ENVIROARM LTD

Group of Companies

HRDROGEOLOGICAL RISK ASSESSMENT
WOODCOTE WOOD QUARRY LANDFILL SITE

REF: HRA/WWQ/NRS/1.00/2023

Carried out for: **NRS Woodcote Aggregates Ltd**

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HYDROGEOLOGICAL RISK ASSESSMENT

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1.0 INTRODUCTION

1.1 Report Context

Enviroarm Ltd were instructed by NRS Woodcote Aggregates Limited, the operators of Woodcote Wood Quarry to undertake a Hydrogeological Risk Assessment for the restoration of the site by way of inert landfilling of the quarry and with non-hazardous waste treatment . This report provides the geological and hydrogeological setting of the site and considers the operational impacts of restoration by inert landfill in line with the Environmental Permit (England and Wales) Regulations 2016.

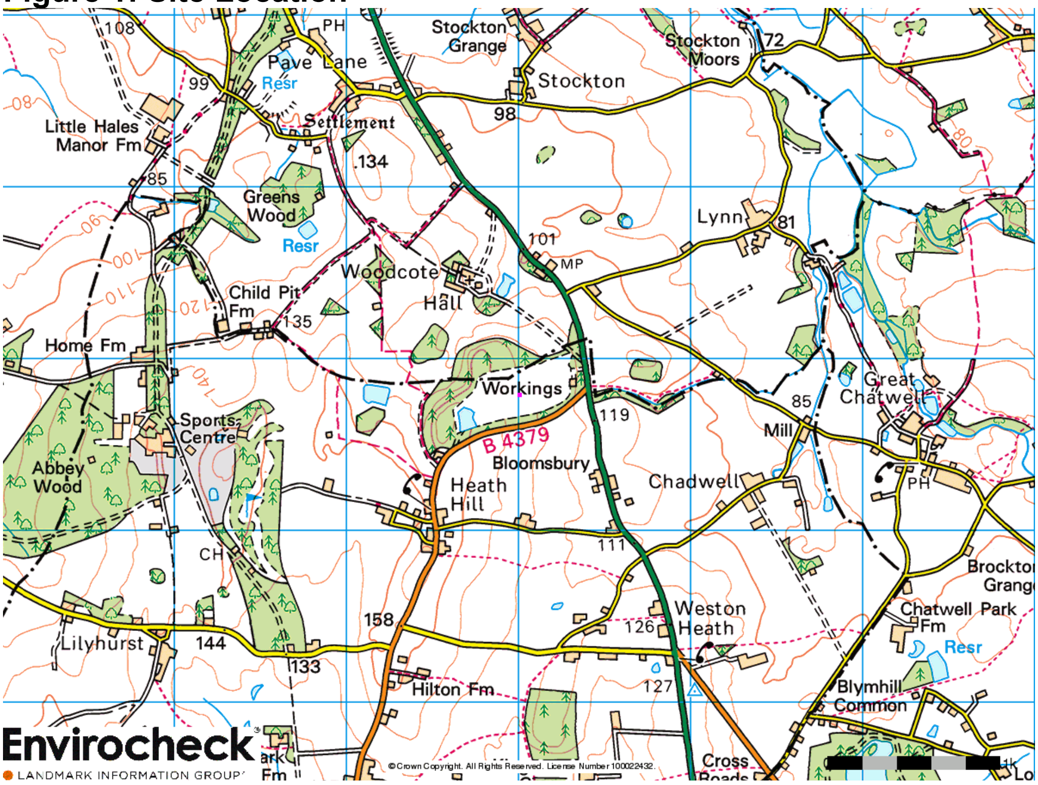
This report covers by way of assessment of Hazardous Substances and Non-Hazardous Polluting Substances, released into the groundwater.

The site is off the A41 in Weston Heath, Sheriffhales, Shropshire, 5km south of Newport town centre and 4.2km north of the A5. The centre of the site is at National Grid reference SJ 77036 14780 and the site entrance is SJ 77388 14944 see Figure 1 and Drawing ESID 1.

The Site comprises 22.4 hectares of agricultural land, which includes a woodland area. The site is a quarry.

The site is to be infilled specifically with inert waste which complies with the Landfill Tax (Qualifying Material) Order or is to be WRAP compliant and therefore outside the scope of the permit and will take 10 years to infill.

Figure 1: Site Location



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

1.2 Conceptual Hydrogeological Site Model

1.2.1 GEOLOGY

Regional Superficial Geology

Regional superficial geology is predominantly till located in the low-lying topographical areas. Glaciofluvial deposits (sand and gravel) and alluvium (clay, silt, sand and gravel) are also present and are associated with water courses. There are no superficial deposits overlying the Woodcote Wood site. Aqualate Mere however, is thought to be formed in a glacial kettle hole, being a depression in the sand and gravel scoured out by the retreating glaciers which has then filled with freshwater. According to the BGS mapping, Aqualate Mere is underlain by the following superficial deposits:

- Peat- underlays the majority of the Aquaate Mere but is mainly found in the central area, underlying the lake.
- Glaciofluvial Deposits, Devensian- Sand and Gravel are found to the northeast and south of the central peat deposits;
- Till, Devensian- Diamicton (clay, gravel, and sand with poorly sorted clasts and boulders) is found to the north of Aqualate Mere and a small area is found to the west of the central peat deposits; and
- Alluvium- Clay Silt and Sand and Gravel are found in a small area in the western extent of Aqualate Mere, where watercourses are present.

Regional Bedrock Geology

Both the Woodcote Wood Quarry and Aqualate Mere are situated on the western fringe of the north-south orientated Stafford Basin; with younger geological Units to the east and older Units to the west. The Woodcate Wood Quarry is entirely underlain by the Kidderminster Formation, comprised of pebble conglomerates and sandstone. Aqualate Mere is underlain by sandstone of the Wildmoor Sandstone Formation. There are two minor faults present in a northeast-southwest orientation between the Woodcote Wood quarry and Aqualate Mere.

Most of the strata are red as a result of the diagenetic alternation of iron oxide (haematite) of detrital ferromagnesian silicates and iron bearing clay minerals and is summarised on British Geological Maps presented at Drawing HRA 1.

Sherwood Sandstone Group

The site lies within this group. The Sherwood Sandstone Group was formally introduced for the formations that comprise the arenaceous lower part of the Triassic succession throughout Britain. This sequence was subdivided into three formations renamed recently (Warrington et al 1980), which are the basis for this report. An additional formation, the Quartzite Breccia, which locally underlies the Kidderminster formation and is therefore included as follows:

SUBDIVISIONS OF THE SHERWOOD SANDSTONE

Hull 1869	Warrington 1980
Lower Keuper Sandstone	Helsby Formation/Bromsgrove Sandstone
Upper Mottled Sandstone	Wildmoor Sandstone
Bunter Pebble Beds	Chester Formation/ Kidderminster Formation
	Quartzite Breccia

Deposition of the Sherwood Sandstone Group was controlled by palaegeographical changes initiated during the Permian. A series of troughs and ridges were formed, orientated roughly north-south in response to east west tensional stresses in the region of the North Atlantic. One such trough was the Worcester Basin.

Chester Formation originally called the Kidderminster Formation

This name was introduced (Warrington et al, 1980) for beds formerly termed Bunter Pebble Beds. In the district relevant to the site, the sequence of fluvial sandstones and conglomerates crops out in the north west, where it attains a thickness of some 175m; it is present at depth in the south west and north east, but is absent in the south east where Ordovician and Silurian rocks prevail. In the location of the site the sequence comprises a basal conglomerate overlain by a mainly sandstone sequence. The Kidderminster formation comprises a sequence of upward fining rhythms, each with an erosional base. The rhythms commence with a hard conglomerate, overlain by sandstone, which is succeeded by mudstone, they are rarely complete and the mudstone is often absent. The average grain size of the sediments decreases upwards through the formation.

The basal conglomerate of the sequence is composed of pebbles and cobbles in a weakly cemented matrix of coarse, micaceous sand. Most of the stones are derived locally from the Lickey Quartzite.

The main part of the Kidderminster Formation is dominated by massive red-brown to yellow-brown sandstones with a weak calcareous cement. The sand grains vary from coarse to fine in grade and are largely subangular. They are largely cross-bedded.

No fossils have been found in the Kidderminster Formation within the district.

Wildmoor Sandstone

The name Wildmoor Sandstone was introduced for beds formerly termed Upper Mottled Sandstone. This formation consists predominantly of sandstone and provides the well-known moulding sands quarried around Wildmoor. The Wildmoor Sandstone is dominated by remarkably uniform, very weakly cemented, fine grained, silty, micaceous sandstone. The formation includes upward fining rhythms which commence with a medium too coarse grained or pebbly sandstone and pass upwards through cross-bedded, fine grained sandstones into plainer bedded fine-grained sandstones and mudstones. The Wildmoor Sandstone rests conformably upon the Chester Formation from which it is distinguished by its fine grain and foxy red colouration.

