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Hydrogeological Risk Assessment
for Finningley Landfill Site

Contents

Disclaimer

1. Introduction

Tetron Finningley LLP is preparing an environmental permit application to landfill part of the remaining void of Finningley Landfill, east of Robin Hood Doncaster Sheffield Airport. This Hydrogeological Risk Assessment is prepared in support of the application and follows Environment Agency guidance for Hydrogeological Risk Assessment Reports.

The original landfill void was filled as a non-hazardous landfill. This application is for an additional discrete phase of landfilling, directly to the east of the existing landfill, which is proposed to comprise inert waste with asbestos.

Information used in the preparation of this report has been taken from the following sources:

- British Geological Survey
- TerraConsult 2010 Borehole Report
- Hydrogeo : 2012 : Derivation of Protective Standards for Importation of Material
- Monitoring data obtained by AA Environmental Limited.
- AAe : 2018 : Environmental Setting and Installation Design, Report No 173263/ESID.

2. The Site

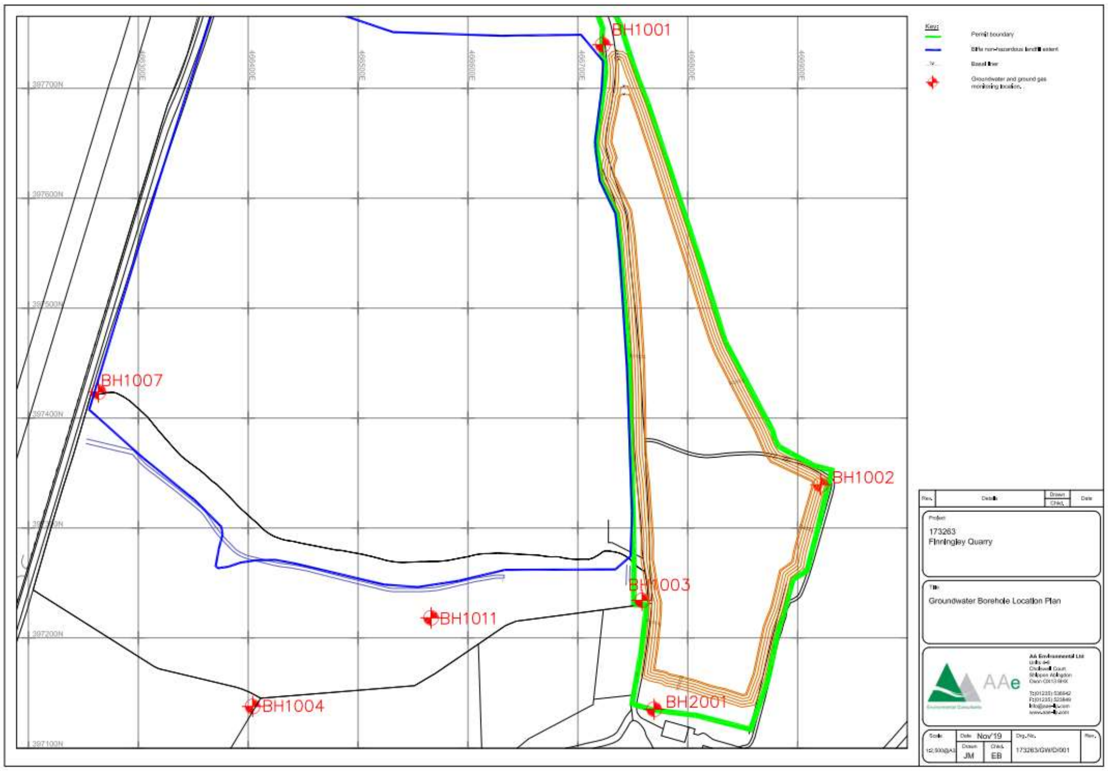
2.1. Location

The site is located approximately 1km southwest of the village of Finningley, Doncaster and can be located by postcode DN9 3BZ. The site is centred on SK667 974. The former Finningley Landfill, understood to have been operated by Biffa from 1977 to 1995, forms the western boundary. Directly west of the Biffa landfill is the Robin Hood Airport. There is wooded land to the north and east, some of which is used for off road motor cycle racing. The A614 runs approximately north to south 150 m east of the site at its closest point. There are a number of buildings at Brancroft, directly south of the site. Further south are open fields and Bawtry Golf Club.

A Site Plan is presented as Figure 1. The boundary of the application site is given in green. The boundary of the adjacent existing waste is given in blue.

Ground levels around the perimeter of the site are approximately 5m AOD. Sand extraction is currently taking place within the boundary of the site and excavations are expected to progress to - 1.5m AOD on average, being slightly shallower in the north and slightly deeper in the south.. There is also active sand extraction directly south of the Biffa Landfill.

Figure 1: Site Plan



2.2. Environmental Setting

The site setting is largely agricultural land, east of Robin Hood Airport and southeast of Doncaster. There are a few residential buildings south of the site and some industrial buildings approximately 500 m north, but much of the surrounding land is open fields. There are several Sites of Special Scientific Interest (SSSI) over 3km south and east of the site, which are protected on the basis of their fenland habitats. Their locations are given in Table 1. There are no Habitats Directive sites within 2km of the site boundary.

