REPORT

Biffa Waste Services Ltd

Eye Landfill, Eastern Extension

Hydrogeological Risk Assessment

Submitted to:

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1.0 INTRODUCTION

1.1 General

This Hydrogeological Risk Assessment (HRA) has been prepared by Golder, member of WSP in UK (Golder), on behalf of Biffa Waste Services Ltd (Biffa) in support of its Environmental Permit variation application (hereafter referred to as the 'variation application') for development of an Eastern Extension at Eye Landfill, Eyebury Road, Eye, Peterborough, Cambridgeshire, PE6 7TH (the 'Site').

1.2 Project Objectives and Description

Biffa currently operates the Southern Extension at Eye Landfill for the disposal of non-hazardous waste with dedicated stable non-reactive hazardous waste cells for asbestos wastes. The Site consists of four main areas compromising the Central Area, Northern Extension, Northeastern Extension, and Southern Extension.

Biffa intends to secure additional void space for non-hazardous waste landfill development at the neighbouring Willow Hall Farm Quarry and Inert Landfill, Willow Hall Lane, Thorney, Peterborough, PE6 0QN, which lies to the east of the existing Site (an 'Eastern Extension'), currently operated by PJ Thory Ltd ('Thory'). This will allow for continuous and uninterrupted landfilling operations after the current Southern Extension is completed. Both planning permission and an Environmental Permit for disposal of non-hazardous waste at the Eastern Extension will be needed.

Thory currently operates its Quarry and Inert Landfill under Environmental Permit (EP) EPR/DB3007TZ for inert landfill, which was issued to TAG Industries Ltd on 4 February 2016 and transferred to Thory on 14 November 2017 (EPR/FB3204MX). In addition, they hold an EP EPR/EB3091VZ for the discharge of trade effluent composed of quarry void/excavation dewatering, which was issued to TAG Industries Ltd on 10 February 2017 and transferred to Thory on 19 June 2017 (EPR/EB3091VZ/T002). It is proposed that these permits will be transferred to Biffa and consolidated with Biffa's existing Landfill Permit.

The Northeastern and Southern Extensions of the Site are currently authorised by EP EPR/BP/3537PP which was issued by the Environment Agency (EA) in 2005. The EP has been varied a number of times since, including to add in the Southern Extension, Miscanthus Beds for leachate treatment and for disposal of asbestos. The EP was last varied and consolidated by the EA in May 2018 (Variation Notice V010). The Site is permitted to accept 400,000 tonnes of non-hazardous waste, and 204,999 tonnes of inert waste per year. It is proposed to vary this permit to include the Eastern Extension as well.

This document forms the HRA to support the Eastern Extension planning and permit applications. The HRA aims to assess the potential impacts of extending the existing landfilled area as part of the proposed extension works. The report is prepared in accordance with the requirements of Schedules 10 and 22 of the Environmental Permitting Regulations, 2016.

1.3 Outline of Current Installation

Willow Hall Farm Quarry and Landfill is an active sand and gravel quarry operated by Thory. The site is being restored to a low level, flat lying restoration through the progressive importation of inert waste.

Pedestrian access to the site can be gained via Willow Hall Lane which runs southwest from the A47 trunk road; however, access for the export of sand and gravel and the import of inert waste is via a long, separate haul road from the east. Planning permission (reference: 12/01008/MMFUL) was obtained in 2013 and an EP (now EPR/FB3204MX/T001) in 2016.

Thory is systematically extracting mineral and filling with inert waste behind in a continuous operation from north to south. The sand and gravel is a shallow deposit of variable thickness. It occurs below the topsoil and silty overburden, and overlies clay. To date, the site has progressed as follows:

- 'Restored Area' (north end of site). Sand and gravel has been extracted at the northern end of the site and the void backfilled with inert waste. Prior to infilling, clay excavated from the base of the quarry has been placed against the sidewalls to provide a geological barrier and to manage groundwater. The Area has been completely filled, graded and restored to a flat lying low level restoration, about 1 m below surrounding ground level.
- 'Active Filling Area'. Sand and gravel has been extracted, clay placed, and inert waste is currently being deposited (back-tipped). Waste exposed in the tipping face appears to comprise primarily brown soil-like material.
- 'Active Extraction Area'. Sand and gravel has been extracted down to the top of clay. The haul road for dump trucks passes across this area to the mineral extraction face that extends west to east and defines the southern edge. All sand and gravel has been removed but all topsoil and overburden remained on site in areas already restored, in screening buns, and primarily in stockpiles on the quarry bottoms. Thory confirmed that 'overburden' refers to the upper mineral layers that compromise silty gravel which is not commercially viable and remains on site.
- 'Soil Stripping Area'. Topsoil has been stripped in advance of the working face to enable archaeological investigation to take place in accordance with the planning permission; and
- 'Unworked Area' (southern end of the site). The Unworked Area remains in agricultural use for the time being. The Green Wheel footpath passes across the Unworked Area but in time will be subject to diversion and then reinstatement as a bridleway on its original route, in accordance with the planning permission.

Thory estimated that mineral extraction will take to about 2025. Consequently, if Biffa enters the Eastern Extension in April 2023, mineral extraction will be advanced but not wholly complete.

The Eastern Extension Area boundary is c. 64.7 ha within which the mineral extraction at Willow Hall Quarry is about 41 ha. Mineral extraction is described by Thory in terms of three phases i.e. Northern, Central, and Southern. The boundary between the Central Phase and the Southern Phase occurs, west to east, just north of the Green Wheel footpath, where the base of the sand and gravel shallows. The recoverable mineral reserve tonnage was identified in the planning application to be 2.25 Mt.

1.3.1 Proposed Development

The Eastern Extension will be divided into 10 landfill cells numbered Cell 9 to Cell 18 in continuation of those in the Southern Extension. The design principles of the landfill lining system have been established through the development of Cells 1 to 8 in the Southern Extension which have been installed in accordance with the Environmental Permit. These design principles will continue in the development of Cells 9 to 18. Two additional cells, Cell 19 and 20, will be developed between the main Eastern Extension landfilling area and the Cat's Water Drain. These cells will receive inert waste previously deposited by Thory in the northern part of Willow Hall Farm Quarry and the Inert Landfill to release the area for acceptance of non-hazardous waste instead.

The classification of Eastern Extension Landfill will be non-hazardous.

The Southern Extension is anticipated to finish for the disposal of non-hazardous waste at end March 2023 and the Eastern Extension will therefore be proposed to open in April 2023. Stable non-reactive hazardous waste (asbestos waste) will continue to be accepted in the Southern Extension until end December 2025 but will not be taken in the Eastern Extension.

The permitted waste list for the Eastern Extension will be the same as that currently approved for the Southern Extension excluding stable non-reactive hazardous waste.

Waste is proposed to be accepted at a constant rate of 220,000 tpa for all years, pro rata during the last year.

At the above waste inputs, the landfill void space will be consumed at a rate of 211,000 m^3/year. Consequently, the Eastern Extension is expected to be operational for a period of about 15 years from April 2023 to about mid-2038.

Leachate will be managed in Cells 9 to 18 by means of pumping and extraction. The principles of leachate management have been established at the Southern Extension and are controlled through the Environmental Permit. Leachate management is not required in Cells 19 and 20 for inert waste.

1.4 Report Structure

This report presents the HRA for the Eastern Extension as follows:

- Section 2 summarises the conceptual hydrogeological site model for the Eastern Extension;
- Section 3 summarises the modelling developed for the Eastern Extension;
- Section 4 summarises the review of technical precautions in place for the Eastern Extension; and
- Section 5 summarises the requisite surveillance in place for the Eastern Extension.

2.0 CONCEPTUAL HYDROGEOLOGICAL SITE MODEL

2.1 Definitions

In the definition that has become accepted by the environmental and waste industries, there are three components to any risk assessment:

- The source is the potentially contaminative components of the leachate that will be generated by the percolation of infiltrating precipitation through the decomposing waste;
- The pathways are any routes linking the source with the receptors including the unsaturated zone and the saturated zone in which degradation processes may occur; and
- The receptors are groundwater and surface water bodies that are connected to the source by the pathways, such as surface watercourses, local supply boreholes, or springs.

These three components are linked within a hydrogeological conceptual model for a site. Should either one of the source, pathway or receptor, be absent from the site setting, negligible risk will be posed to the groundwater and surface water environment.

The three components of the risk posed from the disposal of waste at the Eastern Extension have been described in detail in the Environmental Setting and Installation Design (ESID) (reference 21453458.632) and are summarised in the following sections. The Site hydrogeological conceptual models for both 'normal operating conditions' and the 'failure scenario' are also presented as **Drawing HRA1** and **HRA2**.

2.2 Source

2.2.1 Proposed Design and Construction

The proposed layout for the Eastern Extension is shown on **Drawing HRA3**. Cells will be established in continuity with the Southern Extension starting with Cells 9 and 10 in the southern part of the Eastern Extension and progressing generally northwards in an anticlockwise manner through to Cell 18.

Two additional cells, Cell 19 and 20, will be developed between the main Eastern Extension landfilling area and the Cat's Water Drain. These cells will receive inert waste previously deposited by Thory in the Willow Hall Farm Quarry and Inert Landfill which will now become the Eastern Extension.

The mitigation measures incorporated into the landfill development include the nature of the Site's design and the management of any leachate that is produced. Cells within the existing site have been constructed on a containment basis, and it is proposed that all future landfill cells within the Eastern Extension will also be constructed on a containment basis. Waste disposal will only take place in individual cells thus allowing for the containment and collection of any leachate produced.

The design principles of the landfill lining system have been established through the development of Cells 1 to 8 in the Southern Extension which have been installed in accordance with the Environmental Permit. It is proposed that the cell design principles, including liner, capping, leachate management and groundwater management, will follow those already adopted for the existing site.

It is therefore proposed that each cell in the Eastern Extension is constructed broadly as follows:

- Base and Side Slope Liner – in-situ clay and placement of 1 m of engineered clay with a permeability of no greater than 1×10^{-9} m/s (non-hazardous waste) or 1×10^{-7} m/s (inert waste).

- Leachate Drainage – in the non-hazardous waste cells the leachate drainage blanket will comprise material to conform to the specification presented within the Construction Quality Assurance (CQA) Plan submitted to the Environment Agency prior to construction. Installation and CQA procedures for the leachate drainage blanket will be defined within the CQA Plan. Leachate is not required to be managed in inert waste Cells 19 and 20.
- Capping – 200 mm regulation layer with 1 m of engineered clay with a maximum permeability of 1 x 10^{-9}m/s, Geosynthetic Clay Liner (GCL) or fully welded LLDPE geomembrane above, and then subsoil and topsoil.

2.2.2 Leachate Management

Leachate will be managed in Cells 9 to 18. The principles of leachate management have been established at the Southern Extension and are controlled through the Environmental Permit.

The leachate drainage and removal system will typically comprise a drainage blanket across the cell base, with drainage pipes, at a minimum of a 1% gradient leading to a sump in each cell. The drainage blanket will usually comprise aggregate, recycled aggregate, shredded tyres, or baled tyres adopting the same practice as the Southern Extension. Leachate will be removed from the lowest point in the basal drainage system of each cell by means of a vertical or side slope leachate extraction well extending to the surface of the landfill. The wells will accommodate automatic pumping equipment (eductor or submersible pumps) to extract leachate.

It is proposed that leachate will be pumped via pipework towards the Cat's Water Drain crossing, passed which it will connect with the existing leachate management system for the Northern and Northeastern Extensions. The leachate will be pumped to a leachate storage tank near the Site Reception from where it will be transferred to road tanker for removal.

Whilst the cells are operational, leachate may be re-circulated after collection in the extraction wells. The leachate will be returned to the waste mass to control the leachate level on the basal liner (by increasing evaporative loss and fully utilising the absorptive capacity of the waste) and to accelerate the stabilisation of the waste mass.

The leachate collection and removal system will conform to a specification contained within a CQA Plan submitted to the EA prior to construction in accordance with the Environmental Permit. Design and CQA procedures are defined within the CQA Plan. A CQA Validation Report, which presents the final *as built* construction and engineered details of each cell, is submitted to the EA after construction.

The Eastern Extension Landfill will be hydraulically separated from its immediate surroundings by the engineered lining system and leachate levels across the base will be managed in accordance with the Environmental Permit i.e. Cells 9 to 18 will be hydraulically separated from each other by lined bunds, approximately 2 m high and from Cells 19 and 20 by a full height bund. The use of the inter-cell bunds will ensure that surface water collecting in non-operational sections of the Eastern Extension will remain uncontaminated by leachate. In addition, the bunds would assist in the control, containment and collection of leachate generated by landfilling operations.

Leachate management is not required in Cells 19 and 20 (inert waste cells). Leachate generated within the inert waste landfill will, by definition, not be contaminated and will be allowed to infiltrate to groundwater without collection, treatment or disposal.

2.2.3 Leachate Levels

The Eastern Extension landfill will be operated under the principle of hydraulic containment. This means that leachate levels will need to be maintained at a level below external groundwater levels (in the surrounding Quaternary River Terrace Deposits and underlying Kellaways Sand) to achieve hydraulic containment. As the Eastern Extension is not yet developed, no leachate level data is currently available. It is proposed that the future permitted leachate level is specified at 1.4 m above the base of the cell (which based on data for the Kellaways Sand, and for the river terrace deposits from prior to quarry dewatering should be greater than 1 m below minimum groundwater levels). Provided leachate levels are maintained at this level, no advective pathway exists for the migration of leachate from the Site. Each cell will have infrastructure installed to manage leachate at the required level (described in Section 2.2.2).

2.2.4 Leachate Quality and Priority Contaminants

2.2.4.1 Leachate Quality

The Eastern Extension will be classified as a non-hazardous landfill. It is expected that it will receive the same range of wastes as the existing Southern Extension and the source term is therefore based on leachate concentrations from it until such time as leachate data becomes available for the Eastern Extension. **Table HRA1** summarises the leachate quality taken from boreholes across the Southern Extension during the 2016 – 2021 period, for priority contaminants defined in the HRAR (Hafren Water, 2015). **Table HRA2** provides a summary of the hazardous substances detected in the leachate generated in the Southern Extension between 2016 and 2021.

Table HRA1: Summary of Leachate Concentrations - Southern Extension (2016-2021)

Parameter	Minimum	Median	Maximum	Mean	Standard Deviation
Ammoniacal nitrogen (mg/l)	530	1,690	2,200	1,605	402
Chloride (mg/l)	1,100	3,230	20,500	4,117	3,110
Nickel (mg/l)	0.16	0.50	1.09	0.52	0.20
Cadmium (mg/l)	<0.0006	0.0019	0.0091	0.0026	0.0020
Toluene (µg/l)	5.4	40.3	167.0	58.5	45.0

It is anticipated that the source term in the Eastern Extension will be broadly in-line with the Southern Extension. Future monitoring of leachate, with a full suite of analysis including hazardous substances, in the Eastern Extension will provide a specific source term for the Eastern Extension going forward.

Table HRA2: Summary of Hazardous Substances Detected in Leachate in the Southern Extension between 2016 and 2021

Parameter (µg/l)	Standards (µg/l)			Leachate Borehole ID															
				USR1				USR2				USR3				USR7			
	UK DWS	FW EQS	MRV	Minimum	Mean	95%ile	Maximum	Minimum	Mean	95%ile	Maximum	Minimum	Mean	95%ile	Maximum	Minimum	Mean	95%ile	Maximum
1,2,4-Trimethylbenzene	-	0.4	30	4.65	22.84	68.73	80	5.6	35.20	76.28	80	3.87	31.29	76.19	80	1.86	2.93	3.89	4
1,4-Dichlorobenzene	-	-	-	1.25	21.33	68.60	80	1.28	33.76	76.06	80	1.02	30.34	76.05	80	1	2.50	3.85	4
4-Chlorophenol	-	50	-	2.46	6.23	9.62	10									10	35.00	57.50	60
Arsenic	10	50	-	**32**	**57.21**	**83.60**	**104**	**61**	**95.33**	**135.80**	**137**	**19**	**65.00**	**91.40**	**93**	**40**	**174.55**	**415.00**	**521**
Benzene	1	10	1	**3.46**	**22.19**	**68.60**	**80**	**5.08**	**35.03**	**76.25**	**80**	**5.02**	**31.67**	**76.25**	**80**	**4**	**4.05**	**4.10**	**4.1**
Chlorobenzene	-	-	-	2.87	22.05	68.60	80	1.39	33.80	76.07	80	1	30.33	76.05	80	1	2.50	3.85	4
Chromium	50	3.4	-	**284**	**635.81**	**830.50**	**897**	**509**	**699.46**	**796.30**	**848**	**104**	**542.08**	**827.95**	**856**	**564**	**743.09**	**887.00**	**950**
Dichlobenil	-	-	-	0.118	0.16	0.17	0.165	0.042	0.12	0.17	0.165	0.044	0.12	0.17	0.165	0.056	0.11	0.16	0.165
Dichlorprop	-	-	6	5	8.53	18.10	20	8.34	15.11	25.34	26.1	2	4.51	6.45	6.53	5	12.50	19.25	20
Diuron	-	0.2	-	17.7	184.23	403.85	419	63.8	347.90	632.00	632	23.1	346.55	670.00	670				
Ethyl benzene	-	-	15	14.1	29.60	70.60	80	40.5	56.77	78.49	80	10	36.97	77.05	80	10.1	11.70	13.14	13.3
Fenitrothion	-	0.01	0.001	0.045	0.15	0.18	0.176	0.045	0.13	0.18	0.176	0.045	0.13	0.18	0.176	0.059	0.12	0.17	0.176
Lead	10	1200	-	**28**	**124.29**	**300.40**	**370**	**34**	**119.00**	**200.60**	**212**	**8**	**85.50**	**159.00**	**172**	**6**	**197.00**	**406.50**	**482**
M and P-xylene	-	30	3	15.4	30.62	70.97	80	31.5	52.30	78.27	80	10.7	34.87	76.70	80	5.75	8.33	10.64	10.9
Mercury	1	0.07	0.01	0.1	0.10	0.10	0.1	0.1	0.10	0.10	0.1	0.1	0.10	0.10	0.1				
O-Xylene	-	30	3	8.91	26.00	69.67	80	19	39.67	76.95	80	8.33	32.78	76.42	80	3.9	5.16	6.29	6.42
Styrene	-	50	-	1	21.45	68.60	80	1	33.67	76.05	80	1	30.33	76.05	80	2.42	3.21	3.92	4
Toluene	-	74	4	13.5	29.02	70.43	80	22.2	47.23	77.98	80	10	36.27	76.94	80	27	35.05	42.30	43.1
Xylene (o+p+m)	-	30	3	24.3	27.67	30.51	30.8	64.4	64.40	64.40	64.4	22.2	22.20	22.20	22.2	9.65	13.48	16.92	17.3

Parameter (µg/l)	Standards (µg/l)			Leachate Borehole ID											
				USR8				LEW5				LEW6			
	UK DWS	FW EQS	MRV	Minimum	Mean	95%ile	Maximum	Minimum	Mean	95%ile	Maximum	Minimum	Mean	95%ile	Maximum
1,2,4-Trimethylbenzene	-	0.4	30	1.03	12.41	34.68	40	NR	NR	NR	NR	2.78	3.39	3.94	4
1,4-Dichlorobenzene	-	-	-	1	11.50	34.60	40	NR	NR	NR	NR	1	2.50	3.85	4
4-Chlorophenol	-	50	-	10	65.00	114.50	120	**180**	**180**	**180**	**180**	10	20.00	29.00	30
Arsenic	10	50	-	**28**	**71.92**	**122.80**	**160**	NR	NR	NR	NR	**51**	**71.00**	**91.20**	**96**
Benzene	1	10	1	**1.67**	**14.35**	**35.30**	**40**	NR	NR	NR	NR	**3.74**	**3.87**	**3.99**	**4**
Chlorobenzene	-	-	-	1	11.67	34.60	40	**1040**	**1040**	**1040**	**1040**	1	2.50	3.85	4
Chromium	50	3.4	-	**64**	**587.35**	**838.80**	**850**	NR	NR	NR	NR	**594**	**743.43**	**867.30**	**882**
Dichlobenil	-	-	-	0.034	0.13	0.17	0.165	NR	NR	NR	NR	0.165	0.17	0.17	0.165
Dichlorprop	-	-	6	4.79	13.66	20.00	20	NR	NR	NR	NR	5	12.50	19.25	20
Diuron	-	0.2	-	10.2	53.10	91.71	96	NR	NR	NR	NR				
Ethyl benzene	-	-	15	6.52	67.68	92.84	93.2	NR	NR	NR	NR	19.5	22.50	25.20	25.5
Fenitrothion	-	0.01	0.001	0.036	0.14	0.18	0.176	**325**	**325**	**325**	**325**	0.176	0.32	0.46	0.473
Lead	10	1200	-	**13**	**185.31**	**325.60**	**334**	NR	NR	NR	NR	6	**112.71**	**243.00**	**270**
M and P-xylene	-	30	3	2.37	17.44	36.36	40	NR	NR	NR	NR	12.1	16.35	20.18	20.6
Mercury	1	0.07	0.01	0.1	0.10	0.10	0.1	NR	NR	NR	NR				
O-Xylene	-	30	3	1.76	13.94	35.22	40	NR	NR	NR	NR	6.22	7.81	9.23	9.39
Styrene	-	50	-	1	19.05	37.77	40	NR	NR	NR	NR	2.93	3.47	3.95	4
Toluene	-	74	4	5.36	31.32	40.94	41.1	NR	NR	NR	NR	24.4	95.70	159.87	167
Xylene (o+p+m)	-	30	3	4.13	15.18	23.18	23.8	NR	NR	NR	NR	18.3	24.15	29.42	30

*Notes: Concentrations in **bold** indicate exceedances of UK Drinking Water Standard (UK DWS), concentrations underlined indicate exceedances of Freshwater Environmental Quality Standards (FW EQS), and concentrations with a grey background indicate an exceedance of EA Minimum Reporting Value (MRV). '-' = standard not available. NR = not recorded.*

2.2.4.2 Additional Substances to Those Included in the Southern Extension HRA

During the review of the monitoring data, a consideration has been made of whether the determinands included in the source term for the assessment are the most appropriate on the basis of detected concentrations relative to the lowest relevant quality standard (either FW EQS or UK DWS). The selection of ammoniacal nitrogen and chloride as representative inorganic anion and inorganic cation respectively for the assessment is not required to be reviewed further given their ubiquitous presence in leachate.

2.2.4.2.1 More Mobile Metallic Ions

A more mobile metallic ion considered in the previous HRAs is nickel. A screening of the detected concentrations in the leachate monitoring dataset for the period 2016 to 2021 for nickel and zinc against their respective quality standards is presented in **Table HRA3**. From this comparison, it is identified that at the mean and maximum observed concentration, nickel is the most concentrated more mobile metallic ion in the source term and hence remains the most representative to assess. Two zinc concentrations were disregarded in the statistical analysis; 259 mg/l (26 May 2016) and 4.86 mg/l (20 April 2021) as they are considered anomalies and outliers skewing the final results.

Table HRA3: Screening of More Mobile Metallic Ions in Leachate

Parameter	Units	Mean	Max	FW EQS	UK DWS	Multiples of Mean	Multiples of Max
Nickel	µg/l	521.3	1,090	4	20	130	273
Zinc	µg/l	817.3	2,760	10.9	-	75	253

Notes: The multiples statistic has been compared against the lowest quality standard as worst-case scenario.

2.2.4.2.2 Acid Herbicides

Acid Herbicides were not considered in the Southern Extension HRA. A screening of the detected concentrations in the leachate monitoring dataset for the period 2016 to 2021 for dichlorprop and mecoprop against their respective quality standards is presented in **Table HRA4**. From this comparison, it is identified that at the mean and maximum observed concentration, mecoprop is the most concentrated acid herbicide in the source term and hence it is the most representative parameter to assess.

Table HRA4: Screening of Acid Herbicides in Leachate

Parameter	Units	Mean	Max	FW EQS	UK DWS	Multiples of Mean	Multiples of Max
Dichlorprop	µg/l	10.8	26.1	-	0.1*	108	261
Mecoprop	µg/l	61.2	95	18	0.1	612	950

Notes: The multiples statistic has been compared against the lowest quality standard as worst-case scenario. '' = Dichlorprop does not have a UK DWS; however, the WHO DWS is the same as for mecoprop, and so has been applied. For the purpose of statistical analysis, concentrations at the limit of detection have been put equal to the detection limit concentration.*

2.2.4.2.3 Less Mobile Metallic Ions

Cadmium was considered in the source term as a less mobile metallic ion in the Southern Extension HRA. A screening of the detected concentrations in the leachate monitoring dataset for the period 2016 to 2021 for arsenic, cadmium, chromium, and mercury against their respective quality standards is presented in **Table HRA5**. From this comparison, it is identified that at the mean and maximum observed concentration of chromium are the most concentrated less mobile metallic ion in the source term, however, the report does not differentiate between chromium III and VI. Cadmium and arsenic were detected in the leachate above the limit of detection. According to JAGDAG classification, cadmium is no longer considered a hazardous substance. Therefore arsenic, a hazardous substance and the next most concentrated ion in leachate, is chosen as the most representative less mobile metallic ion of the source term.

Table HRA5: Screening of Less Mobile Metallic Ions in Leachate

Parameter	Units	Mean	Max	FW EQS	UK DWS	Multiples of Mean	Multiples of Max
Arsenic	µg/l	91.6	521	50	10	9.16	52.1
Cadmium	µg/l	1.93	9.1	0.8	5	2.41	11.4
Chromium	µg/l	645	1,040	4.7	50	137	221
Mercury	µg/l	0.1	0.1	0.07	1	1.43	1.43

Notes: The multiples statistic has been compared against the lowest quality standard as worst-case scenario. For the purpose of statistical analysis, concentrations at the limit of detection have been put equal to the detection limit concentration.

