineered containment of the waste will be provided by a high-performance composite engineered liner on the base and side slopes of the landfill. Leachate generation will be minimised by the provision of a high-performance composite engineered cap in the long term. The water balance accounts for recharge through the cap, and leakage through the basal and side slope engineered liners.

The cap recharge is calculated using the effective rainfall, runoff, interflow over the cap geomembrane and leakage through defects within the membrane as predicted using Giroud's formulae for flow through a defect overlain by permeable material.

During the operational phase (estimated at c. 8 years), when only temporary capping is in place, there will be greater ingress of water into the landfill leading to more flushing of the waste and more rapid stabilisation through decline of the source term.

Leachate will be actively managed for 60 years after the Site has been closed. During this phase, leachate levels will continue to be controlled. Once the agreed completion criteria for the Site have been satisfied, there will no longer be a requirement for active management and leachate heads will be allowed to rise until equilibrium is established between inflows through the engineered cap and outflows through the engineered base and side slopes. The leachate head within the waste is calculated taking account of the basal flow, any side flows and any overtopping that could occur if recharge through the cap exceeds the capacity for leakage through the engineered basal and side slope liner systems (note that overtopping is not predicted to occur in the water balance calculations).

The estimated fluxes through both the basal and side slope liners are calculated based on Giroud's formulae for flow through defects in a geomembrane which will be dependent upon

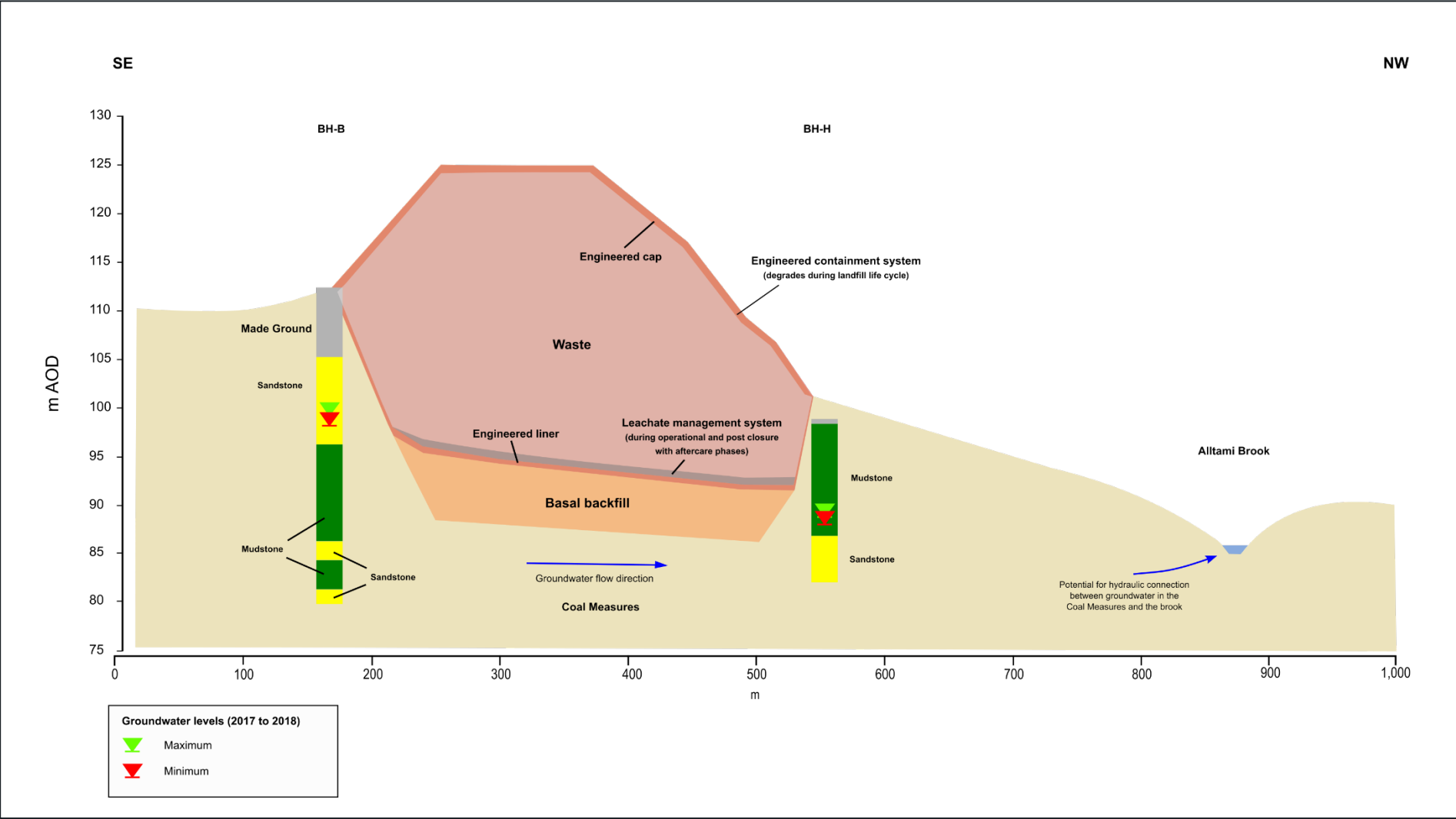
the leachate head within the landfill. The fluxes out of the landfill during the managed phases will be minimised by the active management of leachate heads within the landfill.

The performance of the engineered containment system (i.e. the composite cap, basal and sidewall liners) is predicted to change over time, as described in the Environment Agency's guidance on the medium to long term generation of defects in geomembrane liners (Environment Agency, 2004) and this is represented by distinct stages in the water balance during the post-completion managed phase.

Initially the geomembranes are assumed to perform well. Over time, antioxidants in the geomembranes will be depleted and the geomembranes in the cap and basal and sidewall liners will begin to lose strength and may develop further defects. This is represented by later stages within the water balance with reduced performance of the engineered containment system. Additional defects in the geomembranes are introduced into the model in accordance with the Environment Agency guidance (2004).

For the purposes of the risk assessment model, the basal flux and the side slope flux from the landfill are summed and mixed with groundwater flowing through the basal backfill and Coal Measures towards Alltami Brook. Processes of dispersion, retardation, degradation and dilution occur within the Coal Measures. The velocity of contaminant transport will be governed by the hydraulic conductivity, hydraulic gradient and effective porosity within the Coal Measures strata.

Figure 3.1 Conceptual site model



4 HYDROGEOLOGICAL RISK ASSESSMENT

4.1 The nature of the hydrogeological risk assessment

As identified in Section 1.1 a complex or Detailed Quantitative Risk Assessment (DQRA) is required to support the permit application. This is because the proposed landfill will accept waste material which is likely to produce leachate that contains potentially polluting substances. The DQRA must consider the potential impact of these substances on the identified local groundwater and surface water receptors.

A numerical model has been developed for the DQRA and used to perform probabilistic calculations to assess both the hydrogeological impacts of the proposed landfilling and also the degree of uncertainty in the required input data.

4.2 Proposed assessment scenarios

4.2.1 Lifecycle phases

The following four lifecycle phases have been considered for the landfill, which represent the period of active management and the temporal variation in performance of the engineered containment system:

0. Operational phase
1. Post closure with aftercare
2. Site completion
3. Post site-completion

The assumptions regarding the four lifecycle phases are provided in Table 4.2. In summary, the risk assessment model assumes that the landfill will be managed during the first two phases; as such, leachate will be actively managed prior to any degradation of the engineered containment system. The model therefore considers leachate removal during both the operational (0) and post closure (1) phases. The model also allows for the increased flushing of the waste during the operational phase with higher recharge anticipated prior to construction of the final engineered cap.

At the end of the operational phase (0) the engineered cap will be constructed, and the Site will be closed. Leachate management will then cease when the Site reaches completion (phase 2) and leachate levels will be allowed to reach an equilibrium within the landfill. Eventually the strength of the geomembrane used in the engineered cap and liners will degrade and there is the possibility that additional defects will occur (Environment Agency, 2004). During the post closure with aftercare phase (1) the risk assessment model relies on the engineered containment system having good performance; after this phase a progressively degraded containment system is represented, and recalculated water balances are used in the risk assessment model for the phases after the Site has been completed (2 and 3).

4.3 Priority contaminants to be modelled

The selection of contaminants to be represented in the risk assessment model is based on the need to characterise the performance of the landfill for a range of hazardous substances and non-hazardous pollutants with differing transport properties.