Table 1: Local Receptors

Receptor	Nature of receptor	Distance from site
Residential/Work-Place/Amenity -Within 50 m	Residential - Brancroft Amenity – motor cross	Directly south Directly east
Residential/Work-Place/Amenity - Between 50 and 250 m	n/a	n/a

Receptor	Nature of receptor	Distance from site
Residential/Work-Place/Amenity > 250 m	Robin Hood Airport Industrial units	350 m west 500 m north
Habitats		
Habitats Directive sites	None within 2 km	
CROW Act 2000 sites	River Idle Washlands SSSI Misson Training Area and Misson Line Bank SSSI	3.2 km south and 3.8km east 3.9km east
Other habitat sites	None within 2 km	
Groundwater		
Aquifer	Sherwood Sandstone – principal aquifer	On site
Groundwater protection zone	SPZ3	On site
Groundwater abstractions	Public water supply Golf club borehole Lafarge Aggregates – status unknown	850m southwest 850 m southwest 1km east
Surface Water		
Closest river	River Idle	3.2 km south
Direct runoff from site?	Surface water soakaway	Southeast corner
Surface water abstractions	None within 500 m	
Nitrate vulnerable zone	Yes	
Wells and springs		
Wells	None identified on local maps. None identified by Doncaster Council within 2km.	
Springs	None identified on local maps within 1km	
Air quality management zone	No	
Flood zone	Flood zone 3	

2.3. Site History

The site has been developed for sand and gravel extraction and in 1977 a landfill waste disposal licence was issued to Hoveringham Gravels (Midlands) Limited. The site address at the time was given as New Lane, Finningley, Doncaster, DN9 3DF and the licence was for the acceptance of non-hazardous, industrial and commercial waste. This included asbestos, but did not include putrescible/biodegadable waste. The licence was transferred to Biffa Limited in 1982. It is understood that filling finished in 1995 and therefore, operations pre-dated the Landfill Directive and Environmental Permitting Regulations. In 2012 a partial surrender of the site was completed for areas unfilled.

2.4. Application Summary

This application is for a new landfill phase on the eastern side of the area filled by Biffa. The area is currently completing sand extraction to an average depth of 1.5m below Ordnance Datum, with excavation faces at approximately 1 in 1, subject to the findings of the Stability Risk Assessment. Excavations will then be backfilled with quarry discards to -0.5mAOD and to form suitable side slopes. A geological barrier/ separation layer (GSL) will then be placed to a thickness of 1m, in accordance with an engineering method statement and to achieve a maximum permeability of 1×10^{-7} m/s. The GSL will comprise fines from quarry washings.

It is intended to import inert waste with asbestos. Landfilling will be completed to a domed profile, to a maximum of 7m AOD, in accordance with drawing 173263/PA/D/001. The landfill will be restored to ensure a suitable thickness of cover for asbestos wastes and to enable future agricultural use.

3. Geology and Hydrogeology

3.1. Geology

3.1.1. Site Geology

The geology of the site is the Chester Formation of the Sherwood Sandstone. The superficial deposits present on site are recorded by the British Geological Survey (BGS) geology of Britain viewer to be River Terrace deposits of sand and gravel. These have been largely removed by extraction. There are superficial glacial sands and gravels to the west of the site. To the east of the site and the A614 there are superficial Quaternary clays and silts overlying the Sherwood Sandstone in a north-south trending deposit. Further east, approximately 3 km east of the site boundary the outcrop of Sherwood Sandstone ends and the Mercia Mudstone forms the bedrock geology.

3.1.2. Borehole Records

The British Geological Survey (BGS) holds details of borehole records for locations close to the former landfill entrance, directly east of the airport runway and in the vicinity of the public water supply southwest of the site. All records show Sherwood Sandstone to depth, with the deepest being 173 m, southwest of the site. The borehole log for the location close to the former landfill entrance indicates some clay layers within the sandstone at depths of between 30 and 60 m. Four clay layers are recorded, of thickness varying between 0.3 and 2m.

3.2. Hydrogeology

3.2.1. General Properties

The bedrock geology of the site is designated as a principal aquifer. Surface soils are sandy and of high leaching potential. The BGS hydrogeological sheet of the Northern East Midlands, 1981, records the potentiometric surface in the Sherwood Sandstone in the vicinity of the site to be 0mAOD. The potentiometric contours are circular in this area and a large number of abstraction boreholes are identified within the sandstone.