2.2.4.2.4 Hydrophobic Organic Chemicals

Hydrophobic organic chemicals were not considered in the source term in the Southern Extension HRA. A screening of the detected concentrations in the leachate monitoring dataset for the period 2016 to 2021 for anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(ghi)perylene, benzo(k)fluoranthene, fluoranthene, naphthalene, and total xylene against their respective quality standards is presented in **Table HRA6**. Although hazardous substances anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(ghi)perylene, benzo(k)fluoranthene, and fluoranthene have higher multiples of both the mean and maximum compared to the UK DWS or FW EQS, the concentrations used for this calculation are the limits of detection and were not present in detectable concentrations in the leachate from the Southern Extension. It is therefore considered that naphthalene is the most appropriate hydrophobic organic chemical to be modelled due to its presence in the leachate. From this comparison, it is identified that at the mean and maximum observed concentration of naphthalene is the most concentrated hydrophobic organic chemical present at detectable concentrations in the source term and hence is most representative of the source term.

Table HRA6: Screening of Hydrophobic Organic Chemicals in Leachate

Parameter	Units	Mean	Max	FW EQS	UK DWS	Multiples of Mean	Multiples of Max
Anthracene	µg/l	151	200	0.1	-	1,509	2,000
Benzo(a)pyrene	µg/l	151	200	0.27	0.01	15,091	20,000
Benzo(b)fluoranthene	µg/l	151	200	0.017	0.1*	8,877	11,765
Benzo(ghi)perylene	µg/l	151	200	0.0082	0.1*	18,404	24,390
Benzo(k)fluoranthene	µg/l	151	200	0.017	0.1*	8,877	11,765
Fluoranthene	µg/l	151	200	0.0063	0.1*	23,954	31,746
Naphthalene	µg/l	126	400	2	-	63	200
Xylene (Total)	µg/l	24	64.4	30	-	0.81	2.15

Notes: The multiples statistic has been compared against the lowest quality standard as worst-case scenario. For the purpose of statistical analysis, concentrations at the limit of detection have been put equal to the detection limit concentration.
'' = UK DWS for these PAH is summed up to a maximum of 0.1 µg/l.*

2.2.4.2.5 Hydrophilic Organic Chemicals

Toluene was considered in the source term as a hydrophilic organic chemical in the Southern Extension HRA. A screening of the detected hydrophilic organic substances in the leachate against their respective quality standards is presented in **Table HRA7**. Hydrophilic organic chemicals without a suitable quality limit have not been included in the assessment. From this comparison it is identified that at the mean and maximum observed concentration of phenol is the most concentrated hydrophilic organic chemical in the source term and hence is most representative of the source term replacing toluene.

Table HRA7: Screening of Hydrophilic Organic Chemicals in Leachate

Parameter	Units	Mean	Max	FW EQS	UK DWS	Multiples of Mean	Multiples of Max
2,4-Dimethylphenol	µg/l	104	200	4.2	-	25	48
3,5-Dimethylphenol	µg/l	83	340	-	1*	83	340
Benzene	µg/l	20	80	10	1	20	80
Phenol	µg/l	4,548	46,500	7.7	-	591	6,039
Toluene	µg/l	41	167	74	-	0.56	2.26

Notes: The multiples statistic has been compared against the lowest quality standard as worst-case scenario. For the purpose of statistical analysis, concentrations at the limit of detection have been put equal to the detection limit concentration. '' = Taste threshold (NTP, 1992).*

2.2.4.3 Priority Contaminants

Both hazardous substances and non-hazardous pollutants are anticipated to be present within the leachate to be produced in the Eastern Extension.

In accordance with the analysis provided in Section 2.2.4.2, the priority contaminants to be assessed for the Eastern Extension are:

- Ammoniacal nitrogen – non-hazardous inorganic chemical.
- Arsenic – hazardous less mobile metallic ion.
- Chloride – non-hazardous inorganic chemical.
- Mecoprop – non-hazardous acid herbicide.
- Naphthalene – non-hazardous hydrophobic organic chemical.
- Nickel – non-hazardous more mobile metallic ion.
- Phenol – non-hazardous hydrophilic organic chemical.

2.3 Pathways

2.3.1 Geology

2.3.1.1 Regional Geology

The British Geological Survey Sheet 158 for Peterborough and BGS Geoindex indicates that the Eastern Extension is underlain by Quaternary River Terrace deposits which overlie the Jurassic Oxford Clay Formation and Kellaways Sand. The geological succession is summarised in Table HRA8.

Table HRA8: Summary of Regional Geology

Age	Formation	Description	Approximate Thickness (m)
Quaternary	River Terrace Deposits	Sand and gravel with some silt	Variable
Jurassic	Oxford Clay	Olive grey fossiliferous, bituminous shale and blocky mudstone	63 – 76 m
	Kellaways Sand	Grey clayey silt and mud	1.9 – 6.4 m
	Kellaways Clay	Grey fissile mudstone	1.4 – 5.8 m
	Cornbrash	Fine grained shell-detrital limestone	1.2 – 4.3 m
	Blisworth Clay	Grey/Green mudstone with thin limestone	3.0 – 6.0 m
	Blisworth Limestone	Shell-detrital to micritic limestone with marl and mudstone	1.9 – 5.1 m

2.3.1.2 Local Geology

The Site has been the subject of numerous Site Investigations for both the excavation of mineral reserve and the subsequent landfill development. In total, 93 mineral investigation boreholes were drilled by ARC in 1992 and an additional 18 mineral investigation boreholes were drilled by Thory in 2011 (BH11/01 to BH11/12 and BHP11/01 to BHP11/06). As the elevation of the base of the Oxford Clay was not subject to the site investigation carried out in 1992 or 2011, five further site investigation/monitoring boreholes were installed by Biffa in 2021. The drilling works were undertaken between 22 February 2021 and 10 March 2021 and comprised the drilling of five boreholes (BH21-01 to BH21-05) to depths of between 21.3 and 27.2 m below ground level (bgl) including a minimum of 3 m into the Kellaways Formation, and installation as groundwater monitoring boreholes.

The geological succession beneath the Site can be summarised as:

- River Terrace Deposits:

Site investigation information obtained in 1992 and 2011 shows that the mineral extraction area is underlain by:

  - c. 0.3 m topsoil;
  - c. 0.6 m to c. 2 m of sandy, gravelly, clay subsoil (‘overburden’); and
  - c. 0.8 m to c. 6.3 m of sand and gravel (‘mineral’) (average c. 3.9 m).

- Oxford Clay:

The Oxford Clay is a well-consolidated, calcareous clay which may be silty or sandy with thin cemented siltstone or mudstone bands.

Although the top of the Oxford Clay (i.e. base of the sand and gravel) is well understood, the elevation of the base of the Oxford Clay was not subject to the Site investigation carried out in 1992 or 2011. The full thickness of the Oxford Clay was proven in all five boreholes drilled during the 2021 investigation, and ranged from between 12.3 and 17.5 m.

- Kellaways Sand:

Below the Oxford Clay is the Kellaways Sand which consists predominantly of silty sands, clayey silts with siltstone and mudstone. The strata are underlain by the Cornbrash and Blisworth Limestone.

During the 2021 Site investigation, the interface between the Oxford Clay and Kellaways Sand was difficult to determine exactly due to the drilling method used (cable percussive) and the similarity between the composition of layer within both units (silty or sandy with siltstone and mudstone bands).

A summary of the geology encountered during the 2021 site investigation is presented in **Table HRA9**.

Table HRA9: Summary of 2021 Site Investigation

Original ID	BEDS Name	BEDS Code	Location within the Site	Ground Level (m AOD)	Total Depth (m bgl)	River Terrace Deposits Thickness (m)	Oxford Clay Thickness (m)	Kellaways Sand Thickness (m)
BH21-01	BH46	91002460	NE corner	3.12	26.40	5.10	14.90	2.60
BH21-02	BH49	91002490	NW corner	2.20	22.40	5.50	12.30	1.80
BH21-03	BH51	91002510	SW corner	3.95	21.30	2.90	14.20	2.70
BH21-04	BH52	91002520	SE corner	3.77	23.00	1.10	17.30	>3.60
BH21-05	BH53	91002530	Middle of E side	3.49	27.20	5.40	17.50	>3.50

2.3.2 Groundwater Levels and Hydraulic Containment

2.3.2.1 Groundwater Levels and Flow

The quarry permit requires all boreholes on the MEPP to be monitored on a quarterly basis, although groundwater elevations are routinely monitored monthly at the Site.

Groundwater elevations for boreholes BHP11/01 to BHP11/06, which monitor the River Terrace Deposits, and BH21-01 to BH21-05, which monitor the Kellaways Sand, are presented as hydrographs in **Appendix HRA1** and summarised in **Table HRA10**. The presented boreholes are located around the perimeter of the Eastern Extension as shown on the **Drawing HRA3**.

Table HRA10: Groundwater Level Summary for the Eastern Extension during the period February 2015 to June 2021 (River Terrace Deposits) and September to December 2021 (Kellaways Sand).

Borehole ID		Aquifer	Groundwater Level (m AOD)					
Drill ID	BEDS Name		Min	Max	Median	Mean	St Dev	Count
BHP11/01	BH47	RTD	-3.15	1.43	-1.08	-0.82	-0.982	75
BHP11/02	BH54	RTD	-2.2	0.22	-1.33	-1.31	-0.623	83
BHP11/03	BH56	RTD	1.38	2.75	1.84	1.88	-0.306	76
BHP11/04	BH55	RTD	1.03	2.24	1.44	1.47	-0.229	72
BHP11/05	BH50	RTD	-2.8	1.69	0.64	0.40	-0.823	80
BHP11/06	BH48	RTD	-3.11	0.95	-2.81	-1.95	-1.343	37
BH21-01	BH46	KS	0.89	1.15	1.13	1.08	0.110	5
BH21-02	BH49	KS	-0.66	0.52	0.45	0.09	0.555	5
BH21-03	BH51	KS	1.15	1.32	1.29	1.27	0.069	5
BH21-04	BH52	KS	0.25	0.55	0.44	0.43	0.113	5
BH21-05	BH53	KS	-1.85	-1.48	-1.49	-1.60	0.165	5

Notes: RTD = River Terrace Deposits, KS = Kellaways Sand

Hydrographs for the shallow aquifer in the River Terrace Deposits indicate different trends for the north and the south of the Eastern Extension. Monitoring points located in the southern part have provided generally stable groundwater elevations oscillating from 1.5 to 2.0 m AOD in BHP11/03 and BHP11/04 and from 0.0 to 1.0 m AOD in BHP11/05.

Hydrographs from the monitoring points located along the northern edges show more irregular variations in groundwater elevation. The shallow groundwater system has likely already been affected by the dewatering carried out by Thory in the northern part of the Eastern Extension and will continue to be affected by the planned excavations and landfilling by Biffa. Therefore, groundwater level data collected in 2011, prior to the main quarrying and landfilling phases, is considered more representative of an undisturbed groundwater system. The 2011 data indicates a full range of groundwater levels between 1.25 m AOD and 2.35 m AOD. A groundwater contour plot showing the seasonal minimum groundwater levels is presented in **Drawing HRA4**. The resultant hydraulic gradient indicates general groundwater flow to the west and north, with groundwater elevations of between 1.25 and 1.56 m AOD across the Eastern Extension. The HRA for the Southern Extension (Golder, 2008), estimated the groundwater flow direction to be to the south; however, this is likely to have been disturbed by local groundwater management at the time.

Groundwater level data from the Kellaways Sand in the Eastern Extension is available from September 2021, when monitoring of the newly drilled boreholes commenced. Groundwater levels are typically above the top of the Oxford Clay which indicate that the Kellaways Sand is a confined aquifer recharged at a distance from the site. Trends observed indicate relatively stable groundwater elevations ranging from 0.2 to 1.3 m AOD (excluding BH21-05) with variations within a single borehole typically not exceeding 0.5 m. The only monitoring point diverging from the main trend is BH21-05 with groundwater levels at approximately -1.9 to -1.5 m AOD. **Drawing HRA5** shows the groundwater contours within the Kellaways Sand (monitored in December 2021); from this, it is observed that the groundwater flow direction is to the southeast.

2.3.2.2 Hydraulic Containment Assessment

Under normal operating conditions the existing landfill is operated under the principle of hydraulic containment and this principle will be extended to the Eastern Extension preventing the advective migration of contaminants from the cells. The most recent HRA Review (esi, 2015) indicated that the principle of hydraulic containment has been employed successfully at the currently operating Biffa site.

Dewatering activities undertaken by Thory in the northern part of the proposed Eastern Extension have resulted in anomalously low groundwater elevations within the River Terrace Deposits aquifer. Once the back drains have been installed and the cells are lined, the dewatering is expected to cease, and the groundwater elevation is expected to rebound to the original state similar to what was observed in 2011.

It is proposed to maintain leachate levels below 1.4 m above the base of the cell (which should be 1 m below the minimum groundwater level in the Kellaways Sand and River Terrace Deposits (once rebound occurs). Consequently, leachate elevations in the Eastern Extension will be kept below the surrounding groundwater elevations providing suitable hydraulic containment.

The expected geological setting is in good continuity with that observed at the Site; in particular, the Oxford Clay reaches similar thickness providing a suitable geological barrier. The efficiency of this methodology at the existing landfill provides confidence that it will perform equally well in the Eastern Extension.

2.4 Receptors

The following potential receptors to leachate were indicated in the previous HRA reviews and are considered valid for the proposed Eastern Extension:

- The groundwater beneath and adjacent to the Site (including groundwater abstraction boreholes); and
- Cat's Water Drain and surface water drains.

Groundwater Beneath and Adjacent to the Site (including Groundwater Abstraction Boreholes)

The River Terrace Deposits are designated as a Secondary A aquifer with loamy soils with naturally high groundwater on top. Secondary A aquifers are permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. Underlying the Site at depth, the Kellaways Sand is also classified as a Secondary A aquifer.

The groundwater abstraction boreholes located off-Site have not been considered further specifically as by assessment of the risk to groundwater immediately beneath and adjacent to the Site; this is naturally protective of off-Site groundwater sources also.

The permit currently held by Biffa for the Southern Extension requires groundwater quality to be monitored on a monthly, quarterly, or yearly basis as described in Tables S3.4 and S3.9 of the permit. A similar approach is expected to be undertaken at the Eastern Extension in the future. At present Thory monitor the groundwater quality on a quarterly or yearly basis in BHP11/01 to BHP11/06 as outlined in the Tables S3.1 and S3.3 of the Permit for Willow Farm Quarry and Inert Landfill. A summary of groundwater concentrations for priority contaminants in the River Terrace Deposits for the period January 2016 to December 2021 is presented in **Table HRA11**. Time-series plots created for those priority contaminants for which there is sufficient data (chloride, ammoniacal nitrogen, and nickel) from samples of groundwater collected from shallow boreholes adjacent to the Eastern Extension are presented in **Appendix HRA2**.

Fewer results are available for the deeper aquifer, Kellaways Sand, because the boreholes installed in this formation were recently installed (early 2021) and since then samples have been successfully collected and analysed a total of four times. A summary of results of the conducted analyses is presented in **Table HRA12**.

Table HRA11: Summary of Priority Contaminants Concentrations in Groundwater (River Terrace Deposits)

Borehole ID	Minimum	Median	Maximum	Count	FW EQS	UK DWS
Ammoniacal Nitrogen (mg/l)						
BHP11/01	<0.2	0.3	**0.441**	18	-	0.39
BHP11/02	<0.1	0.3	**1.23**	13		
BHP11/03	<0.1	0.3	**2.19**	14		
BHP11/04	<0.1	0.3	**0.563**	18		
BHP11/05	<0.2	0.3	**0.576**	11		
BHP11/06	<0.2	0.25	**0.354**	8		
Arsenic (mg/l)						
BHP11/01	0.00046	0.00077	0.00099	3	0.05	0.01
BHP11/02	0.0013	0.0038	**0.0140**	3		
BHP11/05	0.0004	0.00045	0.00052	3		
Chloride (mg/l)						
BHP11/01	8.0	36.05	42.3	24	250	-
BHP11/02	22.2	32.2	78	19		
BHP11/03	9.1	12.0	48.4	14		
BHP11/04	7.5	10.1	13.5	17		
BHP11/05	8.0	47.7	57.7	18		
BHP11/06	13.4	32.2	37.9	9		
Mecoprop (mg/l)						
BHP11/01	<0.00004	<0.00004	<0.00004	3	0.018	0.0001
BHP11/02	<0.00004	<0.00004	<0.00004	2		
BHP11/05	<0.00004	<0.00004	<0.00004	3		
Naphthalene (mg/l)						
BHP11/01	<0.00001	<0.00001	<0.0001	7	0.0002	-
BHP11/02	<0.00001	0.000039	0.00013	5		
BH11/03	<0.00001	<0.00001	<0.00001	1		
BHP11/04	<0.00001	0.0001	0.000157	3		
BHP11/05	<0.00001	<0.00001	<0.0001	5		
BHP11/06	<0.00001	<0.00001	<0.00001	1		
Nickel (mg/l)						
BHP11/01	0.00121	0.00294	**0.00411**	14	0.004	0.02
BHP11/02	0.00126	0.003095	**0.01**	12		
BHP11/03	0.00214	0.00227	0.00342	7		

Borehole ID	Minimum	Median	Maximum	Count	FW EQS	UK DWS
BHP11/04	0.000882	0.00214	**0.00414**	9		
BHP11/05	0.0016	0.004035	**0.0162**	12		
BHP11/06	0.00259	0.003505	0.00393	6		
Phenol (mg/l)						
BHP11/01	<0.005	<0.005	<0.005	3	0.0077	-
BHP11/02	<0.005	<0.005	<0.005	2		
BHP11/05	<0.005	<0.005	<0.005	3		

*Notes: All concentrations below Limit of Detection (LoD) were treated as values equal to the LoD in calculations. Minimum or maximum concentrations highlighted in **bold** indicate and exceedance of either the FW EQS or UK DWS (whichever is lowest).*

Table HRA12: Summary of Priority Contaminants Concentrations in Groundwater (Kellaways Sand).

Borehole	Minimum	Median	Maximum	Count	FW EQS	UK DWS
Ammoniacal Nitrogen (mg/l)						
BH21-01	**1.52**	1.97	**2.99**	3	-	0.39
BH21-02	**0.74**	1.075	**1.41**	2		
BH21-03	**1.20**	1.43	**2.18**	3		
BH21-04	**1.13**	2.33	**4.78**	3		
BH21-05	**2.08**	2.84	**2.84**	3		
Arsenic (mg/l)						
BH21-01	0.0023	0.015	**0.018**	3	0.05	0.01
BH21-02	**0.024**	0.0245	**0.025**	2		
BH21-03	0.0006	0.0021	0.0022	3		
BH21-04	0.0014	0.0067	0.0085	3		
BH21-05	0.0015	0.0022	0.0025	3		
Chloride (mg/l)						
BH21-01	**1250**	1780	**1830**	3	250	-
BH21-02	**1280**	1300	**1320**	2		
BH21-03	**1120**	1350	**1620**	3		
BH21-04	**991**	1460	**1630**	3		
BH21-05	**2110**	2210	**2240**	3		
Mecoprop (mg/l)						
BH21-01	<0.00004	<0.00004	<0.00004	3	0.018	0.0001
BH21-02	<0.00004	<0.00004	<0.00004	2		
BH21-03	<0.00004	<0.00004	<0.00004	3		
BH21-04	<0.00004	<0.00004	<0.00004	3		

Borehole	Minimum	Median	Maximum	Count	FW EQS	UK DWS
BH21-05	<0.00004	<0.00004	<0.00004	3		
Naphthalene (mg/l)						
BH21-01	<0.00005	<0.00005	<0.00005	2		
BH21-02	<0.0001	<0.0001	<0.0001	2		
BH21-03	<0.0001	<0.0001	<0.0001	2	0.0002	-
BH21-04	0.000025	0.000025	0.000025	2		
BH21-05	0.000012	0.000012	0.000012	2		
Nickel (mg/l)						
BH21-01	0.0015	0.0015	0.0015	3		
BH21-02	0.0014	0.0014	0.0014	2		
BH21-03	<0.001	<0.001	<0.001	3	0.004	0.02
BH21-04	0.0011	0.00155	0.002	3		
BH21-05	0.0012	0.0012	0.0012	3		
Phenol (mg/l)						
BH21-01	<0.005	<0.005	<0.005	3		
BH21-02	<0.005	<0.005	<0.005	2		
BH21-03	<0.005	<0.005	<0.005	3	0.0077	-
BH21-04	<0.005	<0.005	<0.005	3		
BH21-05	<0.005	<0.005	<0.005	3		

Notes: All concentrations below Limit of Detection (LoD) were treated as values equal to the LoD in calculations. Minimum or maximum concentrations highlighted in ***bold*** *indicate and exceedance of either the FW EQS or UK DWS (whichever is lowest).*

Concentrations of several priority contaminants exceed Freshwater Environmental Quality Standards (FW EQS) and UK Drinking Water Standards (UK DWS) specifically ammoniacal nitrogen, arsenic, and nickel for River Terrace Deposits; and ammoniacal nitrogen, arsenic, and chloride for the Kellaways Sand.

The relationship between ammoniacal nitrogen and chloride in the shallow aquifer, as shown in the contaminant concentration time-series (**Appendix HRA2**), shows that the changes in concentration over time do not rise and fall together, which would be the case if the source was landfill leachate. A similar trend was also observed during the review of data for the Southern Extension (Golder, 2008). This provides confidence that although the boreholes are being impacted, it is another anthropogenic source and not leachate from the adjacent Eye landfill affecting the ammoniacal nitrogen and chloride concentrations across the Site.

The concentrations of chloride are significantly greater in the Kellaways Sand than the River Terrace Deposits. As such it is assumed that the cause of the elevated concentrations in the Kellaways Sands is unlikely to be associated with landfilling, and more likely to be a product of the poor quality, brackish (saline) water. This is further evidenced by poor groundwater quality encountered for this aquifer in the region summarised by Mather et al. (1998).

The concentrations of nickel in the River Terrace Deposits are elevated in all monitoring locations with FW EQS exceedances in four out of six boreholes. These typically are isolated events and increase in concentration is usually noted in all boreholes on the same dates. The peaks do not fall and rise with other contaminants' concentrations indicating that the landfilling activities are not the cause of these patterns.

Arsenic concentrations exceed UK DWS in BH21-01 and BH21-02 whereas results obtained from the remaining shallow and deep boreholes typically show only slightly elevated arsenic levels. These are attributed to poor groundwater quality of the deeper aquifer.

Cat's Water Drain and Surface Water Drains

The Cat's Water Drain was regarded as a receptor of contamination from the landfill in the most recent HRA Review for the Southern and Northeastern Extensions (esi, 2015) although the prevailing groundwater levels were below the average elevation of the drain (1.63 m AOD) with infrequent periods of high groundwater elevations. Similar patterns are observed in the Eastern Extension; typically, groundwater level remains below 1.63 m AOD, preventing any potential pathway between surface and groundwater from forming and only sporadically reaching elevations up to 2 m AOD. In addition, flow in Cat's Water Drain is considered to be ephemeral and controlled by discharges up-stream including quarry workings elsewhere at the Eye Landfill site. Hence, it is concluded that the drain would be providing recharge to groundwater during the short periods of increased groundwater elevations further decreasing the potential for contaminants to migrate into the surface water. In the light of these findings Cat's Water Drain is considered a secondary receptor for the Eastern Extension and is deemed unlikely to be affected by the landfilling activities while groundwater is being actively managed. The possible future cessation of active groundwater management may result in discharge to the Drain. Therefore, it will be necessary to ensure protection of Cat's Water Drain by maintaining acceptable groundwater quality.

A summary of the priority contaminants recorded during surface water sampling from the Cat's Water Drain between October and December 2021 are presented in **Table HRA13**.

Table HRA13: Summary of Priority Contaminants Concentrations in Surface Water (Cat's Water Drain) between October and December 2021.

ID	Minimum	Median	Maximum	Count	Count above LoD	FW EQS (mg/l)	UK DWS (mg/l)
Ammoniacal Nitrogen (mg/l)							
SW13	<0.06	<0.06	<0.06	3	0	-	0.39
SW14	<0.06	<0.06	<0.06	3	0	-	0.39
Arsenic (mg/l)							
SW13	0.00034	0.00055	0.00065	3	3	0.05	0.01
SW14	0.00051	0.00052	0.00059	3	3	0.05	0.01
Chloride (mg/l)							
SW13	28.3	47.0	53.4	3	3	250	-
SW14	28.3	29.7	32.5	3	3	250	-
Mecoprop (mg/l)							
SW13	<0.00004	<0.00004	<0.00004	3	0	0.018	0.0001
SW14	<0.00004	<0.00004	<0.00004	3	0	0.018	0.0001

ID	Minimum	Median	Maximum	Count	Count above LoD	FW EQS (mg/l)	UK DWS (mg/l)
Naphthalene (mg/l)							
SW13	<0.001	<0.001	<0.001	3	0	0.0002	-
SW14	<0.001	<0.001	<0.001	3	0	0.0002	-
Nickel (mg/l)							
SW13	<0.001	0.0015	0.0021	3	2	0.004	0.02
SW14	<0.001	0.0034	0.0039	3	2	0.004	0.02
Phenol (mg/l)							
SW13	<0.001	<0.001	<0.001	1	0	0.0077	-
SW14	<0.001	<0.001	<0.001	1	0	0.0077	-

Notes: All concentrations below Limit of Detection (LoD) were treated as values equal to the LoD in calculations.