- **Ammoniacal Nitrogen** is a common component of landfill leachate and is usually present at the highest concentration relative to the UK DWS. It is retarded and may undergo decay by oxidation to nitrite and nitrate, although as a conservative assumption this latter process has not been modelled.
- **Chloride** is also a common component of leachate and often has high concentrations. The chloride ion is not retarded, nor does it decay so it is useful to quantify its migration as a conservative tracer.
- **Benzene** is a highly mobile hydrocarbon commonly found in leachates. Benzene was chosen due to its relatively high mobility and as it is classified as a hazardous substance. Benzene can be subject to degradation.
- **Phenol** is a highly mobile organic contaminant often found in landfill leachate; it can also be subject to degradation.
- **Naphthalene** is a polycyclic aromatic hydrocarbon (PAH). It is a hydrophobic organic compound and is not readily sorbed by organic material in the aquifer. Naphthalene biodegrades within the groundwater environment, especially in aerobic conditions. A lower rate of biodegradation is considered to occur under anaerobic conditions, which are considered to occur within the clay engineered basal barriers (Howard et al., 1991). Naphthalene is oxidised in the subsurface.
- **Nickel** is an inorganic metal contaminant subject to some retardation but is generally highly mobile. It acts as a good indicator for metal contamination. Nickel does not decay.
- **Arsenic** is an inorganic metal which is subject to some retardation. It is included as it is classified as a hazardous substance. Arsenic does not decay.

As outlined in Section 3.2, since the landfill is yet to be constructed leachate quality data from an analogous landfill which has taken similar waste streams has been used to identify and define the following contaminants within the risk assessment model. For the purposes of the risk assessment model; separate source concentrations have been defined for Cell 6 and for the remainder of the Site (see Table 4.3 and Table 4.4). Concentrations for Cell 6 have been taken as those derived from measured leachate quality from comparable landfill sites accepting putrescible wastes (Municipal Solid Waste landfills) (SLR, 2019c). Concentrations for the remaining cells (Cells 1 to 5; and Cells 7 and 8) were calculated based on predicted blended concentrations during the post closure with aftercare phase for the whole landfill (SLR; 2019c); proportioned according to the relative volume of Cell 6 compared to the remainder of the Site.

4.4 Review of technical precautions

In the context of the technical precautions associated with the hydrogeological risk assessment, the engineered containment system for the landfill will be provided in accordance

with the requirements of the Landfill Directive which will be capable of preventing pollution of local groundwater and surface waters during the both the managed and unmanaged phases of the Site's lifecycle. The technical precautions that will be included in the engineered containment system are as follows:

- An engineered capping system that includes restoration soils; an artificial sealing liner and a regulation layer, designed to reduce infiltration into the landfill and manage surface water run-off at the Site;
- Drainage within each cell to allow the management of leachate (to a maximum head of 2 m above the top of the engineered liner) during the operational and post-closure aftercare phases as described by SLR (2019c); and
- An engineered basal and side slope lining system that includes an artificial geological barrier (a minimum of 0.5 m thick constructed of clay with a permeability of $<5 \times 10^{-10}$ m/s); a GCL and an artificial HDPE sealing liner with a protective geotextile.

All engineering will be constructed according to agreed Construction Quality Assurance (CQA) arrangements including independent inspection, checks and confirmatory testing of materials. Details of construction will be documented in full CQA reports and submitted to National Resources Wales.

These technical precautions are considered sufficient for the landfill to comply with the Environmental Permitting (England and Wales) Regulations (2016).

4.5 Numerical modelling

4.5.1 Justification for modelling approach and software

The risk assessment has been undertaken using Stantec's Risk Assessment Model (RAM) commercial software package (ESI, 2007). The base case model has been run probabilistically to assess the impact of uncertainties in the required input data. Sensitivity analysis has also been undertaken to further explore the effects of parameter uncertainty.

The RAM software package, together with a number of allied groundwater risk assessment tools, has been benchmarked for the Environment Agency (ESI, 2001). Additionally, the equations used in RAM have been verified by comparison between direct evaluation of an analytical solution and the semi-analytic transform approach applied for more complex pathways, and by comparison with published solutions used for verification as part of the nuclear waste industry code comparison exercise INTRACON (Robinson and Hodgkinson, 1986).

Section 4.6 presents the parameterisation for the risk assessment model. Where it was considered important to evaluate the effect of uncertainties with these values in the base case model probabilistically, ranges were used to define realistic input values, with an informed assumption of the distribution of values within the range.

In line with Environment Agency guidance (UK Government, 2019b), predicted 95th percentile concentrations of the modelled contaminants at the identified receptors are included for the base case model in Section 4.7.1 and are used to assess the acceptability of the output values.

As outlined in Section 4.6.7, a deterministic approach was used to undertake the sensitivity analysis model runs; the results of which are presented in Section 4.7.2.

An electronic copy of the model is provided in Appendix A.

4.6 Model parameterisation

The parameters adopted in the base case risk assessment model and justification for their selection are presented in Sections 4.6.1 to 4.6.6. Parameter ranges and assumed distributions used in the probabilistic assessment are presented where relevant. The parameters changed for the purposes of the sensitivity analysis are presented in Section 4.6.7.

4.6.1 Landfill design and engineering

Table 4.1 Landfill geometry and elevations

Parameter		Value	Distribution	Units	Justification
Width of landfill		400	Constant	m	Estimated from Drawing ESID2 (perpendicular to assumed groundwater flow direction)
Length of basal area		400	Constant	m	Estimated from Drawing ESID2 (parallel to assumed groundwater flow direction)
Length of slope area		1,176	Constant	m	Estimated from Drawing ESID6
Side slope		0.31	Constant	-	Estimated from Drawing ESID6 (vertical rise/horizontal distance)
Basal area	Whole site	46,260	Constant	m ²	Estimated from Drawing ESID2
	Cell 6	4,989			
Cap area	Whole site	102,626	Constant	m ²	SLR (2019a)
	Cell 6	10,799			
Approximate average thickness of waste		22.3	Constant	m	Estimated from Drawing ESID6
Volume of waste	Whole site	2,050,133	Constant	m ³	SLR (2019a)
	Cell 6	264,717	Constant		
Field Capacity		0.3	Constant	-	Beavan (1996) and Robinson (1996)

Parameter	Value	Distribution	Units	Justification
Limited leachate head (applied during Phases 0 and 1)	2	Constant	m	Leachate Management and Design Plan (SLR, 2019c)
Maximum leachate head (before overtopping would occur)	14.1	Constant	m	Estimated from average elevations of basal liner and top of side slope

Table 4.2 Landfill lifecycle phases

Phase	Period	Inputs	Assumptions
0: Operational	0 to 8 years	Leachate extracted based on mean pumping rate defined in Leachate Management and Design Plan (SLR, 2019c).	Significant infiltration occurs to open waste during operations; leachate heads will be controlled by pumping.
1: Post closure with aftercare (engineering performance as designed)	8 to 68 years	The basal, side slope and cap liner systems have geomembrane with underlying regulation layer. Leachate extraction will manage the leachate head at no more than 2 m above the basal liner.	The Leachate Management Plan (SLR, 2019a) assumes that leachate extraction will continue for 60 years (following cessation of landfilling)
2: Site completion (engineering performance degraded)	68 to 1,500 years	Maximum (i.e. worst-case) of default defect range for LandSim 2.5 are used for pin defects and holes within the geomembrane. Number of stress cracks due to holes is estimated based on duration of this period (see assumptions column). Active leachate management ceased; a steady state leachate head is calculated based on landfill water balance including liner system specification.	Environment Agency (2004) gives 1,500 years as the end of Stage 4 for a non-hazardous landfill (main period of antioxidant depletion). During this stage the number of stress cracks in the geomembranes will increase. Conservatively, the number of cracks assumed at the end of Stage 4 is used throughout this period.
3: Post site-completion (engineering performance further degraded)	1,500 years onwards	Leakage through base, side slope and cap are controlled by the regulation layer element of the liner systems. Active leachate management ceased; a steady state leachate head is calculated based on landfill water balance including liner system specification.	The basal, side slope and cap liner systems geomembrane has degraded (end of Stage 6 in Environment Agency (2004)).

Table 4.3 Source concentrations (Cells 1 to 5; and Cells 7 and 8)

Parameter	Value	Distribution	Units	Justification
Ammoniacal Nitrogen as N	188.5 224.1 366.2	Triangular	mg/l	Minimum, mean and maximum concentrations for blended leachate.
Chloride	970.0 3,745 7,747	Triangular	mg/l	
Benzene ¹	0.01785	Constant	mg/l	
Phenol	0.216 0.220 0.227	Triangular	mg/l	
Naphthalene	0.00031 0.00147 0.00380	Triangular	mg/l	
Nickel	0.0583 0.0882 0.1367	Triangular	mg/l	
Arsenic	0.0589 0.0666 0.0729	Triangular	mg/l	

¹ Benzene has only been detected in leachate from the four example landfill sites accepting putrescible wastes (i.e. equivalent to wastes planned for Cell 6). Therefore, for the purposes of deriving a suitable source concentration for the remaining cells the laboratory limit of detection has been used to represent a constant source value.