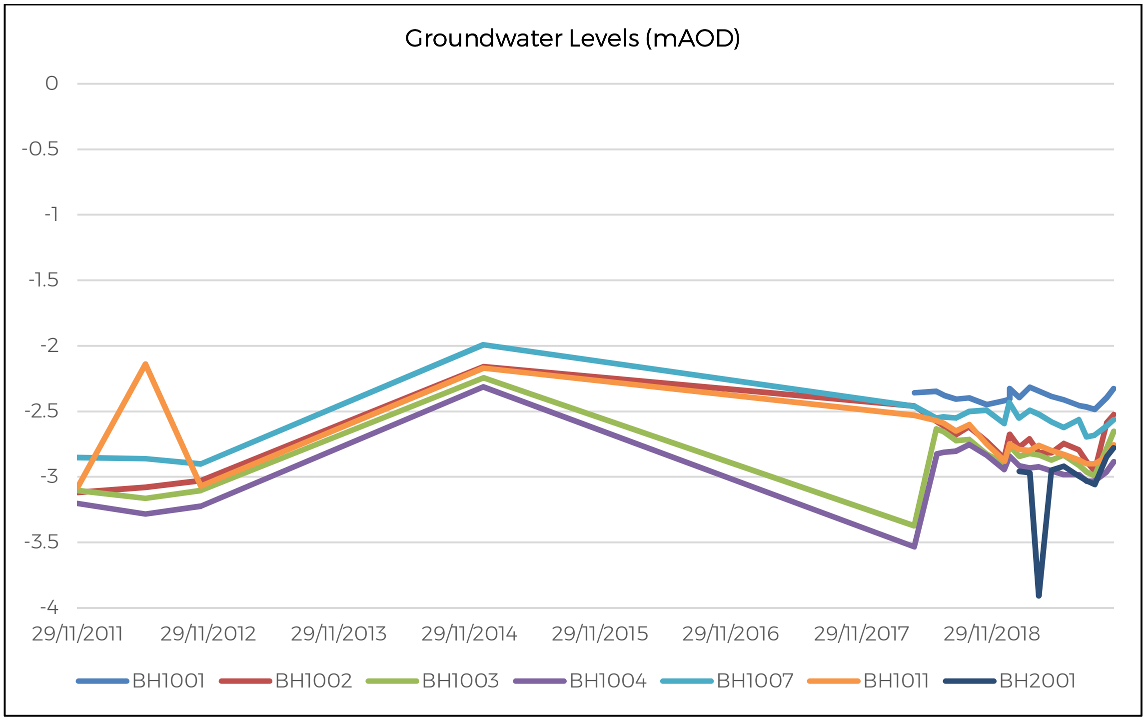
3.2.2. Abstractions and Springs

The closest abstraction to the site is the public supply borehole, approximately 850 m to the southwest, which is listed in the appendices to the ESID to have begun abstraction in 1993. There is also an abstraction associated with the local golf club in this location. Approximately 1km to the east is an abstraction in the name of Lafarge Aggregates. The status of this abstraction is unknown. There are no springs recorded on maps of the area close to the site. Approximately 3km east a number of properties have "spring" in their name. Here the ground level is very low, at around 3m AOD and the bedrock geology changes from Sherwood Sandstone to Mercia Mudstone.

3.2.3. Local Hydrogeology

Groundwater monitoring installations were constructed by TerraConsult in 2010, refer to Finningley Landfill Factual Report, Monitoring Well Installations. Groundwater monitoring has been undertaken by AAe Limited on several occasions between 2011 and present, with more regular monitoring undertaken in the last year. During this time the groundwater levels may have been affected locally in relation to the phasing of sand and gravel extraction, but show a general fall in levels towards the south, in the direction of the public water supply borehole. Groundwater level monitoring data is presented in Figure 2. All levels are below Ordnance Datum. BH1001 was not correctly located until April 2018, when monitoring was undertaken more regularly, so has a shorter monitoring record.

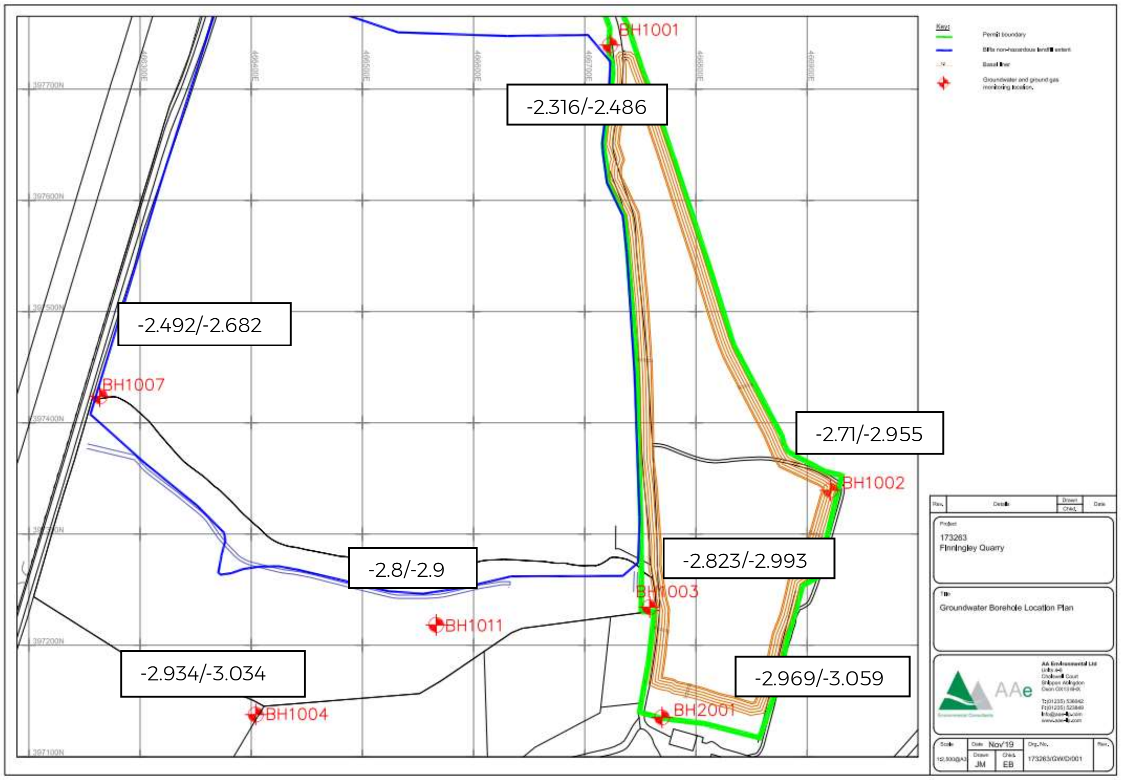
Figure 2: Groundwater Levels



Groundwater levels for March 2019 (the highest in the last 12 months) and September 2019 (the lowest in the last 12 months) are presented in Figure 3. The perimeter boreholes are approximately 15 to 16m deep and screened 3m below ground level. The data indicates a hydraulic gradient of between 0.0011 and 0.00095 across the site.

Hydrogeo, 2012, as part of an assessment for a potential waste recovery operation, presented the results of rising head permeability tests conducted in site boreholes during 2011. Results ranged from 3.2×10^{-7} to 4.7×10^{-5} m/s. The BGS borehole record for close to the former landfill entrance (SK 664 981) gives a transmissivity value of 560m^2/d. The rest water level was reported as 6m below ground level (bgl) and pumping water level at 18 m bgl. The borehole depth was reported as 122 m. This gives an overall permeability of 5 to 6 $\times 10^{-5}$ m/s.