LOCAL GEOLOGY

The Woodcote Wood Quarry is located in sands of the Chester Formation. The quarry consists of a uniform, brownish red sandstone. The sandstone is medium too coarse grained, micaceous and feldspathic.

The strata dips easterly. The local strata dips at approximately 7°.

The local bedrock geology is also presented at Figure 2. The bedrock geological map is presented at Drawing HRA 1.

Figure 2: Bedrock Geology

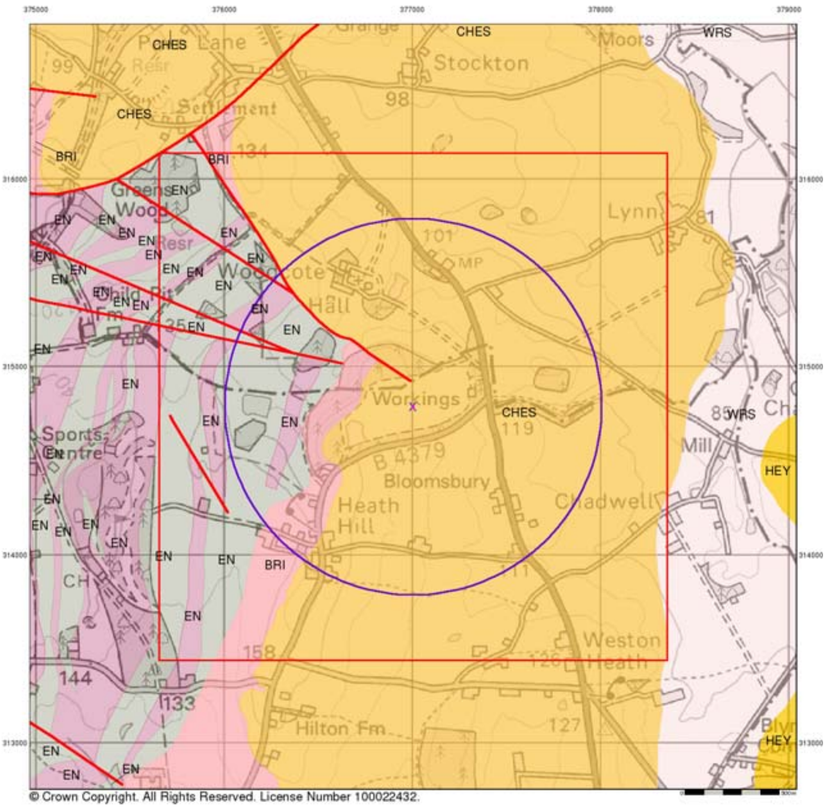


Figure 2 shows the site to consist of Chester Formation sand and graavel.

The site has no superficial covering. The superficial geological map is presented at Figure 3.

Figure 3: Superficial Geology

The Superficial Geological Plan is presented at Drawing HRA 1. A conceptual geological cross-sectional plan is presented as Drawing HRA3.

1.2.2 Man-made Subsurface Pathways

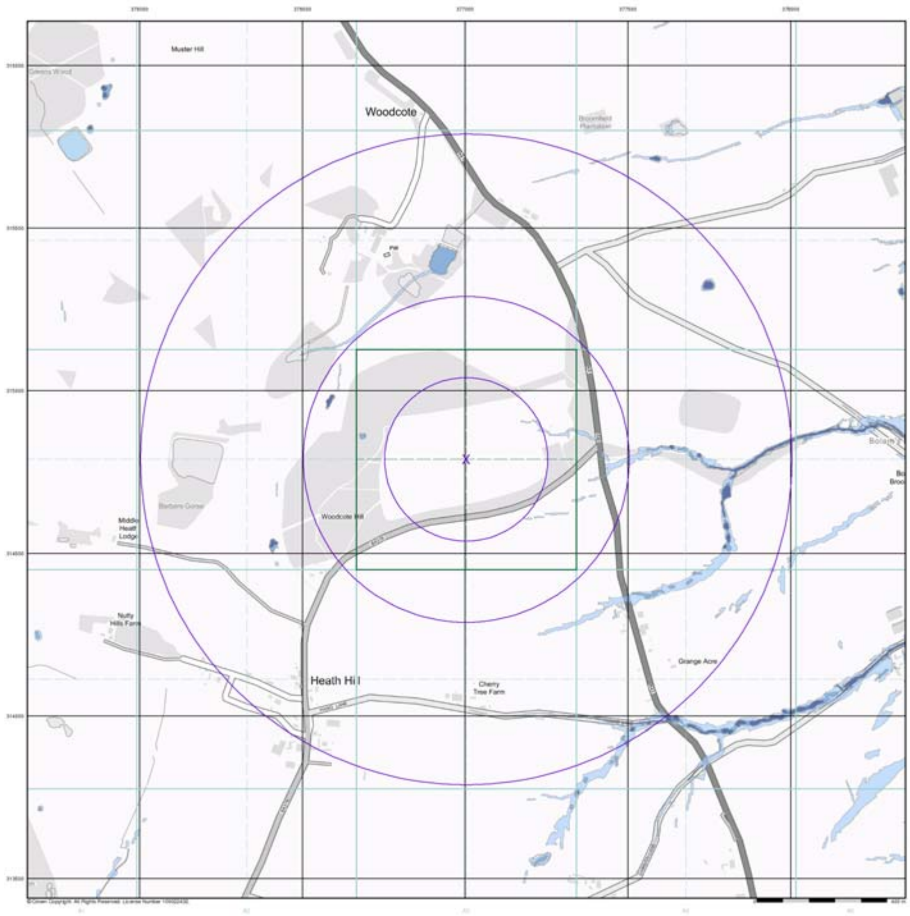
The following man made subsurface pathways have been identified;

- No field drains exist in any of the fields around the site.
- Mine workings do not occur in the area of the site with no underground saline of coal workings present.
- No services run through the proposed extraction area and landfill area.

1.2.3 Hydrology

The site is not within a Flood Zone. The local indicative flood map is presented as Figure 4 and shown in detail on Drawing HRA2.

Figure 4: Indicative Flood Zone Map



HYDROGEOLOGY

1.2.4 Regional Hydrogeology

The Permo-Triassic Sandstone is a high yielding aquifer and is regionally important for groundwater supply within the Shropshire Area. Recharge of the bedrock aquifers occurs mainly in the up-gradient areas of outcrop, inducing flow down-gradient to the surrounding rivers. To the east, recharge is severely limited by the presence of overlying low permeability superficial deposited (Till). Underlying bedrock aquifers can also be recharged by inter-aquifer flows from the surrounding aquifers and by stream bed leakage from surface waters such as during high flow or flood conditions.

Based on regional geology and hydrogeology, regional groundwater flows are likely to be to the east with recharge occurring where there is exposed Chester Formation sandstone and Wildmoor Sandstone Formation sandstone. Groundwater flow thereafter towards and underneath the till covered Mercia Mudstone in the east, unless captured by a public water abstraction.

Between Aqualate Mere and the Woodcote Wood site there are many groundwater Source Protection Zones (SPZ) and associated public water abstractions. The Woodcote Wood quarry and the west of Aqualate Mere are located within a SPZ 3: Total; Catchment. The purpose of the SPZ 3 is to define the total catchment area for a public supply abstraction. All groundwater recharge within this area is presumed to discharge to the associated water abstraction. There are also known to be many licensed and private groundwater abstractions in the area and creates uncertainty around the groundwater flow directions on the regional scale. Groundwater elevations are similar either side of the fault at Pave Lane suggesting a hydraulic connection across the fault.

Regional Groundwater Catchment

The Woodcote Wood quarry and Aqualate Mere both lie within the Shropshire Middle Severn-Permo Triassic Sandstone East groundwater catchment. However, due to the high clay content in the Till and Glaciofluvial deposits underlying the Aqualate Mere and acting as an impermeable barrier to vertical groundwater movement from the underlying bedrock aquifer, if there is a groundwater input into Aqualate Mere it is likely to be locally derived from permeable layers of sand and gravel within the glaciofluvial and alluvium deposits. Groundwater flow and direction in the superficial deposits surrounding Aqualate Mere tends to reflect local topography and be towards Aqualate Mere lake.