The concentrations of the priority contaminants detected both upstream and downstream in Cat's Water Drain are below UK DWS and FW EQS.

2.5 Compliance Points

Current EA guidance[1] states that '*for predictive modelling of hazardous substances, your compliance point will normally be set immediately downgradient of the discharge, at a point just below the water table adjacent to the edge of the discharge area and within the expected vertical mixing depth. Practically, compliance with control levels and compliance limits for hazardous substances are assessed at monitoring points which are normally one or more boreholes directly adjacent to the landfill. This reflects the practical problems in collecting samples from beneath a landfill.*

For non-hazardous pollutants the compliance point will also normally be the monitoring boreholes adjacent to the landfill. Where groundwater has no current or potential future resource value, boreholes for monitoring non-hazardous pollutants further from the site may be appropriate.'

In light of this guidance, compliance points for assessing the risk posed by contamination originating at the Eastern Extension are as follows:

- For Hazardous Substances, the receptor point will be the edge of the sidewall liner in contact with the groundwater in the River Terrace Deposits above the Oxford Clay, and the base of the Oxford Clay above the Kellaways Sands; and
- For Non-Hazardous Substances, the primary receptor point will be the downstream boundary of the Site within the River Terrace Deposits and Kellaways Sands. Surface streams, most notably the Cat's Water Drain will form secondary receptors.

[1] https://www.gov.uk/guidance/landfill-developments-groundwater-risk-assessment-for-leachate#compliance-points.

2.6 Environmental Assessment Levels

Receptor sensitivity can be gauged by the specification of Environmental Assessment Levels (EALs). EALs may be used to benchmark the results of predictive modelling. The modelling approach taken for this Site is not borehole or location specific. EALs, therefore, differ from compliance limits, which are borehole/location specific and, therefore reflect potential spatial variation in groundwater concentrations from off-Site sources.

An input of a hazardous substance is considered to have been prevented if the substance concerned is not discernible in the groundwater above natural background conditions or a relevant minimum reporting value (MRV) after the immediate dilution as the leachate enters the groundwater. Therefore, to be protective of groundwater as a potential resource, EALs for hazardous substances have been set at the EA's MRV[2]. If no MRV has been developed a Limit of Quantification (LoQ) has been used, which is either defined by the UK Technical Advisory Group (UK TAG) on the Water Framework Directive[3], or in a commercial laboratory is defined as being three times a commercially available limit of reporting.

For non-hazardous pollutants, the EALs have been set at the UK DWS preferentially, or Freshwater EQS if a UK DWS is not available.

Table HRA14: Environmental Assessment Levels (EALs).

Determinand	Water Standard (mg/l)	Source
Ammoniacal nitrogen	0.39	UK DWS
Arsenic	0.005	UK TAG LoQ
Chloride	250	UK DWS
Mecoprop	0.0001	UK DWS*
Nickel	0.02	UK DWS
Naphthalene	0.002	FW EQS
Phenol	0.0077	FW EQS

Notes: '' = although mecoprop does not have a specific UK DWS, a value has been chosen as appropriate for mecoprop based on other acid-based herbicides UK DWS limits.*

2.7 Summary of Conceptual Model

A summary review of the hydrogeological conceptual model has identified only minor and expected differences between the existing landfill, last reviewed in 2015, and the Eastern Extension.

The planned extension is to be constructed eastwards of the existing landfill across the Cat's Water Drain and divided into ten cells numbered from 9 to 18 and two additional cells, 19 and 20, that will receive inert waste. All cells are planned to be designed and constructed in a similar manner to previous cells at the existing landfill, albeit with different geometry.

The same type of waste is expected to be deposited at the proposed Eastern Extension as at the existing landfill and the leachate quality is therefore expected to be the same as that in the existing landfill. An assessment of the priority contaminants to be modelled has been undertaken to ensure that the contaminants remain appropriate for the current leachate concentrations (i.e. the list of hazardous substances and non-hazardous

[2] https://www.gov.uk/government/publications/values-for-groundwater-risk-assessments/hazardous-substances-to-groundwater-minimum-reporting-values

[3] Technical report on Groundwater Hazardous Substances, working paper 11b(iii) v12, dated September 2016 - available at https://www.wfduk.org/sites/default/files/Media/UKTAG_Technical%20report_GW_Haz-Subs_ForWebfinal.pdf

pollutants was updated in 2019 and has been reflected in the updated priority contaminants list (WFD TAG, 2019)). Further to this it was ensured that the priority contaminants represented the different fates and subsurface behaviours. As such, updates to the list of priority contaminants are proposed based on the contaminant concentrations in the Southern Extension.

Boreholes drilled within the Eastern Extension prove geology consistent with that observed at the existing landfill. Pathways for contaminant migration from the Eastern Extension are therefore the same as from the existing landfill. There are no long-term changes in groundwater levels across the Site, and as such the Eastern Extension will, like the existing landfill, be managed using the principle of hydraulic containment.

The receptors for leachate from the Eastern Extension are the same as those from the existing landfill; the groundwater surrounding the Site, groundwater abstraction wells, and adjacent surface water bodies (including Cat's Water Drain).

Groundwater compliance points are the same as for the existing landfill and reflect EA guidance for both hazardous substances and non-hazardous pollutants.

3.0 HYDROGEOLOGICAL RISK ASSESSMENT

The adopted risk assessment methodology for the Eastern Extension is analogous to that applied at the currently operating site and is in-line with the Environment Agency guidance on hydraulic containment landfills. This approach recognises that provided the conditions for hydraulic containment are maintained, there is a negligible risk of the landfill impacting on the water environment by diffusion of contaminants through the lining system. Calculations have been made using the Environment Agency's *"Contaminant fluxes from hydraulic containment landfills spreadsheet v1.0"* (EA, 2004) (hereafter called the 'hydraulic containment spreadsheet').

3.1 Justification for Modelling Approach and Software

Within this Hydrogeological Risk Assessment, the complexity of the hydrogeological site setting was taken into account. The hydraulic containment spreadsheet allows for three different scenarios, depending on the hydrogeological situation at the Site. The following 'normal operating conditions' scenarios (as shown in **Drawing HRA1**) are considered:

- The basal lining system constitutes a vertical pathway beneath the landfill, with the receptor represented by the Kellaways Sand (Scenario 1); and
- The sidewall lining system constitutes a lateral pathway, with the receptor represented by the River Terrace Deposits (Scenario 3).

As a possible 'failure scenario', the following situation was considered (as shown in **Drawing HRA2**):

- Leachate management is not controlled, and leachate head build up inside the landfill to elevations above the surrounding piezometric surfaces in the River Terrace Deposits and/or Kellaways Sand.

3.2 Model Parametrisation

3.2.1 Infiltration

Prior to capping, infiltration will be directly on top of the open waste surface. The Eastern Extension is to be capped with the following: a regulation layer, a nominal 200 mm layer of sand or clay (or similar inert material); a sealing layer, a low permeability liner; a drainage layer, minimum 500 mm of free draining overburden material; and restoration materials, cover soils and minimum 200 mm topsoil. Infiltration is not included in the hydraulic containment spreadsheet calculation since the leachate head is fixed to 1 m below groundwater heads outside the landfill. However, infiltration to the waste mass after capping is of relevance to the failure scenario, and the applied infiltration to the landfill cap is presented in **Table HRA15** below.

Table HRA15: Predicted Infiltration

Parameter	Units	Value	Justification
Cells capped and system performing as installed			
Cap design infiltration	mm/yr	50	Golder estimate using previous experience

3.2.2 Site Geometry and Leachate Heads

The Site has been divided into ten cells, which will receive non-hazardous waste. The HRA has taken into account the finished landfill as a whole, with the overall length and width of the combined cells/phases defining the dimensions used in the spreadsheet model. Note that hydraulic containment spreadsheet treats the landfill as a void with vertical walls, i.e. the landfill area at the base of the landfill is equal to that at the top.

Landfill geometry and construction parameters required for the Eastern Extension model are presented in **Table HRA16**.

Table HRA16: Landfill Geometry

Parameter	Units	Value	Justification
Length of landfill	m	475*	Drawing ESID11
Width of landfill	m	400*	Drawing ESID11
Landfill area	m²	190,000*	Calculated
Base of landfill (top of the liner)	m AOD	-4.3	Maximum depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety

Notes: '' = The ESID provides the exact area of the Site, these model input values have been used as a representation of the landfill for modelling purposes.*

3.2.3 Source Term

There is currently no leachate quality data available for the Eastern Extension as Biffa have not commenced waste deposition in the area. Once the permit is granted and landfill becomes operational, the leachate quality data will be obtained, and the source term will be updated accordingly in the next HRA review.

For the purposes of this modelling approach, data from the Southern Extension, which receives similar types of waste and hence produces leachate of compositions anticipated in the Eastern Extension, is used. The adopted source term concentrations are taken as maximum concentrations observed in the leachate over the 2016 to 2021 period. These are often notably higher than concentrations observed on average and are as such treated as conservative.

Table HRA17: Source Term for the Eastern Extension

Determinand	Units	Source Term Concentration
Ammoniacal nitrogen	mg/l	2,200
Arsenic	mg/l	0.521
Chloride	mg/l	20,500
Mecoprop	mg/l	0.095
Nickel	mg/l	1.09
Naphthalene	mg/l	0.0389*
Phenol	mg/l	46.5

Notes: '' = The maximum LoD is higher than the maximum actual reported concentration; therefore, for the modelling, the maximum highest actual concentration has been used.*

3.2.4 Properties of Liner

The lining system to be placed will follow the same construction design as the liner installed at the currently operating Southern Extension. It will comprise engineered clay or reworked Oxford Clay materials with a minimum thickness of 1 m and the properties presented in Table HRA18.

Table HRA18: Properties of Landfill Liner

Parameter	Units	Value	Justification
Thickness	m	1	Minimum design thickness
Hydraulic conductivity	m/s	1×10^{-9}	Maximum design value
Average pore radius	m	4×10^{-7}	D10 value of clay (estimated as 10% of maximum particle size)
Effective porosity	fraction	0.2	Golder 2003 (Eye Northeastern Extension Hydrogeological Risk Assessment)
Dry bulk density	kg/m^3	1,800	Golder estimate
Tortuosity	dimensionless	10	Table 3.3, Report SC0310/SR, Environment Agency 2004

3.2.5 Aquifer Geometry ad Properties

Representative groundwater levels and assumed maximum allowable leachate elevations are presented in **Table HRA19**. Elevations for both aquifers were chosen to recreate a conservative but representative hydrogeological setting at the Eastern Extension.

Groundwater level for River Terrace Deposits was chosen based on the 2011 data even though more recent measurements are available. Since 2011, Thory have been quarrying the Site and have recently commenced inert waste deposition within the northern area. These operations require localised groundwater management, such as dewatering, that is thought to have disturbed the natural state of the shallow groundwater system within the River Terrace Deposits. As a result, the groundwater levels observed more recently are not a true representation of the aquifer's 'natural' state and that which will be present during landfilling by Biffa; therefore, the 2011 data is considered a better input for the model.

The Kellaways Sand groundwater level was estimated based on the data collected from newly drilled boreholes (BH21-01 to BH21-05) as a part of the 2021 Site investigation. As only a few measurements are available for the deep aquifer an average value was calculated.

Table HRA19: Groundwater and Leachate Levels for the Eastern Extension

Parameter		Units	Value	Justification
River Terrace Deposits	Leachate head inside landfill	m AOD	0.25	1 m below the groundwater elevation
	Groundwater head outside landfill	m AOD	1.25	Minimum groundwater elevation observed in 2011
Kellaways Sand	Leachate head inside landfill	m AOD	-0.75	1 m below the groundwater elevation
	Groundwater head outside landfill	m AOD	0.25	Average groundwater elevation observed in the newly installed boreholes

3.2.6 Contaminant Properties

The contaminant type, classification, source concentration in leachate, free water diffusion coefficient, partition coefficient, and half-life in clay are required by the hydraulic containment spreadsheet. **Table HRA20** summarises the values used for the priority contaminants.

Table HRA20: Priority Contaminant Properties Modelled

Parameter	Units	Model Input	Justification
Ammoniacal Nitrogen			
Contaminant type	n/a	Inorganic	Ammonium is inorganic substance
Contaminant Classification	n/a	List I	Conservatively assumed
Free water diffusion coefficient	m/s²	1.96×10^{-9}	Table 3.1 in SC0310/SR (Review)
Kd in clay	l/kg	0.15	Conservative value from App.2 in NGWCLC Report NC/02/49
Half-life in clay	days	0*	Assumed to not degrade
Arsenic			
Contaminant type	n/a	Inorganic	Arsenic is inorganic substance
Contaminant Classification	n/a	List I	Hazardous according to JAGDAG classification
Free water diffusion coefficient	m/s²	1.0×10^{-9}	Conservative value for diffusive contaminants
Kd in clay	l/kg	249.6	Expected value ConSim help files for Glacial till (most similar lithology available)
Half-life in clay	days	0*	Assumed to not degrade
Chloride			
Contaminant type	n/a	Inorganic	Chloride is inorganic substance
Contaminant Classification	n/a	List I	Conservatively assumed
Free water diffusion coefficient	m/s²	2.03×10^{-9}	Table 3.1 in SC0310/SR (Review)
Kd in clay	l/kg	0	Chloride assumed to be unretarded
Half-life in clay	days	0*	Assumed to not degrade
Mecoprop			
Contaminant type	n/a	Organic	Mecoprop is organic substance
Contaminant Classification	n/a	List I	Hazardous according to JAGDAG classification
Free water diffusion coefficient	m/s²	3.9×10^{-10}	Table 3.1 in SC0310/SR (Review)
Kd in clay	l/kg	2.328	Calculated based on USEPA and NC/03/12 data
Half-life in clay	days	92	Maximum value suggested by Howard et al. (1991

Parameter	Units	Model Input	Justification
Nickel			
Contaminant type	n/a	Inorganic	Nickel is inorganic substance
Contaminant Classification	n/a	List I	Conservatively assumed
Free water diffusion coefficient	m/s²	2.03 x 10^{-9}	Assumed high value (chloride's) from Table 3.1 in SC0310/SR Review
Kd in clay	l/kg	20	Conservative value from ConSim help-files
Half-life in clay	days	0*	Assumed to not degrade
Naphthalene			
Contaminant type	n/a	Organic	Naphthalene is organic substance
Contaminant Classification	n/a	List I	Conservatively assumed
Free water diffusion coefficient	m/s²	6.0 x 10^{-10}	Table 3.1 in SC0310/SR Review
Kd in clay	l/kg	61.824	Calculated based on ConSim and NC/03/12 data
Half-life in clay	days	1000	Maximum value from ConSim help-files
Phenol			
Contaminant type	n/a	Organic	Phenol is organic substance
Contaminant Classification	n/a	List I	Conservatively assumed
Free water diffusion coefficient	m/s²	9.1 x 10^{-10}	From *'Review of the Fate and Transport of Selected Contaminants in the Soil Environment'*
Kd in clay	l/kg	1.296	Calculated based on ConSim and NC/03/12 data
Half-life in clay	days	300	Maximum value from ConSim help files

Notes: '' = For compounds with a value of 0 for half-life, degradation is ignored in SC0310.*

3.3 Emissions to Groundwater

The Eastern Extension landfill will be operated under the principle of hydraulic containment such that leachate levels will be maintained at levels below external groundwater levels resulting in an inward hydraulic gradient. Therefore, under normal operating conditions there will be no leakage by advective transport and therefore no impact from these processes upon the water environment.

However, the role of diffusion as a mechanism for contaminant transport has to be considered as this process occurs irrespective of the successful operation of hydraulic containment. If diffusive contaminant flux out of the landfill is significant compared to advective inward flux of groundwater, contaminants have the potential to impact on the water environment.

In the event that the leachate extraction system fails, and no measures are immediately undertaken to remediate the situation, the leachate level within the landfill can be expected to rise and ultimately equilibrate or exceed the surrounding groundwater. The leachate level will rise according to the infiltration rate through the cap and groundwater seepage through the base and sides of the landfill. A model calculating the time it would take for the leachate head to rise by 1 m in case of loss of control was used for the Failure Scenario presented.

3.3.1 Normal Operating Conditions

3.3.1.1 River Terrace Deposits as Receptor (Scenario 3)

Scenario 3 in the hydraulic containment spreadsheet was chosen as the most appropriate to represent the hydrogeological relationship between the Eastern Extension and the River Terrace Deposits. This approach allows for the potential impact of leachate on the aquifer lateral to the landfill with the sidewall liner as a pathway to be modelled. The results are evaluated from breakthrough curves of the contaminants. It has been assumed for the hydrogeological risk assessment that the sidewall liner will consist of a 1 m thick barrier of engineered clay without any further lining. In addition, the non-hazardous substances were conservatively treated as hazardous substances, in the past, and in the spreadsheet, these are referred to as List II (non-hazardous) and List I (hazardous) substances. It is a more conservative approach because the compliance point is moved closer to the landfill, i.e. they are assessed at the edge of the sidewall liner in contact with the groundwater in the River Terrace Deposits above the Oxford Clay, and no dilution in groundwater has been assumed. The concentrations at the edge of the sidewall liner calculated by the hydraulic containment spreadsheet are compared against the EALs as defined in Section 0.

The spreadsheets for Scenario 3 are given electronically in **Appendix HRA3**. The time to maximum concentrations (breakthrough times), the maximum concentrations, and a comparison to the relevant EALs for the River Terrace Deposits are presented in **Table HRA21**.

Table HRA21: Modelled Concentrations and Breakthrough Times for the River Terrace Deposits

Priority Contaminant	Maximum concentration (mg/l)	Time to maximum concentration (yrs)	EAL (mg/l)
Ammoniacal nitrogen	1.8×10^{-8}	32	0.39
Arsenic	1.0×10^{-22}	30,200	0.005
Chloride	4.1×10^{-7}	13	250
Mecoprop	3.6×10^{-64}	240	0.0001
Nickel	2.2×10^{-11}	2,291	0.02
Naphthalene	5.31×10^{-39}	6,026	0.002
Phenol	4.8×10^{-25}	126	0.0077

The calculated maximum concentrations are significantly below the EALs for the priority contaminants modelled. It is therefore considered that the risk of contamination from leachate to the River Terrace Deposits during normal operating conditions is negligible.

3.3.1.2 Kellaways Sand as Receptor (Scenario 1)

Scenario 1 in the hydraulic containment spreadsheet was chosen as the most appropriate to represent the hydrogeological relationship between the Eastern Extension and the Kellaways Sand. This approach allows the potential impact of leachate on the aquifer below the landfill with the basal liner as a pathway to be modelled. The results are evaluated from breakthrough curves of the contaminants.

It has been assumed for the hydrogeological risk assessment that the basal liner will consist of a 1 m thick barrier of engineered clay without any further lining. In addition, the non-hazardous (called List II in the spreadsheet) pollutants were conservatively treated as hazardous substances (called List I in the spreadsheet) and have been used to predict the River Terrace Deposits impact.

The concentrations at the edge of the basal liner calculated by the hydraulic containment spreadsheet have been compared to the EALs as defined in Section 0. The spreadsheets for Scenario 1 are given electronically in **Appendix HRA3**. The time to maximum concentrations (breakthrough time), the maximum concentrations, and the relevant EALs for the Kellaways Sand are presented in **Table HRA22**.

Table HRA22: Modelled Concentrations and Breakthrough Times for the Kellaways Sand

Priority Contaminant	Maximum concentration (mg/l)	Time to maximum concentration (yrs)	EAL (mg/l)
Ammoniacal nitrogen	1.8×10^{-8}	5,012	0.39
Arsenic	1.0×10^{-22}	5,248,075	0.005
Chloride	4.1×10^{-7}	2,512	250
Mecoprop	8.9×10^{-288}	4,365	0.0001
Nickel	2.2×10^{-11}	398,107	0.02
Naphthalene	1.5×10^{-85}	288,403	0.002
Phenol	8.4×10^{-105}	3,162	0.0077

The calculated maximum concentrations are significantly below the EALs for the priority contaminants. It is therefore considered that the risk of contamination from leachate to the Kellaways Sand during normal operating conditions is negligible.

3.3.2 Failure Scenario

After landfilling is completed in each cell, the Site will be progressively capped. Infiltration through the cap will occur, and the rate presented in Section 3.2.1 has been assumed for the purpose of the calculations. With regard to the head difference between the groundwater and leachate, a more conservative value (for advective flux calculations) of 2 m has been assumed for the head difference across the liners for both aquifers. In addition, a higher value than used in the hydraulic containment spreadsheet was used for the groundwater level in the River Terrace Deposits to more conservatively use a larger aquifer thickness and resulting surface area across which flow can occur into the landfill. The calculations presented for the rate of rise of leachate are based on the size of the whole landfill.

A printout of the spreadsheet is given in **Appendix HRA4**, and a spreadsheet presenting the calculations and justifications in electronic form is given in **Appendix HRA5**. A summary of the calculations is presented in **Table HRA23**.

Table HRA23: Summary of Failure Scenario: Loss of Leachate Management Control Calculations.

Parameter	Units	Model Input Value
Total flux into landfill	m^3/yr	13,141.48
Rate of leachate head increase	m/yr	0.22
Time to increase leachate head by 1 m	yrs	4.45

As it can be seen from **Table HRA23**, it is estimated that it will take approximately four and a half years for leachate to rise 1 m after failure of the extraction system. Hydraulic containment will still be maintained whilst groundwater levels exceed leachate levels. Given the slow rate of rise of leachate in the Site as a result of the loss of leachate management, it is considered that, taking into account the frequency of leachate monitoring and reporting likely required for the Eastern Extension, sufficient time is available to reinstate leachate extraction before hydraulic containment is lost.

4.0 REVIEW OF TECHNICAL PRECAUTIONS

A series of essential and technical precautions were identified as part of the HRAs for the existing Site. These are detailed below and are also considered applicable for the Eastern Extension.

4.1 Capping

To reduce the amount of precipitation which can infiltrate the waste, a low permeability cap will be constructed as waste in each cell is completed to final pre-settlement levels. Analogous methodology has been successfully employed at the currently operating Biffa Eye Landfill site.

The capping system employed across all phases is and will remain compliant with the requirements of the Environmental Permitting Regulations, 2016. Details of the capping system are described in the ESID (ref. 21453458.632) and will be further refined in CQA Plans for each cell.

4.2 Lining Design

The geological barrier for the basal lining system in the cells comprises an engineered barrier system of clay with a maximum permeability of 1×10^{-9} m/s. The design is considered compliant with the Environmental Permitting Regulations, 2016.

4.3 Leachate Management

Leachate will be managed in accordance with the Leachate Management Plan (ref. 21453458.641), Appendix 4 to this variation application, and Environmental Permit in order to maintain hydraulic containment.

4.4 Groundwater Management

Shallow groundwater is present in the River Terrace Deposits and currently discharges into the quarry from the lower parts of the quarry face from where it is pumped to the surface water lagoon in the northwest corner. Water is pumped from the lagoon to the Cat's Water Drain.

To facilitate working of sand and gravel in the Eastern Extension, groundwater removal will be required. Groundwater will continue to be managed and back-drains installed behind the exterior lining system of Cells 10 to 19 so that groundwater will drain into the undeveloped parts of the quarry from where it will be pumped to the surface water lagoon for discharge to the Cat's Water Drain. A back-drain is not required along the Cat's Water Drain or the full height engineered bund. Groundwater will be managed in accordance with the Groundwater Management Plan (ref. 21453458.640), Appendix 3 to this variation application. In the future once landfilling is complete and pumping ceased, rebound of the surrounding groundwater will occur increasing the degree of hydraulic containment at the Site.

4.5 Surface Water Management

Surface water management practices at the Eastern Extension will follow procedures as outlined in the Surface Water Management Plan (ref. 21453458.642), Appendix 5 to this variation application. The main focus will be to protect Cat's Water Drain.

Currently, Thory pumps surface water collected within the existing quarry to a settlement pond in the northwest corner of the Site. It is discharged to the Cat's Water Drain. This area will become an inert landfill in the future and the settlement pond will be moved to a new suitable location.

5.0 REQUISITE SURVEILLANCE

The purpose of this section is to present monitoring infrastructure for the planned Eastern Extension.

Drawing HRA5 shows the location of current groundwater and surface water monitoring points. The proposed locations of leachate extraction and monitoring points and additional groundwater monitoring points are presented in the same drawing.

The requisite surveillance has been reviewed with reference to EA landfill monitoring guidance[4].

5.1 Leachate Monitoring

Leachate monitoring is essential to develop an understanding of the quality of leachate present at the Site and how it evolves with time. It is important that leachate levels are monitored regularly across the Eastern Extension to ensure the Site remains in compliance in respect of leachate levels. In the event that leachate levels approach or exceed compliance limits then emergency measures can be implemented e.g. increased active leachate abstraction, in order to bring the Eastern Extension back into compliance.

Each cell will have two leachate monitoring points (LMPs) to allow monitoring of leachate levels remote to the leachate extraction well (LEW). Leachate monitoring infrastructure is described as a part of the ESID report (ref. 21453458.632) and presented in Drawings ESID7.

It is proposed that the leachate levels are monitored on a monthly basis for operational cells. This approach is currently adopted and regulated by an Environmental Permit at the Site and is considered appropriate for the Eastern Extension.