Figure 3: Groundwater Levels, March/September 2019



3.2.4. Groundwater Quality

BGS Technical report CR/02/102N: Baseline Report Series : The Triassic Sandstones of the Vale of York indicates the following concentrations of common determinands within the Sherwood Sandstone, as summarised in Table 2.

Table 2: Background Groundwater Quality – Triassic Sandstone

Determinand	Minimum	Maximum	Mean
pH	6.49	7.88	7.25
DO (mg/l)	0	9.1	2.3
Cl (mg/l)	12.5	307	52.45
SO4 (mg/l)	6.1	1760	471
Cd (ug/l)	<0.05	0.15	<0.05
Hg (ug/l)	<0.1	0.3	<0.1
Ni (ug/l)	<0.2	25.3	4.68
Zn (ug/l)	1.7	548	56.1

Monitoring data available from AAe indicates the following groundwater conditions prior to the landfilling of the proposed inert cell, based on data from boreholes BH1001, BH1002, BH1003 and BH2001. The data is compared to the UK Drinking Water Standards as the environmental assessment level (EAL).

Table 3: Groundwater Quality Monitoring Data

Determinand	Average	Maximum	Minimum	UKDWS as EAL unless indicated (ug/l)
Arsenic (total) ug/l	1.68	8	1	10
Cadmium (total) ug/l	0.39	3	0.08	5
Chromium (total) ug/l	2.31	8.8	1	50
Copper (total) ug/l	1.22	3.2	1	2
Mercury (inorganic) ug/l	0.50	0.5	0.5	1
Nickel (total) ug/l	8.38	44	1	20
Lead (total)ug/l	1.08	4.4	1	10
Selenium (total) ug/l	1.46	4.5	1	10
Zinc (total) ug/l	13.35	68	1	10.9 [1] bioavailable + background
Ammoniacal nitrogen	1.67	6.3	0.01	0.39
Chloride (total) mg/l	34.92	450	7.7	250 mg/l
Sulphate (as SO4) mg/l	117.95	510	63	250 mg/l
Phenol (total) mg/l	<0.03	<0.03	<0.03	0.0077 [1]
TPH ug/l	13.07	110	10	10 [2]
PAH (total) ug/l	LOD = 0.1	LOD = 0.1	LOD = 0.1	0.1

1 – Freshwater EQS in the absence of available UKDWS
2 – WHO most stringent guideline for TPH, CL:AIRE : 2017: Petroleum Hydrocarbons in Groundwater. Guidance on assessing petroleum hydrocarbons using existing hydrogeological risk assessment methodologies.

The groundwater quality monitoring data indicates that maximum concentrations of copper, nickel, ammoniacal nitrogen, chloride and sulphate have exceeded the UK drinking water standard (UKDWS) on occasion. There is no current UKDWS for zinc. Recorded concentrations fail the bioavailable EQS. WHO guidelines (2002) suggest drinking water should be limited to 3mg/l of zinc. There are concentrations of TPH above the most stringent World Health Organisation (WHO) guideline.

3.3. Hydrology

The closest surface water course is a drain trending eastwards between Brancroft and the A614. East of the A614 drains form many of the field boundaries. There are ponds north and northeast of the site. The River Idle flows eastwards approximately 3.2km south of the site.

There are no surface water abstraction points within 1km of the site, according to Envirocheck records within the ESID report.

4. Conceptual Hydrogeological Site Model

4.1. Source

The source will be the inert wastes with asbestos placed in the proposed landfill cell as indicated in Figure 1. The area of the cell is approximately 5 ha. The waste will be placed above the geological separation layer (GSL) between 0.5 and 7m AOD, giving a range of thickness of between 4.5 and 6.5m. Council Directive 2003/33/EC lists those wastes which may be accepted at inert landfills without testing. The acceptable codes are presented in Table 4.

Table 4: Waste which can be accepted without testing

EWC Code	Description
10 11 03	Waste glass based fibrous materials, only without organic binders
15 01 07	Glass packaging
17 01 01	Concrete
17 01 02	Bricks
17 01 03	Tiles and ceramics
17 01 07	Mixtures of concrete, bricks, tiles and ceramics
17 02 02	Glass
17 05 04	Soil and stones, excluding topsoil, peat and soil and stones from contaminated sites
19 12 05	Glass
20 01 02	Glass
20 02 02	Soil and stones, from gardens and parks, excluding topsoil and peat

In addition to the EWC codes above, there will be asbestos wastes and inert waste which requires testing prior to acceptance. These wastes are controlled by inert Waste Acceptance Criteria (WAC), giving a likely maximum concentration for a range of determinands. WAC are expressed as mg/kg within the incoming wastes, but the majority of determinands are tested for their potential to leach from the waste. An equivalent leachate concentration in mg/l is 10% of the WAC concentration expressed in mg/kg. Council Directive 2003/33/EC also presents "first flush" leachate concentrations (C_o) and these are incorporated in to the leachate source term.

For organic determinands an equivalent leachability and C_o concentration is available for phenol. Other organics are limited by a total soil concentration.