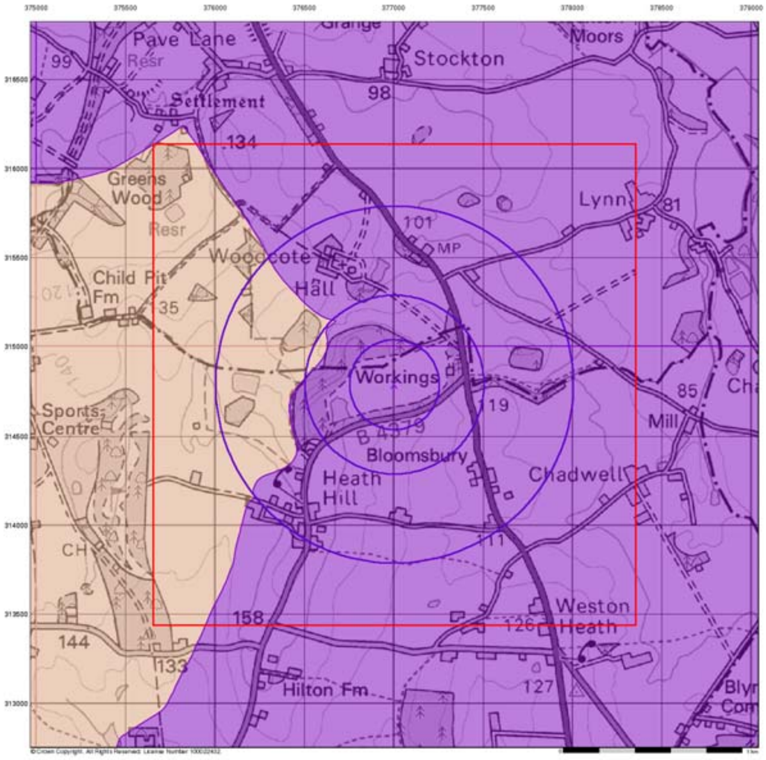
From 1st April 2010 new aquifer designations replace the old system of classifying aquifers as Major, Minor and Non-Aquifer. This new system is in line with our Groundwater Protection Policy (GP3) and the Water Framework Directive (WFD) and is based on British Geological Survey mapping.

The site is located on a bedrock Principal aquifer with rock deposits having high intergranular permeability and providing a high level of water storage. They may support water supply and or river base flow on a strategic scale. Areas of secondary A aquifer (supporting water supplies (locally) are located up hydraulic gradient north-east of the site and a Secondary B aquifer (predominantly lower permeability with limited storage and flow is located to the south west as the Mercia Mudstone Group.

The site is located within a Total Protection Zone (Zone 3). The nearest outer SPZ (SPZII) is located circa. 1000m to the south of the permit boundary and the public abstraction borehole is 1681metres from the site as shown in Figure 6.

Figure 5 shows the bedrock geology aquifer designation for the site. The dark purple area represents the Sherwood Sandstone major aquifer with the brown areas being secondary aquifer of the Mercia Mudstone Group.

Figure 5: Aquifer designation map for Solid Geology



The regional supplies come from the Sherwood Sandstone in the Trias. The water resources are administered by Severn Trent Water. In the Trias, the Chester Formation, and all sub-units form a single aquifer, although it may contain aquicludes.

Figure 6: Source Protection Zones

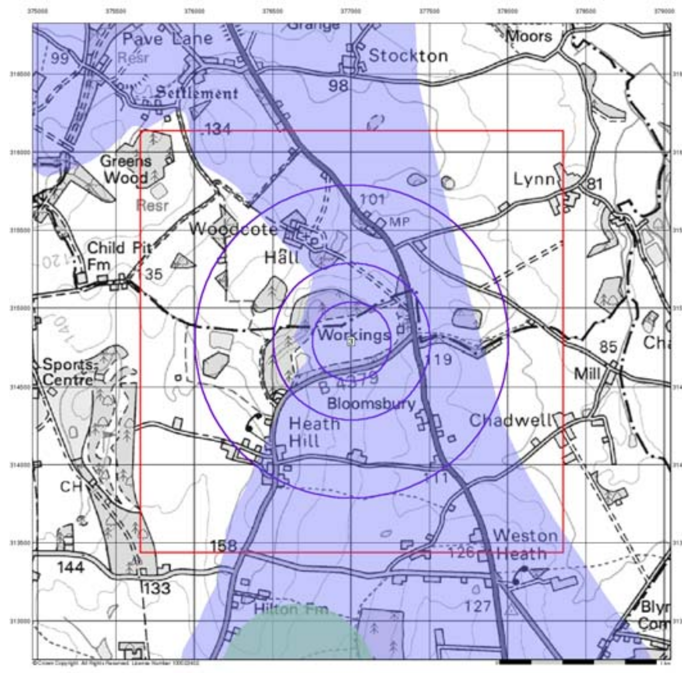


Table HRA1 shows the groundwater and surface water abstraction boreholes located nearest to the site. The main public abstraction borehole is at Hilton Bank, 1828 metres south west of the site, and W Maddocks has boreholes 1491m away to the south east and B and PJ Davies & Son have boreholes 1656m to the north east.

No private groundwater borehole data is on record at Telford District Council within a 1000 metre radius search of the site.

Table HRA1: Abstraction Licence Details

Map ID	Details	Quadrant Reference (Compass Direction)	Estimated Distance From Site	Contact	NGR
	Water Abstractions Operator: W Maddocks Ltd Licence Number: 18/54/04/0592 Permit Version: 103 Location: Chadwell Court Farm, Sherriffhales - Borehole Authority: Environment Agency, Midlands Region Abstraction: General Agriculture: Transfer Between Sources Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Not Supplied Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 13th January 2015 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	A10NW (SE)	1491	2	378333 314115
	Water Abstractions Operator: W Maddocks Ltd Licence Number: 18/54/04/0592 Permit Version: 102 Location: Chadwell Court Farm, Sherriffhales - Borehole Authority: Environment Agency, Midlands Region Abstraction: General Agriculture: Spray Irrigation - Direct Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Seven Areas Of Land At Chadwell Court Farm Authorised Start: 01 March Authorised End: 31 October Permit Start Date: 22nd March 2004 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	A10SW (SE)	1491	2	378330 314110
	Water Abstractions Operator: W Maddocks Ltd Licence Number: 18/54/04/0592 Permit Version: 102 Location: Chadwell Court Farm, Sherriffhales - Borehole Authority: Environment Agency, Midlands Region Abstraction: General Agriculture: Transfer Between Sources Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Compensation Release Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 22nd March 2004 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	A10SW (SE)	1491	2	378330 314110
	Water Abstractions Operator: W Maddocks Ltd Licence Number: 18/54/04/0592 Permit Version: 101 Location: Chadwell Court Farm, Sherriffhales - Borehole Authority: Environment Agency, Midlands Region Abstraction: General Agriculture: Spray Irrigation - Direct Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: 7 Areas At Chadwell Court Farm, Sherriffhales Authorised Start: 01 March Authorised End: 31 October Permit Start Date: 31st March 1999 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	A10SW (SE)	1491	2	378330 314110

Map ID	Details	Quadrant Reference (Compass Direction)	Estimated Distance From Site	Contact	NGR
	Water Abstractions Operator: Mr M Bubb Licence Number: 18/54/04/1051 Permit Version: 100 Location: Woodcote - Field Ditches Authority: Environment Agency, Midlands Region Abstraction: General Agriculture: Spray Irrigation - Storage Abstraction Type: Water may be abstracted from a single point Source: Surface Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Land Near Woodcote - Field Ditches Authorised Start: 01 November Authorised End: 31 March Permit Start Date: 25th February 1982 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	A16NE (NW)	1510	2	375800 315700
	Water Abstractions Operator: J M Bubb & Son Licence Number: 18/54/04/0379 Permit Version: 101 Location: Woodcote Estate - Chadwell Mill Spring Authority: Environment Agency, Midlands Region Abstraction: Private Water Undertaking: General Farming And Domestic Abstraction Type: Water may be abstracted from a single point Source: Surface Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Woodcote Estate - Chadwell Mill Spring Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 26th September 2012 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 100m	A10NE (E)	1575	2	378500 314300
	Water Abstractions Operator: Woodcote Estate Water Supply Co Licence Number: 18/54/04/0379 Permit Version: 100 Location: Woodcote Estate - Chadwell Mill Spring Authority: Environment Agency, Midlands Region Abstraction: Private Water Undertaking: General Farming And Domestic Abstraction Type: Water may be abstracted from a single point Source: Surface Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Woodcote Estate - Chadwell Mill Spring Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 1st April 2008 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 100m	A10NE (E)	1575	2	378500 314300
	Water Abstractions Operator: B & P J Davies & Son Licence Number: 18/54/04/1105 Permit Version: 100 Location: North Lynn Manor,Newport - Borehole Authority: Environment Agency, Midlands Region Abstraction: General Agriculture: Spray Irrigation - Direct Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Land At Moreton Park,North Lynn Manor & Sherriffhales - Borehole Authorised Start: 01 April Authorised End: 31 October Permit Start Date: 3rd December 1996 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 100m	A20NW (NE)	1656	2	378330 315780