The leachate level compliance limit will initially be set to 1.4 m above base of cell. This is 1 m below the minimum groundwater level in the Kellaways Sand and River Terrace Deposits (prior to quarry dewatering). As the cells are constructed and groundwater levels adjacent to them are better understood, compliance limits should be regularly reviewed and amended to reflect ongoing groundwater monitoring to ensure that leachate limits are at least 1 m below the minimum groundwater level.

Leachate quality monitoring is required at the existing site on a quarterly basis for operational cells. An annual hazardous substance screen is required for operational cells, and once every four years for non-operational cells. This practice should be continued for the Eastern Extension.

5.2 Groundwater Monitoring

It is essential to monitor groundwater adjacent to the Eastern Extension for groundwater elevation and quality. This is because an increase in contaminant concentrations beyond compliance limit concentrations may indicate that leachate is migrating from the landfill in a fashion that is not consistent with the predicted landfill behaviour. In such an instance, remedial steps can be taken rapidly and effectively to minimise any further detrimental effects on the groundwater environment.

Groundwater levels and quality are currently required to be monitored at the Willow Hall Quarry and Landfill quarterly in accordance with Table S3.3 of the EP EPR/DB3007TZ, similar to the Biffa-operated Site, and this is also considered appropriate for the Eastern Extension.

The pre-existing Thory and the recently (2021) drilled Biffa boreholes that should be included in the Eastern Extension groundwater monitoring regime include: BHP11/01, BHP11/02, BHP11/03, BHP11/05, BHP11/06, BH21-01, BH21-02, BH21-03, BH21-04, and BH21-05.

[4] https://www.gov.uk/guidance/landfill-operators-environmental-permits/monitor-and-report-your-performance

New groundwater monitoring wells will be drilled around the Eastern Extension into both the shallow and deep aquifers. Locations of the proposed monitoring points were determined taking into consideration the EA guidance (LFTGN02) (which recommends a 50 m spacing between perimeter groundwater monitoring boreholes), the pre-existing groundwater monitoring network and site constraints for reaching drilling locations. The proposed monitoring points are presented in MEPP (**Drawing HRA5**).

Current groundwater elevations, and therefore flow direction, in the River Terrace Deposits is variable, which is likely caused by local groundwater management systems. Therefore, whilst localised groundwater management, such as dewatering, continues, it is recommended that in absence of clearly defined downgradient monitoring points, the shallow groundwater monitoring points shown on the MEPP continue to be monitored.

It should be noted that data for the Kellaways Sand in the Eastern Extension has only been obtained for up to three data points per contaminant to date. Several of the River Terrace Deposits monitoring points also have a reduced sampling frequency. It is therefore recommended that the data should be revisited in 12 months following the collection and analysis of more samples from both the River Terrace Deposits and Kellaways Sand.

Following twelve months of groundwater level data collection the information should be analysed and groundwater flow direction in each aquifer should be confirmed. Subsequently, up-gradient boreholes should be identified and the compliance limits and control levels for these boreholes should be removed.

5.2.1 Groundwater Compliance Limits

Schedule 10 of the Environmental Permitting Regulations requires that groundwater compliance limits are set for potentially polluting substances.

Proposed groundwater compliance limits and control levels have been chosen based on the groundwater quality analysis presented in Section 2.4, as follows:

- For contaminants with concentrations that did not exceed UK DWS, the UK DWS was chosen as the compliance limit;
- Where UK DWS was not available FW EQS was used instead; and
- The control level was set as the maximum concentration previously detected.

In cases where the concentrations did exceed the UK DWS:

- The compliance limit was set at 10% above the historical maximum detected concentration; and
- The control level was set as the maximum concentration previously detected.

If a borehole has not previously been monitored for a specific parameter, the control level was set at the compliance limit (UK DWS) minus 10%.

It should be noted that groundwater from each Kellaways Sand monitoring point was analysed a maximum of three times. It is proposed that the compliance limits and control levels are revisited following a further 12 months of collection of data.

The twelve months following the cessation of current dewatering practices will allow for collection of groundwater level data that will in turn provide confirmation of the local groundwater flow direction in the shallow aquifer as well as validation of the groundwater flow system established for the deep aquifer. Once the groundwater flow direction is verified for each aquifer, compliance limits and control levels for monitoring points located upgradient of the local flow will no longer require monitoring regime including Compliance Limits and Control Levels.

Compliance limits and control levels for the priority contaminants are shown for the River Terrace Deposits (all MEPP boreholes until down and/or cross-gradient boreholes are determined) and Kellaways Sand (down and cross-gradient boreholes) in Table HRA24 and Table HRA25 respectively. Table HRA26 provides a summary of the monitoring requirements (parameters and frequencies) for the MEPP boreholes.

Table HRA24: Proposed Groundwater Compliance Limits and Control Levels for River Terrace Deposits

Borehole Drill ID	BEDS Name	BEDS Code	Compliance Limit (mg/l) and Justification		Control Level (mg/l) and Justification	
Ammoniacal Nitrogen						
BHP11/01	BH47	91002470	0.49	Maximum concentration + 10%	0.44	Maximum concentration
BHP11/02	BH54	91002540	0.53	Maximum concentration + 10% (excl outlier)	0.48	Maximum concentration (excl outlier)
BHP11/03	BH56	91002560	0.43	Maximum concentration + 10% (excl outlier)	0.39	Maximum concentration (excl outlier)
BHP11/05	BH50	91002500	0.64	Maximum concentration + 10%	0.58	Maximum concentration
BHP11/06	BH48	91002480	0.39	UK DWS	0.36	Maximum concentration
Arsenic						
BHP11/01	BH47	91002470	0.01	UK DWS	0.00099	Maximum concentration
BHP11/02	BH54	91002540	0.015	Maximum concentration + 10%	0.014	Maximum concentration
BHP11/03	BH56	91002560	0.01	UK DWS	0.009	UK DWS – 10%
BHP11/05	BH50	91002500	0.01	UK DWS	0.00052	Maximum concentration
BHP11/06	BH48	91002480	0.01	UK DWS	0.009	UK DWS – 10%
Chloride						
BHP11/01	BH47	91002470	250	UK DWS	42.3	Maximum concentration
BHP11/02	BH54	91002540	250	UK DWS	78.0	Maximum concentration
BHP11/03	BH56	91002560	250	UK DWS	48.4	Maximum concentration
BHP11/05	BH50	91002500	250	UK DWS	57.7	Maximum concentration
BHP11/06	BH48	91002480	250	UK DWS	37.9	Maximum concentration
Mecoprop						
BHP11/01	BH47	91002470	0.0001	UK DWS	0.00004	Maximum concentration

Borehole Drill ID	BEDS Name	BEDS Code	Compliance Limit (mg/l) and Justification		Control Level (mg/l) and Justification	
BHP11/02	BH54	91002540	0.0001	UK DWS	0.00004	Maximum concentration
BHP11/03	BH56	91002560	0.0001	UK DWS	0.00004	Maximum concentration
BHP11/05	BH50	91002500	0.0001	UK DWS	0.00004	Maximum concentration
BHP11/06	BH48	91002480	0.0001	UK DWS	0.00004	Maximum concentration
Naphthalene						
BHP11/01	BH47	91002470	0.0002	FW EQS	0.0001	Maximum concentration
BHP11/02	BH54	91002540	0.0002	FW EQS	0.00013	Maximum concentration
BHP11/03	BH56	91002560	0.0002	FW EQS	0.00001	Maximum concentration
BHP11/05	BH50	91002500	0.0002	FW EQS	0.0001	Maximum concentration
BHP11/06	BH48	91002480	0.0002	FW EQS	0.00001	Maximum concentration
Nickel						
BHP11/01	BH47	91002470	0.02	UK DWS	0.00411	Maximum concentration
BHP11/02	BH54	91002540	0.02	UK DWS	0.00426	Maximum concentration (excl outlier)
BHP11/03	BH56	91002560	0.02	UK DWS	0.00342	Maximum concentration
BHP11/05	BH50	91002500	0.02	UK DWS	0.00584	Maximum concentration (excl outlier)
BHP11/06	BH48	91002480	0.02	UK DWS	0.00393	Maximum concentration
Phenol						
BHP11/01	BH47	91002470	0.0077	FW EQS	0.005	Maximum concentration
BHP11/02	BH54	91002540	0.0077	FW EQS	0.005	Maximum concentration
BHP11/03	BH56	91002560	0.0077	FW EQS	0.0069	FW EQS – 10%
BHP11/05	BH50	91002500	0.0077	FW EQS	0.005	Maximum concentration
BHP11/06	BH48	91002480	0.0077	FW EQS	0.0069	FW EQS – 10%

Table HRA25: Proposed Groundwater Compliance Limits and Control Levels for Kellaways Sand

Borehole ID	BEDS Name	BEDS Code	Compliance Limit (mg/l)		Control Level (mg/l)	
Ammoniacal Nitrogen						
BH21-03	BH51	91002510	2.40	Maximum concentration + 10%	2.18	Maximum concentration
BH21-04	BH52	91002520	5.26	Maximum concentration + 10%	4.78	Maximum concentration
BH21-05	BH53	91002530	3.12	Maximum concentration + 10%	2.84	Maximum concentration
Arsenic						
BH21-03	BH51	91002510	0.01	UK DWS	0.002	Maximum concentration
BH21-04	BH52	91002520	0.01	UK DWS	0.009	Maximum concentration
BH21-05	BH53	91002530	0.01	UK DWS	0.003	Maximum concentration
Chloride						
BH21-03	BH51	91002510	1782	Maximum concentration + 10%	1620	Maximum concentration
BH21-04	BH52	91002520	1793	Maximum concentration + 10%	1630	Maximum concentration
BH21-05	BH53	91002530	2464	Maximum concentration + 10%	2240	Maximum concentration
Mecoprop						
BH21-03	BH51	91002510	0.0001	UK DWS	0.00004	Maximum concentration
BH21-04	BH52	91002520	0.0001	UK DWS	0.00004	Maximum concentration
BH21-05	BH53	91002530	0.0001	UK DWS	0.00004	Maximum concentration
Naphthalene						
BH21-03	BH51	91002510	0.0002	FW EQS	0.0001	Maximum concentration
BH21-04	BH52	91002520	0.0002	FW EQS	0.00003	Maximum concentration
BH21-05	BH53	91002530	0.0002	FW EQS	0.00001	Maximum concentration
Nickel						
BH21-03	BH51	91002510	0.004	FW EQS	0.001	Maximum concentration
BH21-04	BH52	91002520	0.004	FW EQS	0.002	Maximum concentration

Borehole ID	BEDS Name	BEDS Code	Compliance Limit (mg/l)		Control Level (mg/l)	
BH21-05	BH53	91002530	0.004	FW EQS	0.001	Maximum concentration
Phenol						
BH21-03	BH51	91002510	0.0077	FW EQS	0.005	Maximum concentration
BH21-04	BH52	91002520	0.0077	FW EQS	0.005	Maximum concentration
BH21-05	BH53	91002530	0.0077	FW EQS	0.005	Maximum concentration

Table HRA26: Proposed Groundwater Monitoring Requirements

Monitoring Point Ref./description	Parameter	Monitoring frequency	Monitoring standard or method
Up gradient MEPP	Water level, electrical conductivity, chloride, ammoniacal nitrogen, pH	Quarterly	As specified in Environment Agency Guidance TGN02 'Monitoring of Landfill Leachate, Groundwater and Surface Water' (February 2003), Horizontal Guidance Note H1 - Environmental Risk Assessment for permits, Annex J3, version 2.1, Dec 2011, or such other subsequent guidance as may be agreed in writing with the Environment Agency.
	Total alkalinity, magnesium, potassium, total sulphates, calcium, sodium, chromium, copper, iron, lead, nickel, zinc, manganese	Annually	
	Hazardous substances (also including phenol, naphthalene, mecoprop)	Annually for first six years of operation	
Down or cross gradient MEPP	Water level, electrical conductivity, chloride, ammoniacal nitrogen, pH	Quarterly	
	Total alkalinity, magnesium, potassium, total sulphates, calcium, sodium, chromium, copper, iron, lead, nickel, zinc, manganese	Annually	
	Hazardous substances (also including phenol, naphthalene, mecoprop) detected in leachate	Annually for first six years of operation then every two years	
MEPP	Base on monitoring point (mAoD)	Annually	

5.3 Surface Water Monitoring

Surface water is proposed to be monitored at three points, one upstream (SW13) and one downstream (SW14) of the landfill in Cat's Water Drain, and one at the discharge point (SW15) into Cats Water Drain from the settlement pond located in the northwestern corner of the landfill, following the EA guidance (LFTGN02). The surface water monitoring points locations are presented in **Drawing HRA5**.

Proposed compliance limits for surface water at SW14 and SW15 are presented in Table HRA27, set at the Permit limit for the existing Site, FW EQS or, where FW EQS is unavailable, UK DWS. SW13 will not require compliance limits as it is located upgradient. Surface water quality analysis is described in Section 2.4 and it found no exceedances of UK DWS and FW EQS. Table HRA28 provides a summary of the monitoring requirements (parameters and frequencies) for the surface water monitoring points shown on the MEPP.

Table HRA27: Proposed Compliance Limits for Surface Water

Determinand	Compliance Limit (mg/l)
Suspended Solids	20
pH	Not <6 nor >9 pH units
Oil and grease	None visible
Ammoniacal Nitrogen	0.39
Arsenic	0.05
Chloride	250
Mecoprop	0.018
Naphthalene	0.0002
Nickel	0.004
Phenol	0.0077

Table HRA28: Proposed Surface Water Monitoring Requirements

Location	Parameter	Frequency	Monitoring Standard or Method
MEPP	Ammoniacal nitrogen, chloride, suspended solids, visual oil and grease, pH, electrical conductivity	Monthly	As specified in Environment Agency Guidance TGN02 'Monitoring of Landfill Leachate, Groundwater and Surface Water' (February 2003), Horizontal Guidance Note H1 - Environmental Risk Assessment for permits, Annex J3, version 2.1, Dec 2011, or such other subsequent guidance as may be agreed in writing with the Environment Agency.
	Arsenic, mecoprop, naphthalene, nickel, phenol	Annually	

It should be noted that only up to three data points are currently available per contaminant for SW13 and SW14 monitoring points; therefore, it is recommended that the data should be revisited in 12 months following the collection of more samples.

6.0 CONCLUSIONS

In accordance with Schedule 22 of the Environmental Permitting Regulations, necessary measures will be taken to prevent the input of hazardous substances to groundwater. Discharges of hazardous substances will not be discernible in groundwater immediately downgradient of the landfill. Both hazardous substances and non-hazardous pollutants are present within the leachate produced at the existing site and are expected to also be present in leachate that will be generated in the Eastern Extension. There is potential for small amounts of leachate to migrate through the liner system; however, the breakthrough times for the maximum concentrations have been calculated to remain significantly below the relevant quality standards and therefore are considered to pose negligible risk to groundwater and surface water quality. Leachate levels within the infilled cells will be managed to remain in compliance.

The proposed technical precautions including the liner system, capping, and management of leachate and groundwater, will prevent unacceptable discernible discharge of hazardous substances and non-hazardous pollutants to groundwater throughout the Site's lifecycle and are therefore considered compliant with Schedule 22 of the Environmental Permitting Regulations.

The provision of suitable requisite surveillance of groundwater is a requirement of Schedule 22 of the Environmental Permitting Regulations. The requisite surveillance for the Eastern Extension is considered to be in accordance with EA guidance.

7.0 REFERENCES

1) Environment Agency (2004) Contaminant Fluxes from Hydraulic Containment Landfills Worksheet Version 1.0. Produced under Science Group: Air, Land and Water project SC0310.

2) ESI, 2015. Eye Landfill – Northeastern and Southern Extensions: Hydrogeological Risk Assessment Review, Report Reference 63356R1D1, dated October 2015.

3) Golder, 2008. Section B Hydrogeological Risk Assessment Eye Southern Extension Landfill, Report Reference 075142900224.521/A.0, dated May 2008.

4) Hafren Water, 2015. Hydrogeological Risk Assessment report, Report Reference 1941/HRA, Version 1.1, dated April 2015.

5) Mather J., Halliday D, Joseph J, 1998. Is all groundwater worth protecting? The example of Kellaways Sand. Geological Society, London, Special Publications, v. 130, p. 211-217. doi: 10.1144/GSL.SP.1998.130.01.19

6) National Toxicity Program (NTP), Institute of Environmental Health Sciences, National Institutes of Health (1992) *National Toxicity Program Chemical Repository Database.* Research Triangle Park, North Carolina.

7) WFD TAG (2019) *Confirmed Hazardous Substances and Non-Hazardous Pollutants* list. https://www.wfduk.org/sites/default/files/Confirmed_Haz-NonHaz_January2019.pdf (accessed February 2022).

Signature Page

Golder WSP

Aniela Adamus
Graduate Hydrogeologist

Nicola White
Associate Hydrogeologist

AA/EMc/NW/ab

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At WSP House, 70 Chancery Lane, London, WC2A 1AF
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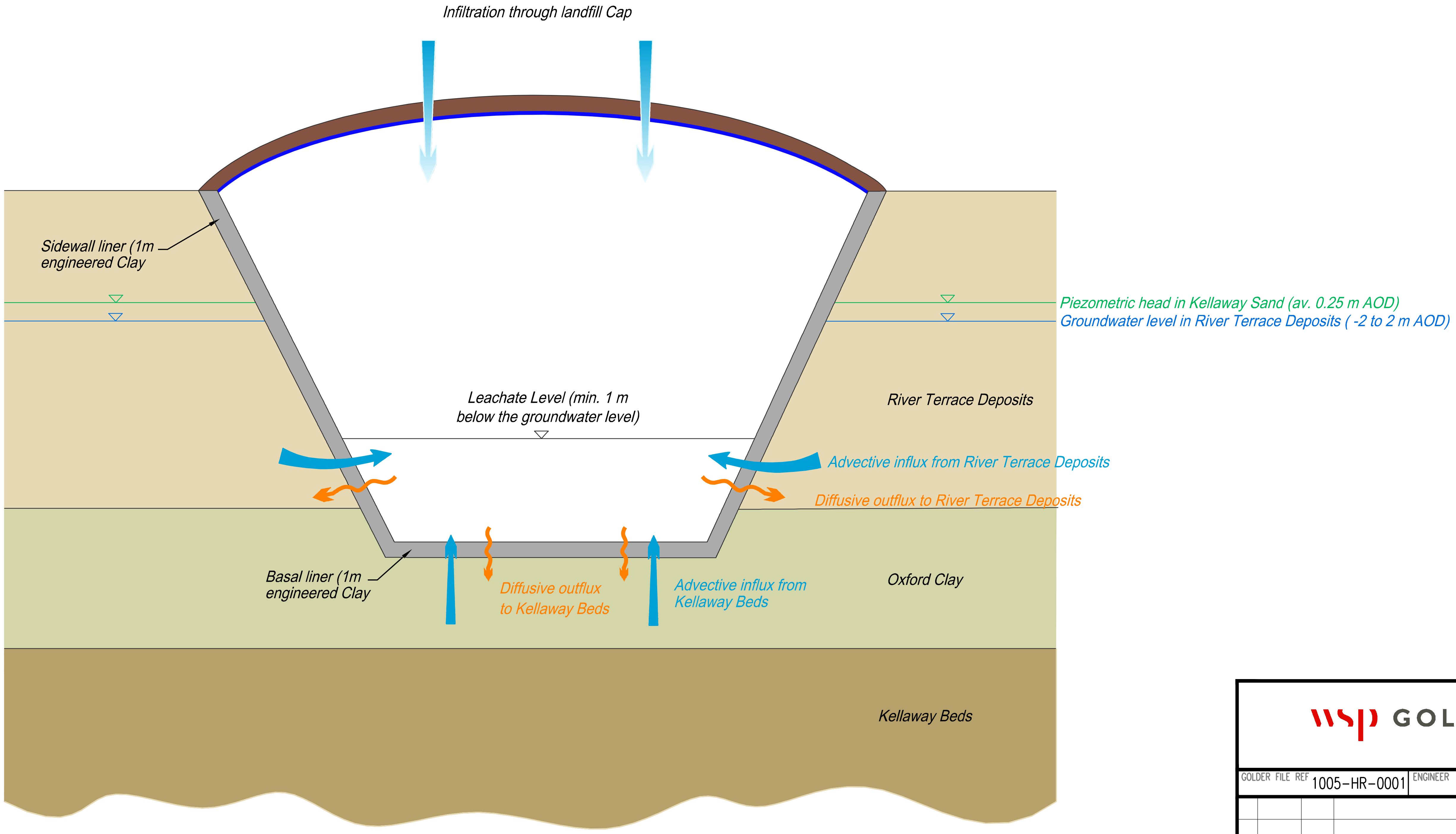
DRAWINGS



wsp GOLDER

GOLDER FILE REF	1005-HR-0001	ENGINEER	AA	REVIEWED BY	EMcA

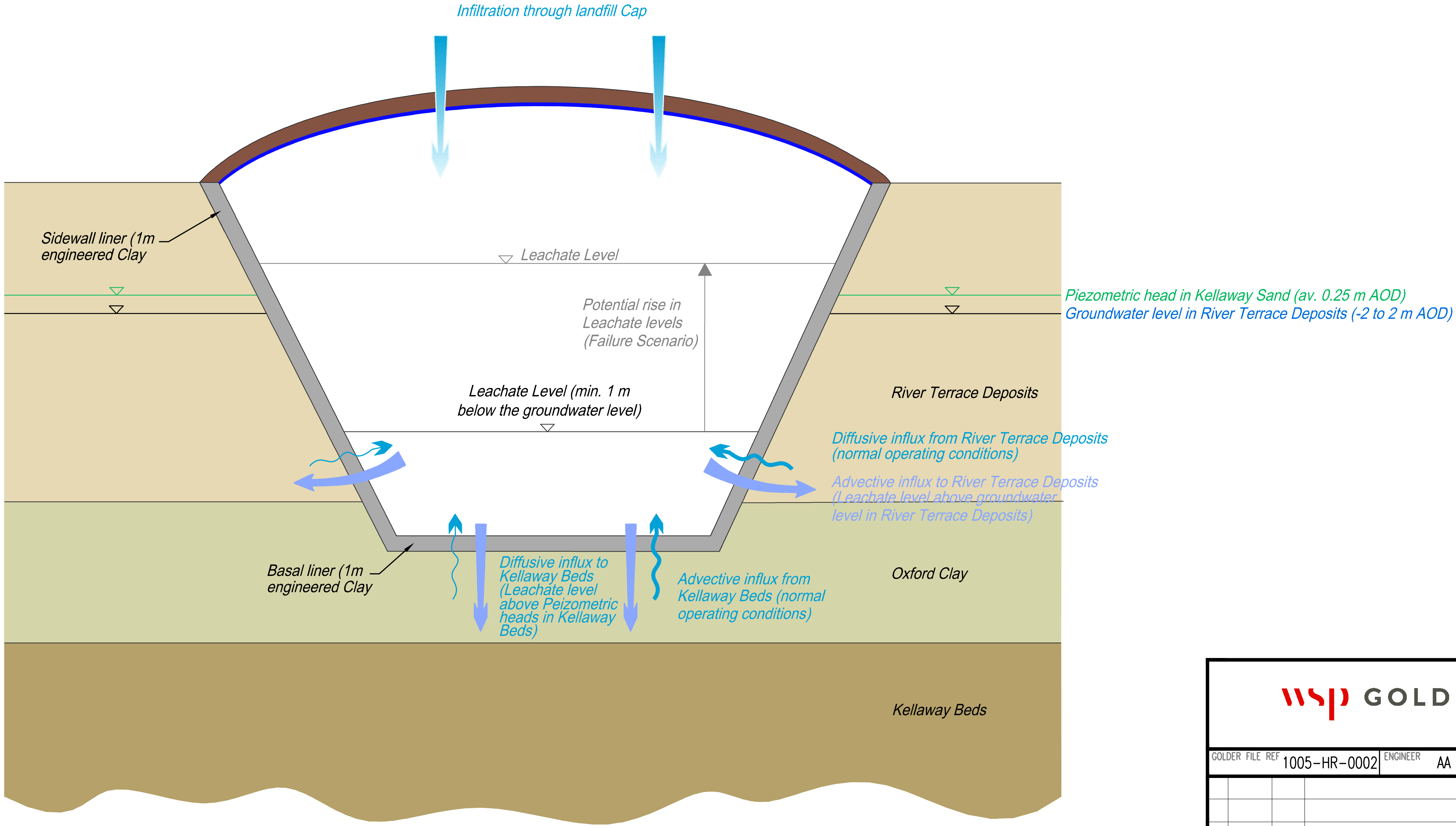
REV.	DATE	DRAWN	DESCRIPTION

Biffa

Biffa Waste Services Ltd
Redhill Landfill Site
Cormongers Lane,
Nutfield, Redhill
RH1 4ER
Tel. 01737 765042
Mob: 07921 386021

E-mail phil.mumford@biffa.co.uk

PROJECT	Eye Eastern Extension
LOCATION	Eye Landfill, Peterborough
DRAWING TITLE	Hydrogeological Conceptual Site Model (Normal Operating Conditions)
DRAWING No.	HRA1
COMPUTER REF.	E5239400
DRAWN	ECS
DATE	25/01/2022
SCALE(S)	Not to Scale