Table 5: Waste Acceptance Criteria for Leachates

Determinand	WAC Leachate Criteria (LS=10l/kg) (mg/kg)	Equivalent leachability (mg/l)	Co concentration 2.1.2.1 2003/33/EC (mg/l)	EAL (mg/l) UKDWS unless noted otherwise
Arsenic (total)	0.5	0.05	0.06	0.01
Barium (total)	20	2	4	0.7 [1]
Cadmium (total)	0.04	0.004	0.02	0.005
Chromium (total)	0.5	0.05	0.1	0.05
Copper (total)	2.0	0.2	0.6	2
Mercury (inorganic)	0.01	0.001	0.002	0.001
Molybdenum (total)	0.5	0.05	0.2	0.07 [1]
Nickel (total)	0.4	0.04	0.12	0.02
Lead (total)	0.5	0.05	0.15	0.01
Antimony (total)	0.06	0.006	0.1	0.005
Selenium (total)	0.1	0.01	0.04	0.01
Zinc (total)	4.0	0.4	1.2	0.0109 [2] bioavailable + background
Chloride (total)	800	80	460	250
Fluoride (total)	10	1	2.5	1.5
Sulphate (as SO4)*	1000	100	1500	250
TDS	4000	n/a	n/a	n/a
Phenol Index	1.0	0.1	0.3	0.0077 [2]

1- World Health Organisation (WHO) Molybdenum is a health-based value as no guideline available
2- EQS – freshwater environmental quality standard
The values of TDS can be used instead of Cl or SO4.

In most instances, as demonstrated by Table 6 the equivalent leachability, or Co concentration exceeds the EAL (see highlighted cells) and therefore, it must be demonstrated that sufficient attenuation is available below the wastes.

4.2. Pathways

The chemical constituents within the leachate are separated from the underlying Sherwood Sandstone aquifer by a 1m thick geological barrier/GSL and underlying unsaturated zone. The GSL will comprise quarry fines from washing the sands quarried from site and will achieve a maximum permeability of 1 x 10^{-7} m/s, in line with regulatory requirements. It will be constructed between -0.5 and 0.5m AOD.

Sand extraction will take place to an average depth of -1.5m, being slightly shallower (-1m AOD) to the northern extent and slightly deeper (-2.5m AOD) towards the southern extent of the quarry. Quarry discards will be placed between the limit of excavation and -0.5m AOD. The discards are in the form of fine sands which are naturally darker in colour and of less commercial value. Recent testing of such material indicates a permeability of 5 x 10^{-7} m/s.

Below the quarry discards is a further unsaturated thickness of Sherwood Sandstone before groundwater is encountered. Groundwater level rests at an average of -2.75m AOD below the site, but levels can vary between -2 and -3.5m AOD. The permeability of the unsaturated zone is likely to be lower than that of the saturated zone, where flow paths are better developed. Values for permeability are likely to be at the lower end of those reported for the productive aquifer. The lower inter-quartile value for the permeability of the Sherwood Sandstone in this region of the country, taken from the BGS 1997, is 5.4 x 10^{-6} m/s.

The saturated Sherwood Sandstone is designated as a principal aquifer. The Environmental Permitting Regulations 2016 require that there is no discernible discharge of hazardous substances to groundwater and therefore, the pathway for hazardous substances (in Table 6 this applies to arsenic, lead and mercury) is limited to the base of the unsaturated zone. For non-hazardous pollutants it is required that input is limited to ensure there is no pollution. Non-hazardous pollutants will, therefore, be assessed once they have entered the aquifer, but the length of pathway will be limited to a position on the downgradient boundary of the site, the Landsim Monitor Well. Refer to section 5 for more details of the Landsim model.

4.3. Receptors

The closest receptor to the site is the public supply borehole, which is located approximately 850 m to the southwest. The site itself is in SPZ3 associated with this abstraction. The distance to SPZ2 is approximately 500m. There is a permitted abstraction approximately 1km to the east, but the status is unknown. There are no surface water receptors in the vicinity of the site.

Given that the groundwater in the Sherwood Sandstone is used locally for public water supply the UK Drinking Water Standards (UKDWS), given in the Water Supply (Water Quality) Regulations 2018, are considered to be the appropriate EAL.

5. Hydrogeological Risk Assessment

5.1. The Nature of the Hydrogeological Risk Assessment

Environment Agency guidance on landfill developments (EA webpage accessed September 2018: Landfill Developments: Groundwater Risk Assessment for Leachate) indicates that, if an inert waste landfill is in a sensitive area, such as in an aquifer, source protection zone (SPZ), or below the water table, then a simple risk assessment is insufficient and a more detailed risk assessment is required. Finningley is in a SPZ3 and therefore the potential risks posed to groundwater are assessed quantitatively using Landsim, the probabilistic software developed for the Environment Agency for this purpose.

5.2. The proposed assessment scenarios

Finningley will be an inert landfill, with a geological barrier and therefore, no long term management controls. The geological barrier will be assessed to determine the degree to which attenuation can be provided before potential contaminants reach the saturated zone, however, it is not designed as a leachate containment system.

5.3. The Priority Contaminants

The priority contaminants are considered to be those listed within the inert waste acceptance criteria to which a leachate limit is applied and where this limit exceeds the EAL as presented in Table 6. These determinands are listed below:

> Non-hazardous pollutants: Barium, Cadmium, Chromium, Molybdenum, Nickel, Antimony, Selenium, Zinc, Chloride, Fluoride, Sulphate,
> Hazardous substances: Arsenic, Lead and Mercury
> Organic contaminant: Phenol

5.4. Review of Technical Precautions

The technical precautions appropriate to an inert landfill with asbestos are:

- A geological barrier, of 1m thickness and permeability of maximum 1×10^{-7} m/s;
- Suitable capping to enable restoration and prevention of fibre release from buried asbestos.

A leachate containment system is not required. The permeability of the geological barrier will control the rate of release of any leachate, but prevent a build up which would require long term management. The Landsim model confirms that only a minimal head of leachate can be generated.

5.5. Numerical Modelling

5.5.1. Justification for Modelling Approach and Software

Landsim has been selected as the assessment tool. This is an Environment Agency approved assessment tool for landfill. The Landsim model allows selection of properties for the geological barrier separate to those of the rest of the unsaturated zone.