Table 4.4 Source concentrations (Cell 6)

Parameter	Value	Distribution	Units	Justification
Ammoniacal Nitrogen as N	1,460	Constant	mg/l	Mean leachate concentrations from four representative landfills accepting putrescible wastes (Municipal Solid Waste landfills) as defined in the Leachate Management and Design Plan (SLR, 2019c).
Chloride	1,793	Constant	mg/l	
Benzene	0.0034	Constant	mg/l	
Phenol	0.19	Constant	mg/l	
Naphthalene	0.0024	Constant	mg/l	
Nickel	0.148	Constant	mg/l	
Arsenic	0.18	Constant	mg/l	

Table 4.5 Cap engineering parameters (all lifecycle phases)

Parameter	Value	Distribution	Units	Justification
Slope	0.18	Constant	-	Estimated from site drawings

Parameter	Value	Distribution	Units	Justification
Thickness of drainage layer above LDPE membrane	1	Constant	m	Assumed
Hydraulic conductivity of drainage layer	1×10^{-5}	Constant	m/s	Estimate
Thickness of regulation layer	1	Constant	m	SLR (2019b)
Hydraulic conductivity of regulation layer	1×10^{-9}	Uniform	m/s	SLR (2019b)

Table 4.6 Basal and side slope engineering parameters (all lifecycle phases)

Parameter	Value	Distribution	Units	Justification
Thickness of engineered geological barrier	0.5	Constant	m	SLR (2019b)
Hydraulic conductivity of engineered geological barrier	1×10^{-10} - 1×10^{-9}	Uniform	m/s	Range based on 5×10^{-10} m/s from SLR (2019b)
Thickness of GCL	0.0075	Constant	m	Typical value for a GCL
Hydraulic conductivity of GCL	1×10^{-11}	Constant	m/s	Typical value for a GCL
Effective porosity	0.01 0.05	Uniform	-	Estimate
Bulk dry density	1800	Constant	kg/m ³	Estimate
f_{oc}	0.003	Constant	-	Estimate

Table 4.7 Defect distribution parameters for the geomembrane in the engineered cap, side slope and basal liners (Phase 1: Post closure with aftercare phase)

Parameter	Value	Distribution	Units	Justification
No. pin holes	0 2.5×10^{-3}	/ m ²	Uniform	LandSim 2.5 defaults (Golders, 2004)
Area of pin holes	1.0×10^{-7} 5.3×10^{-6}	m ²	Uniform	LandSim 2.5 defaults (Golders, 2004)
No. holes	0 5.0×10^{-4}	/ m ²	Uniform	LandSim 2.5 defaults (Golders, 2004)
Area of holes	5.0×10^{-6} 1.0×10^{-4}	m ²	Uniform	Environment Agency (2004) Section 9.4

Parameter	Value	Distribution	Units	Justification
No. tears	0 1.0×10^{-5} 2.0×10^{-4}	/ m ²	Triangular	LandSim 2.5 defaults (Golders, 2004)
Length of tears	0.1 10	m	Uniform	Environment Agency (2004) Section 9.4
Width of tears	0.001	m	Constant	Environment Agency (2004) Section 9.4

Table 4.8 Defect distribution parameters for the geomembrane in the engineered cap (Phase 2: Site-completion phase)

Parameter	Value	Distribution	Units	Justification
No. pin holes	2.5×10^{-3}	/m ²	Constant	Maximum of LandSim 2.5 default distribution (Golders, 2004).
Area of pin holes	5.3×10^{-6}	m ²	Constant	Maximum of LandSim 2.5 default distribution (Golders, 2004).
No. holes	5.0×10^{-4}	/m ²	Constant	Maximum of LandSim 2.5 default distribution (Golders, 2004).
Area of holes	1×10^{-4}	m ²	Constant	Maximum of LandSim 2.5 default distribution (Golders, 2004).
No. tears	2×10^{-4}	/m ²	Constant	Maximum of LandSim 2.5 default distribution (Golders, 2004).
Length of tears	10	m	Constant	Maximum of distribution from Environment Agency (2004) Section 9.4
Width of tears	0.001	m	Constant	Environment Agency (2004) Section 9.4

Table 4.9 Defect distribution parameters for the geomembrane in the engineered side slope and basal liners (Phase 2: Site completion phase)

Parameter	Value	Distribution	Units	Justification
No. pin holes	2.5×10^{-3}	/ m ²	Constant	Maximum of LandSim 2.5 default distribution (Golders, 2004).
Area of pin holes	5.3×10^{-6}	m ²	Constant	Maximum of LandSim 2.5 default distribution (Golders, 2004).
No. holes	5.0×10^{-4}	/ m ²	Constant	Maximum of LandSim 2.5 default distribution (Golders, 2004).
Area of holes	1×10^{-4}	m ²	Constant	Maximum of LandSim 2.5 default distribution (Golders, 2004).
No. tears	1.5×10^{-3}	/ m ²	Constant	Estimate based on the distribution in Table 9.3 of Environment Agency (2004) Section 9.4
Length of tears	10	m	Constant	Maximum of distribution from Environment Agency (2004) Section 9.4
Width of tears	0.001	m	Constant	Environment Agency (2004) Section 9.4

Table 4.10 Properties for basal backfill

Parameter	Value	Distribution	Units	Justification
Thickness of basal backfill	8	Constant	m	Average between 5 m and 11 m (SLR, 2019b)
Hydraulic conductivity of basal backfill	5.0×10^{-8} 1.0×10^{-7} 5.0×10^{-7}	Triangular	m/s	Estimate for placed reworked clay
Effective porosity	0.01 0.05	Uniform	-	Estimate
Bulk dry density	1,800	Constant	kg/m ³	Estimate
f _{oc}	0.003	Constant	-	Estimate

4.6.2 Hydrology

Table 4.11 Hydrology parameters

Parameter	Value	Distribution	Units	Justification
Effective annual rainfall for bare soil	262	mm/a	Constant	SLR (2019a)
Run-off	0	-	Constant	Conservative estimate

4.6.3 Hydrogeology

Table 4.12 Properties for Carboniferous strata

Parameter	Value	Distribution	Units	Justification
Hydraulic conductivity	5.8×10^{-6} 3.5×10^{-5}	Uniform	m/s	TerraConsult (2015)
Hydraulic gradient	0.02	Constant	-	Based on observed gradients between monitoring wells (SLR, 2019a)
Effective porosity	0.05 0.1	Uniform	-	Estimate
Effective porosity of unsaturated zone	0.01	Constant	-	Estimate
Bulk dry density	2,000	Constant	kg/m ³	Estimate
f_{oc}	0.0005 0.001	Uniform	-	Estimate for sandstones/mudstones

4.6.4 Contaminants

Table 4.13 Partition coefficients parameters

Parameter	Value	Distribution	Units	Justification
Ammoniacal Nitrogen as N: K_d	0.5 - 2	Uniform	L/kg	LandSim 2.5 default
Chloride	Not retarded	-	-	-
Benzene: K_{oc}	62	Constant	L/kg	USEPA (1999)
Phenol: K_{oc}	22	Constant	L/kg	USEPA (1999) (as pH=7)
Naphthalene: K_{oc}	1,190	Constant	L/kg	USEPA (1999)
Nickel: K_d	20 800	Uniform	L/kg	LandSim 2.5 default

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Report Status: Final

Parameter	Value	Distribution	Units	Justification
Arsenic: K_d	25 250	Uniform	L/kg	LandSim 2.5 default

Table 4.14 Half-life parameters

Parameter		Value	Distribution	Units	Justification
Ammoniacal Nitrogen as N	Carboniferous strata	3,650	Constant	Days	Environment Agency (2003a)
	Liner and backfill	No decay in anaerobic conditions	-	-	
Benzene		720	Constant	Days	Anaerobic half-life from Howard et al. (1991)
Phenol		28	Constant	Days	Anaerobic half-life from Howard et al. (1991)
Naphthalene		258	Constant	Days	Anaerobic half-life from Howard et al. (1991)

Table 4.15 Diffusion coefficients

Parameter	Value	Distribution	Units	Justification
Ammoniacal Nitrogen as N	1×10^{-9}	Constant	m^2/s	Assumed
Chloride	1×10^{-9}	Constant	m^2/s	
Benzene	1×10^{-9}	Constant	m^2/s	
Phenol	1×10^{-9}	Constant	m^2/s	
Naphthalene	1×10^{-9}	Constant	m^2/s	
Nickel	1×10^{-9}	Constant	m^2/s	
Arsenic	1×10^{-9}	Constant	m^2/s	