Map ID	Details	Quadrant Reference (Compass Direction)	Estimated Distance From Site	Contact	NGR
	Water Abstractions Operator: J M Bubb & Son Licence Number: 18/54/04/1297/1/R01 Permit Version: 1 Location: Lynn South Farm, Newport - Borehole Authority: Environment Agency, Midlands Region Abstraction: General Agriculture: Spray Irrigation - Direct Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Lynn South Farm, Newport - Borehole Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 1st April 2015 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	A20NE (NE)	1696	2	378443 315685
	Water Abstractions Operator: J M Bubb & Son Licence Number: 18/54/04/1297/1/R01 Permit Version: 1 Location: Lynn South Farm, Newport - Borehole Authority: Environment Agency, Midlands Region Abstraction: General Agriculture: Transfer Between Sources Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Lynn South Farm, Newport - Borehole Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 1st April 2015 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	A20NE (NE)	1696	2	378443 315685
	Water Abstractions Operator: J M Bubb & Son Licence Number: 18/54/04/1297/1 Permit Version: 3 Location: Lynn South Farm, Newport - Borehole Authority: Environment Agency, Midlands Region Abstraction: General Agriculture: Spray Irrigation - Direct Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Lynn South Farm, Newport - Borehole Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 16th July 2012 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	A20NE (NE)	1699	2	378450 315680
	Water Abstractions Operator: J M Bubb & Son Licence Number: 18/54/04/1297/1 Permit Version: 3 Location: Lynn South Farm, Newport - Borehole Authority: Environment Agency, Midlands Region Abstraction: General Agriculture: Transfer Between Sources Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Lynn South Farm, Newport - Borehole Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 16th July 2012 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	A20NE (NE)	1699	2	378450 315680

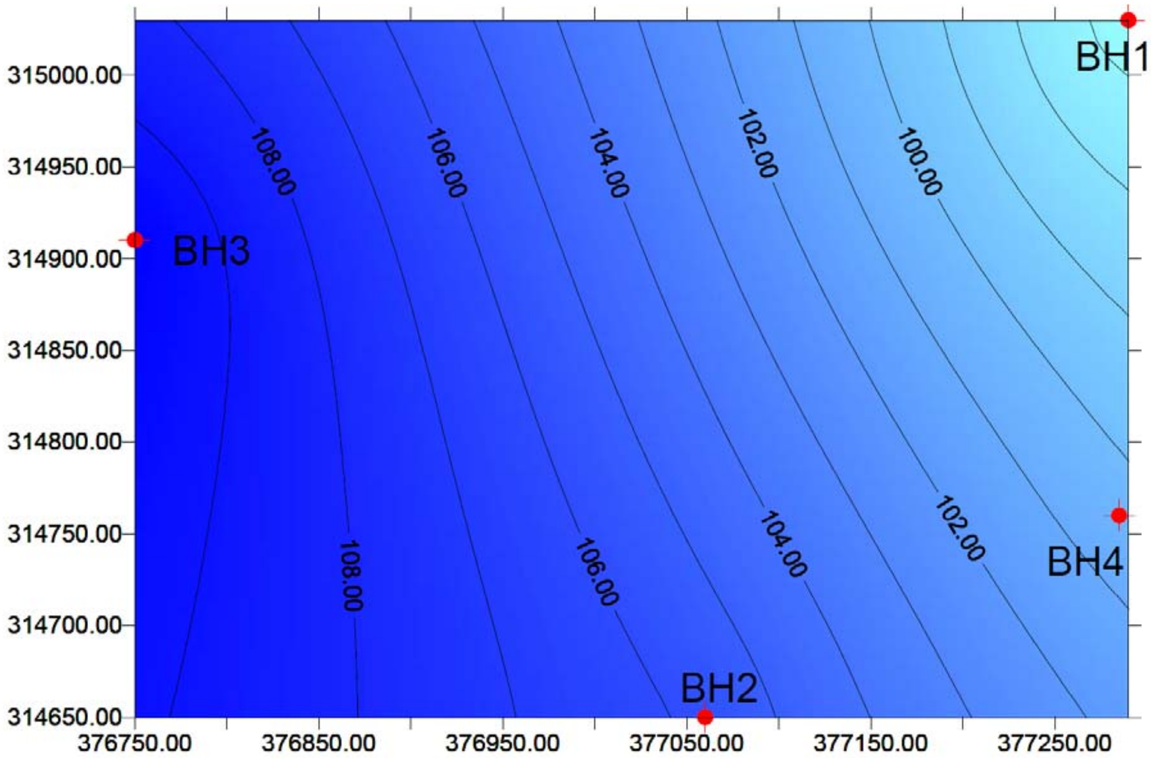
Map ID	Details	Quadrant Reference (Compass Direction)	Estimated Distance From Site	Contact	NGR
	Water Abstractions Operator: Severn Trent Water Limited Licence Number: 18/54/05/0044 Permit Version: 101 Location: Hilton Bank Authority: Environment Agency, Midlands Region Abstraction: Public Water Supply: Potable Water Supply - Direct Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Hilton Bank Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 22nd October 2010 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 100m	A2SW (SW)	1828	2	376100 313200
	Water Abstractions Operator: Severn Trent Water Limited Licence Number: 18/54/05/0044 Permit Version: 102 Location: Hilton Bank Authority: Environment Agency, Midlands Region Abstraction: Public Water Supply: Potable Water Supply - Direct Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Hilton Bank Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 22nd October 2010 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 100m	A2SW (SW)	1828	2	376100 313200
	Water Abstractions Operator: Severn Trent Water Limited Licence Number: 18/54/05/0044 Permit Version: 100 Location: Hilton Bank Authority: Environment Agency, Midlands Region Abstraction: Public Water Supply: Potable Water Supply - Direct Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Hilton Bank Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 1st April 2002 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	A2SW (SW)	1828	2	376100 313200
	Water Abstractions Operator: J E Hill Licence Number: 18/54/04/0989 Permit Version: 100 Location: Lynn Mill Farm, Lynn - Borehole Authority: Environment Agency, Midlands Region Abstraction: General Farming And Domestic Abstraction Type: Water may be abstracted from a single point Source: Groundwater Daily Rate (m3): Not Supplied Yearly Rate (m3): Not Supplied Details: Lynn Mill Farm, Lynn - Borehole Authorised Start: 01 April Authorised End: 31 March Permit Start Date: 8th March 1996 Permit End Date: Not Supplied Positional Accuracy: Located by supplier to within 10m	(NE)	1840	2	378700 315500

1.2.5 Groundwater Flow

Groundwater levels have been monitored around Woodcote Wood Quarry and the hydrograph and results are presented at Appendix HRA 5. The borehole logs are presented at Appendix HRA 4.

The groundwater flow is eastwards and is presented at Figure 7 and the groundwater flows are presented at Drawing HRA 2 and has a hydraulic gradient between 0.0235m/m.

Figure 7: Groundwater contour model (average values)



The unsaturated zone permeability range for use in LANDSIM modelling has been set at as follows: Lower 2.46×10^{-5}m/s. Average 1.95×10^{-5}m/s Upper limit of 1.007×10^{-4}m/s.

Porosity is averaged at 28.3% for the Chester Formation.

1.2.6 Summary

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

Source: The source of potential contamination is inert wastes to be placed within the site. The surface area of these phases is 22.4 ha. The total volume of waste to be tipped in the phases is 5,396,175 cubic metres of sub soils which equates to 8,094,262 tonnes of soil.

Waste to be accepted will be classified as inert under the Environmental Permitting Regulations and defined within the Planning Permission. As such, it will be subject to basic characterisation by the waste producer and verification testing by the landfill operator.

The source term is based on waste Landfill Waste Acceptance Criteria and from analyses. The results are presented at Appendix HRA 1. The impact of this source is modelled, and resultant concentrations at the receptor presented. The risk assessment model is also used to demonstrate the maximum possible source term concentrations that could be accepted and to show that these are consistent with the waste acceptance limits for inert waste.

Table HRA 2: Summary of leaching

Ammonical Nitrogen

Cadmium

Copper

Mercury

Zinc

Chloride

Naphthalene

Toluene

On this basis, the priority contaminants selected to represent the inert source term in the risk assessment model are ammoniacal nitrogen, cadmium, chloride, copper, and zinc as non-hazardous substances and mercury, naphthalene and toluene as hazardous substances. Source term characteristics are detailed in a section below.

The source term is considered to decline over time, at a rate governed by the water flux through the waste.

Pathway: As the landfill will be developed for inert waste, there are no proposals to install an artificial sealing liner, nor to collect leachate.

The pathway segments represented by the model include the following.

<u>Artificially established geological barrier</u> In line with the requirements of the Environmental Permitting Regulations, an artificially established geological barrier will be required. The nature of this barrier will be agreed with the Agency via the Environmental Permit application, as will the means to ensure its performance. The maximum permeability will be 1 x 10^{-7}m/s, the medium at 1 x 10^{-8}m/s and a minimum permeability of 1x10^{-9}m/s and will be at least 1 m thick.

Within the artificially established geological barrier contaminants will be subject to advection, dispersion, degradation and retardation.

<u>Unsaturated zone</u> For the purposes of this assessment, it is assumed that at least it is 0.5m and 14.00m unsaturated zone will be maintained at the site.

Within the artificially established geological barrier contaminants will be subject to advection, dispersion, degradation and retardation.