5.5.2. Model Parameterisation

Input parameters are sourced from site information where possible. Where there is insufficient site specific data, values are sourced from literature, much of which is described in the preceding sections of this report. The leachate source term is derived from inert waste acceptance criteria and includes both the equivalent leachability values and the Co values as a more conservative assumption. The leachate source chemistry is presented in Table 6.

Table 6: Input Criteria, Leachate

Determinand	Modelled concentration	Comment	Partition coefficient (ml/g)
Arsenic	0.06	Co	Uni (25, 31) [1]
Barium	4	Co	Uni (11,52) [2]
Cadmium	LogTri (0.004, 0.01, 0.02)	Range: equivalent leachability to Co	LogTri (3.7, 74, 1500) [1]
Chromium	0.1	Co	LogTri (1, 67, 4400) [1]
Mercury	0.002	Co	450 [1]
Molybdenum	0.2	Co	110 [1]
Nickel	0.12	Co	LogTri (20, 400, 8100) [1]
Lead	0.15	Co	LogTri (27, 270, $2.7e^{4}$) [1]
Antimony	0.1	Co	Uni(45,550) [2]
Selenium	0.04	Co	9.5 [1]
Zinc	1.2	Co	LogTri (1.1, 200, $3.6e^{4}$) [1]
Chloride	LogTri (80, 230, 460)	Range: equivalent leachability to Co	-
Fluoride	2.5	Co	0.8 [1]
Sulphate (as SO4)	LogTri (100, 750, 1500)	Range: equivalent leachability to Co	-
Phenol	Tri (0.03, 0.08, 0.3)	Range: (0.1Co – Co)	0.22 [1]
Phenol half life	GSL: Uni (0.03, 0.82) [1]		
Phenol half life	Unsaturated: Uni (0.03, 0.27) [1]		
Notes	Phenol half life: potential anaerobic conditions allowed for at base of waste in GSL		

1 = Consim Help File
2 = US EPA : 1996 : Soil Screening Guidelines: Technical Background Document

Other model input parameters are detailed in Table 7, with their derivations.

Table 7: Landsim Input Parameters

Parameter	Unit	Value	Source
Waste			
Infiltration to open waste	mm/yr	100	Effective rainfall
Cap design infiltration	mm/yr	100	Low permeability capping not required
End of filling	yr	20	
Cell dimensions	ha	6	Top area
Thickness	m	Uni (4.5, 6.5)	Landfill design contours
Waste porosity	fraction	Single (0.3)	Inert waste
Waste Dry Density	g/cm^3	Uni (1.15, 1.25)	Inert waste
Waste field capacity	fraction	Uni (0.2, 0.4)	Inert waste
Head of leachate when breakout occurs	m	4.5	Site surveys
Drainage System			
Head on EBS	m	Tri(0.04, 0.075, 0.2)	Derived from maximum head calculation
Waste hydraulic conductivity	m/s	Uni ($1e^{-7}$, $1e^{-3}$)	Silt to gravel
Primary drainage system		None	
Sump diameter	m	85	No sump. Value input to represent whole cell base.
Geological barrier			
Thickness	m	1	
Moisture content	fraction	0.22	Lab data
Hydraulic conductivity	m/s	$1e^{-7}$	
Longitudinal dispersivity	m	0.1	10% pathway length
Density	Kg/l	2	Laboratory data
Unsaturated zone – Quarry discards and Sherwood Sandstone			
Thickness	m	2 m	Thickness includes quarry discard backfill (1m) and underlying unsaturated zone to high groundwater level.
Moisture content	fraction	0.22	

Parameter	Unit	Value	Source
Hydraulic conductivity	m/s	Uni (5e-^{7}, 5.4e-^{6})	Lab data for quarry discards, lower interquartile value for Sherwood Sandstone North Region
Aquifer Pathway			
Pathway width	m	150	
Thickness	m	Uni (175, 200)	Local borehole record, BGS
Density	kg/l	2	Quarry data
Mixing zone thickness	%	Model calculation	
Relative vertical dispersivity	m	8.5m	1% of pathway length
Hydraulic conductivity	m/s	Uni (5.4e-6, 2.4e-5)	Interquartile range, Sherwood Sandstone, North Region, BGS Major Aquifers
Hydraulic gradient	-	Uni (0.00095 – 0.0011)	Site monitoring data, 2019
Pathway porosity	fraction	Uni(0.1,0.3)	
Distance to receptor	m	850	Public water supply southwest of site
Longitudinal dispersivity	m	85	10% of pathway length
Lateral dispersivity	m	8.5	10% of longitudinal

5.5.3. Sensitivity Analysis and Results

Modelled outputs are presented in Table 8. Results are displayed for arsenic, lead and mercury at the base of the unsaturated zone. Results for all other determinands are assessed at the monitor well. The position of the monitor well is fixed by Landsim to be 5 m downgradient of each landfill phase. In the instance of Finningley the whole site is represented as one cell and therefore, the monitor well is the appropriate point of assessment. The results presented are the 95th percentile peak concentrations, as determined from Landsim graphical outputs.

In addition to the main modelled scenario the sensitivity of two key parameters is assessed. The thickness of the unsaturated zone is reduced to 1.5m and increased to 2.5m. This is to allow for seasonal variation in the groundwater level. The hydraulic gradient of the Sherwood Sandstone aquifer is varied to single values equal to the maximum and minimum within the observed range. The gradient is varied between the extremes to ensure this potential variation is reflected in the model and does not generate a significantly different outcome.

The results show slight changes in concentrations between sensitivity runs, but all results are within the same order of magnitude and all remain below environmental assessment levels.