WSP GOLDER

GOLDER FILE REF	1005-HR-0002	ENGINEER	AA	REVIEWED BY	EMcA

REV.	DATE	DRAWN	DESCRIPTION

Biffa

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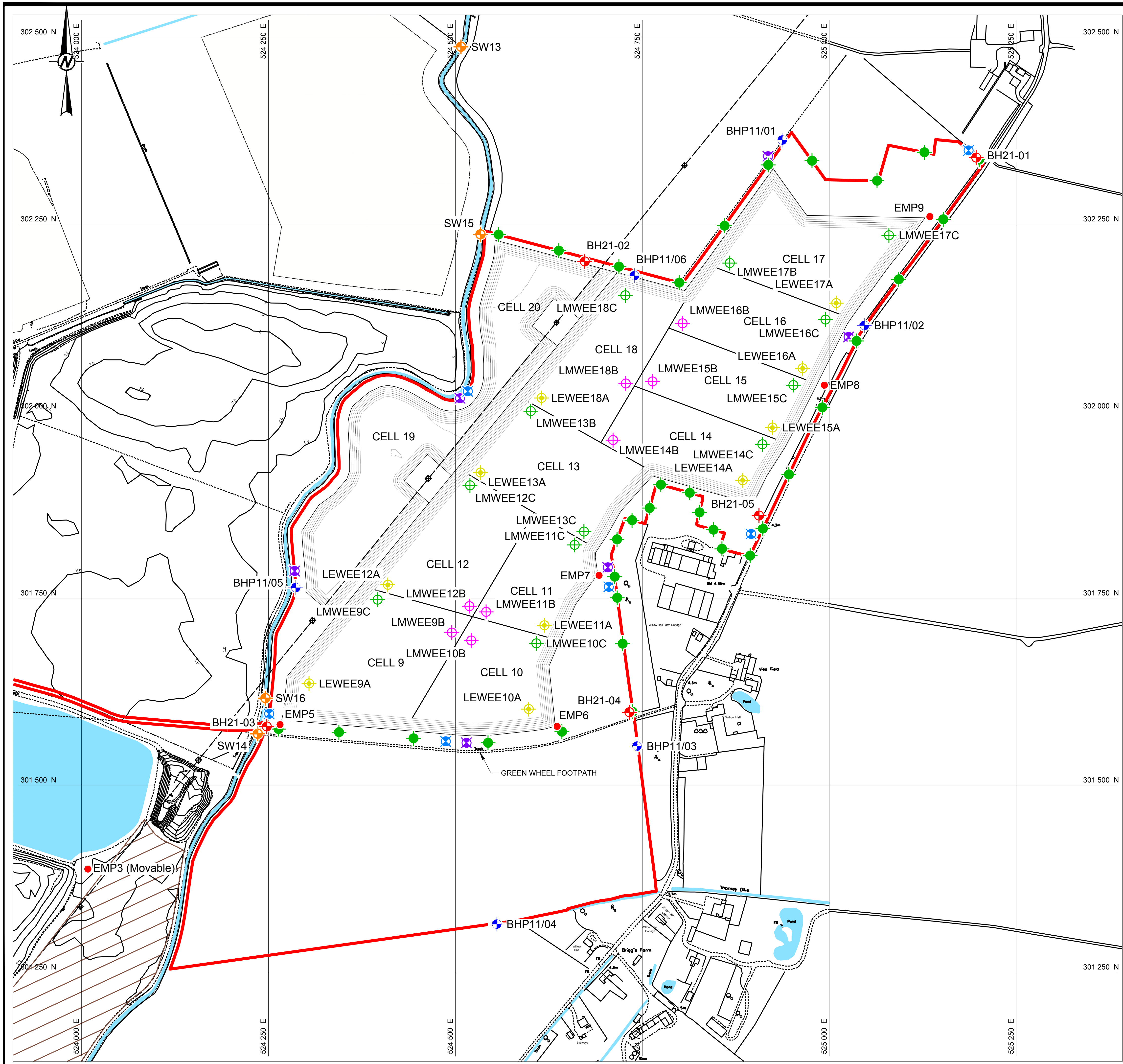
Tel. 01737 765042
Mob: 07921 386021
E-mail phil.mumford@biffa.co.uk

PROJECT	Eye Eastern Extension
LOCATION	Eye Landfill, Peterborough
DRAWING TITLE	Hydrogeological Conceptual Site Model (Failure Scenario)
DRAWING No.	HRA2
COMPUTER REF.	E5239500
DRAWN	ECS
DATE	25/01/2022
SCALE(S)	Not to Scale



LEGEND

- PLANNING APPLICATION BOUNDARY
- EXISTING GROUNDWATER MONITORING BOREHOLE (SAND AND GRAVEL)
- EXISTING GROUNDWATER MONITORING BOREHOLE (KELLAWAYS SANDS)
- SURFACE WATER MONITORING POINT
- PROPOSED GROUNDWATER MONITORING POINT (RIVER TERRACE DEPOSITS)
- PROPOSED GROUNDWATER MONITORING POINT (KELLAWAYS SAND)
- PROPOSED PERIMETER GAS MONITORING POINT
- LEACHATE EXTRACTION WELL EASTERN EXTENSION (UPSLOPE RISER)
- LEACHATE MONITORING WELL EASTERN EXTENSION (UPSLOPE RISER)
- LEACHATE MONITORING WELL EASTERN EXTENSION (VERTICAL)
- ENVIRONMENTAL MONITORING POINT

NAME	BEDS DESCRIPTION AND CODE
BH21-01	BH46 - 91002460
BHP11/01	BH47 - 91002470
BHP11/06	BH48 - 91002480
BH21-02	BH49 - 91002490
BHP11/05	BH50 - 91002500
BH21-03	BH51 - 91002510
BHP11/04	BH55 - 91002550
BHP11/03	BH56 - 91002560
BH21-04	BH52 - 91002520
BH21-05	BH53 - 91002530
BHP11/02	BH54 - 91002540

NOTE(S)

1. INDICATIVE POSITIONS SHOWN ONLY. EXACT LOCATIONS TO BE CONFIRMED IN CELL SPECIFIC CQA PLAN.

0 100 200

1:5,000 METRES

WSP GOLDER

GOLDER FILE REF	1005-HR-0005	ENGINEER	EMcA	REVIEWED BY	CMcD

REV.	DATE	DRAWN	DESCRIPTION

Biffa

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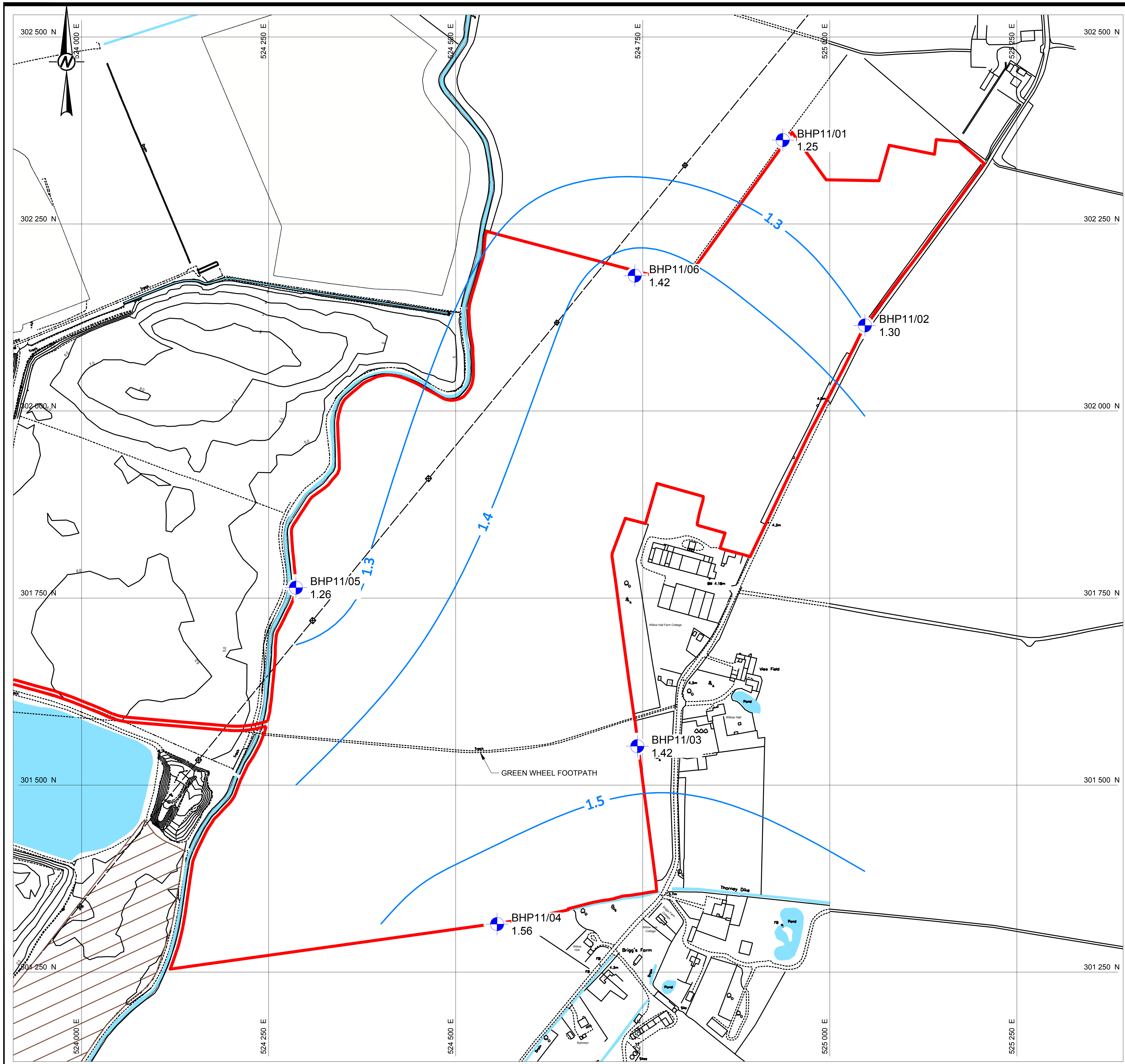
PROJECT	Eye Eastern Extension
LOCATION	Eye Landfill, Peterborough
DRAWING TITLE	Monitoring and Extraction Point Plan
DRAWING No.	HRA3
COMPUTER REF.	E5239600
DRAWN	TS
DATE	21/02/2022
SCALE(S)	1:5,000



LEGEND

- EASTERN EXTENSION BOUNDARY
- EXISTING MONITORING POINT (RIVER TERRACE DEPOSITS)
- GROUNDWATER LEVEL - RIVER TERRACE DEPOSITS (2011)

wsp GOLDER

GOLDER FILE REF 1005-HR-0003	ENGINEER AA	REVIEWED BY EMcA

REV.	DATE	DRAWN	DESCRIPTION

Biffa

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Cormongers Lane,
Nutfield, Redhill
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Mob: 07921 386021
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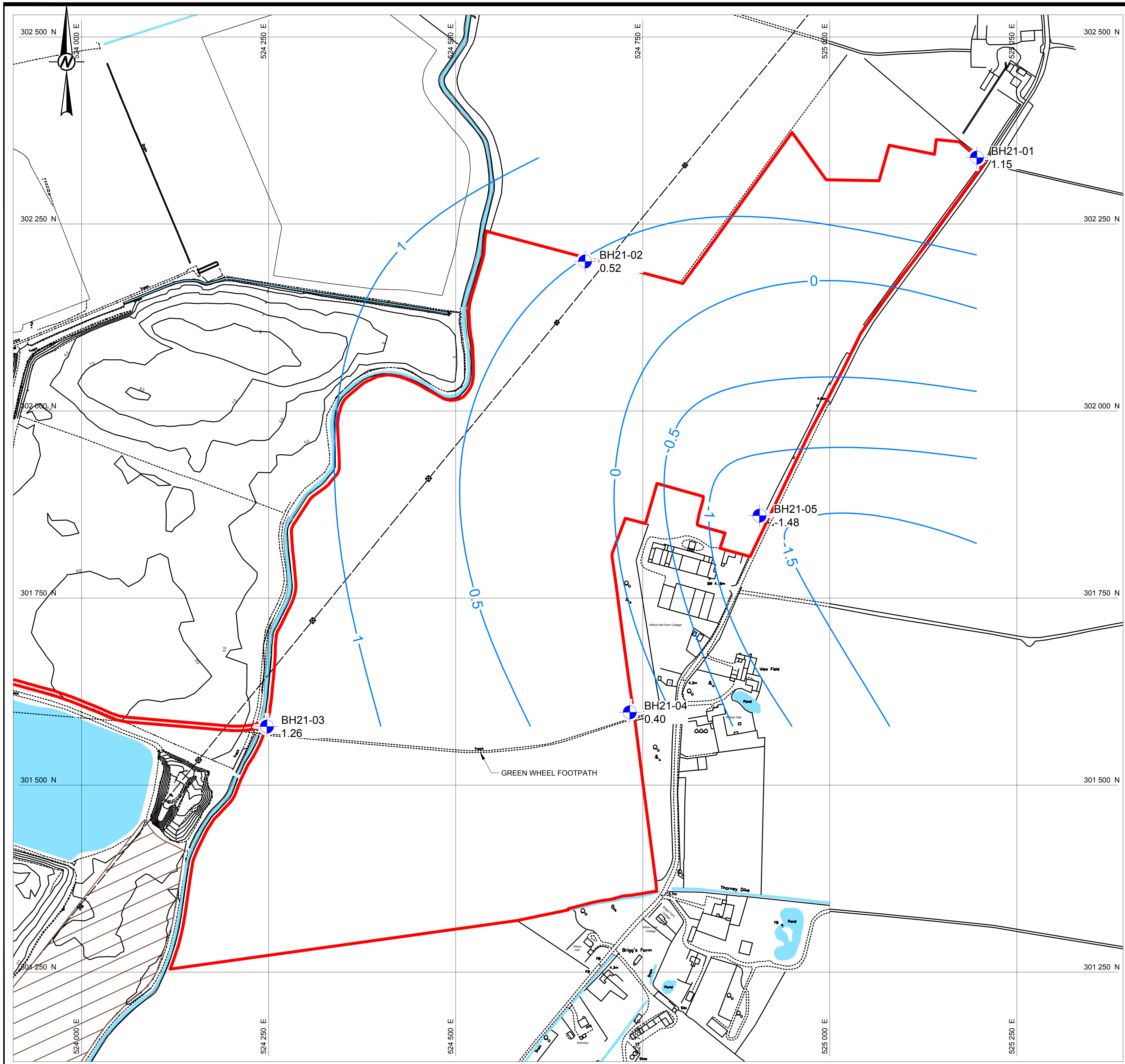
PROJECT	Eye Eastern Extension
LOCATION	Eye Landfill, Peterborough
DRAWING TITLE	Groundwater Contour Plot-River Terrace Deposits (2011)
DRAWING No.	HRA4
COMPUTER REF.	E5239700
DRAWN	ECS
DATE	25/01/2022
SCALE(S)	1:5,000



LEGEND

- EASTERN EXTENSION BOUNDARY
- EXISTING MONITORING POINT (KELLAWAYS SAND)
- GROUNDWATER LEVEL - KELLAWAYS SAND (DECEMBER 2021)

wsp GOLDER

GOLDER FILE REF	1005-HR-0004	ENGINEER	AA	REVIEWED BY	EMcA

REV.	DATE	DRAWN	DESCRIPTION

Biffa

Biffa Waste Services Ltd
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Cormongers Lane,
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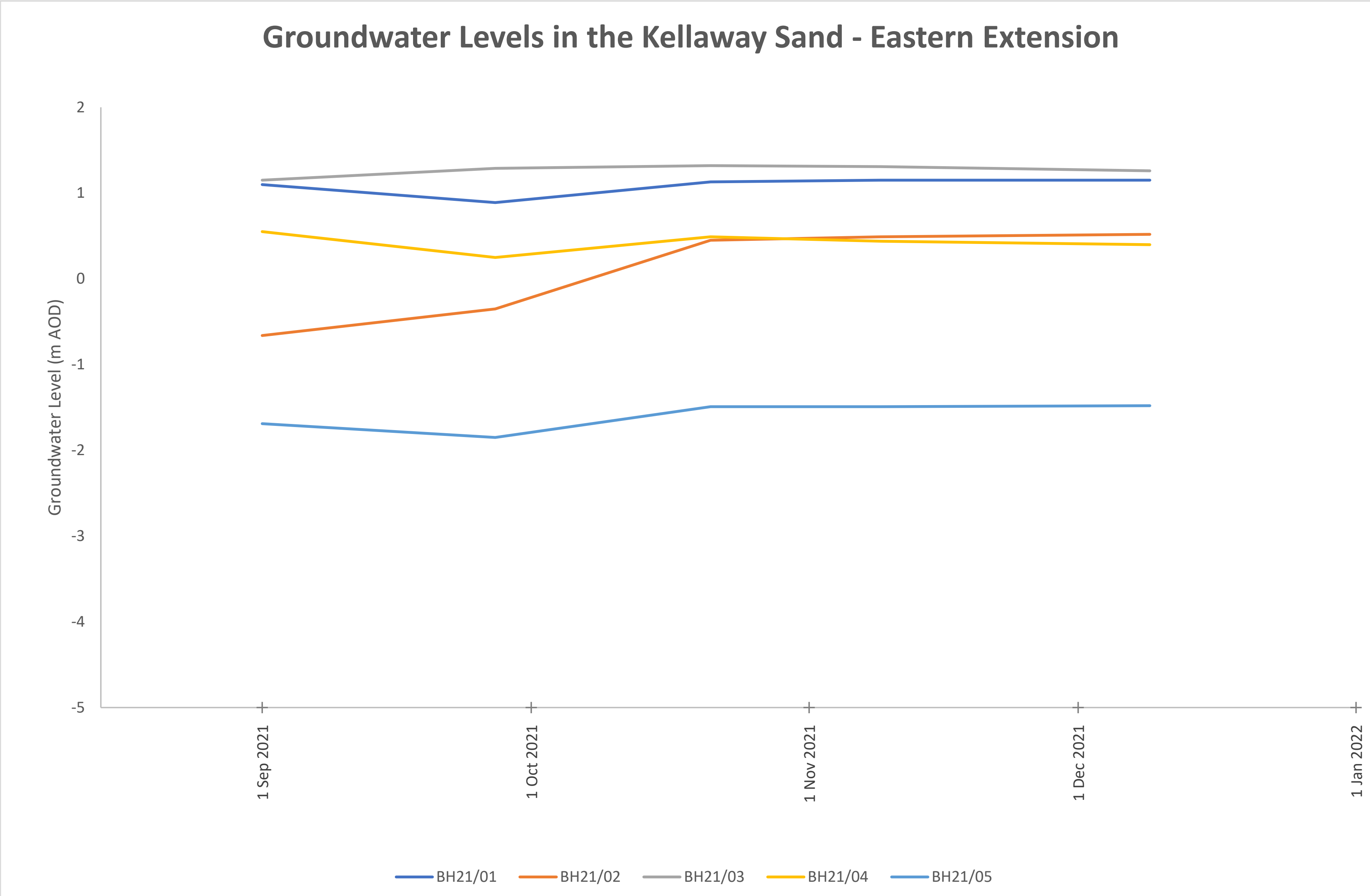
E-mail phil.mumford@biffa.co.uk

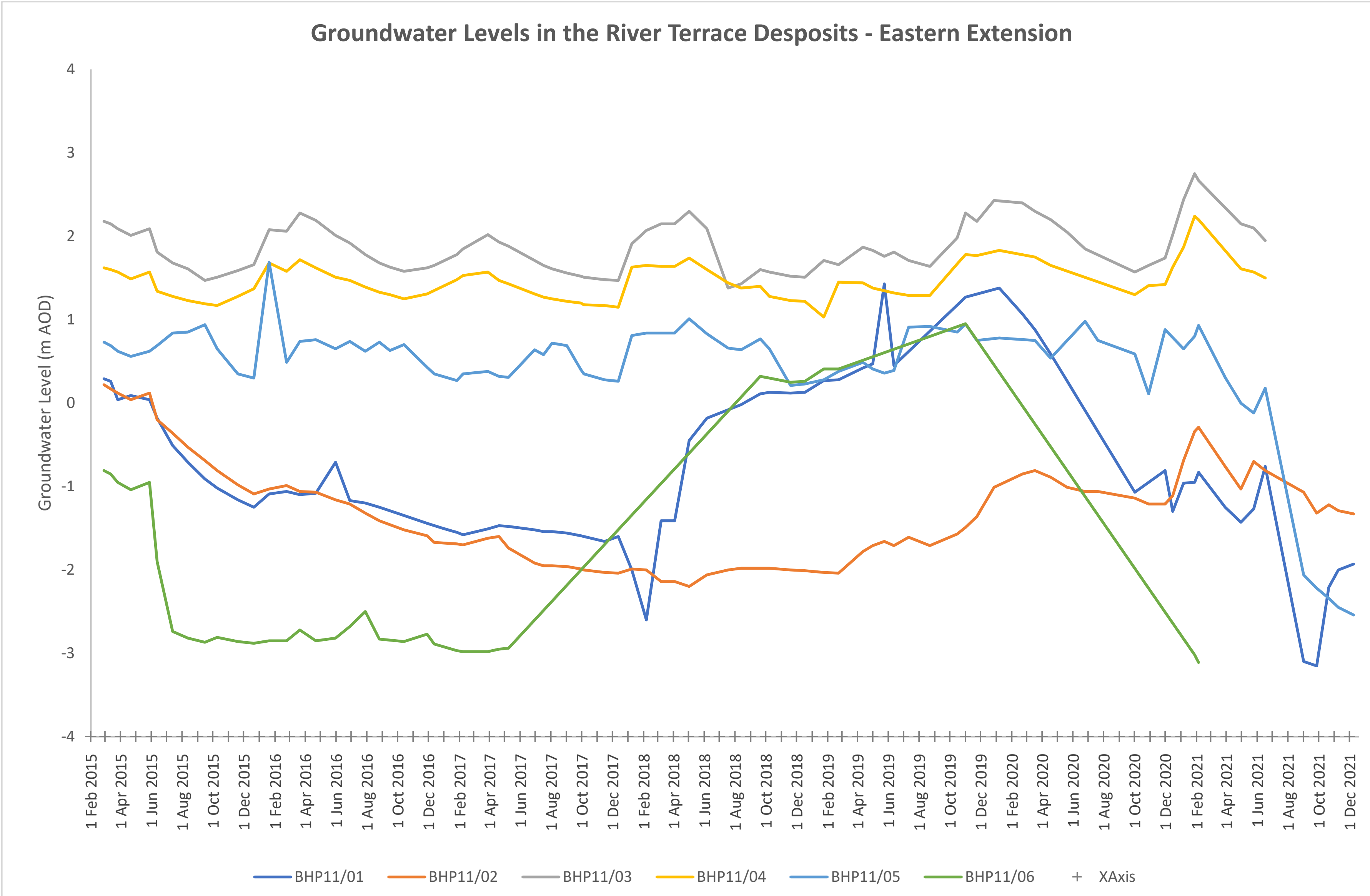
PROJECT	Eye Eastern Extension
LOCATION	Eye Landfill, Peterborough
DRAWING TITLE	Groundwater Contour Plot-Kellaways Sand (December 2021)
DRAWING No.	HRA5
COMPUTER REF.	E5239800
DRAWN	ECS
DATE	08/02/2022
SCALE(S)	1:5,000