<u>Saturated zone</u> Once contaminants migrate below the water table, they will

move with the prevailing groundwater flow towards the site boundary groundwater receptor. Within this pathway segment, contaminants, depending on their characteristics, may be subject to advection, dispersion, degradation, retardation and dilution.

Receptor: In the foregoing discussion about the pathway component of risk, it has been implicitly assumed that the receptor is the groundwater in the Sherwood Sandstone This is a conservative approach because the detrimental affects of leachate entering the groundwater are unlikely to be realised immediately adjacent to the site or beneath the site.

For the assessment of hazardous substances this is groundwater directly beneath the site below the unsaturated zone.

The "off-site" receptor is considered to be groundwater in the Sherwood Sandstone at the edge of the inert landfilling boundary down hydraulic gradient.

No groundwater pumping occurs near to the site and the nearest licensed abstraction is the Severn Trent Water boreholes at Hilton Bank located some 1828 metres southwest.

The conceptual model is presented at Drawing HRA 3.

1.2.2 Source Term Characteristics

The site is permitted to accept up to 350,000 tonnes of inert waste per annum and will take approximately 23 years to infill.

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

In assessing the risks posed by the site operations to groundwater, the source term has been derived using eluate criteria and assuming 1:1 from eluates obtained from WAC testing as input values. Upper WAC criteria +10% has been used as an upper limit is assessing rogue loads.

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

For inert landfills, there is a limited list of wastes presented at Table HRA 3 below that are deemed to meet the criteria for inert waste. These wastes are acceptable if:

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

The Environment Agency interpret these two points to mean that any waste load containing only a material on the list, or a mixture of them, is inert waste. To decide whether other materials or substances are present, the operator must consider:

- whether any are visible;
- if none are visible, but there are grounds for suspecting that they might be present. Such grounds could be based on non-numerical information contained within the basic characterisation or in any numerical data from testing.

Table HRA 3: Inert waste list

17	**CONSTRUCTION AND DEMOLITION WASTES (INCLUDING EXCAVATED SOIL FROM CONTAMINATED SITES)**
17 01	**concrete, bricks, tiles and ceramics**
17 01 01	concrete
17 01 02	bricks
17 01 03	tiles and ceramics
17 01 07	mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06
17 05	**soil (including excavated soil from contaminated sites), stones and dredging spoil**
17 05 04	soil and stones other than those mentioned in 17 05 03
17 05 06	dredging spoil other than those mentioned in 17 05 05
17 05 08	track ballast other than those containing dangerous substances
20	**MUNICIPAL WASTES (HOUSEHOLD WASTE AND SIMILAR COMMERCIAL, INDUSTRIAL AND INSTITUTIONAL WASTES) INCLUDING SEPARATELY COLLECTED FRACTIONS**
20 02	**garden and park wastes (including cemetery waste)**
20 02 02	soil and stones

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

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

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

Waste acceptance criteria have been agreed by the European Council. They applied from 16 July 2005 under the Landfill (England and Wales) (Amendment) Regulations 2004 transposed under the Environmental Permitting Regulations 2010. These criteria are referred to as ‘full waste Decomposition of inert waste is not considered highly complex like a non-hazardous waste landfill, with microbiological, physical and chemical processes acting simultaneously within each operational and closed landfill phase, and acting in a relatively consistent manner within an inert landfill site. Leachate is formed by the percolation of water through the inert waste mass coupled with the decay and release of contaminants from the waste itself.

Ammoniacal nitrogen has been chosen to simulate the effects of small quantities of wood or other biodegradable material being accidentally placed into the landfill. Although biodegradable material will not be deliberately disposed, it is possible that some residual biodegradable material may be placed in the landfill. Therefore, it is possible that some degradation products, such as ammonium may be produced. The purpose of including ammonium in the risk model is to demonstrate that, even if it is present in the leachate from the inert source term, it does not pose a risk to groundwater. The review of ammonium attenuation in soil and groundwater by NGCLC states an average decay half-life for ammonia as 6 years. The Kd value used for ammonia is based on a loam soil for the waste mass and for sands for the unsaturated zone based on the CONSIM database. Ammonical nitrogen is associated with small amounts of wood, leaves etc in waste and accounts for some of the breakdown of the organic matter which can be up to 3% in inert waste.

Cadmium Copper and Zinc are Non-Hazardous Substances. Adsorption is the primary attenuation mechanism for these. All Kd values for the inputs are contained in Table HRA 5. Input values are based on typical WAC test data and leachate samples from the site to provide real values for the modelling.

Chloride is a conservative contaminant in that it is not retarded, nor undergoes degradation. It is often present in inert waste at concentrations in excess of background and can provide an early warning of contaminant migration into groundwater. It is associated with construction and demolition waste which have or include concrete.

Mercury, Napthelene and Toluene are Hazardous Substances. Adsorption is the primary attenuation mechanism for these. All Kd values for the inputs are contained in Table HRA 5. Input values are based on typical WAC test data and leachate samples from the site to provide real values for the modelling.

Given the deterministic approach the triangular distributions based on testing previously carried out on the adjoining site has been used.

Compliance WAC Testing

Compliance testing was carried out on soils delivered to original site and all results were found to be within inert landfill WAC. Therefore the WAC procedures previously adopted at the site were effective and the input values are justified. The test results are presented at Appendix HRA 6.

1.2.6 Geological Barrier

An assessment has been made of the natural unsaturated zone as a single entity in comparison to the requirements of the Landfill Regulations. The principle for the calculation was taken from “Geotechnical Aspects of Landfill Design and Construction” Qian, Koerner, Gray 2002.

A source valuation has been carried out on the clay material available on site for construction of the geological barrier. The material has been demonstrated to far exceed the requirements for an inert landfill site geological barrier with field permeability values ranging from 1.2 x 10^{-10}m/s to 3.9 x 10^{-10}m/s and remoulded permeability 2.3 x 10^{-9}m/s. The average permeability value obtained from triaxial testing of the geological barrier in the adjoining Chadwich Lane site was 1.28 x 10^{-9}m/s. Source evaluation testing of the former site is presented at Appendix ESSD2.

Geological Barrier Requirements Landfill Regulation requirements

Leachate Head	**h =1**
Landfill liner	**D = 1m K= 1 x 10^{-7}m/s**

A=area-assume per 1m^2

The calculation to determine the seepage rate of a mineral liner geological barrier has been

$$Q=K\frac{(h+D)}{D}a$$

$$Q= 1\times10^{-7}\frac{(1+1)}{1}1$$

$$Q= 2\times10^{-7}\ m^2/s$$

The calculated value based on the average permeability would give a seepage rate of 2.56 x 10^{-9}m/s. Two orders of magnitude lower than required.

A water balance calculation has been carried out to assess for leachate potential on site.

Table HRA 4: Water Balance Calculation

Operational lifetime 13 years
3 Phases operational commencing in 2024 Average volume assuming 950,000 tonnes. Maximum input 950,000 tonnes per annum 5% air voids and 5% absorptive capacity. Total effective annual rainfall based on ERAIN using data is 160mm/annum. 190000m^3 absorptive capacity per annum 0.3 Surface area is 19 hectares = which equates to 31666m^2 per cell Volume of rain of cell per annum 0.16 X 31666m^2 = 5066m^3 per annum Note some of the rain waters are diverted away by surface water cut off ditches around the outside of the site 1425000m^3- 5066m^3=1419934m^3 remaining available capacity If one assumes a worst case scenario of 5% absorptive capacity this still a large soil moisture deficit in the waste mass
3 years monitoring provision required under Regulations for inert landfill.

2.0 HYDROGEOLOGICAL RISK ASSESSMENT

2.1 The Nature of the Hydrogeological Risk Assessment

2.1.1 General

Analytical models of leachate migration through the bottom layer of the geological barrier and underlying unsaturated zone and dispersion in hydrogeological environment, and probabilistic analysis have been used to provide an evaluation of the possible likelihood and consequences of leachate release and migration from the base of the inert landfill site at the Woodcote Wood Quarry landfill site into the groundwater, based on differing unsaturated zones.

The effect of contamination on receptors (water users or sources) is related to concentration of the particular contaminants at the point of contact and water usage.

Two types of assessment have been used for the site, and they are stated against scenario for the sites as follows

1. Standard Operation of the site operation up to restoring the site in extension area.

Advective migration of leachate through the base geological barrier and surcharged and compressed lower waste mass of the inert landfill site and release of leachate into the unsaturated zone into the groundwater. Assessment methodology LANDSIM 2.5

2. Non-Standard Operation of the site during the restoration of the site.

Rogue loads entering the site which are greater than the inert landfill limits. However in modelling this would assume that the upper bound levels exceed the limits by 10%. However this is extremely conservative as the model will assume all upper limits achieve this constantly through the operational lifetime of the site

2.1.2 Risk Estimation Model for Woodcote Wood Quarry

Unsaturated Zone

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

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

Due to the inert nature of the waste and little leachate within the waste mass and the low permeability of the soil, the concentration of chemicals within the landfill was assumed to not decline over time after waste placement; a source and the results are based on actual data from the leachability tests carried out from site soil sampling through the adjoining deposited waste mass presented at Appendix HRA 6. The conclusion is that the extension site will be dry with no leachate head within the waste mass and that the field capacity of the soils on site is unlikely to be used up. The model has therefore run with a conservative risk assuming a 1 metre head above the landfill liner.