Table 8: Model Results and Sensitivity Analysis (mg/l)

Determinand	Scenario 1	Sensitivity 1 Unsat. zone = 1.5m	Sensitivity 2 Unsat zone = 2.5m	Sensitivity 3 hydraulic gradient single (0.0011)	Sensitivity 4 Hydraulic gradient single (0.00095)	EAL (mg/l) UKDWS unless stated
Arsenic	<1e-8	<1e-8	<1e-8	<1e-8	<1e-8	0.01
Barium	<1e-8	<1e-8	<1e-8	<1e-8	<1e-8	0.7 [1]
Cadmium	<1e-8	<1e-8	<1e-8	<1e-8	<1e-8	0.005
Chromium	3.6e-5	5.6e-5	2.9e-5	3.6e-5	3.7e-5	0.05
Mercury	<1e-8	<1e-8	<1e-8	<1e-8	<1e-8	0.001
Molybdenum	<1e-8	<1e-8	<1e-8	<1e-8	<1e-8	0.07
Nickel	<1e-8	<1e-8	<1e-8	<1e-8	<1e-8	0.02
Lead	<1e-8	<1e-8	<1e-8	<1e-8	<1e-8	0.01
Antimony	<1e-8	<1e-8	<1e-8	<1e-8	<1e-8	0.005
Selenium	<1e-8	<1e-8	<1e-8	<1e-8	<1e-8	0.01
Zinc	5.5e-7	4.6e-7	3.6e-7	3.8e-6	3.4e-6	0.0109 [2] bioavailable + background
Chloride	64	63	64	65	68	250
Fluoride	0.14	0.142	0.14	0.142	0.144	1.5
Sulphate (as SO4)	195	208	197	191	201	250
Phenol	3.7e-5	6.1e-5	2.2e-5	3.8e-5	3.9e-5	0.0077 [2]
	Results for hazardous substances					

[1] – WHO; [2] - EQS

Results for hazardous substances are assessed at the base of the unsaturated zone. Results for non-hazardous pollutants are assessed at the monitor well

5.5.4. Model Validation

The model suggests that there will be very little potential for build up of leachate within the wastes. Ongoing visual inspections of the site once operational will be used to validated this assumption.
The model predicts no deterioration in groundwater relative to the existing background conditions. Future groundwater monitoring of the site will be used to validate these predictions.

5.5.5. Accidents and their consequences

An accident which requires assessment within an inert landfill is the potential for the site to receive non-inert waste. In order to assess the consequence of such a scenario the Landsim model has been run iteratively to determine the increase in concentrations within the leachate which could be tolerated without adverse impact at the appropriate point of assessment. Leachate concentrations used in the initial scenario (Finn 1) have been varied by a factor of up to 10 in rogue load assessment one (RLA1) and up to 100 for metals in RLA2. The increased leachate source concentrations and results are presented in Table 9 below.

The results indicate no exceedances of the EAL for metallic determinands for an increase in concentration of a factor of 100.

For the non-metallic determinands the following increase in concentrations can be tolerated without exceedance of the EAL at the monitor well:

- Chloride – factor of 4
- Fluoride – factor of 10 or more
- Sulphate – factor of 1.25
- Phenol – factor of 3

It should be noted that this is a whole site assessment and therefore, a worst case scenario, as the waste acceptance procedures on site will minimise the likelihood that non-inert waste is accepted and should this occur it is unlikely to affect the entire waste mass. Leachate concentrations used in all models have been the C_o concentrations, which are much higher than the inert WAC criteria. This builds further conservatism into the assessment.

Table 9: Assessment of receipt of non-inert waste

Determinand	Initial Modelled concentration	RLA1 input Metals x 10	RLA2 input Metals x 100	RLA1 results	RLA2 results	EAL (mg/l) UKDWS unless stated
Arsenic	0.06	0.6	6	<1e-8	<1e-8	0.01
Barium	4	40	400	<1e-8	1.3e-8	0.7 [1]
Cadmium	Log Tri (0.004, 0.01, 0.02)	LogTri (0.04, 0.1, 0.2)	LogTri (0.4, 1, 2)	<1e-8	2.5e-8	0.005
Chromium	0.1	1	10	8.3e-5	0.001	0.05
Mercury	0.002	0.02	0.2	<1e-8	<1e-8	0.001
Molybdenum	0.2	2	20	<1e-8	<1e-8	0.07 [1]
Nickel	0.12	1.2	12	<1e-8	<1e-8	0.02
Lead	0.15	1.5	15	<1e-8	<1e-8	0.01
Antimony	0.1	1	10	<1e-8	<1e-8	0.005
Selenium	0.04	0.4	4	<1e-8	1.4e-8	0.01
Zinc	1.2	12	120	4.8e-6	6.7e-5	0.0109 [2] bioavailable + background
Chloride	LogTri (80, 230, 460)	X 5 (400, 1150, 2300)	X 4 (320, 920, 1840)	313	251	250
Fluoride	2.5	X 5 (12.5)	X 10 (25)	0.66	1.28	1.5
Sulphate (as	Tri (100, 750, 1500)	X 2 (200, 1500, 3000)	X 1.25 (125, 938, 1875)	387	263	250
Phenol	Tri (0.03, 0.08, 0.3)	X 2 (0.06, 0.16, 0.6)	X 3 (0.09, 0.27, 0.9)	7.4e-5	0.00011	0.0077 [2]
	Hazardous substance					

[1] – WHO; [2] - EQS

Results for hazardous substances are assessed at the base of the unsaturated zone. Results for non-hazardous pollutants are assessed at the monitor well.

5.6. Emissions to Groundwater

5.6.1. Hazardous Substances

The modelling and sensitivity analysis shows that the acceptance of inert waste at Finningley Landfill should not release discernible concentrations of hazardous substances in to the groundwater. The assessment of accidents in the form of receipt of non-inert waste indicates that there is some tolerance in the inert waste acceptance criteria in relation to this site and the accidental receipt of non-inert waste may not cause discernible discharge of hazardous substances.