APPENDIX HRA1

Groundwater Hydrographs

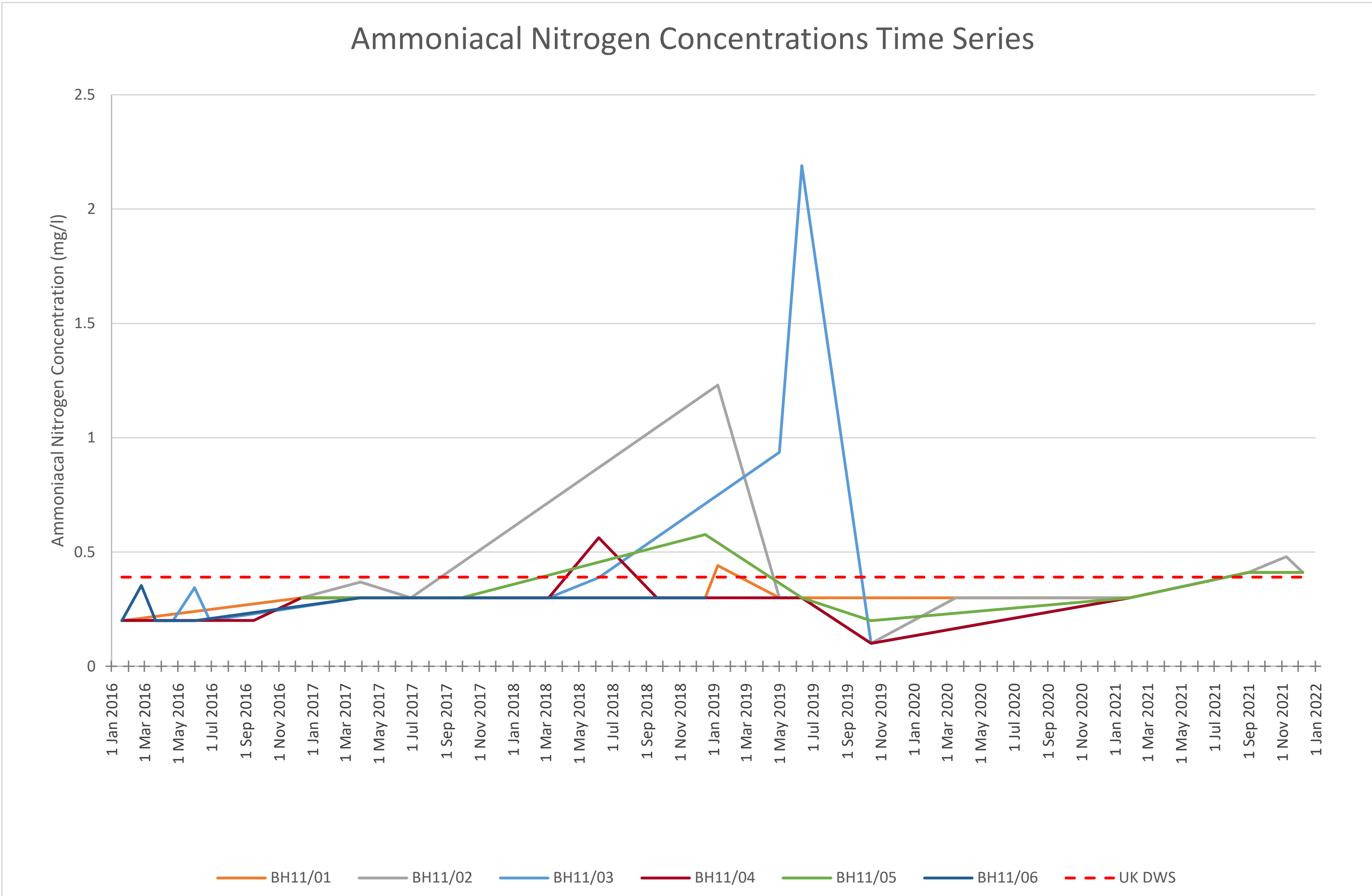


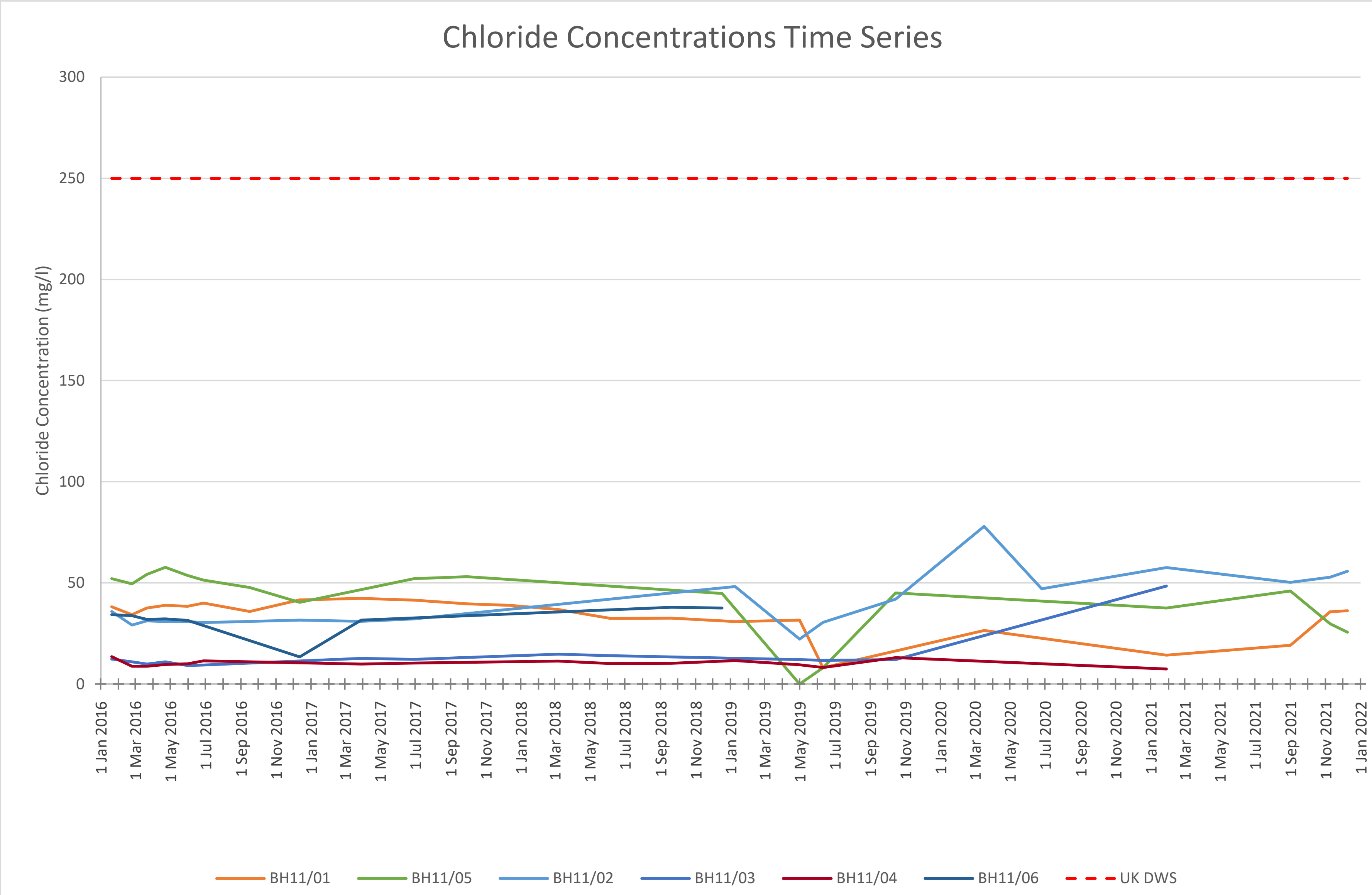
GOLDER
MEMBER OF WSP


Groundwater Levels in the River Terrace Desposits - Eastern Extension
Groundwater Level (m AOD)
4
3
2
1
0
-1
-2
-3
-4
1 Feb 2015
1 Apr 2015
1 Jun 2015
1 Aug 2015
1 Oct 2015
1 Dec 2015
1 Feb 2016
1 Apr 2016
1 Jun 2016
1 Aug 2016
1 Oct 2016
1 Dec 2016
1 Feb 2017
1 Apr 2017
1 Jun 2017
1 Aug 2017
1 Oct 2017
1 Dec 2017
1 Feb 2018
1 Apr 2018
1 Jun 2018
1 Aug 2018
1 Oct 2018
1 Dec 2018
1 Feb 2019
1 Apr 2019
1 Jun 2019
1 Aug 2019
1 Oct 2019
1 Dec 2019
1 Feb 2020
1 Apr 2020
1 Jun 2020
1 Aug 2020
1 Oct 2020
1 Dec 2020
1 Feb 2021
1 Apr 2021
1 Jun 2021
1 Aug 2021
1 Oct 2021
1 Dec 2021
BHP11/01
BHP11/02
BHP11/03
BHP11/04
BHP11/05
BHP11/06
XAxis

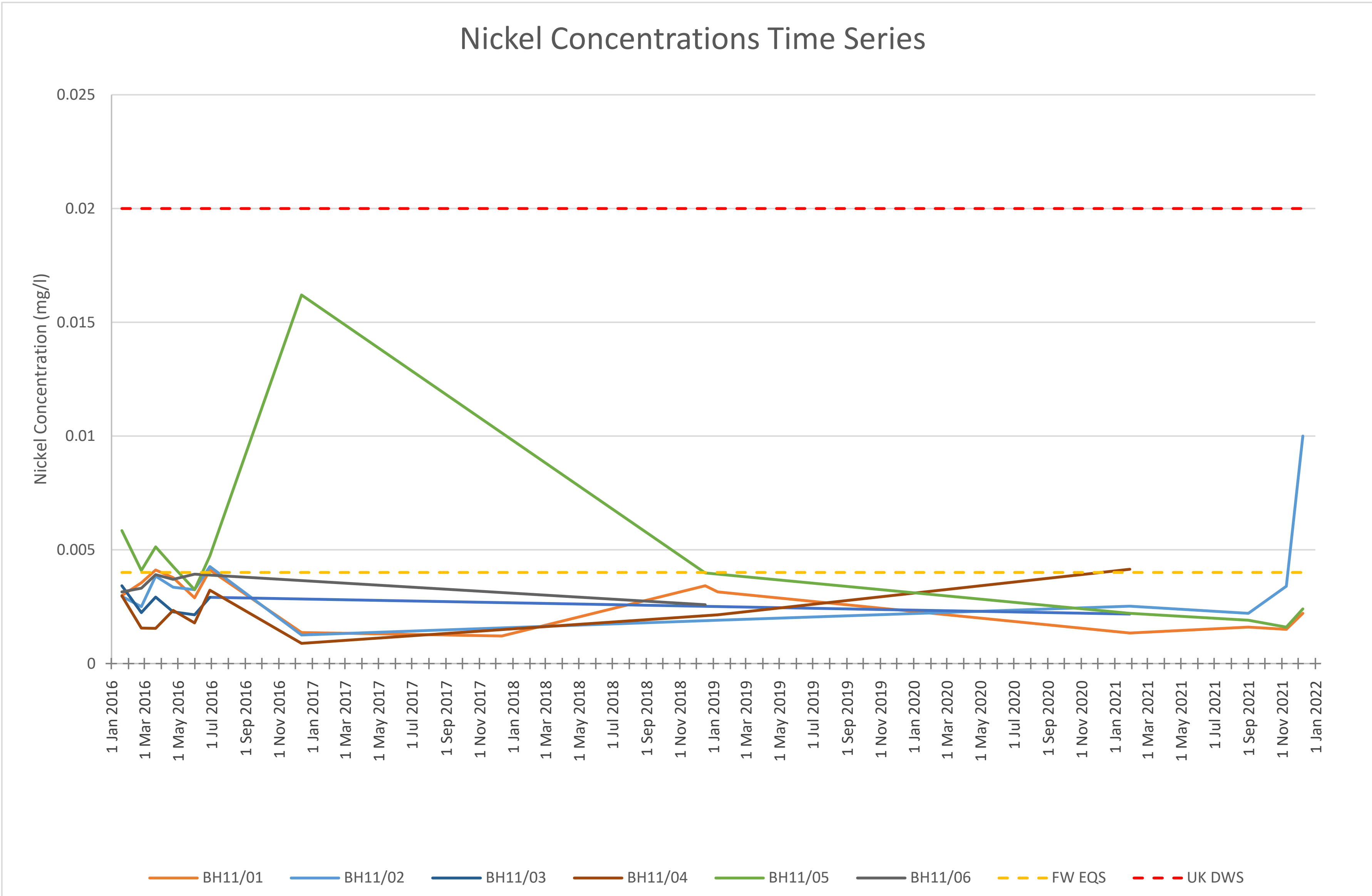
APPENDIX HRA2

Groundwater Quality Time Series


Ammoniacal Nitrogen Concentrations Time Series
Ammoniacal Nitrogen Concentration (mg/l)
2.5
2
1.5
1
0.5
0
1 Jan 2016
1 Mar 2016
1 May 2016
1 Jul 2016
1 Sep 2016
1 Nov 2016
1 Jan 2017
1 Mar 2017
1 May 2017
1 Jul 2017
1 Sep 2017
1 Nov 2017
1 Jan 2018
1 Mar 2018
1 May 2018
1 Jul 2018
1 Sep 2018
1 Nov 2018
1 Jan 2019
1 Mar 2019
1 May 2019
1 Jul 2019
1 Sep 2019
1 Nov 2019
1 Jan 2020
1 Mar 2020
1 May 2020
1 Jul 2020
1 Sep 2020
1 Nov 2020
1 Jan 2021
1 Mar 2021
1 May 2021
1 Jul 2021
1 Sep 2021
1 Nov 2021
1 Jan 2022
BH11/01
BH11/02
BH11/03
BH11/04
BH11/05
BH11/06
UK DWS



Chloride Concentrations Time Series
Chloride Concentration (mg/l)
300
250
200
150
100
50
0
1 Jan 2016
1 Mar 2016
1 May 2016
1 Jul 2016
1 Sep 2016
1 Nov 2016
1 Jan 2017
1 Mar 2017
1 May 2017
1 Jul 2017
1 Sep 2017
1 Nov 2017
1 Jan 2018
1 Mar 2018
1 May 2018
1 Jul 2018
1 Sep 2018
1 Nov 2018
1 Jan 2019
1 Mar 2019
1 May 2019
1 Jul 2019
1 Sep 2019
1 Nov 2019
1 Jan 2020
1 Mar 2020
1 May 2020
1 Jul 2020
1 Sep 2020
1 Nov 2020
1 Jan 2021
1 Mar 2021
1 May 2021
1 Jul 2021
1 Sep 2021
1 Nov 2021
1 Jan 2022
BH11/01
BH11/05
BH11/02
BH11/03
BH11/04
BH11/06
UK DWS


Nickel Concentrations Time Series
Nickel Concentration (mg/l)
0.025
0.02
0.015
0.01
0.005
0
1 Jan 2016
1 Mar 2016
1 May 2016
1 Jul 2016
1 Sep 2016
1 Nov 2016
1 Jan 2017
1 Mar 2017
1 May 2017
1 Jul 2017
1 Sep 2017
1 Nov 2017
1 Jan 2018
1 Mar 2018
1 May 2018
1 Jul 2018
1 Sep 2018
1 Nov 2018
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1 May 2019
1 Jul 2019
1 Sep 2019
1 Nov 2019
1 Jan 2020
1 Mar 2020
1 May 2020
1 Jul 2020
1 Sep 2020
1 Nov 2020
1 Jan 2021
1 Mar 2021
1 May 2021
1 Jul 2021
1 Sep 2021
1 Nov 2021
1 Jan 2022
BH11/01
BH11/02
BH11/03
BH11/04
BH11/05
BH11/06
FW EQS
UK DWS

APPENDIX HRA3

Hydraulic Containment Models Printout

Contaminant Fluxes from Hydraulic Containment Landfills Worksheet Version 1.0

Produced under Science Group: Air, Land & Water Project SC0310

Statement of Use

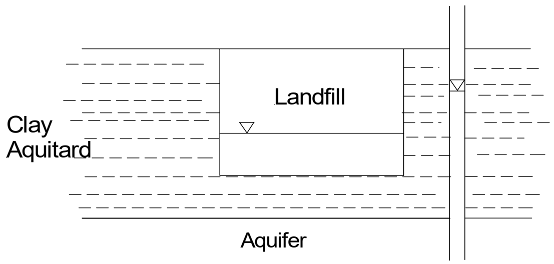
This worksheet has been prepared to help assessors quantify the contaminant flux from a hydraulic containment landfill constructed to the specifications in the Landfill Regulations (2002). It has been prepared to allow Agency staff to assess third party calculations of the diffusive contaminant flux from hydraulic containment landfills.

Data needs to be entered only in YELLOW cells. Assessors have to specify a preferred option from a pull-down menu in BLUE cells, interim calculation results are presented in GREY cells and final results in GREEN cells.
Only data in YELLOW or BLUE cells may be changed.

Site name
Eye Landfill
Assessor's name
Golder, member of WSP in the UK
Date
January 2022

SELECT LANDFILL CONSTRUCTION SCENARIO

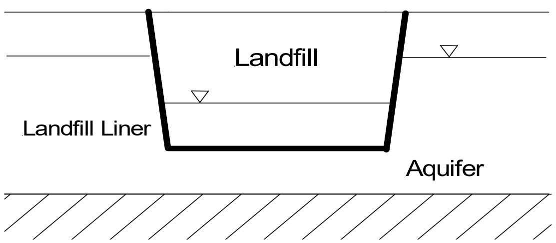
Scenario 1



The landfill is constructed in a clay pit, underlain by a confined aquifer.
Water and contaminant fluxes occur across the bottom of the landfill only.

◉ Select Scenario 1

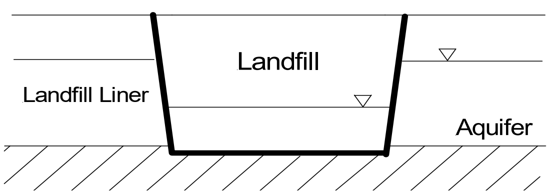
Scenario 2



The landfill is lined and located in a permeable formation a finite distance above an impermeable layer. The water and contaminant fluxes can occur through the base and sides of the landfill.

○ Select Scenario 2

Scenario 3



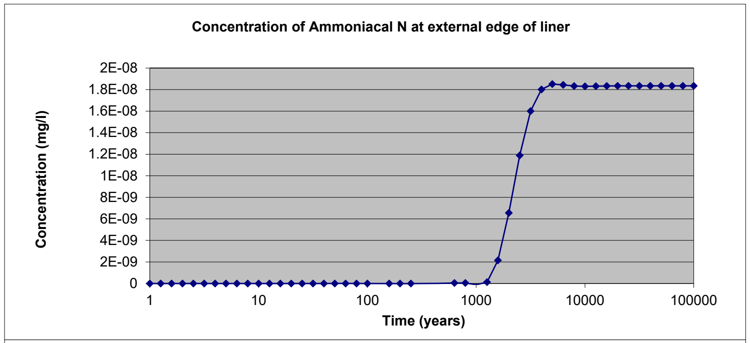
The landfill is lined and located in a permeable formation a finite distance below an impermeable layer. The water and contaminant fluxes can occur through the sides of the landfill only.

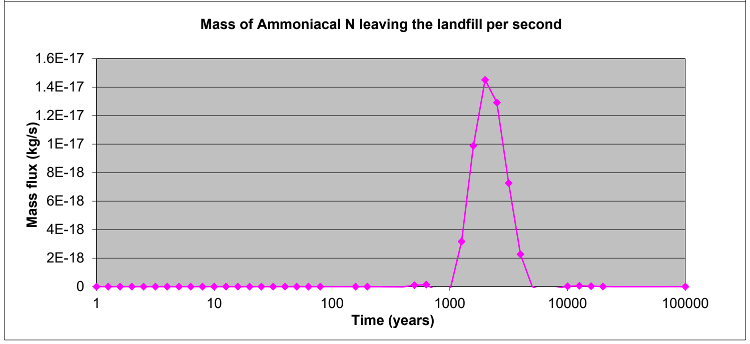
○ Select Scenario 3

Eye Landfill		13 January 2022	
CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION			
Conceptual model of landfill construction	CM	1	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD
Maximum thickness of underlying aquifer	Aq_max	5	m
Leachate head inside landfill	Head_inLF	-0.75	maOD
Groundwater head outside landfill	Head_outLF	0.25	maOD
Area of liner below the water table	Area_contact	190000	m2
CONTAMINANT PARAMETERS			
Contaminant name	Cont_Nme	Ammoniacal N	-
Contaminant type	Cont_Type	Inorganic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	2200	mg/l
Free water diffusion coefficient	Dw_cl	1.96E-09	m2/s
Partition coefficient in clay	Kd_cl	0.15	l/kg
Retardation factor in clay	R_cl	2.35	-
Half life in clay (0 for no decay)	thalf_cl	0	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	0	1/s
MINERAL BARRIER / LINER			
Thickness of mineral barrier is calculated as 12.5m			
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

Ammoniacal N

CONTAMINANT AND WATER FLUXES			
Groundwater flux into landfill		0.0000304	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	1.8512E-08	mg/l
CHART PARAMETERS			
Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+05	years





Eye Landfill	**13 January 2022**	
Golder, member of WSP in the UK		

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				**Justification / Reference / Notes**
Scenario		1		scenario for Kellaway Sands
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD	average depth taken from borehole logs
Maximum thickness of underlying aquifer	Aq_max	5	m	maximum thickness as described in ESID
Leachate head inside landfill	Head_inLF	-0.75	maOD	taken as 1 m below groundwater level in Kellaway Sands
Groundwater head outside landfill	Head_outLF	0.25	maOD	average gw level observed in the months following the bhs installation (Sep-Dec 2021)

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Ammoniacal N	-	n/a
Contaminant type	Cont_Type	Inorganic	-	Ammoniacal Nitrogen is inorganic substance
Contaminant classification	Cont_Class	List I	-	according to the JAGDAG classification
Concentration in landfill leachate	Conc_LF	2200	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	1.96E-09	m2/s	Table 3.1 in SC0310/SR (Review) (value for 25 deg C)
Partition coefficient in clay	Kd_cl	0.15	l/kg	conservative value given in App. 2 of NGWCLC Report NC/02/49
Half life in clay (0 for no decay)	thalf_cl	0	days	Ammoniacal nitrogen assumed to not degrade
Decay in sorbed phase?	Decay_sorb	No	-	Ammoniacal nitrogen assumed to not degrade

MINERAL BARRIER / LINER				
Thickness of mineral barrier is calculated as 12.5m	thick_clbr	1	m	fixed by model
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered basal liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; Eye NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill 14 January 2022

Arsenic

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	1	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD
Maximum thickness of underlying aquifer	Aq_max	5	m
Leachate head inside landfill	Head_inLF	-0.75	maOD
Groundwater head outside landfill	Head_outLF	0.25	maOD
Area of liner below the water table	Area_contact	190000	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Arsenic	-
Contaminant type	Cont_Type	Inorganic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	0.521	mg/l
Free water diffusion coefficient	Dw_cl	1.00E-09	m2/s
Partition coefficient in clay	Kd_cl	249.6	l/kg
Retardation factor in clay	R_cl	2247.4	-
Half life in clay (0 for no decay)	thalf_cl	0	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	0	1/s

MINERAL BARRIER / LINER

Thickness of mineral barrier is calculated as 12.5m

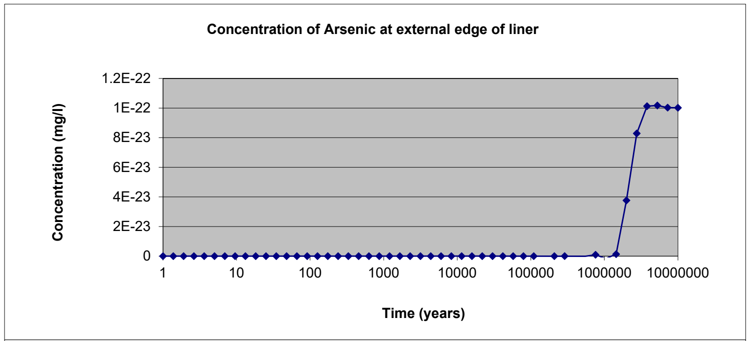
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

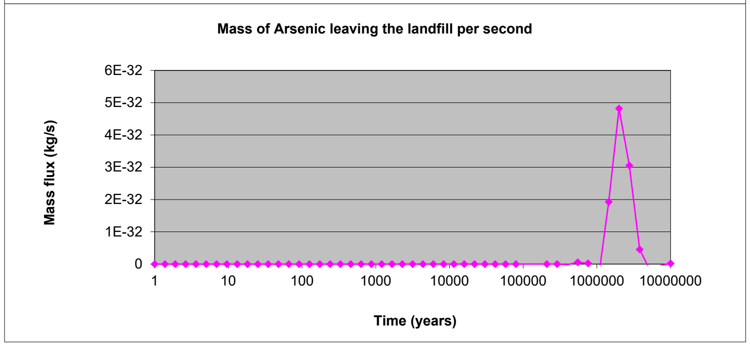
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		0.0000304	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	1.01746E-22	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+07	years





Eye Landfill **14 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				Justification / Reference / Notes
Scenario		1		scenario for Kellaway Sands
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD	average depth taken from borehole logs
Maximum thickness of underlying aquifer	Aq_max	5	m	maximum thickness as described in ESID
Leachate head inside landfill	Head_inLF	-0.75	maOD	taken as 1m below groundwater level in Kellaway Sands
Groundwater head outside landfill	Head_outLF	0.25	maOD	average gw level observed in the months following the bhs installation (Sep-Dec 2021)

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Arsenic	-	n/a
Contaminant type	Cont_Type	Inorganic	-	Arsenic is inorganic substance
Contaminant classification	Cont_Class	List I	-	Arsenic is List I = hazardous substance according to the JAGDAG classification
Concentration in landfill leachate	Conc_LF	0.521	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	0.000000001	m2/s	conservative value for diffusive contaminants
Partition coefficient in clay	Kd_cl	249.6	l/kg	value from ConSim help-files for glacial till (most similar lithology available)
Half life in clay (0 for no decay)	thalf_cl	0	days	Arsenic assumed to not degrade
Decay in sorbed phase?	Decay_sorb	No	-	Arsenic assumed to not degrade

MINERAL BARRIER / LINER				
Thickness of mineral barrier is calculated as 12.5m	thick_clbr	1	m	fixed by model
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered basal liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate, as used in Golder (2003; NE Extension HRA)
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill - Eastern Extension 14 January 2022

Chloride

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	1	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD
Maximum thickness of underlying aquifer	Aq_max	5	m
Leachate head inside landfill	Head_inLF	-0.75	maOD
Groundwater head outside landfill	Head_outLF	0.25	maOD
Area of liner below the water table	Area_contact	190000	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Chloride	-
Contaminant type	Cont_Type	Inorganic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	20500	mg/l
Free water diffusion coefficient	Dw_cl	2.03E-09	m2/s
Partition coefficient in clay	Kd_cl	0	l/kg
Retardation factor in clay	R_cl	1	-
Half life in clay (0 for no decay)	thalf_cl	0	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	0	1/s

MINERAL BARRIER / LINER

Thickness of mineral barrier is calculated as 12.5m

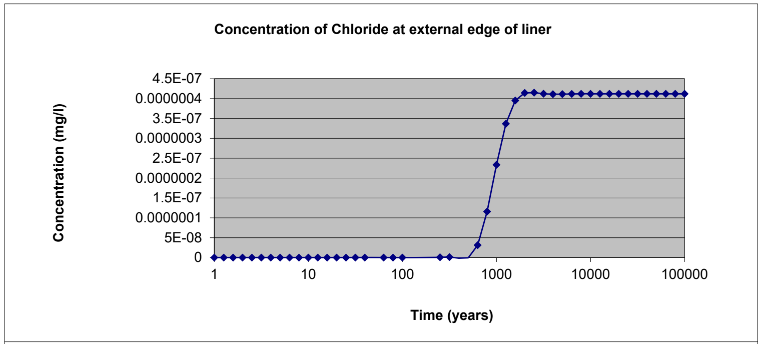
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