ESI (2006) gives a typical recharge rate to the Sandstone aquifer of 160 mm/a in the original HRA for the site. This is taken to be equivalent to the hydrogeologically effective rainfall after allowing for run off and is thus equivalent to the flux entering the restoration soils overlying the waste. This flux is equivalent to $5.1x10^{-9}$ m/s. With a likely waste permeability of around $1x10^{-8}$ – $1x10^{-9}$ m/s (typical values for modern inert waste.

On the basis of a water balance, it is considered that the same flux will discharge from the base of the waste as enters at the top. As this flux per unit area is smaller than the maximum permeability of the artificially established geological barrier, the artificially established geological barrier will remain unsaturated and the saturated permeability of this pathway segment is not used by the model.

Due to the actual permeability of the liner and the assumed head and permeability of waste and direct throughflow of the waste mass the model runs at a worst case scenario.

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

Uncertainty in the natural processes of leachate migration through the base and the unsaturated zone and contamination transportation in groundwater were incorporated in the modelling process by the inclusion of stochastic values to represent certain controlling parameters (e.g. permeability of the basal soil material and underlying strata). The stochastic values were defined by probability density functions based on the findings of the field investigations carried out at the site, and appropriate published information such as BGS Aquifer Property taken from the BGS Technical Report WD/00/04 Environment Agency R&D Publication 68 The physical properties of minor aquifers in England and Wales, Chapter 8 Carboniferous Minor Aquifers-Central England. Uniform (represented by a minimum and maximum value) and triangular distributions (represented by a minimum, most-likely and maximum value) have been used to incorporate judgements on parameter values into the modelling. Triangular distributions are appropriate for representing judgements on values for risk analysis (Megill, 1984). Logarithmic triangular distributions have been used where the uncertainty relates to order of magnitude.

- **Leachate Screening Analysis**

  Due to the inert nature of the waste and detailed WAC criteria and Waste Inspection Form use it is unlikely for Hazardous substances to enter the site. The only makeup would be low level concentrations of background of cadmium, possibly phenol and mercury.

  WAC input levels have been modelled and an increase model was run with an additional 10% above concentrations of inert WAC to account for potential contaminated loads delivered to the site which are undetected as rogue loads.

- **Leachate Head in Waste**; in order to account for the probable variation in leachate generation in the landfill on the base of the site a 1metre head has been assumed above the geological barrier.

- **Hydraulic Properties of Underlying Strata;** values for the properties of the underlying strata were derived from BGS data sources. Hydraulic gradients are based on the groundwater contours monitored on site and presented at Drawing HRA 2.

- **Distance to Critical Receptor:** For Mercury, Napthelene and Toluene this is the direct contact point of the groundwater in the unsaturated zone beneath the landfill site. For non-hazardous polluting substances this is at the quarry edge.

  Due to the high sensitivity of the receiving waters the modelling has been carried out on a precautionary approach.

2.2 The Proposed Assessment Scenarios

The hydrogeological risk assessment has been carried out for the whole lifecycle of the landfill operations at the site, i.e. from the start of the operational phases until the point at which the site is no longer capable of posing an unacceptable environmental risk. Different scenarios have been considered, to assess the hydrogeological risks at different stages of the site lifecycle. Plausible external influences, failure scenarios and accidents must also be considered.

2.2.1 Lifecycle Phases

The inert nature of the waste to be deposited and the further tight controls that will be set by the Waste Acceptance Criteria and the lack of biodegradable matter within the waste mean that the site is stable and inert. The waste will not degrade and the restoration of the site will reduce further infiltration due to the formation of the domed landform allowing free drainage off the surface. The vegetated cover will also help to reduce infiltration into the waste mass.

The site will have an engineered geological barrier constructed using on site clay materials and silts produced as part of the mineral processing on site, which are unlikely to change over time.

2.3 The Priority Contaminants to be Modelled

The potential leachate generated at the permitted landfill will contain hazardous substances and non-hazardous pollutants. Determinands have been selected.

The determinands modelled for inclusion in the source term for this HRA model are also based on the presence of the determinand in groundwater at the site, the mobility of the determinand in groundwater, persistence of the determinand in the leachate, the concentration of the determinand in the leachate and/or the nature of the determinand as an indicator species.

The first normal operating models used the following parameters as previously approved

Ammonia (Ammoniacal Nitrogen) is attenuated during migration by cation exchange and biological uptake. Cation exchange is not included in LANDSIM 2.5. Half-life decay values for ammonia have been included with a value of 6 years based on the report entitled “Review of ammonium attenuation in soil and groundwater” produced by the NGWCL, published July 2003. Ammonia is most likely to be associated with the 35 organic matter limit within sub soils and formation during anaerobic degradation of the sub soils. This is an inorganic cation.

Cadmium Cadmium is a Non-Hazardous Substance and is associated with contaminated land. Adsorption is the primary attenuation mechanism for Cadmium.. Input values are based on typical WAC test data and leachate samples from the site to provide real values for the modelling.

Copper Copper is a Non-Hazardous Substance. Adsorption is the primary attenuation mechanism for Copper. Input values are based on typical WAC test data and leachate samples from the site to provide real values for the modelling.

Chloride Chloride accounts for the salty nature of the leachate and is only removed in the environment by dilution. Chloride is a primary constituent of metal oxide residues and is an inorganic anion.

Mercury Mercury is a Hazardous Substance. Adsorption is the primary attenuation mechanism for Mercury. Input values are based on typical WAC test data and leachate samples from the site to provide real values for the modelling.

Naphthalene. Naphthalene is an organic compound with formula **C10H8**. It is the simplest polycyclic aromatic hydrocarbon, and is a white crystalline solid with a characteristic odor that is detectable at concentrations as low as 0.08 ppm by mass

Toluene The chemical formula for toluene is $C_6H_5CH_3$, and its molecular weight is 92.15 g/mol. Toluene is added to gasoline, used to produce benzene, and used as a solvent. Toluene occurs as a colorless, flammable, refractive liquid, that is slightly soluble in water. Toluene has a sweet, pungent odour, with an odour threshold of 2.9 parts per million (ppm). Toluene will be associated with contaminated soils.

Zinc is a metal that is relatively mobile compared to other metals. Metals are often found in inert waste. However, their high retardation means that they rarely pose a threat to groundwater.

The selected priority contaminants together with the source term concentrations are presented in Table HRA 5. A failure scenario has also been considered with an increase in the contaminants by 10% and this is also presented at Table HRA 6. Table HRA 5 and 6 sets out the source term input data based on inert WAC and leachate testing from previously deposited soils at the site. It is considered that this is likely to be conservative.

Table HRA 5: Selected leachate source term concentrations and justifications for Normal Operating mode

NORMAL OPERATIONS				
Determinant	**Value**	**Units**	**Distribution**	**Justification**
Ammonia	0.1-0.6-1.6	mg/l	Log Triangular	Typical eluate and WAC for Inert
Cadmium	0.0001-0.00176-0.004	mg/l	Log Triangular	Typical eluate
Copper	0.009-0.016-0.076	mg/l	Log Triangular	Typical eluate and WAC for Inert
Mercury	0.0005-0.00045-0.0001	mg/l	Log Triangular	Typical eluate and WAC for Inert
Napthalene	0.01-0.1-0.2	mg/l	Log Triangular	Typical eluate
Toluene	0.01-0.05-0.15	mg/l	Log Triangular	Typical eluate
Zinc	0.01-0.023-0.4	mg/l	Log Triangular	Typical eluate and WAC for Inert
Chloride	0.01-19.1-160	mg/l	Log Triangular	Typical eluate and WAC for Inert

Table HRA 6: Selected leachate source term concentrations and justifications for Failure Mode with Rogue Loads

FAILURE MODE				
Determinant	**Value**	**Units**	**Distribution**	**Justification**
Ammonia	0.11-0.66-1.716	mg/l	Log Triangular	
Cadmium	0.00011-0.014-0.0044	mg/l	Log Triangular	
Copper	0.0099-0.016-0.0836	mg/l	Log Triangular	
Mercury	0.00055-0.00009-0.00011	mg/l	Log Triangular	
Napthalene	0.011-0.11-0.22	mg/l	Log Triangular	
Toluene	0.011-0.055-0.165	mg/l	Log Triangular	
Zinc	0.011-0.0253-0.44	mg/l	Log Triangular	
Chloride	0.011-21.01-176	mg/l	Log Triangular	

Co values are specified om page L11/34 of EU 2003 Council Decision of 19 December 2002 establishing a criteria and procedures for the acceptance of waste to landfills pursuant to Article 16 and Annex II TO Directive 1999/31/EC. We have also used to WAC criteria for inert landfills with 10% added.