4.6.5 Pathways

Table 4.16 Basal pathway through Carboniferous Strata

Parameter	Value	Distribution	Units	Justification
Travel distance to Site boundary from centre of the landfill	240	Constant	m	Distance from centre of landfill to edge of Site measured from Drawing ESID1
Travel distance to Alltami Brook from centre of the landfill	500	Constant	m	Distance from centre of landfill to nearest point of the Brook measured from Drawing ESID1
Dispersivity	1/10 th aquifer travel path	Constant	-	Assumed
Mixing depth	1/10 th aquifer travel path	Constant	-	Assumed
Mixing width	400	Constant	m	Width of landfill perpendicular to groundwater flow

4.6.6 Receptors

Table 4.17 Environmental assessment limits (EAL)

Parameter	Value	Distribution	Units	Justification
Ammoniacal Nitrogen as N	0.39	Constant	mg/l	UK DWS (2000)
Chloride	250	Constant	mg/l	UK DWS (2000)
Benzene	0.001	Constant	mg/l	MRV (same as UK DWS (2016))
Phenol	0.0005	Constant	mg/l	UK DWS (1989)
Naphthalene	0.002	Constant	mg/l	Annual Average EQS (2019)
Nickel	0.02	Constant	mg/l	UK DWS (2016)
Arsenic	0.01	Constant	mg/l	No MRV defined; adopt UK DWS (2016)

4.6.7 Sensitivity analysis

Seven aspects of the conceptual site model and risk assessment model parameterisation have been explored during the sensitivity analysis. The parameters, the original and altered values

and a description of the effect on the relevant aspect of the conceptual model are presented in Table 4.18.

Table 4.18 Parameters for sensitivity analysis

Run	Parameter altered	Unit	Description	Base case	Sensitivity
1	f_{oc} of basal and side slope liner and backfill	-	Organic contaminants will have reduced retardation giving faster travel times and less opportunity to decay	0.003	0.001
2a	Hydraulic conductivity of Carboniferous strata	m/s	Higher: more dilution, shorter travel times	2.04×10^{-5} *[5.8×10^{-6} 3.5×10^{-5}]	1.0×10^{-4}
2b			Lower: less dilution, longer travel times		1.0×10^{-6}
3	Thickness of unsaturated zone in Carboniferous strata	m	Reducing thickness of the unsaturated zone will impact concentrations of the hazardous substances (arsenic and benzene) on the pathway through the side slope liner	1	0.5
4a	Effective porosity of the Carboniferous strata	-	Increasing the porosity will decrease the velocity increasing the travel time	0.075 *[0.05 0.1]	0.01
4b			Decreasing the porosity will increase the velocity decreasing the travel time		0.2
5	Design of basal liner	-	Removing the GCL to reduce the effectiveness of the basal liner	GCL included	GCL excluded
6	Hydraulic conductivity of regulation layer	m/s	An increase of infiltration through the cap and an increase in leachate within the landfill	1×10^{-9}	1×10^{-8}
7	Travel distance through the Basal Backfill	m	Reducing the travel distance through the basal backfill decreasing the travel time	8	1

*Range adopted in base case probabilistic model.

4.7 Emissions to groundwater

4.7.1 Base case

The results of the base case model are presented in Table 4.19 to Table 4.21. The peak deterministic, 50th percentile and 95th percentile concentrations are presented for the base case models. As the probabilistic distributions are skewed for some of the model parameters, the deterministic results can be quite different to the 50th percentile results. This occurs

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Report Status: Final

because the deterministic concentrations are based on the most-likely value of a probabilistic distribution whilst the 50th percentile concentrations will derive from the median and these values can be quite different for skewed distributions.

Table 4.19 presents the results for the two hazardous substances (arsenic and benzene) that were included in the model. For the purposes of the assessment, the receptor used in relation to hazardous substances (i.e., the hazardous substance compliance point) is assumed to be at the water table immediately beneath / at the edge of the landfill. Predicted peak hazardous substance concentrations are presented for both Cell 6 separately and the entire Site (including Cell 6) due to the different source concentrations that were adopted within the model.

The model results show that in the long term (i.e. over 5,000 years) even for results at the 95th percentile level no concentrations are predicted to exceed the adopted EALs for benzene or arsenic. Results are presented for both pathways via of the basal liner and the side slope liner; the differences in concentrations are due to the differences in travel distance to the water table.

Table 4.20 and Table 4.21 present the results for the non-hazardous pollutants (ammoniacal nitrogen, chloride, phenol, naphthalene and nickel) that were included in the model. For the purposes of the assessment, the receptors used in relation to non-hazardous pollutants (i.e., the non-hazardous pollutants compliance points) are assumed to be the edge of the Site (see Table 4.20) and the groundwater immediately prior to discharge into Alltami Brook (Table 4.21).

For concentrations at the Site boundary receptor (Table 4.20), the 95th percentile concentration of ammoniacal nitrogen is the only exceedance where the simulated concentration of 0.55 mg/l at 1,600 years exceeds the EAL of 0.39 mg/l by less than 50%. This time slice corresponds to conditions during Phase 3 of the landfill lifecycle phases (Table 4.2), where the basal and cap geomembrane are no longer effective. It should be noted that the model does not consider decay of the contaminants within the waste and, in reality, source concentrations of ammoniacal nitrogen will have undergone significant degradation by Phase 3 of the landfill lifecycle. It is noted that the 50th percentile concentration of ammoniacal nitrogen peaks at 0.12 mg/l.

For groundwater concentrations adjacent to Alltami Brook (Table 4.21), the model results show that in the long term (i.e. over 5,000 years) even for results at the 95th percentile level no peak concentrations are predicted to exceed the adopted EALs for these substances. The modelled concentrations at Alltami Brook (Table 4.21) are naturally lower than the concentrations at the Site boundary (Table 4.20) due to the longer travel times and increased dilution; the concentrations of contaminants that decay decrease by a greater factor (compared to those with no assigned half-life) since the longer travel times provide more opportunity for decay.

Table 4.19 Base case results (peak concentrations) for hazardous substances

	Site (including Cell 6)				Cell 6			
	Basal		Side slope		Basal		Side slope	
	Benzene	Arsenic	Benzene	Arsenic	Benzene	Arsenic	Benzene	Arsenic
Deterministic results	2.66x10 ⁻⁷ mg/l @ 1600 years	1.05x10 ⁻¹² mg/l @ 5,000 years	1.46x10 ⁻⁴ mg/l @ 1600 years	1.90x10 ⁻⁶ mg/l @ 5,000 years	7.04x10 ⁻⁸ mg/l @ 1600 years	2.78x10 ⁻¹² mg/l @ 5,000 years	3.92x10 ⁻⁵ mg/l @ 1600 years	5.07x10 ⁻⁶ mg/l @ 5,000 years
50th percentile	3.99x10 ⁻⁶ mg/l @ 100 years	2.02x10 ⁻⁶ mg/l @ 5,000 years	4.46x10 ⁻⁵ mg/l @ 1600 years	3.61x10 ⁻⁴ mg/l @ 5,000 years	7.75x10 ⁻⁷ mg/l @ 100 years	6.77x10 ⁻⁶ mg/l @ 5,000 years	1.83x10 ⁻⁵ mg/l @ 1600 years	0.0011 mg/l @ 5,000 years
95th percentile	6.44x10 ⁻⁵ mg/l @ 100 years	0.0016 mg/l @ 5,000 years	6.55x10 ⁻⁵ mg/l @ 100 years	0.0025 mg/l @ 5,000 years	1.25x10 ⁻⁵ mg/l @ 100 years	0.0053 mg/l @ 5,000 years	1.03x10 ⁻⁴ mg/l @ 1600 years	0.0079 mg/l @ 5,000 years
EAL	0.001 mg/l	0.01 mg/l	0.001 mg/l	0.01 mg/l	0.001 mg/l	0.01 mg/l	0.001 mg/l	0.01 mg/l

Table 4.20 Base case results (peak concentrations) for non-hazardous pollutants at the Site boundary

	Ammoniacal Nitrogen	Chloride	Benzene	Phenol	Naphthalene	Nickel	Arsenic
Deterministic results	0.21 mg/l @ 1600 years	20 mg/l @ 1600 years	1.09x10 ⁻⁷ mg/l @ 1600 years	1.05x10 ⁻⁷ mg/l @ 1600 years	No breakthrough	No breakthrough	1.20x10 ⁻¹⁴ mg/l @ 5000 years
50th percentile	0.12 mg/l @ 1600 years	27 mg/l @ 100 years	2.40x10 ⁻⁷ mg/l @ 1600 years	9.66x10 ⁻⁸ mg/l @ 100 years	No breakthrough	No breakthrough	3.63x10 ⁻⁹ mg/l @ 5000 years
95th percentile	0.55 mg/l @ 1600 years	94 mg/l @ 100 years	1.72x10 ⁻⁶ mg/l @ 1600 years	1.52x10 ⁻⁶ mg/l @ 100 years	1.55x10 ⁻²⁰ mg/l @ 1600 years	2.55x10 ⁻⁷ mg/l @ 5000 years	4.63x10 ⁻⁵ mg/l @ 5000 years
EAL	0.39 mg/l	250 mg/l	0.001 mg/l	0.0005 mg/l	0.002 mg/l	0.02 mg/l	0.01 mg/l

Note: Results for benzene and arsenic (i.e. hazardous substances) shown in grey and are included for completeness only. Concentrations that exceed the EAL are highlighted in bold.