5.6.2. Non-hazardous pollutants

The modelling and sensitivity analysis shows that the acceptance of inert waste at Finningley Landfill should not cause pollution of groundwater by non-hazardous pollutants. The assessment of accidents in the form of receipt of non-inert waste indicates that there is some tolerance in the inert waste acceptance criteria in relation to this site and the accidental receipt of non-inert waste will not automatically lead to pollution, depending on the volume and concentration of contaminants in the rogue load..

5.6.3. Surface water management

There are no surface water bodies on site. Temporary ditches will be used to direct rainfall away from the open waste during filling. An area of soakaway is designated in the southeastern corner of the site. This will be a temporary feature. While in operation it is recommended that visual inspection for oil and grease is made on a daily basis. Monitoring for pH and conductivity by hand held probe should be undertaken monthly. Analysis for metals, chloride, fluoride and sulphate should be undertaken quarterly.

5.7. Hydrogeological Completion Criteria

The site will receive inert waste and asbestos and will have no active leachate controls. The Landsim modelling indicates that the site is unlikely to fail to comply with the requirement of the Environmental Permitting Regulations in the absence of leachate control. Therefore, no hydrogeological completion criteria are required.

6. Requisite Surveillance

6.1. The Risk Based Monitoring Scheme

6.1.1. Leachate Monitoring

Leachate infrastructure is not required for an inert landfill and therefore, no leachate monitoring will be undertaken. Visual inspections of the site will be made on a regular basis as good working practice. This will include checks for any unusual seepages, or discolouration in low lying areas of the site that might indicate the landfill is generating unexpected leachate. This will enable investigation and any corrective measures to be undertaken. While this is an unlikely scenario, routine inspections should include such checks rather than assume that the potential for leachate generation is so low as to be disregarded.

6.1.2. Groundwater Monitoring – control and trigger levels

The Landsim modelling has indicated that the most sensitive chemical determinands with the potential to leach form the inert waste are chloride, chromium, sulphate and phenol. It is proposed that initial trigger/compliance levels for these determinands are set based on the historical monitoring of the site. It is also recommended that ammoniacal nitrogen is added to the compliance levels. The incoming waste will be inert and waste acceptance criteria do not assess ammoniacal nitrogen. However, ammoniacal nitrogen is a key indicator of biodegrading waste and this determinand is added as an additional control for the assessment of the potential receipt of biodegradable rogue loads.

It must, however, be considered that the site is adjacent to an existing landfill, which will also influence the local hydrogeological regime and groundwater quality. Therefore, it is proposed that the boreholes selected to be assigned both control and trigger/compliance levels are limited to locations BH1002 and BH2001, which are downgradient of the proposed new area of fill. Control levels will also be derived for boreholes BH1001 and BH1003, for reference purposes only. These boreholes have the potential to be influenced by the existing wastes to the west, so the control levels will be used to inform site management of any change in conditions and for comparison with downgradient BH1002 and BH2001.

Control levels are set based on mean concentration plus 2 x standard deviation. Trigger levels are set based on mean concentration plus 3 x standard deviation.

Table 10: Control and Trigger Levels

		NH4 (mg/l)	Chloride (mg/l)	Chromium (ug/l)	Sulphate (mg/l)	Phenol (mg/l)
BH1001	Min	0.05	20.0	1.00	92.00	0.03
	Max	5.40	24.0	3.50	140.00	0.03
	Average	1.83	22.2	1.32	103.71	0.03
	STDEV	2.00	1.1	0.70	11.33	0.00
	Control	5.83	24.5	2.72	126.37	0.03
BH1002	Min	0.01	7.7	1.00	63.00	0.03
	Max	4.70	130.0	8.80	400.00	0.03
	Average	1.55	23.7	2.96	91.44	0.03
	STDEV	1.67	27.2	2.43	75.07	0.00
	Control	4.90	78.0	7.81	241.59	0.03
	Trigger	6.57	105.2	10.24	316.67	0.03
BH1003	Min	0.01	7.7	1.00	65.00	0.03
	Max	6.30	450.0	6.30	160.00	0.03
	Average	1.72	36.6	2.48	90.50	0.03
	STDEV	1.97	100.4	1.98	27.51	0.00
	Control	5.67	237.4	6.44	145.52	0.03
BH2001	Min	0.05	52.0	1.00	100.00	0.03
	Max	4.20	150.0	6.70	510.00	0.03
	Average	1.50	105.0	2.14	352.00	0.03
	STDEV	1.59	36.6	2.28	142.32	0.00
	Control	4.68	178.3	6.70	636.65	0.03
	Trigger	6.27	214.9	8.98	778.97	0.03

[1] - Minimum reporting value; [2] – EQS

6.1.3. Surface Water Monitoring

There are no surface water bodies on site. The temporary soakaway in the southeastern corner of the site will be monitored in line with section 5.6.3.

7. Conclusions

7.1. Compliance with the Environmental Permitting Regulations

A quantitative hydrogeological risk assessment of the site has been undertaken using the Environment Agency approved assessment tool. This indicates that the site is unlikely to cause discernible discharge of hazardous substances, or pollution by non-hazardous pollutants. The site will be engineered with a 1m geological barrier to a maximum permeability of 1×10^{-7} m/s. The site is, therefore, considered to be compliant with the Environmental Permitting Regulations, 2016.

Trigger/compliance levels have been derived for downgradient boreholes. These, together with control levels for boreholes on the upgradient side of the site and adjacent to the existing non-hazardous waste, will be used to monitor the condition of the groundwater regime throughout the life of the permit.

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