Half-lives and attenuation parameters for the species modelled are Table summarised in Table HRA 7.

Table HRA 7: Kd and Half Life Values used for LANDSIM

Determinant	Paramter	Value/Range	Justification
Ammonia	Half Life(years) Kd (l/kg)	6 7.3-8.5 0.43-1.79	Half life decay values for ammonia have been included with a value of six years based on the report entitled “Review of ammonium attenuation in soil and groundwater” produced by the NGWCL, published July 2003. Clay Sandstone
Cadmium	Kd (l/kg) Half Life(years)	222-240 ∞: no decay	Range of Kd values obtained Golders and USEPA
Copper	Kd (l/kg) Half Life(years)	295 126.5 0:no decay	Sandstone Clay LANDSIM Manual 2.5 CONSIM
Mercury	Kd (l/kg) Half Life(years)	450 3835.5 0:no decay	Sandstone Clay LANDSIM Manual 2.5 CONSIM
Napthalene	Half Life(years) Kd (l/kg)	488-1102-2309 488-1102-2309	LANDSIM Manual 2.5 Clay Sandstone
Toluene	Half Life(years) Kd (l/kg)	57-130-272 57-130-272	Clay Sandstone
Zinc	Kd (l/kg) Half Life(years)	1.1,200,600 20.7 0:no decay	Sandstone Clay LANDSIM Manual 2.5 CONSIM
Chloride	Kd (l/kg) Half Life(years)	∞ no decay 0:no sorption	LANDSIM Manual 2.5 CONSIM

2.4 Review of Technical Precautions

In the context of a hydrogeological risk assessment, the necessary essential and technical precautions required by the Groundwater Regulations and Environmental Permitting Regulations are likely to include limitations on the rates of input and concentrations of permitted waste types. The waste types to be accepted the site are strictly inert wastes as detailed in Table HRA 1 for the landfill and pre-treated waste from the recycling facility.

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

All waste will be accepted in accordance with the Waste Acceptance Criteria Protocol for the site WAC/Woodcote Wood. A proposed WAC is presented at Appendix HRA 8 for reference but will be subject to review as part of the detailed permit application.

The failure model assumes that there will be some breach of the WAC due to rogue loads and this has been considered as 10% increase on contamination.

2.5 Numerical Modelling

2.5.1 Justification for Modelling Approach and Software

Probabilistic analysis of an analytical model allows the uncertainty in processes or uncertainty in parameters controlling processes to be quantified. Using mathematical sampling techniques, a direct estimate of risk associated with the model and assessed parameter uncertainty can be produced. The results combine magnitude of event (consequence) with likelihood of occurrence and define a probability density function for the model and parameters.

Infiltration and Cap Degradation

The infiltration rate used for the main models is 160mm per year and for the model with increased infiltration this was 320mm per year.

In order to get the LANDSIM models to function appropriately (in order to get a consistent leakage through the base of the modelled fill materials) the management period for the model was set at 1,000 years and the cap degradation parameters were set at 100 and 200 years for the start and finish respectively. This was found to be necessary even though the cap degradation option is set to off, since the cap design is assumed to be clay only, with no membrane. The management period is found to have no effect on the head within the fill material, as shown by the hydraulics calculation results within the model.

Base above unsaturated zone

In the case of the LANDSIM 2.5, the results are the range of possible leachate leakage from the site and contaminant concentration levels and breakthrough times at a receptor beneath the site at a given time after the commencement of leachate leakage. Using these results, it is possible to quantify the likelihood of a certain leakage rate or concentration occurring from the landfill within the Sherwood Sandstone at the water table and boundary of the site.

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

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

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

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

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

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

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

The results of the models are presented probabilistically to facilitate the application of confidence levels to the results. The 95th percentile results are presented at Tables HRA 8 to HRA 9. The 50th percentile represents the most likely occurrence as there is a 50% chance of it happening. The 95th percentile represents the worst-case scenario as there is only a 5% chance of occurrence.

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

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

2.5.2 Model Parameterisation

This has included details relating to the following.

- The nature of the parameterisation process including all model inputs, probability density functions and model calibration where appropriate.
- The justification for using model defaults against providing field measurements.

All of the above are justified in the LANDSIM models.

2.5.3 Sensitivity Analysis

The purpose of a sensitivity analysis is to quantify the variation in the model output caused by uncertainty in the input parameters. A sensitivity analysis has been performed by considering both poor source control, reduced unsaturated zone and increased infiltration.

The inert nature of the waste is a limiting factor. Sensitivity analysis has considered increase of the concentrations using LANDSIM with a 10% increase in the source term at the upper concentration above the WAC limit set for inert landfill sites and the upper values used in Co values specified on page L11/34 of EU (2003).

Unsaturated zone

The values for the input parameters for the landfill have been entered into LANDSIM version 2.5 using probability density functions to accommodate variations or uncertainty in the data. The results of the model are presented probabilistically to facilitate the application of confidence levels to the results. The 50th and 95th percentile results are presented in the HRA. The 50th percentile represents the most likely occurrence as there is a 50% chance of it happening. The 95th percentile represents the worst case scenario as there is only a 5% chance of exceeding the 95th percentile value. It is considered that given the nature of the model, the selection of input values from a range of values for input parameters and the probabilistic nature of the results substantial sensitivity is inherent in the models and a separate sensitivity analysis is not necessary.

The LANDSIM Models have been run with 1001 iterations and the summary results for release into the unsaturated zone in Table HRA 8 for normal operations and Table 9 including rogue loads.

Sensitivity analysis has been run firstly at 1001 iterations increasing the contaminant source term component values by 10% above the WAC criteria and an unsaturated zone of 1 metre.

2.5.4 Model Validation

The groundwater monitoring from original monitoring compared to data from would suggest a confidence in the groundwater table levels remaining as they are. The Wildmoor/Fairfield boreholes do not currently influence groundwater levels beneath the Wildmoor site and therefore will have no impact of Chadwich Lane. The location of the site near to the high point would suggest little by way of change with global warming.

2.5.5 Accidents and their Consequences

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

2.5.5.1 **Fluctuations in Groundwater Elevations**

It is not considered likely that groundwater levels will rise or fall at the site.

Groundwater monitoring has shown that groundwater fluctuation is due to aquifer recharge from infiltration.

Provision for routine groundwater level monitoring is included in the ESSD.

2.5.5.2 **Differential Settlement**

Differential settlement across the landfill is considered unlikely due to the inert nature of the waste. No lining systems using composite materials are to be used and no landfill cap is required. The geological barrier will be constructed using on site source tested derived clays. The inert nature of the waste means that movement will be minimal to structures within the waste mass (such as gas monitoring points which are also to be retro fitted) and is therefore not considered further as part of this assessment. Pre and post settlement contours are presented as Drawing HRA 4 and are considered as one and the same with no surcharging allowed.

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

- Regular site surveys of completed and restored areas of the site;

- Completion of walk over surveys across restored areas;

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

Should monitoring points be damaged through excessive or differential settlement within the waste mass, retrospectively installed wells will be constructed adjacent to the damaged monitoring point using conventional drilling techniques for drilling into inert waste (i.e. open hole air flush). Given the maximum thickness of the waste in the site (typically less than 39m), the retrospective installation of such wells is not considered to be problematic.

2.5.5.3 **A line of weakness in the mineral liner/geological barrier**

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

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

2.5.5.4 **Failure of the Side Wall Lining System**

A side wall liner is required, but is to be constructed in small 2 metre lifts and held in place with inert waste and a firm outer sub grade of in situ sandstone. Side wall failure is not considered likely and a line of weakness would be similar to that for the base.

2.5.5.5 **Diesel Fuel Storage Tank Qualitative Assessment**

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

The tank capacity for Woodcote Wood is likely to not exceed 32m^3 as a maximum volume. Degradation rates in the aerobic phase range from 1.9 to 9.5 years. Dilution would also play an important role.

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

2.5.5.6 **Mining Subsidence**

Subsidence of mine workings is not considered a risk at this site based on BGS and Coal Authority data and is not considered further as part of this assessment.

2.6 Emissions to Groundwater

The hydrogeological risk assessment must establish whether the predicted discharge from the land raise complies with the requirements of the Groundwater Framework Directive, and the Environmental Permitting Regulations. This must be carried out for each of the considered scenarios (i.e. the different modelled phases of the lifecycle and the potential impact of accidents) and must include both Hazardous and Non-Hazardous Substances.

2.6.1 Hazardous Substances

- The predicted concentrations of Hazardous Substances at the point that they enter the groundwater from the base of the landfill is presented at from the modelling presented at Appendix HRA 3 and the failure model which is to take account of Rogue Loads is presented at Appendix HRA 4 are summarised in Table HRA 8 and are compared to the Minimum Reporting Values set out in the Environment Agency Guidance on Hydrogeological Risk Assessment and the concentrations are indiscernible and the site has no Hazardous Substance release predicted from the site.