Table 4.21 Base case results (peak concentrations) for non-hazardous pollutants at Alltami Brook

	Ammoniacal Nitrogen	Chloride	Benzene	Phenol	Naphthalene	Nickel	Arsenic
Deterministic results	0.013 mg/l @ 1600 years	10 mg/l @ 1600 years	2.16x10 ⁻⁸ mg/l @ 1600 years	1.70x10 ⁻¹⁰ mg/l @ 1600 years	No breakthrough	No breakthrough	4.39x10 ⁻¹⁹ mg/l @ 5000 years
50th percentile	0.0087 mg/l @ 1600 years	13 mg/l @ 100 years	4.25x10 ⁻⁸ mg/l @ 1600 years	1.38x10 ⁻¹⁰ mg/l @ 100 years	No breakthrough	No breakthrough	6.99x10 ⁻¹³ mg/l @ 5000 years
95th percentile	0.084 mg/l @ 1600 years	46 mg/l @ 100 years	3.48x10 ⁻⁷ mg/l @ 1600 years	1.10x10 ⁻⁸ mg/l @ 100 years	No breakthrough	1.49x10 ⁻⁹ mg/l @ 5000 years	8.31x10 ⁻⁶ mg/l @ 5000 years

Report Reference: 66388R1

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	Ammoniacal Nitrogen	Chloride	Benzene	Phenol	Naphthalene	Nickel	Arsenic
EAL	0.39 mg/l	250 mg/l	0.001 mg/l	0.0005 mg/l	0.002 mg/l	0.02 mg/l	0.01 mg/l

Note: Results for benzene and arsenic (i.e. hazardous substances) shown in grey and are included for completeness only.

4.7.2 Sensitivity analysis

Based on the results of the base case model selected aspects of the conceptual site model, and the associated input parameters, have been modified and the model has been re-run to explore the effects of parameter uncertainty.

Seven aspects of the model were altered giving a total of nine sensitivity analysis model runs, which are summarised and discussed in Table 4.22. The predicted concentrations from the sensitivity runs are compared to the results from the base case model in in Table 4.23 to Table 4.25. In summary, the results of the sensitivity analysis show some relatively modest changes to the predicted concentrations at the identified receptors. However, with two modest exceptions concentrations remain below their respective EALs. The exceptions relate to chloride at the Site boundary under Run SA2b (300 mg/l at 1,600 years compared to the EAL of 250 mg/l); and arsenic (for Cell 6 only) under Run SA7 (0.011 mg/l at 6,000 years compared to the EAL of 0.01 mg/l).

Table 4.22 Summary of sensitivity analysis results

Run	Parameter altered	Description	Summary of results
SA1	f_{oc} of basal and side slope liner and backfill	Organic contaminants will have reduced retardation giving faster travel times and less opportunity to decay	No change for inorganic contaminants. Benzene is influenced the most as it is the only organic contaminant that is retarded and decays in the liner and backfill pathway segments, so the reduced travel time leads to less decay and slightly increased concentrations at the compliance point. The influence on phenol is less significant as it does not decay in these segments and is not heavily retarded.
SA2a	Hydraulic conductivity of Carboniferous strata	Higher: more dilution, shorter travel times	Dilution is the key process for chloride so a higher hydraulic conductivity within the Coal Measures increases the amount of dilution and reduces the predicted concentrations (and vice versa). Chloride is predicted to exceed the EAL by 20% at the Site Boundary receptor for Run 2b; no exceedance is however predicted at Alltami Brook.
SA2b		Lower: less dilution, longer travel times	Decay processes dominate the fate and transport of ammoniacal nitrogen and phenol, hence their predicted concentrations increase with the increase in higher hydraulic conductivity as the associated decrease in travel time reduces the mass lost due to degradation. Conversely, predicted concentrations decrease as with a lower hydraulic conductivity as velocity decreases (which allows more time for degradation).

Run	Parameter altered	Description	Summary of results
SA3	Thickness of unsaturated zone in Carboniferous strata	Reducing thickness of the unsaturated zone will impact concentrations of the hazardous substances (arsenic and benzene) on the pathway through the side slope liner	Reducing the thickness of the unsaturated zone in the Carboniferous strata only impacts those pathways through the side slope liner. Concentrations at the hazardous substance receptors are influenced the most as the transport processes through the saturated Carboniferous strata dominates for the non-hazardous pollutants. However, concentrations of all model substances remain below their respective EALs.
SA4a	Effective porosity of the Carboniferous strata	Decreasing the porosity will increase the velocity decreasing the travel time	Concentrations of the two hazardous substances at the water table immediately beneath / at the edge of the landfill are not influenced by this change as this linkage does not consider contaminant transport onwards through the Carboniferous strata.
SA4b		Increasing the porosity will decrease the velocity increasing the travel time	Decreasing the effective porosity of the Carboniferous strata increases the velocity and so gives less opportunity (i.e. time) for decay, so concentrations increase for those substances that degrade (i.e. ammoniacal nitrogen and phenol). Conversely, decreases in concentrations are observed when the porosity is increased as this causes a reduction in velocity which allows more time for decay.
SA5	Design of basal liner	Removing the GCL to reduce the effectiveness of the basal liner	Removing the GCL from the engineered basal and side liner systems gives a slight increase in the effective permeability of the system. However, this has a negligible influence on the predicted contaminant concentrations.
SA6	Hydraulic conductivity of regulation layer	An increase of infiltration through the cap and an increase in leachate within the landfill	Increasing the hydraulic conductivity of the regulation layer within the engineered cap increases the amount of infiltration that occurs through the cap, which in turn increases the leachate head, the flux from the landfill and ultimately the velocity through the basal and sidewall liner systems. This has the effect of increasing predicted concentrations and reducing the breakthrough timescales.
SA7	Travel distance through the basal backfill	Decreasing the travel distance through the basal backfill	Decreasing the travel distance to 1 m and using a velocity calculated from the flux from the landfill does not have a significant impact of the concentrations at the non-hazardous receptors as transport along these pathways are dominated by the liner behaviour and the Coal Measures pathway. The hazardous substance concentrations for the basal pathway increase, with arsenic marginally exceeding the EAL of 0.01 mg/l at 5,000 years.

Table 4.23 Sensitivity analysis results (peak concentrations) for hazardous substances