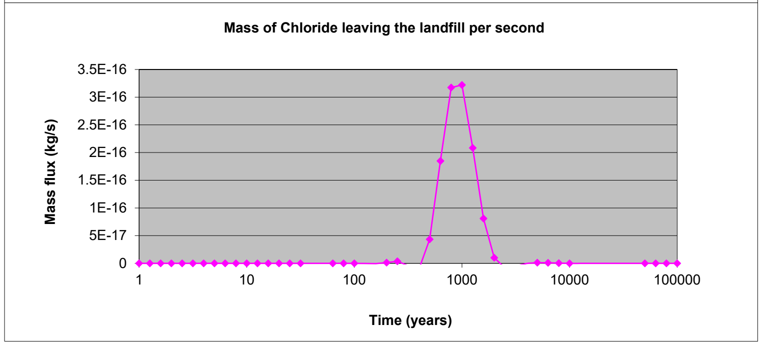
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		0.0000304	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	4.14903E-07	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+05	years





Eye Landfill - Eastern Extension **14 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				Justification / Reference / Notes
Scenario		1		scenario for Kellaway Sands
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD	average depth taken from borehole logs
Maximum thickness of underlying aquifer	Aq_max	5	m	maximum thickness as described in ESID
Leachate head inside landfill	Head_inLF	-0.75	maOD	taken as 1m below groundwater level in Kellaway Sands
Groundwater head outside landfill	Head_outLF	0.25	maOD	average gw level observed in the months following the bhs installation (Sep-Dec 2021)

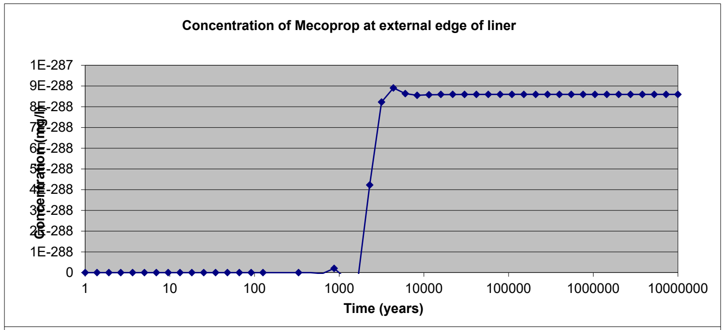
CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Chloride	-	n/a
Contaminant type	Cont_Type	Inorganic	-	chloride is inorganic substance
Contaminant classification	Cont_Class	List I	-	according to the JAGDAG classification
Concentration in landfill leachate	Conc_LF	20500	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	2.03E-09	m2/s	Table 3.1 in SC0310/SR (Review) (value for 25 deg C)
Partition coefficient in clay	Kd_cl	0	l/kg	chloride is assumed to be unretarded
Half life in clay (0 for no decay)	thalf_cl	0	days	chloride assumed to not degrade
Decay in sorbed phase?	Decay_sorb	No	-	chloride assumed to not degrade

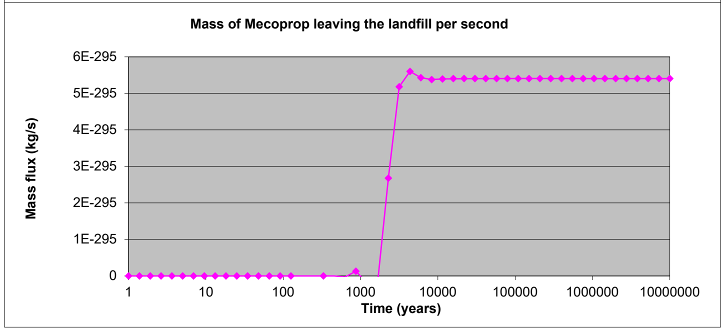
MINERAL BARRIER / LINER				
Thickness of mineral barrier is calculated as 12.5m	thick_clbr	1	m	fixed by model
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered basal liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; Eye NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill - Eastern Extension		18 January 2022	
CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION			
Conceptual model of landfill construction	CM	1	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD
Maximum thickness of underlying aquifer	Aq_max	5	m
Leachate head inside landfill	Head_inLF	-0.75	maOD
Groundwater head outside landfill	Head_outLF	0.25	maOD
Area of liner below the water table	Area_contact	190000	m2
CONTAMINANT PARAMETERS			
Contaminant name	Cont_Nme	Mecoprop	-
Contaminant type	Cont_Type	Organic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	0.095	mg/l
Free water diffusion coefficient	Dw_cl	3.90E-10	m2/s
Partition coefficient in clay	Kd_cl	2.328	l/kg
Retardation factor in clay	R_cl	21.952	-
Half life in clay (0 for no decay)	thalf_cl	92	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	3.97237E-09	1/s
MINERAL BARRIER / LINER			
Thickness of mineral barrier is calculated as 12.5m			
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

Mecoprop

CONTAMINANT AND WATER FLUXES			
Groundwater flux into landfill		0.0000304	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	8.9086E-288	mg/l
CHART PARAMETERS			
Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+07	years





Eye Landfill - Eastern Extension **18 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				Justification / Reference / Notes
Scenario		1		scenario of Kellaway Sands
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD	average depth taken from borehole logs
Maximum thickness of underlying aquifer	Aq_max	5	m	maximum thickness as described in ESID
Leachate head inside landfill	Head_inLF	-0.75	maOD	taken as 1 m below groundwater level in Kellaway Sands
Groundwater head outside landfill	Head_outLF	0.25	maOD	average gw level observed in the months following the bhs installation (Sep-Dec 2021)

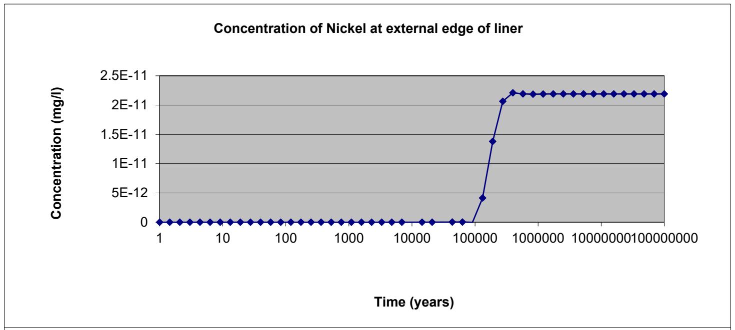
CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Mecoprop	-	n/a
Contaminant type	Cont_Type	Organic	-	Mecoprop is organic substance
Contaminant classification	Cont_Class	List I	-	according to the JAGDAG classification
Concentration in landfill leachate	Conc_LF	0.095	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	3.9E-10	m2/s	from report SC0310/SR Table 3.1
Partition coefficient in clay	Kd_cl	2.328	l/kg	from Kd=Koc*foc assuming Koc=48.5 (USEPA) and foc=0.048 for Oxford Clay (EA report NC/03/12)
Half life in clay (0 for no decay)	thalf_cl	92	days	maximum value suggested by Howard et al. (1991)
Decay in sorbed phase?	Decay_sorb	No	-	conservatively, no degradation in sorbed phase assumed

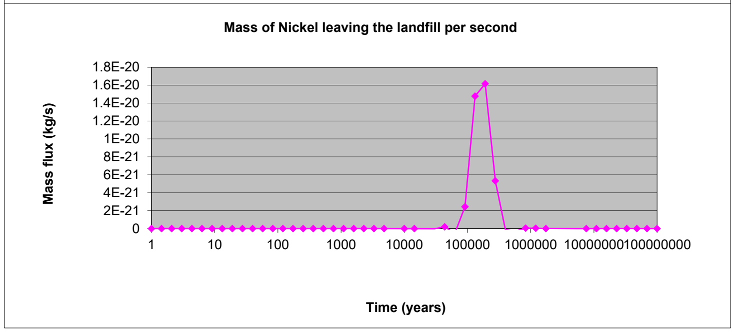
MINERAL BARRIER / LINER				
Thickness of mineral barrier is calculated as 12.5m	thick_clbr	1	m	fixed by model
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered basal liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; Eye NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill		14 January 2022	
CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION			
Conceptual model of landfill construction	CM	1	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD
Maximum thickness of underlying aquifer	Aq_max	5	m
Leachate head inside landfill	Head_inLF	-0.75	maOD
Groundwater head outside landfill	Head_outLF	0.25	maOD
Area of liner below the water table	Area_contact	190000	m2
CONTAMINANT PARAMETERS			
Contaminant name	Cont_Nme	Nickel	-
Contaminant type	Cont_Type	Inorganic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	1.09	mg/l
Free water diffusion coefficient	Dw_cl	2.03E-09	m2/s
Partition coefficient in clay	Kd_cl	20	l/kg
Retardation factor in clay	R_cl	181	-
Half life in clay (0 for no decay)	thalf_cl	0	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	0	1/s
MINERAL BARRIER / LINER			
Thickness of mineral barrier is calculated as 12.5m			
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

Nickel

CONTAMINANT AND WATER FLUXES			
Groundwater flux into landfill		0.0000304	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	2.21001E-11	mg/l
CHART PARAMETERS			
Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+08	years





Eye Landfill **14 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				**Justification / Reference / Notes**
Scenario		1		scenario for Kellaway Sands
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD	average depth taken from borehole logs
Maximum thickness of underlying aquifer	Aq_max	5	m	maximum thickness as described in ESID
Leachate head inside landfill	Head_inLF	-0.75	maOD	taken as 1m below groundwater level in Kellaway Sands
Groundwater head outside landfill	Head_outLF	0.25	maOD	average gw level observed in the months following the bhs installation (Sep-Dec 2021)

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Nickel	-	n/a
Contaminant type	Cont_Type	Inorganic	-	nickel is inorganic substance
Contaminant classification	Cont_Class	List I	-	according to JAGDAG classification
Concentration in landfill leachate	Conc_LF	1.09	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	2.03E-09	m2/s	assumed high value (Cl's) from Table 3.1 in SC0310/SR (Review)
Partition coefficient in clay	Kd_cl	20	l/kg	conservative value from ConSim help-files
Half life in clay (0 for no decay)	thalf_cl	0	days	nickel assumed to not degrade
Decay in sorbed phase?	Decay_sorb	No	-	nickel assumed to not degrade

MINERAL BARRIER / LINER				
Thickness of mineral barrier is calculated as 12.5m	thick_clbr	1	m	fixed by model
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered basal liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill - Eastern Extension

14 January 2022

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	1	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD
Maximum thickness of underlying aquifer	Aq_max	5	m
Leachate head inside landfill	Head_inLF	-0.75	maOD
Groundwater head outside landfill	Head_outLF	0.25	maOD
Area of liner below the water table	Area_contact	190000	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Naphthalene	-
Contaminant type	Cont_Type	Organic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	0.0389	mg/l
Free water diffusion coefficient	Dw_cl	6.00E-10	m2/s
Partition coefficient in clay	Kd_cl	61.824	l/kg
Retardation factor in clay	R_cl	557.416	-
Half life in clay (0 for no decay)	thalf_cl	1000	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	1.43924E-11	1/s

MINERAL BARRIER / LINER

Thickness of mineral barrier is calculated as 12.5m

Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

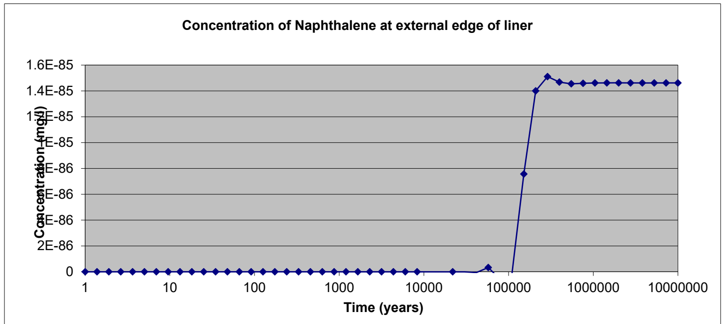
Naphthalene

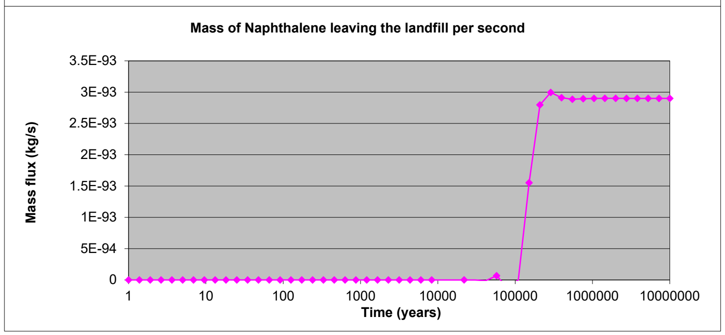
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		0.0000304	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	1.51105E-85	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+07	years





Eye Landfill - Eastern Extension **14 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				**Justification / Reference / Notes**
Scenario		1		scenario of Kellaway Sands
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD	average depth taken from borehole logs
Maximum thickness of underlying aquifer	Aq_max	5	m	maximum thickness as described in ESID
Leachate head inside landfill	Head_inLF	-0.75	maOD	taken as 1 m below groundwater level in Kellaway Sands
Groundwater head outside landfill	Head_outLF	0.25	maOD	!!! TBD; UPON RECEIVING INFO FROM BIFFA !!!

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Naphthalene	-	n/a
Contaminant type	Cont_Type	Organic	-	Naphthalene is organic substance
Contaminant classification	Cont_Class	List I	-	conservative assumption
Concentration in landfill leachate	Conc_LF	0.0389	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	6E-10	m2/s	from report SC0310/SR Table 3.1
Partition coefficient in clay	Kd_cl	61.824	l/kg	Kd=Koc*foc where Koc=1288 (ConSim) and foc=0.048 for Oxford Clay (EA report NC/03/12)
Half life in clay (0 for no decay)	thalf_cl	1000	days	maximum value suggested by ConSim help files
Decay in sorbed phase?	Decay_sorb	No	-	conservatively, no degradation in sorbed phase assumed

MINERAL BARRIER / LINER				
Thickness of mineral barrier is calculated as 12.5m	thick_clbr	1	m	fixed by model
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered basal liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; Eye NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill - Eastern Extension — 14 January 2022

Phenol

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	1	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD
Maximum thickness of underlying aquifer	Aq_max	5	m
Leachate head inside landfill	Head_inLF	-0.75	maOD
Groundwater head outside landfill	Head_outLF	0.25	maOD
Area of liner below the water table	Area_contact	190000	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Phenol	-
Contaminant type	Cont_Type	Organic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	46.5	mg/l
Free water diffusion coefficient	Dw_cl	9.10E-10	m2/s
Partition coefficient in clay	Kd_cl	1.296	l/kg
Retardation factor in clay	R_cl	12.664	-
Half life in clay (0 for no decay)	thalf_cl	300	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	2.11164E-09	1/s

MINERAL BARRIER / LINER

Thickness of mineral barrier is calculated as 12.5m

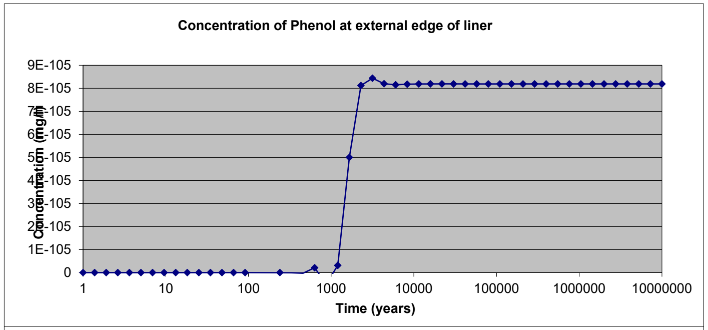
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

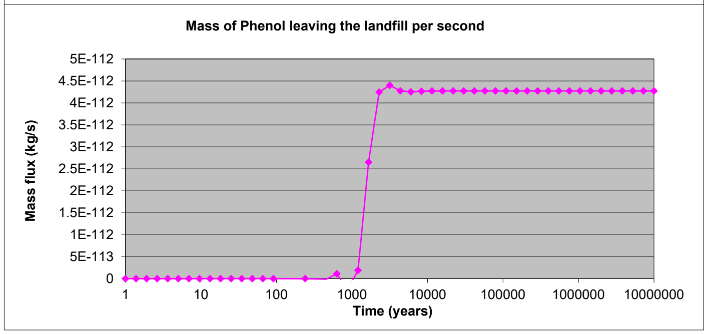
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		0.0000304	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	8.4398E-105	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+07	years





Eye Landfill - Eastern Extension **14 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				Justification / Reference / Notes
Scenario		1		scenario of Kellaway Sands
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of top of aquifer	Aqbound_elev	-16.8	maOD	average depth taken from borehole logs
Maximum thickness of underlying aquifer	Aq_max	5	m	maximum thickness as described in ESID
Leachate head inside landfill	Head_inLF	-0.75	maOD	taken as 1 m below groundwater level in Kellaway Sands
Groundwater head outside landfill	Head_outLF	0.25	maOD	average gw level observed in the months following the bhs installation (Sep-Dec 2021)

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Phenol	-	n/a
Contaminant type	Cont_Type	Organic	-	Phenol is organic substance
Contaminant classification	Cont_Class	List I	-	according to the JAGDAG classification
Concentration in landfill leachate	Conc_LF	46.5	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	9.1E-10	m2/s	from Review of the fate and Transport of Selected Contaminants in the Soil Environment
Partition coefficient in clay	Kd_cl	1.296	l/kg	Kd=Koc*foc where Koc=27(ConSim) and foc=0.048 for Oxford Clay (EA report NC/03/12)
Half life in clay (0 for no decay)	thalf_cl	300	days	maximum value from ConSim help files
Decay in sorbed phase?	Decay_sorb	No	-	conservatively, no degradation in sorbed phase assumed

MINERAL BARRIER / LINER				
Thickness of mineral barrier is calculated as 12.5m	thick_clbr	1	m	fixed by model
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered basal liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; Eye NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Contaminant Fluxes from Hydraulic Containment Landfills Worksheet Version 1.0

Produced under Science Group: Air, Land & Water Project SC0310

Statement of Use

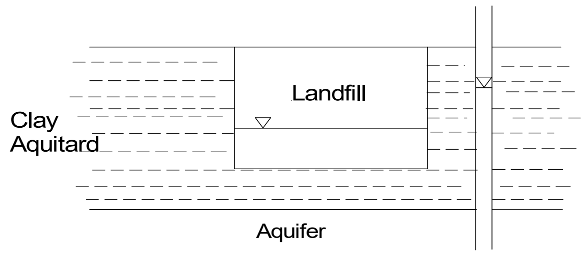
This worksheet has been prepared to help assessors quantify the contaminant flux from a hydraulic containment landfill constructed to the specifications in the Landfill Regulations (2002). It has been prepared to allow Agency staff to assess third party calculations of the diffusive contaminant flux from hydraulic containment landfills.

Data needs to be entered only in YELLOW cells. Assessors have to specify a preferred option from a pull-down menu in BLUE cells, interim calculation results are presented in GREY cells and final results in GREEN cells.
Only data in YELLOW or BLUE cells may be changed.

Site name
Eye Landfill
Assessor's name
Golder, member of WSP in the UK
Date
January 2022

SELECT LANDFILL CONSTRUCTION SCENARIO

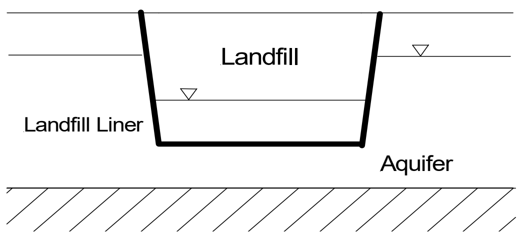
Scenario 1



The landfill is constructed in a clay pit, underlain by a confined aquifer. Water and contaminant fluxes occur across the bottom of the landfill only.

○ Select Scenario 1

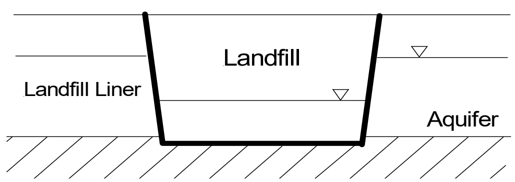
Scenario 2



The landfill is lined and located in a permeable formation a finite distance above an impermeable layer. The water and contaminant fluxes can occur through the base and sides of the landfill.

○ Select Scenario 2

Scenario 3



The landfill is lined and located in a permeable formation a finite distance below an impermeable layer. The water and contaminant fluxes can occur through the sides of the landfill only.

◉ Select Scenario 3

Eye Landfill 18 January 2022

Ammoniacal N

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	3	-
Is a geomembrane present?	GM_opt	No	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD
Leachate head inside landfill	Head_inLF	0.25	maOD
Groundwater head outside landfill	Head_outLF	1.25	maOD
Area of liner below the water table	Area_contact	3185	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Ammoniacal N	-
Contaminant type	Cont_Type	Inorganic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	2200	mg/l
Free water diffusion coefficient	Dw_cl	1.96E-09	m2/s
Partition coefficient in clay	Kd_cl	0.15	l/kg
Retardation factor in clay	R_cl	2.35	-
Half life in clay (0 for no decay)	thalf_cl	0	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	0	1/s

MINERAL BARRIER / LINER

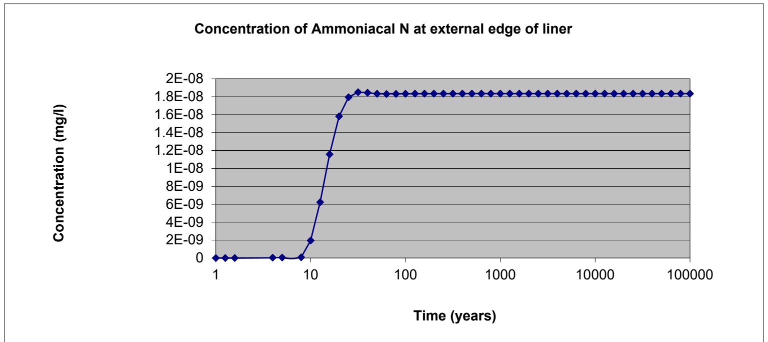
Thickness of mineral liner	thick_clbr	1	m
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

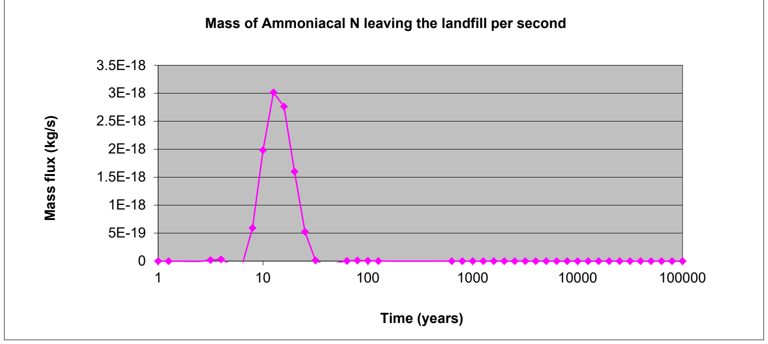
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		0.00000637	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	1.85061E-08	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+05	years





Eye Landfill **18 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				Justification / Reference / Notes
Scenario		3		scenario for River Terrace Deposits
Is a geomembrane present?		No		conservatively assumed
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD	average depth taken from borehole logs BH21-01 to BH21-05
Leachate head inside landfill	Head_inLF	0.25	maOD	taken as 1 m below groundwater level in River Terrace Deposits
Groundwater head outside landfill	Head_outLF	1.25	maOD	lowest level noted in 2011

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Ammoniacal N	-	n/a
Contaminant type	Cont_Type	Inorganic	-	Ammoniacal Nitrogen is inorganic substance
Contaminant classification	Cont_Class	List I	-	according to the JAGDAG classification
Concentration in landfill leachate	Conc_LF	2200	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	1.96E-09	m2/s	Table 3.1 in SC0310/SR (Review) (value for 25 deg C)
Partition coefficient in clay	Kd_cl	0.15	l/kg	conservative value given in App. 2 of NGWCLC Report NC/02/49
Half life in clay (0 for no decay)	thalf_cl	0	days	Ammoniacal nitrogen assumed to not degrade
Decay in sorbed phase?	Decay_sorb	No	-	Ammoniacal nitrogen assumed to not degrade

MINERAL BARRIER / LINER				
Thickness of mineral liner	thick_clbr	1	m	design thickness of engineered sidewall liner
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered sidewall liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; Eye NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill

18 January 2022

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	3	-
Is a geomembrane present?	GM_opt	No	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD
Leachate head inside landfill	Head_inLF	0.25	maOD
Groundwater head outside landfill	Head_outLF	1.25	maOD
Area of liner below the water table	Area_contact	3185	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Arsenic	-
Contaminant type	Cont_Type	Inorganic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	0.521	mg/l
Free water diffusion coefficient	Dw_cl	1.00E-09	m2/s
Partition coefficient in clay	Kd_cl	249.6	l/kg
Retardation factor in clay	R_cl	2247.4	-
Half life in clay (0 for no decay)	thalf_cl	0	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	0	1/s

MINERAL BARRIER / LINER

Thickness of mineral liner	thick_clbr	1	m
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