Table HRA8. Hazardous Substances Maximum concentrations in Normal

Determinant	Model Concentration 50th percentile	Model Concentration 95th percentile	Minimum Reporting Value
Mercury	1.97E-6	1.35E-5	0.00001
Napthalene	No Breakthrough	No Breakthrough	0.004
Toluene	No Breakthrough	No Breakthrough	0.004

2.6.2 Non-Hazardous Substances

- The predicted concentrations of Non-Hazardous Pollutants are not likely to exceed relevant Drinking Water Standards at the monitoring boreholes and are summarised below in Table HRA 10 for the hydraulic containment model. The Drinking Water Standards have been used as the Environmental Acceptable Levels (EAL).

- The predicted concentrations of Non-Hazardous Pollutants are not likely to exceed relevant Drinking Water Standards at the monitoring boreholes and are summarised below in Table HRA 9. The Drinking Water Standards have been used as the Environmental Acceptable Levels (EAL).

- The determination of whether the introduction of Non-Hazardous Pollutants to groundwater has been sufficiently limited so as to avoid pollution. The model has not used cationic exchange and the maximum values have been used which for some are reported as less than which means the actual concentrations would be less than reported.

Table HRA 9. Non-Hazardous Pollutant Maximum Concentrations Normal Operations

Determinant	Model Concentration at the monitoring point 50%	Model Concentration at the monitoring point 95%	Drinking Water Standard	Time to Peak
Ammonia	0.06	0.06	0.39	20,000
Cadmium	0	0	0.005	20,000
Chloride	41.96	58.34	250	10,500
Copper	0	0	2.0	20,000
Zinc	0.092	0.140	5.0	20,000

The model shows that it will not affect the groundwater pumping station.

The PWS will also draw additional waters from all around the well with large areas with no influence from current of historic landfill activities.

2.6.3 Model results for other scenarios for Hazardous Substances

The results for the hazardous substances at the monitoring well are enclosed below for the models.

Table HRA10. Hazardous Substances Maximum concentrations

Determinant	Normal Operation	Poor Source Control	Reduced Unsaturated Zone	Increased Infiltration
Mercury	0.00014 50th percentile 0.00023 95th percential	0.00014 50th percentile 0.00022 95th percential	0.00014 50th percentile 0.0002 95th percential	0.0001 50th percentile 0.0002 95th percential
Napthalene	No Breakthrough	No Breakthrough	No Breakthrough	No Breakthough
Toluene	No Breakthrough	No Breakthrough	No Breakthrough	No Breakthrough

2.6.4 Model results for other scenarios for Non-Hazardous Substances

The results for the hazardous substances for the poor source control, reduced unsaturated zone and increased infiltration are presented below for the models.

Table HRA11. Non-Hazardous Substances Failure Scenarios

Determinant	Normal Operation	Poor Source Control	Reduced Unsaturated Zone	Increased Infiltration
Ammonia	0.06 50th percentile 0.06 95th percentile	0.06 50th percentile 0.06 95th percentile	0.06 50th percentile 0.06 95th percentile	0.06 50th percentile 0.06 95th percentile
Cadmium	No Breakthrough 50th percentile No Breakthrough 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile
Chloride	37.49 50th percentile 48.86 95th percentile	31.39 50th percentile 33.50 95th percentile	41.81 50th percentile 58.52 95th percentile	42.86 50th percentile 64.65 95th percentile
Copper	No Breakthrough 50th percentile No Breakthrough 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile
Zinc	0.094 50th percentile 0.143 95th percentile	0.009 50th percentile 0.140 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile	0.09 50th percentile 0.144 95th percentile

2.6.5 Model results for other scenarios for Hazardous Substances

The results for the hazardous substances for the poor source control, reduced unsaturated zone and increased infiltration are presented below for the models.

Table HRA10. Hazardous Substances Maximum concentrations

Determinant	Poor Source Control	Reduced Unsaturated Zone	Increased Infiltration	Minimum Reporting Value
Mercury	2.17E-6 50th percentile 1.47E-5 95th percential	8.85E-6 50th percentile 2.10E-5 95th percential	2.33E-6 50th percentile 1.63E-5 95th percential	0.00001

Napthalene	No Breakthrough	No Breakthrough	No Breakthough	
Toluene	No Breakthrough	No Breakthrough	No Breakthrough	0.004

All of the models do not show hazard substances in the unsaturated zone. All of the models and results are provided.

2.6.6 Model results for other scenarios for Non-Hazardous Substances

The results for the hazardous substances for the poor source control, reduced unsaturated zone and increased infiltration are presented below for the models.

Table HRA11. Non-Hazardous Substances Failure Scenarios

Determinant	Poor Source Control	Reduced Unsaturated Zone	Increased Infiltration	Drinking Water Standard
Ammonia	0.06 50th percentile 0.006 95th percentile	0.06 50th percentile 0.06 95th percentile	0.06 50th percentile 0.06 95th percentile	0.39
Cadmium	No Breakthrough 50th percentile No Breakthrough 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile	0.005
Chloride	32.71 50th percentile 38.05 95th percentile	41.81 50th percentile 58.52 95th percentile	75.22 50th percentile 144.80 95th percentile	250
Copper	No Breakthrough 50th percentile No Breakthrough 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile	No Breakthrough 50th percentile No Breakthrough 95th percentile	2.0
Zinc	0.09 50th percentile 0.139 95th percentile	0.092 50th percentile 0.139 95th percentile	0.09 50th percentile 0.139 95th percentile	5.0

The results from all of the failure scenarios show non hazardous pollutants are not likely to cause pollutions at the PWS. All of the results are below the Drinking Water Standards.

2.6.7 Surface Water Management

The site will not discharge surface water directly to any water course.

No breaches have been reported following construction of the lagoon and installation of the hydro brake.

2.6.6 Diesel Spillage

Di9esel will not be kept on site but brought to site for all vehicles using double skinned drums.

3.0 REQUISITE SURVEILLANCE

3.1 The Risk Based Monitoring Scheme

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

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

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

3.1.1 Leachate Monitoring

Leachate monitoring is not required at inert landfill sites.

3.1.2 Groundwater monitoring

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

Proposed borehole locations are presented at Drawing HRA 2.

It is intended that the additional borehole would be drilled under full time Construction Quality Assurance supervision and that six sets of groundwater would be obtained from each borehole so that Compliance Limits could be developed as part of the permit application.

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

Quality assurance of groundwater quality monitoring and sampling

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

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

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

Making and submission of records

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

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

A proposed action plan for groundwater the site is detailed below.

Table HRA 12: Proposed Action Plan in the Event of a Breached Compliance Level Concentration in Groundwater Monitoring Boreholes

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

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

Quality assurance of groundwater quality monitoring and sampling

Samples will be collected using a dedicated groundwater inertial pumps in individual boreholes or dedicated balers, to avoid cross contamination with groundwater samples, and which will be cleaned or rinsed with the first sampling between successive wells.

Appropriate protective equipment will be worn when handling groundwater. Samples will, where possible, be despatched to the laboratory on the same day, and in any event no later than the following day. Samples which are stored overnight will either be stored in a refrigerator or cool box. All samples will be analysed at UKAS accredited laboratory for the full suite listed in the permit.

Sampling will be undertaken by staff appropriately trained in environmental monitoring procedures, and who are familiar with the equipment and its limitations.

Making and submission of records

Records will be kept on site of determinands analysed, date of sampling, sampler, results, units and any repeat analysis or laboratory comment, or internal assessment, on the validity of the results. A copy of the results of sampling and analysis will be forwarded to the Agency within 1 month of being carried out.

Compliance Limits

The compliance levels will be set at geometric mean plus three times the standard deviation, based on all of the groundwater monitoring carried out from the installed and proposed boreholes.

Determinant	BH1
Ammonia	0.06
Cadmium	0.00006
Copper	0.1018
Mercury	0.000184
Napthalene	0.305
Toluene	0.1525
Zinc	0.227
Chloride	110.11

3.1.3 Surface Water Monitoring

Surface water monitoring is not required at the site.

4.0 CONCLUSIONS

4.1 Compliance with the Environmental Permitting Regulations 2010

The proposed extension to the Woodcote Wood inert landfill site complies with the following requirements of the Environmental Permitting Regulations 2016.

- The geological barrier complies with the requirements constructed under CQA will achieve an overall minimum permeability of 1 x 10^{-7}m/s
- The compliance of the installation with the specified engineering standards
- Hazardous substance release is below MRV
- Non-Hazardous Pollutants releases are in accordance with the Drinking Water Standards.
- Monitoring strategies are in place and recommended in line with the Environmental Permitting Regulations 2016 for inert landfill sites.

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

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

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