	All Site (including Cell 6)				Cell 6			
	Basal		Side slope		Basal		Side slope	
	Benzene	Arsenic	Benzene	Arsenic	Benzene	Arsenic	Benzene	Arsenic
Base case	2.66x10 ⁻⁷ mg/l @ 1600 years	1.05x10 ⁻¹² mg/l @ 5000 years	1.46x10 ⁻⁴ mg/l @ 1600 years	1.90x10 ⁻⁶ mg/l @ 5000 years	7.04x10 ⁻⁸ mg/l @ 1600 years	2.78x10 ⁻¹² mg/l @ 5000 years	3.92x10 ⁻⁵ mg/l @ 1600 years	5.07x10 ⁻⁶ mg/l @ 5000 years
SA1	2.73x10 ⁻⁵ mg/l @ 1600 years	1.05x10 ⁻¹² mg/l @ 5000 years	4.07x10 ⁻⁴ mg/l @ 1600 years	1.90x10 ⁻⁶ mg/l @ 5000 years	7.31x10 ⁻⁶ mg/l @ 1600 years	2.78x10 ⁻¹² mg/l @ 5000 years	1.10x10 ⁻⁴ mg/l @ 1600 years	5.07x10 ⁻⁶ mg/l @ 5000 years
SA2a	2.66x10 ⁻⁷ mg/l @ 1600 years	1.05x10 ⁻¹² mg/l @ 5000 years	1.46x10 ⁻⁴ mg/l @ 1600 years	1.90x10 ⁻⁶ mg/l @ 5000 years	7.04x10 ⁻⁸ mg/l @ 1600 years	2.78x10 ⁻¹² mg/l @ 5000 years	3.92x10 ⁻⁵ mg/l @ 1600 years	5.07x10 ⁻⁶ mg/l @ 5000 years
SA2b	2.66x10 ⁻⁷ mg/l @ 1600 years	1.05x10 ⁻¹² mg/l @ 5000 years	1.46x10 ⁻⁴ mg/l @ 1600 years	1.90x10 ⁻⁶ mg/l @ 5000 years	7.04x10 ⁻⁸ mg/l @ 1600 years	2.78x10 ⁻¹² mg/l @ 5000 years	3.92x10 ⁻⁵ mg/l @ 1600 years	5.07x10 ⁻⁶ mg/l @ 5000 years
SA3	2.66x10 ⁻⁷ mg/l @ 1600 years	1.05x10 ⁻¹² mg/l @ 5000 years	2.46x10 ⁻⁴ mg/l @ 1600 years	1.92x10 ⁻⁴ mg/l @ 5000 years	7.04x10 ⁻⁸ mg/l @ 1600 years	2.78x10 ⁻¹² mg/l @ 5000 years	6.62x10 ⁻⁵ mg/l @ 1600 years	5.52x10 ⁻⁴ mg/l @ 5000 years
SA4a	2.66x10 ⁻⁷ mg/l @ 1600 years	1.05x10 ⁻¹² mg/l @ 5000 years	1.46x10 ⁻⁴ mg/l @ 1600 years	1.90x10 ⁻⁶ mg/l @ 5000 years	7.04x10 ⁻⁸ mg/l @ 1600 years	2.78x10 ⁻¹² mg/l @ 5000 years	3.92x10 ⁻⁵ mg/l @ 1600 years	5.07x10 ⁻⁶ mg/l @ 5000 years
SA4b	2.66x10 ⁻⁷ mg/l @ 1600 years	1.05x10 ⁻¹² mg/l @ 5000 years	1.46x10 ⁻⁴ mg/l @ 1600 years	1.90x10 ⁻⁶ mg/l @ 5000 years	7.04x10 ⁻⁸ mg/l @ 1600 years	2.78x10 ⁻¹² mg/l @ 5000 years	3.92x10 ⁻⁵ mg/l @ 1600 years	5.07x10 ⁻⁶ mg/l @ 5000 years
SA5	2.60x10 ⁻⁷ mg/l @ 1600 years	9.74x10 ⁻¹³ mg/l @ 5000 years	4.51x10 ⁻⁴ mg/l @ 1600 years	3.27x10 ⁻⁴ mg/l @ 5000 years	6.88x10 ⁻⁸ mg/l @ 1600 years	2.57x10 ⁻¹² mg/l @ 5000 years	1.22x10 ⁻⁴ mg/l @ 1600 years	9.88x10 ⁻⁴ mg/l @ 5000 years
SA6	7.18x10 ⁻⁷ mg/l @ 100 years	1.54x10 ⁻¹⁰ mg/l @ 5000 years	2.77x10 ⁻⁴ mg/l @ 100 years	0.0017 mg/l @ 4000 years	1.41x10 ⁻⁷ mg/l @ 100 years	2.80x10 ⁻⁹ mg/l @ 5000 years	5.46x10 ⁻⁵ mg/l @ 100 years	0.0052 mg/l @ 4000 years
SA7	4.14x10 ⁻⁴ mg/l @ 1600 years	0.0036 mg/l @ 5000 years	1.46x10 ⁻⁴ mg/l @ 1600 years	1.90x10 ⁻⁶ mg/l @ 5000 years	1.11x10 ⁻⁴ mg/l @ 1600 years	0.011 mg/l @ 5000 years	3.92x10 ⁻⁵ mg/l @ 1600 years	5.07x10 ⁻⁶ mg/l @ 5000 years
EAL	0.001 mg/l	0.01 mg/l	0.001 mg/l	0.01 mg/l	0.001 mg/l	0.01 mg/l	0.001 mg/l	0.01 mg/l

Note: Results for aspects of the conceptual model which were not affected by the changes are shown in grey and are included for completeness only. Concentrations that exceed the EAL are highlighted in bold.

Table 4.24 Sensitivity analysis results (peak concentrations) for non-hazardous pollutants at the Site boundary

	Ammoniacal Nitrogen	Chloride	Benzene	Phenol	Naphthalene	Nickel	Arsenic
Base case	0.21 mg/l @ 1600 years	20 mg/l @ 1600 years	1.09x10 ⁻⁷ mg/l @ 1600 years	1.05x10 ⁻⁷ mg/l @ 1600 years	No breakthrough	No breakthrough	1.20x10 ⁻¹⁴ mg/l @ 5000 years
SA1	0.21 mg/l @ 1600 years	20 mg/l @ 1600 years	6.36x10 ⁻⁷ mg/l @ 1600 years	9.74x10 ⁻⁸ mg/l @ 1600 years	No breakthrough	No breakthrough	1.20x10 ⁻¹⁴ mg/l @ 5000 years
SA2a	0.32 mg/l @ 1600 years	4.2 mg/l @ 1600 years	4.94x10 ⁻⁸ mg/l @ 1600 years	1.47x10 ⁻⁵ mg/l @ 1600 years	No breakthrough	No breakthrough	2.51x10 ⁻¹¹ mg/l @ 5000 years

Report Reference: 66388R1

Report Status: Final

	Ammoniacal Nitrogen	Chloride	Benzene	Phenol	Naphthalene	Nickel	Arsenic
SA2b	1.53x10 ⁻⁸ mg/l @ 1800 years	300 mg/l @ 1600 years	8.38x10 ⁻¹¹ mg/l @ 1600 years	No breakthrough	No breakthrough	No breakthrough	No breakthrough
SA3	0.21 mg/l @ 1600 years	20 mg/l @ 1600 years	1.82x10 ⁻⁷ mg/l @ 1600 years	1.05x10 ⁻⁷ mg/l @ 1600 years	No breakthrough	No breakthrough	1.68x10 ⁻¹¹ mg/l @ 5000 years
SA4a	0.23 mg/l @ 1600 years	20 mg/l @ 1600 years	1.57x10 ⁻⁷ mg/l @ 1600 years	9.61x10 ⁻⁶ mg/l @ 1600 years	No breakthrough	No breakthrough	1.21x10 ⁻¹⁴ mg/l @ 5000 years
SA4b	0.19 mg/l @ 1600 years	21 mg/l @ 1600 years	5.78x10 ⁻⁸ mg/l @ 1600 years	2.49x10 ⁻¹⁰ mg/l @ 1600 years	No breakthrough	No breakthrough	1.20x10 ⁻¹⁴ mg/l @ 5000 years
SA5	0.21 mg/l @ 1600 years	20 mg/l @ 1600 years	5.45x10 ⁻⁷ mg/l @ 1600 years	1.01x10 ⁻⁷ mg/l @ 1600 years	No breakthrough	No breakthrough	6.25x10 ⁻¹¹ mg/l @ 5000 years
SA6	0.098 mg/l @ 600 years	59 mg/l @ 100 years	3.39x10 ⁻⁷ mg/l @ 100 years	2.44x10 ⁻⁷ mg/l @ 100 years	No breakthrough	4.30x10 ⁻¹⁸ mg/l @ 5000 years	1.54x10 ⁻⁶ mg/l @ 5000 years
SA7	0.13 mg/l @ 1600 years	20 mg/l @ 1600 years	5.25x10 ⁻⁶ mg/l @ 1600 years	9.27x10 ⁻⁸ mg/l @ 1600 years	No breakthrough	3.81x10 ⁻¹⁸ mg/l @ 5000 years	4.64x10 ⁻⁷ mg/l @ 5000 years
EAL	0.39 mg/l	250 mg/l	0.001 mg/l	0.0005 mg/l	0.002 mg/l	0.02 mg/l	0.01 mg/l

Note: Results for benzene and arsenic (i.e. hazardous substances) shown in grey and are included for completeness only. Concentrations that exceed the EAL are highlighted in bold.