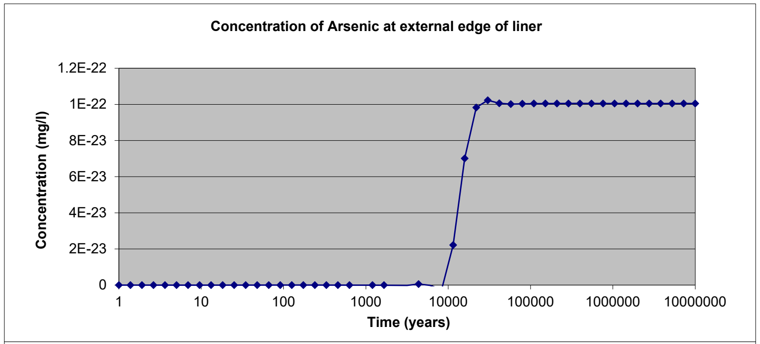
Arsenic

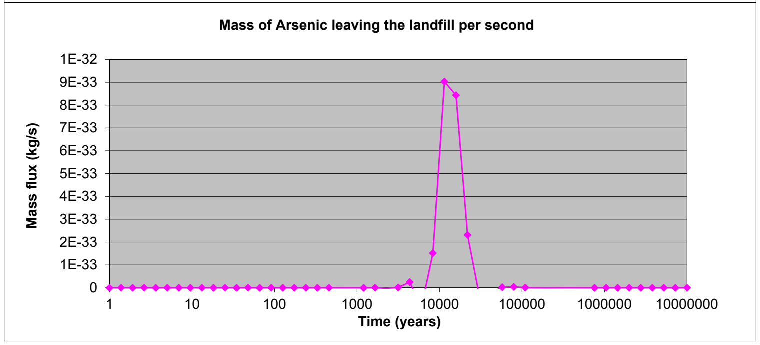
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		0.00000637	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	1.02302E-22	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+07	years





Eye Landfill **18 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				**Justification / Reference / Notes**
Scenario		3		scenario for River Terrace Deposits
Is a geomembrane present?		No		conservatively assumed
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD	lowest elevation in landfill area taken from borehole logs
Leachate head inside landfill	Head_inLF	0.25	maOD	taken as 1 m below groundwater level in River Terrace Deposits
Groundwater head outside landfill	Head_outLF	1.25	maOD	lowest level noted in 2011

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Arsenic	-	n/a
Contaminant type	Cont_Type	Inorganic	-	Arsenic is inorganic substance
Contaminant classification	Cont_Class	List I	-	Arsenic is List I = hazardous substance according to the JAGDAG classification
Concentration in landfill leachate	Conc_LF	0.521	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	0.000000001	m2/s	conservative value for diffusive contaminants
Partition coefficient in clay	Kd_cl	249.6	l/kg	value from ConSim help-files for glaical till (most similar lithology available)
Half life in clay (0 for no decay)	thalf_cl	0	days	Arsenic assumed to not degrade
Decay in sorbed phase?	Decay_sorb	No	-	Arsenic assumed to not degrade

MINERAL BARRIER / LINER				
Thickness of mineral liner	thick_clbr	1	m	design thickness of engineered sidewall liner
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered sidewall liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate, as used in Golder (2003; NE Extension HRA)
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill - Eastern Extension — 18 January 2022

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	3	-
Is a geomembrane present?	GM_opt	No	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD
Leachate head inside landfill	Head_inLF	0.25	maOD
Groundwater head outside landfill	Head_outLF	1.25	maOD
Area of liner below the water table	Area_contact	3185	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Chloride	-
Contaminant type	Cont_Type	Inorganic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	20500	mg/l
Free water diffusion coefficient	Dw_cl	2.03E-09	m2/s
Partition coefficient in clay	Kd_cl	0	l/kg
Retardation factor in clay	R_cl	1	-
Half life in clay (0 for no decay)	thalf_cl	0	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	0	1/s

MINERAL BARRIER / LINER

Thickness of mineral liner	thick_clbr	1	m
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

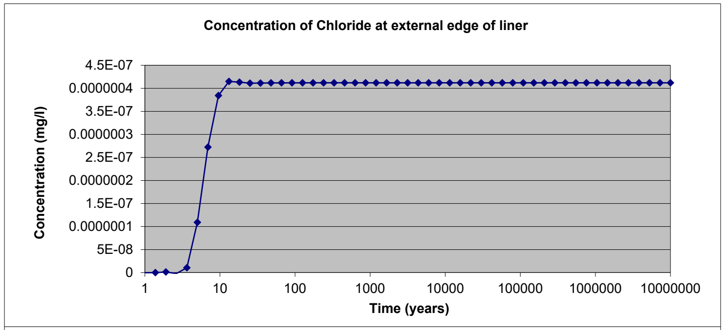
Chloride

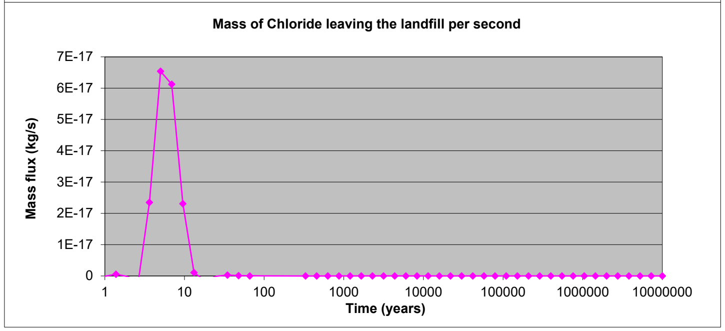
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		0.00000637	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	4.14987E-07	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+07	years





Eye Landfill - Eastern Extension **18 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				**Justification / Reference / Notes**
Scenario		3		scenario for River Terrace Deposits
Is a geomembrane present?		No		conservatively assumed
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD	average depth taken from borehole logs BH21-01 to BH21-05
Leachate head inside landfill	Head_inLF	0.25	maOD	Taken as 1m below groundwater level in River Terrace Deposits
Groundwater head outside landfill	Head_outLF	1.25	maOD	lowest level noted in 2011

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Chloride	-	n/a
Contaminant type	Cont_Type	Inorganic	-	chloride is inorganic substance
Contaminant classification	Cont_Class	List I	-	according to the JAGDAG classification
Concentration in landfill leachate	Conc_LF	20500	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	2.03E-09	m2/s	Table 3.1 in SC0310/SR (Review) (value for 25 deg C)
Partition coefficient in clay	Kd_cl	0	l/kg	chloride is assumed to be unretarded
Half life in clay (0 for no decay)	thalf_cl	0	days	chloride assumed to not degrade
Decay in sorbed phase?	Decay_sorb	No	-	chloride assumed to not degrade

MINERAL BARRIER / LINER				
Thickness of mineral liner	thick_clbr	1	m	design thickness of engineered sidewall liner
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered sidewall liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; Eye NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill - Eastern Extension

14 January 2022

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	3	-
Is a geomembrane present?	GM_opt	No	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD
Leachate head inside landfill	Head_inLF	0.25	maOD
Groundwater head outside landfill	Head_outLF	1.25	maOD
Area of liner below the water table	Area_contact	3185	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Mecoprop	-
Contaminant type	Cont_Type	Organic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	0.095	mg/l
Free water diffusion coefficient	Dw_cl	3.90E-10	m2/s
Partition coefficient in clay	Kd_cl	2.328	l/kg
Retardation factor in clay	R_cl	21.952	-
Half life in clay (0 for no decay)	thalf_cl	92	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	3.97237E-09	1/s

MINERAL BARRIER / LINER

Thickness of mineral liner	thick_clbr	1	m
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

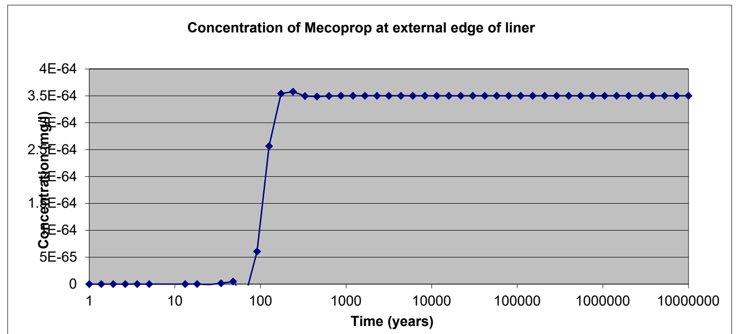
Mecoprop

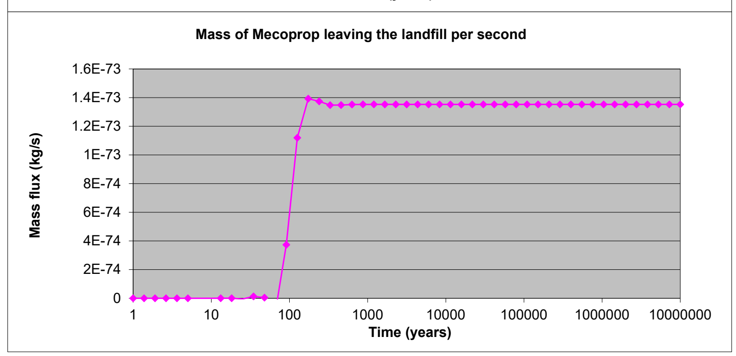
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		0.00000637	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	3.57708E-64	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+07	years





Eye Landfill - Eastern Extension **14 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				**Justification / Reference / Notes**
Scenario		3		scenario of River Terrace Deposits
Is a geomembrane present?		No		
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD	average depth taken from borehole logs BH21-01 to BH21-05
Leachate head inside landfill	Head_inLF	0.25	maOD	taken as 1 m below groundwater level in River Terrace Deposits
Groundwater head outside landfill	Head_outLF	1.25	maOD	lowest level noted in 2011

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Mecoprop	-	n/a
Contaminant type	Cont_Type	Organic	-	Mecoprop is organic substance
Contaminant classification	Cont_Class	List I	-	according to the JAGDAG classification
Concentration in landfill leachate	Conc_LF	0.095	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	3.9E-10	m2/s	from report SC0310/SR Table 3.1
Partition coefficient in clay	Kd_cl	2.328	l/kg	from Kd=Koc*foc assuming Koc=48.5 (USEPA) and foc=0.048 for Oxford Clay (EA report NC/03/12)
Half life in clay (0 for no decay)	thalf_cl	92	days	maximum value suggested by Howard et al. (1991)
Decay in sorbed phase?	Decay_sorb	No	-	conservatively, no degradation in sorbed phase assumed

MINERAL BARRIER / LINER				
Thickness of mineral liner	thick_clbr	1	m	fixed by model
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered basal liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; Eye NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill - Eastern Extension

18 January 2022

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	3	-
Is a geomembrane present?	GM_opt	No	-
Basal width perpendicular to groundwater flow	Width_LF	700	m
Basal length parallel to groundwater flow	Length_LF	270	m
Basal area	Base_Area	189000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD
Leachate head inside landfill	Head_inLF	0.25	maOD
Groundwater head outside landfill	Head_outLF	1.25	maOD
Area of liner below the water table	Area_contact	3530.8	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Nickel	-
Contaminant type	Cont_Type	Inorganic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	1.09	mg/l
Free water diffusion coefficient	Dw_cl	2.03E-09	m2/s
Partition coefficient in clay	Kd_cl	20	l/kg
Retardation factor in clay	R_cl	181	-
Half life in clay (0 for no decay)	thalf_cl	0	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	0	1/s

MINERAL BARRIER / LINER

Thickness of mineral liner	thick_clbr	1	m
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

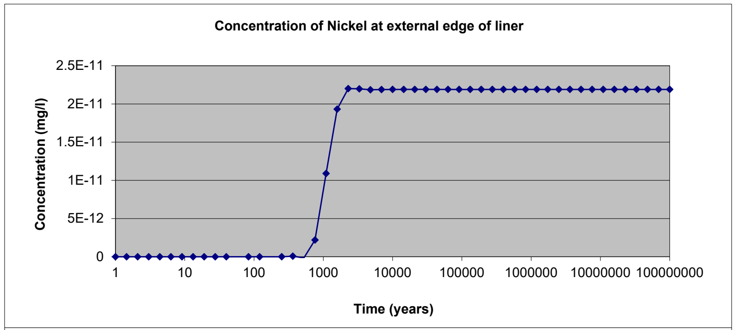
Nickel

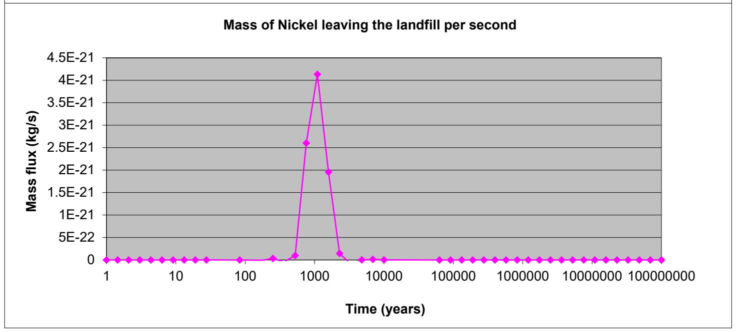
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		7.0616E-06	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	2.20127E-11	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+08	years





Eye Landfill - Eastern Extension **18 January 2022**
Golder, member of WSP in the UK

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				Justification / Reference / Notes
Scenario		3		scenario for River Terrace Deposits
Is a geomembrane present?		No		conservatively assumed
Basal width perpendicular to groundwater flow	Width_LF	700	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	270	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD	average depth taken from borehole logs BH21-01 to BH21-05
Leachate head inside landfill	Head_inLF	0.25	maOD	taken as 1 m below groundwater level in River Terrace Deposits
Groundwater head outside landfill	Head_outLF	1.25	maOD	lowest level noted in 2011
CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Nickel	-	n/a
Contaminant type	Cont_Type	Inorganic	-	nickel is inorganic substance
Contaminant classification	Cont_Class	List I	-	according to JAGDAG classification
Concentration in landfill leachate	Conc_LF	1.09	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	2.03E-09	m2/s	assumed high value (Cl's) from Table 3.1 in SC0310/SR (Review)
Partition coefficient in clay	Kd_cl	20	l/kg	conservative value from ConSim help-files
Half life in clay (0 for no decay)	thalf_cl	0	days	nickel assumed to not degrade
Decay in sorbed phase?	Decay_sorb	No	-	nickel assumed to not degrade
MINERAL BARRIER / LINER				
Thickness of mineral liner	thick_clbr	1	m	design thickness of engineered sidewall liner
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered sidewall liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill - Eastern Extension 14 January 2022

Naphthalene

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	3	-
Is a geomembrane present?	GM_opt	No	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD
Leachate head inside landfill	Head_inLF	0.25	maOD
Groundwater head outside landfill	Head_outLF	1.25	maOD
Area of liner below the water table	Area_contact	3185	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Naphthalene	-
Contaminant type	Cont_Type	Organic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	0.0389	mg/l
Free water diffusion coefficient	Dw_cl	6.00E-10	m2/s
Partition coefficient in clay	Kd_cl	61.824	l/kg
Retardation factor in clay	R_cl	557.416	-
Half life in clay (0 for no decay)	thalf_cl	1000	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	1.43924E-11	1/s

MINERAL BARRIER / LINER

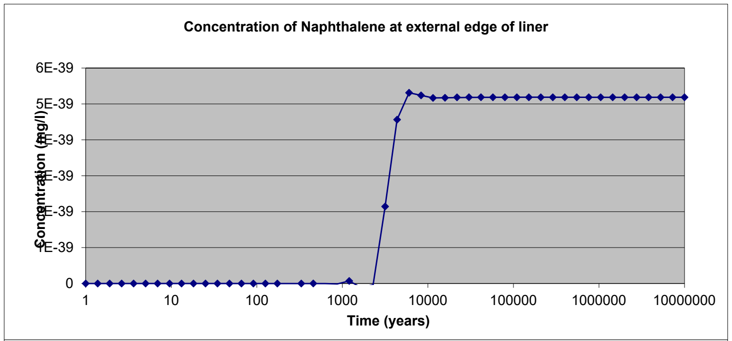
Thickness of mineral liner	thick_clbr	1	m
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

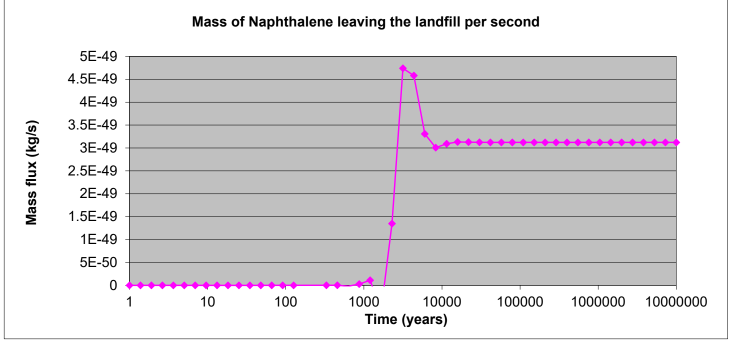
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		0.00000637	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	5.31257E-39	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+07	years





Eye Landfill - Eastern Extension **14 January 2022**
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CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				Justification / Reference / Notes
Scenario		3		scenario of River Terrace Deposits
Is a geomembrane present?		No		conservatively assumed
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD	average depth taken from borehole logs BH21-01 to BH21-05
Leachate head inside landfill	Head_inLF	0.25	maOD	taken as 1 m below groundwater level in River Terrace Deposits
Groundwater head outside landfill	Head_outLF	1.25	maOD	lowest level noted in 2011

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Naphthalene	-	n/a
Contaminant type	Cont_Type	Organic	-	Naphthalene is organic substance
Contaminant classification	Cont_Class	List I	-	conservative assumption
Concentration in landfill leachate	Conc_LF	0.0389	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	6E-10	m2/s	from report SC0310/SR Table 3.1
Partition coefficient in clay	Kd_cl	61.824	l/kg	Kd=Koc*foc where Koc=1288 (ConSim) and foc=0.048 for Oxford Clay (EA report NC/03/12)
Half life in clay (0 for no decay)	thalf_cl	1000	days	maximum value suggested by ConSim help files
Decay in sorbed phase?	Decay_sorb	No	-	conservatively, no degradation in sorbed phase assumed

MINERAL BARRIER / LINER				
Thickness of mineral liner	thick_clbr	1	m	fixed by model
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered basal liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; Eye NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

Eye Landfill - Eastern Extension 14 January 2022

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	3	-
Is a geomembrane present?	GM_opt	No	-
Basal width perpendicular to groundwater flow	Width_LF	400	m
Basal length parallel to groundwater flow	Length_LF	475	m
Basal area	Base_Area	190000	m2
Elevation of base of landfill	LFbase_elev	-4.3	maOD
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD
Leachate head inside landfill	Head_inLF	0.25	maOD
Groundwater head outside landfill	Head_outLF	1.25	maOD
Area of liner below the water table	Area_contact	3185	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	Phenol	-
Contaminant type	Cont_Type	Organic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	46.5	mg/l
Free water diffusion coefficient	Dw_cl	9.10E-10	m2/s
Partition coefficient in clay	Kd_cl	1.296	l/kg
Retardation factor in clay	R_cl	12.664	-
Half life in clay (0 for no decay)	thalf_cl	300	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	2.11164E-09	1/s

MINERAL BARRIER / LINER

Thickness of mineral liner	thick_clbr	1	m
Hydraulic conductivity	k_cl	1.00E-09	m/s
Average pore radius	pore_radius	4.00E-07	m
Effective porosity	n	0.2	-
Dry bulk density	rho	1800	kg/m3
Tortuosity	tau_cl	10	-

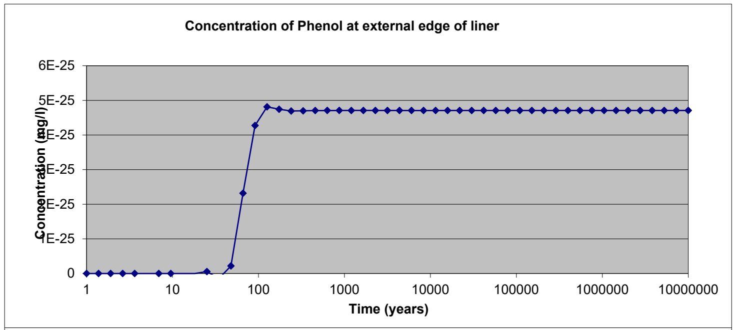
Phenol

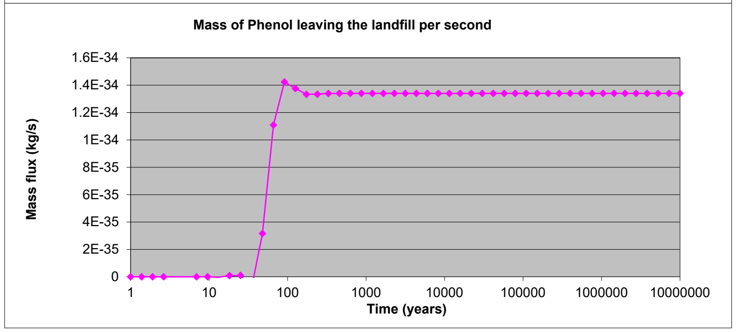
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		0.00000637	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	4.81293E-25	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+07	years





Eye Landfill - Eastern Extension **14 January 2022**
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CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				Justification / Reference / Notes
Scenario		3		scenario of River Terrace Deposits
Is a geomembrane present?		No		conservatively assumed
Basal width perpendicular to groundwater flow	Width_LF	400	m	taken from layout drawing
Basal length parallel to groundwater flow	Length_LF	475	m	taken from layout drawing
Elevation of base of landfill	LFbase_elev	-4.3	maOD	Max. depth as per engineering design to achieve suitable basal cell gradients without compromising basal heave Factory of Safety
Elevation of base of aquifer	Aqbound_elev	-1.57	maOD	average depth taken from borehole logs BH21-01 to BH21-05
Leachate head inside landfill	Head_inLF	0.25	maOD	taken as 1 m below groundwater level in River Terrace Deposits
Groundwater head outside landfill	Head_outLF	1.25	maOD	lowest level noted in 2011

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	Phenol	-	n/a
Contaminant type	Cont_Type	Organic	-	Phenol is organic substance
Contaminant classification	Cont_Class	List I	-	according to the JAGDAG classification
Concentration in landfill leachate	Conc_LF	46.5	mg/l	maximum value noted in the S Extension (2016-2021)
Free water diffusion coefficient	Dw_cl	9.1E-10	m2/s	from Review of the fate and Transport of Selected Contaminants in the Soil Environment
Partition coefficient in clay	Kd_cl	1.296	l/kg	Kd=Koc*foc where Koc=27(ConSim) and foc=0.048 for Oxford Clay (EA report NC/03/12)
Half life in clay (0 for no decay)	thalf_cl	300	days	maximum value from ConSim help files
Decay in sorbed phase?	Decay_sorb	No	-	conservatively, no degradation in sorbed phase assumed

MINERAL BARRIER / LINER				
Thickness of mineral liner	thick_clbr	1	m	fixed by model
Hydraulic conductivity	k_cl	0.000000001	m/s	design value of engineered basal liner
Average pore radius	pore_radius	0.0000004	m	D10 value of clay (estimated as 10% of maximum grain size)
Effective porosity	n	0.2	-	Golder estimate, as used in Golder (2003; Eye NE Extension HRA)
Dry bulk density	rho	1800	kg/m3	Golder estimate
Tortuosity	tau_cl	10	-	Table 3.3 in SC0310/SR (Review)

APPENDIX HRA4

Leachate Rise Model Printout

Biffa Eye Landfill, Eastern Extension: Failure Scenario

	Value	Unit	Comment
Infiltration			
Infiltration through landfill cap	50	mm/yr	Golder estimate - see HRA
Landfill			
Length of landfill	550	m	See HRA
Width of landfill	425	m	See HRA
Area available for infiltration through top and inflow from Kellaway Sands through base of landfill	233750	m^2	Assumed that sidewalls are vertical (therefore, area is shown as larger than the normal operating conditions)
Head difference between groundwater & leachate	2	m	Conservative assumption
Landfill Basal Liner			
Hydraulic conductivity of liner	1.00E-09	m/s	Minimum design value of clay liner
River Terrace Deposits			
Base of River Terrace Deposits	-1.57	m AOD	Average value based on the bh logs from the 2021 Site Investigation
Water level in River Terrace Deposits	2.35	m AOD	Maximum value from 2011 data set
Vertical extent available for inward advective flux from River Terrace Deposits	3.92	m	Calculated
Area of sidewall liner available for inward advective flux from River Terrace Deposits	7644	m^2	Area across which flow into the landfill can occur from River Terrace Deposits, i.e. aquifer thickness times twice length and width of the landfill
Distance across which head difference applies	1	m	Design thickness of sidewall liner
Kellaway Beds			
Distance across which head difference applies	15.17	m	Combined thickness of clay liner and remaining Oxford Clay above Kellaway Sand calculated based on boreholes logs from 2021 Site Investigation
Results			
Flux into landfill from infiltration	3.71E-04	m^3/s	Infiltration through FML
Flux into landfill from groundwater in River Terrace Deposits	1.53E-05	m^3/s	Horizontal flux from groundwater in River Terrace Deposits
Flux into landfill from groundwater in Kellaway Beds	3.08E-05	m^3/s	Vertical flux from goundwater in Kellaway Beds
Combined flux	**13141.48**	**m^3/yr**	Sum of infiltration and flux from groundwater in both aquifers
Rate of leachate head increase	**0.22**	**m/yr**	Assuming top area is equal to basal area, and available waste porosity is 25%
Time to increase leachate head by 1m	**4.45**	**yrs**	

APPENDIX HRA5

Electronic Copies of the Model

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