Table 4.25 Sensitivity analysis results (peak concentrations) for non-hazardous pollutants at Alltami Brook

	Ammoniacal Nitrogen	Chloride	Benzene	Phenol	Naphthalene	Nickel	Arsenic
Base case	0.013 mg/l @ 1600 years	10 mg/l @ 1600 years	2.16E-8 mg/l @ 1600 years	1.70E-10 mg/l @ 1600 years	No breakthrough	No breakthrough	4.39E-19 mg/l @ 5000 years
SA1	0.013 mg/l @ 1600 years	10 mg/l @ 1600 years	1.25x10 ⁻⁷ mg/l @ 1600 years	1.57x10 ⁻¹⁰ mg/l @ 1600 years	No breakthrough	No breakthrough	4.39x10 ⁻¹⁹ mg/l @ 5000 years
SA2a	0.085 mg/l @ 1600 years	2.0 mg/l @ 1600 years	1.90x10 ⁻⁸ mg/l @ 1600 years	7.61x10 ⁻⁷ mg/l @ 1600 years	No breakthrough	No breakthrough	5.99x10 ⁻¹³ mg/l @ 5000 years
SA2b	1.03x10 ⁻¹³ mg/l @ 1900 years	210 mg/l @ 1600 years	9.19x10 ⁻¹⁴ mg/l @ 1600 years	No breakthrough	No breakthrough	No breakthrough	No breakthrough
SA3	0.013 mg/l @ 1600 years	10 mg/l @ 1600 years	3.59x10 ⁻⁸ mg/l @ 1600 years	1.70x10 ⁻¹⁰ mg/l @ 1600 years	No breakthrough	No breakthrough	2.48x10 ⁻¹⁵ mg/l @ 5000 years
SA4a	0.014 mg/l @ 1600 years	9.8 mg/l @ 1600 years	4.18x10 ⁻⁸ mg/l @ 1600 years	1.58x10 ⁻⁷ mg/l @ 1600 years	No breakthrough	No breakthrough	4.42x10 ⁻¹⁹ mg/l @ 5000 years
SA4b	0.011 mg/l @ 1600 years	10 mg/l @ 1600 years	7.03x10 ⁻⁹ mg/l @ 1600 years	2.25x10 ⁻¹⁴ mg/l @ 1600 years	No breakthrough	No breakthrough	4.35x10 ⁻¹⁹ mg/l @ 5000 years

	Ammoniacal Nitrogen	Chloride	Benzene	Phenol	Naphthalene	Nickel	Arsenic
SA5	0.013 mg/l @ 1600 years	10.0 mg/l @ 1600 years	1.08x10 ⁻⁷ mg/l @ 1600 years	1.64x10 ⁻¹⁰ mg/l @ 1600 years	No breakthrough	No breakthrough	7.49x10 ⁻¹⁵ mg/l @ 5000 years
SA6	0.0062 mg/l @ 600 years	29 mg/l @ 100 years	6.58x10 ⁻⁸ mg/l @ 100 years	3.89x10 ⁻¹⁰ mg/l @ 100 years	No breakthrough	No breakthrough	2.24x10 ⁻⁹ mg/l @ 5000 years
SA7	0.0092 mg/l @ 1600 years	9.8 mg/l @ 1600 years	1.04x10 ⁻⁶ mg/l @ 1600 years	1.49x10 ⁻¹⁰ mg/l @ 1600 years	No breakthrough	No breakthrough	2.61x10 ⁻¹⁰ mg/l @ 5000 years
EAL	0.39 mg/l	250 mg/l	0.001 mg/l	0.0005 mg/l	0.002 mg/l	0.02 mg/l	0.01 mg/l

Note: Results for benzene and arsenic (i.e. hazardous substances) shown in grey and are included for completeness only.

4.7.3 Summary

The results of the base case model and sensitivity analysis suggest that the presence of hazardous substances and non-hazardous pollutants within leachate generated from the waste materials deposited within the landfill are unlikely to cause a discernible impact on local groundwater or surface waters.

5 REQUISITE SURVEILLANCE

5.1 Leachate monitoring

In accordance with Environment Agency guidance (2003b), leachate monitoring will be undertaken at three locations within each cell. The two dedicated monitoring points will be positioned within each cell so that they are remote from the leachate pumping and monitoring points. Indicative locations of the leachate monitoring points are presented in Drawing ESID9.

5.1.1 Leachate levels

Leachate levels will be monitored according to the schedule proposed in Table 5.1.

Table 5.1 Proposed leachate level monitoring schedule

Cell	Monitoring points	Parameter	Frequency
1	LMP01 LMP01.1 LMP01.2	Depth to leachate (m bGL) Depth to base (m bGL)	Monthly
2	LMP02 LMP02.1 LMP02.2	Leachate depth above liner top (m) Leachate level (m AOD)	
3	LMP03 LMP03.1 LMP03.2		
4	LMP04 LMP04.1 LMP04.2		
5	LMP05 LMP05.1 LMP05.2		
6	LMP06 LMP06.1 LMP06.2		
7	LMP07 LMP07.1 LMP07.2		
8	LMP08 LMP08.1 LMP08.2		

5.1.2 Leachate quality

Leachate quality will be monitored according to the schedule proposed in Table 5.2.

Table 5.2 Proposed leachate quality monitoring schedule

Cell	Monitoring points	Parameter	Frequency
1	LMP01	Extracted leachate volume (m ³)	Monthly
2	LMP02		
3	LMP03		
4	LMP04		
5	LMP05	pH, electrical conductivity, temperature, ammoniacal nitrogen, chloride, COD, BOD, sodium, potassium, calcium, magnesium, sulphate, iron, manganese, cadmium, chromium, copper, arsenic, lead, nickel and zinc.	Quarterly (during operational phase); annually thereafter
6	LMP06		
7	LMP07	Hazardous substances	Annually (during operational phase); every four years thereafter
8	LMP08		

5.1.3 Leachate depth assessment and compliance limits

The leachate level assessment and compliance limits presented in Table 5.3 are proposed to allow performance of the landfill to be monitored.

Table 5.3 Proposed leachate depth assessment and compliance limits

Cell	Monitoring points	Leachate depth above base level (m)	
		Assessment limit	Compliance limit
1	LMP01.1 LMP01.2	1.0 m	2.0 m
2	LMP02.1 LMP02.2		
3	LMP03.1 LMP03.2		
4	LMP04.1 LMP04.2		

Cell	Monitoring points	Leachate depth above base level (m)	
		Assessment limit	Compliance limit
5	LMP05.1 LMP05.2		
6	LMP06.1 LMP06.2		
7	LMP07.1 LMP07.2		
8	LMP08.1 LMP08.2		

5.2 Groundwater monitoring

Groundwater monitoring will be undertaken at the monitoring points that have previously been installed around the perimeter of the Site; their locations are presented in Drawing ESID9.

5.2.1 Groundwater levels

Groundwater levels will be monitored according to the schedule proposed in Table 5.4

Table 5.4 Proposed groundwater level monitoring schedule

Monitoring points			Parameter	Frequency
<i>Up-gradient</i>	<i>Cross-gradient</i>	<i>Down-gradient</i>	Depth to groundwater (m bGL)	Monthly
BH-A	BH-D	BH-G	Depth to base (m bGL)	
BH-B	BH-E	BH-I	Groundwater level (m AOD)	
BH-C	BH-F			
BH-C1	BH-H			
	BH-J			
	BH-K			
	BH-K1			

5.2.2 Groundwater quality

Groundwater quality will be monitored according to the schedule proposed in Table 5.5.

Table 5.5 Proposed groundwater quality monitoring schedule

Monitoring points			Parameter	Frequency
<i>Up-gradient</i>	<i>Cross-gradient</i>	<i>Down-gradient</i>	pH, electrical conductivity, temperature, ammoniacal nitrogen, chloride, COD, BOD, sodium, potassium, calcium, magnesium, sulphate, iron, manganese, cadmium, chromium, copper, arsenic, lead, nickel and zinc.	Quarterly (during operational phase); annually thereafter
BH-A	BH-D	BH-G	Hazardous substances	Annually (during operational phase); every four years thereafter
BH-B	BH-E	BH-I		
BH-C	BH-F			
BH-C1	BH-H			
	BH-J			
	BH-K			
	BH-K1			

5.2.3 Groundwater quality assessment and compliance limits

The groundwater quality assessment and compliance limits presented in Table 5.6 are proposed to allow performance of the landfill to be monitored. Limits have been set for the two groundwater monitoring points (BH-G and BH-I) located on the down-gradient boundary of the Site.

Limits have been set for ammoniacal nitrogen, chloride and nickel based on available background groundwater monitoring data (SLR, 2019a). Limits for arsenic, naphthalene, phenol and benzene will be set once sufficient background groundwater quality data have been collected for these substances.

Groundwater quality data collected at the selected monitoring points have been analysed and used to derive the limits (see Appendix B). Assessment levels have been set at the mean concentration plus two standard deviations, and Compliance limits are either set at the mean concentration plus three standard deviations or at the respective EALs.

Table 5.6 Proposed groundwater quality assessment levels and Compliance limits

Monitoring points	Chloride (mg/l)		Ammoniacal Nitrogen (mg/l as N)		Nickel (mg/l)	
	Assessment level	Compliance limit	Assessment level	Compliance limit	Assessment level	Compliance limit
BH-G	40	250 ^a	0.06	0.39 ^a	0.007	0.020 ^a
BH-I	500	555	0.50	0.55	0.022	0.024

Note: a) Compliance Limit set as EAL.

5.3 Surface water monitoring

Surface water quality will be monitored at two locations on Alltami Brook up-stream and down-stream of the Site as shown on drawing ESID9. Surface water discharges from the Site will be monitored at the discharge point according to the requirements of the associated Environmental Permit. Surface water quality will be monitored according to the schedule proposed in Table 5.7.

Table 5.7 Proposed surface water quality monitoring schedule

Monitoring points			Parameter	Frequency
<i>Alltami Brook (up-stream)</i> SW1	<i>Alltami Brook (down-stream)</i> SW2	<i>Discharge point</i>	pH, electrical conductivity, suspended solids, ammoniacal nitrogen, chloride, sulphate, nitrate, nickel (dissolved), manganese (dissolved), visible oil / grease	Monthly (during operational phase); quarterly thereafter

6 CONCLUSIONS

6.1 Compliance with Landfill Directive

The landfill has been designed to be an above water table with a fully engineered containment system. Compliance with the Landfill Directive is demonstrated through the engineering design which incorporates the following requirements of the Directive:

- An engineered cap to control the amount of water entering the landfill; and preventing the ingress of surface water;
- An engineered basal and side slope liner (including an artificial geological barrier) constructed to a standard in excess of the protection provided by 1 m mineral layer with a permeability of $<1 \times 10^{-9}$ m/s; and
- An active leachate management and collection system (enhanced by a sloped base and high permeability drainage layer).

As required by the Landfill Directive, requisite monitoring for leachate, groundwater and surface water is proposed. Assessment and Compliance limits for leachate heads and down-hydraulic gradient groundwater quality have been derived. The limits for groundwater quality have been derived based on the observed background water quality. Site monitoring data will be compared to these limits to provide an early warning if groundwater quality begins to deteriorate, allowing sufficient time to take remedial action prior to Compliance Limits being exceeded. It is not proposed to set Compliance limits for surface water.

6.2 Compliance with the Groundwater Directive

The Site is located within the Middle Coal Measures; and locally strata are dominated by low permeability mudstones with siltstones and sandstones. Groundwater flows are expected to occur predominately within joints and fractures within these units. The Coal Measures are classified as a Secondary A Aquifer. The Site is not located within a Source Protection Zone and no groundwater abstractions local to the Site have been identified. Groundwater within the Coal Measures is likely to form a base flow contribution to the nearby Alltami Brook.

The risk assessment presented in this report has demonstrated that the presence of hazardous substances and non-hazardous pollutants within leachate generated from the waste materials deposited within the landfill are unlikely to cause a discernible impact on local groundwater or surface waters.

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Appendices

Appendix A

RAM model (electronic)

Appendix B

Groundwater quality assessment and compliance limit calculations

Chloride (mg/l)

Date	BHA	BHB	BHC	BHC1	BHD	BHE	BHF	BHF1	BHG	BHH	BHI	BHJ	BHK	BHK1	
24/02/2017	80			95	35	37	44	34	55	36	149	442	179	147	60
24/03/2017	80			92	34	37	44	35	55	36	153	441	170	158	62
18/04/2017	77	230	90	35	37	44	35	56	37	154	448	176	165	61	
18/05/2017	76	12	80	36	37	53	21	40	32	264	430	123	252	60	
23/06/2017	76	14	73	40	37	40	22	38	32	273	425	92	154	60	
05/09/2017	77	53	47	42	42	31	22	35	31	225	286	86	475	61	
04/10/2017	78	52	51	36	39	31	22	35	33	348	406	78	342	61	
15/01/2018	86	65	371	36	38	29	22	38	38	271	359	358	533	60	
15/02/2018	84	58	386	35	38	30	22	38	38	261	348	102	522	61	
15/03/2018	85	47	390	34	37	31	22	39	37	266	362	105	519	61	
Mean	79.9	66.375	167.5	36.3	37.9	37.7	25.7	42.9	35	236.4	394.7	146.9	326.7	60.7	
SD	3.8	69.0	149.2	2.6	1.6	8.4	6.2	8.7	2.7	65.6	53.6	83.5	170.7	0.7	
Mean + 2SD	87.5	204.3	465.9	41.6	41.1	54.4	38.1	60.3	40.4	367.6	501.9	313.9	668.1	62.0	
Mean + 3SD	91.3	273.3	615.1	44.2	42.7	62.8	44.3	69.1	43.1	433.2	555.5	397.5	838.8	62.7	

EAL 250

300 Value in excess of EAL

Assessment limit 40 250

Compliance limit 250 555

Nickel (mg/l)

Date	BHA	BHB	BHC	BHC1	BHD	BHE	BHF	BHF1	BHG	BHH	BHI	BHJ	BHK	BHK1
18/04/2017	0.012	0.002	0.006	0.002	0.001	0.005	0.005	0.026	0.002	0.014	0.017	0.023	0.017	0.009
18/05/2017	0.011	0.001	0.002	0.002	0.002	0.005	0.002	0.028	0.006	0.02	0.017	0.024	0.013	0.008
23/06/2017	0.011	0.001	0.002	0.002	0.002	0.003	0.002	0.03	0.006	0.018	0.017	0.024	0.011	0.008
05/09/2017	0.011	0.002	0.002	0.003	0.002	0.002	0.0005	0.032	0.002	0.016	0.018	0.023	0.014	0.008
04/10/2017	0.01	0.0005	0.001	0.0005	0.002	0.002	0.0005	0.03	0.002	0.013	0.017	0.023	0.015	0.007
15/01/2018	0.011	0.009	0.005	0.002	0.0005	0.004	0.0005	0.022	0.001	0.011	0.02	0.018	0.022	0.007
15/03/2018	0.011	0.007	0.005	0.002	0.0005	0.005	0.0005	0.023	0.001	0.011	0.022	0.018	0.022	0.007
Mean	0.0110	0.0032	0.0033	0.0019	0.0014	0.0037	0.0016	0.0273	0.0029	0.0147	0.0183	0.0219	0.0163	0.0077
SD	0.0006	0.0034	0.0020	0.0007	0.0007	0.0014	0.0017	0.0038	0.0022	0.0035	0.0020	0.0027	0.0043	0.0008
Mean + 2SD	0.0122	0.0099	0.0072	0.0034	0.0029	0.0065	0.0049	0.0348	0.0072	0.0216	0.0222	0.0272	0.0249	0.0092
Mean + 3SD	0.0127	0.0133	0.0092	0.0041	0.0036	0.0079	0.0066	0.0386	0.0094	0.0251	0.0242	0.0299	0.0292	0.0100
Assessment limit									0.007		0.022			
Compliance limit									0.02		0.024			

EAL 0.02

0.03 Value in excess of EAL

Ammoniacal Nitrogen (mg/l as N)

Date	BHA	BHB	BHC	BHC1	BHD	BHE	BHF	BHF1	BHG	BHH	BHI	BHJ	BHK	BHK1
24/02/2017	0.14		0.4	0.05	0.04	0.01	0.03	0.02	0.005	1.2	0.4	0.17	0.19	0.13
24/03/2017	0.4		0.3	0.04	0.03	0.005	0.005	0.03	0.005	1.1	0.4	0.4	0.04	0.16
18/04/2017	0.4	0.05	0.2	0.05	0.01	0.01	0.07	0.02	0.01	1.2	0.4	0.17	0.4	0.2
18/05/2017	0.4	0.01	0.1	0.07	0.02	0.005	0.03	0.02	0.06	2	0.4	0.4	0.3	0.15
23/06/2017	0.2	0.02	0.02	0.07	0.08	0.02	0.03	0.05	0.03	1.4	0.4	0.03	0.14	0.12
05/09/2017	0.2	0.005	0.03	0.02	0.02	0.005	0.005	0.005	0.01	0.7	0.5	0.15	0.15	0.15
04/10/2017	0.3	0.005	0.005	0.03	0.06	0.005	0.005	0.03	0.005	0.9	0.4	0.22	0.3	0.005
15/01/2018	0.08	0.16	0.005	0.04	0.11	0.02	0.01	0.03	0.01	0.09	0.5	0.4	0.5	0.1
15/02/2018	0.06	0.13	0.005	0.05	0.11	0.02	0.005	0.01	0.02	0.13	0.4	0.5	0.5	0.11
15/03/2018	0.08	0.12	0.005	0.04	0.11	0.02	0.02	0.03	0.04	0.1	0.4	0.3	0.5	0.1
Mean	0.226	0.0625	0.107	0.046	0.059	0.012	0.021	0.0245	0.0195	0.882	0.42	0.274	0.302	0.1225
SD	0.140	0.064	0.144	0.016	0.041	0.007	0.021	0.013	0.018	0.633	0.042	0.149	0.169	0.052
Mean + 2SD	0.505	0.191	0.395	0.078	0.140	0.026	0.062	0.050	0.056	2.148	0.504	0.571	0.640	0.226
Mean + 3SD	0.645	0.255	0.539	0.093	0.181	0.033	0.083	0.062	0.075	2.781	0.546	0.720	0.810	0.277

EAL 0.39

0.5 Value in excess of EAL

Assessment limit 0.06 0.5

Compliance limit 0.39 0.55