firth consultants
environmental risk assessment

Hydrogeological Risk Assessment Review
Penhesgyn Landfill,
Llansadwrn
Menai Bridge
Anglesey

Final Report

on behalf of

Egniol Environmental Ltd.

Report fc37224
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1 INTRODUCTION

Firth Consultants Ltd has been commissioned by Egniol Environmental Ltd (Egniol) to conduct a Hydrogeological Risk Assessment (HRA) review for Penhesgyn Landfill, Llansadwrn, Menai Bridge, Anglesey, LL59 5RY (hereafter referred to as “the site”). The location of the site is shown on Figure 1.

1.1 Background

Penhesgyn Landfill is a non-hazardous landfill which was used for the disposal of waste from before 1968 until 2007. The landfill comprises two distinct areas:

- Area 2 located in the south west of the site. This was the first area to be filled. It is unlined and operates on the dilute and disperse principal. This part of the site was closed and restored (with low permeability cap) in 1999/2000.
- Area 3 located in the north east of the site. Waste disposal commenced in this area in 1998. It comprises four lined engineered cells and has a leachate collection system. The area was closed and restored (with low permeability cap) in 2007.

Annual monitoring of leachate, groundwater and surface water is on-going at the site but the last HRA review was conducted (by Entec UK Ltd) in 2007 (Entec, 2007a). This concluded that the assumptions and input parameters of the LandSim modelling described in Entec’s 2003 HRA remained valid and therefore Entec did not conduct further modelling. Entec did however revise the aftercare phase control and trigger levels for leachate, groundwater and surface water based on monitoring data collected since 2003.

1.2 Objectives

In accordance with Environment Agency (EA) guidance (EA, 2009), the objective of the HRA review is to assess whether the input parameters and assumptions of the original HRA modelling remain valid. If it is determined that the variation in input parameters could have a significant impact on the outcome of the HRA, then the original models should be re-run with the input parameters appropriately amended.

Irrespective of the above, a second objective of this HRA review will be to review and revise (where necessary) the control and trigger levels (now referred to as control levels and compliance limits) for leachate, groundwater and surface water.

1.3 Scope of Work

The following work has been undertaken by Firth Consultants Ltd to achieve these objectives:

- Task 1: Review available relevant reports and information. Firth Consultants has reviewed the HRA update report (Entec, 2007a), closure report (Entec 2008), annual monitoring reports (Egniol 2016, 2017, 2018 and 2019), leachate level and analytical data (October 2016 to May 2020) and groundwater level data (April 2017 to November 2019). Available geological and hydrogeological maps and information available on the web were also evaluated. It is noted that the original HRA report undertaken by Entec in 2003 was not available for review.

- Task 2: Comparison of data with previously available HRAs. The information reviewed in task 1 has been used to review and, where necessary, refine the conceptual site model (CSM) for Controlled Waters receptors and determine whether the inputs and assumptions used for the 2003 HRA remain valid. Specifically, the following aspects were reviewed:
    - Has the hydrogeological flow regime changed (i.e. has there been a significant change on groundwater flow direction and gradient)?
    - Have the leachate concentrations diminished as predicted in the original 2003 HRA?
    - Are the risks to Controlled Waters receptors still low?

- Task 3: Review and update control and trigger values. The control and trigger values for leachate, groundwater and surface water derived by Entec in 2007 have been reviewed and where necessary revised.

- Task 4: Reporting. This report was prepared to describe the work undertaken.

1.4 Available Information

The following information has been used to prepare this HRA:

- Hydrogeological Risk Assessment Update Report for Penhesgyn Landfill, (Entec, 2007a). The objectives of this update was to assess whether the input parameters and assumptions in the original HRA (undertaken by Entec in 2003) remained valid, re-assess the risks to controlled waters and review the adequacy of the monitoring network. Trigger and control levels for groundwater were revised based on an improvement in groundwater quality in 2007.

- Closure report for Penhesgyn Landfill, (Entec, 2008). The purpose of this report was to demonstrate that appropriate infrastructure and monitoring schedules are in place for the closure period of the landfill. Specific requirements include procedures for the management and control and monitoring of landfill gas, leachate, groundwater and surface water. It also includes the HRA update undertaken in 2007, a stability risk assessment (Entec, 2007b) together with Environment Agency correspondence.

- Annual Environmental Monitoring Reports, 2016, 2017, 2018 and 2019 for Penhesgyn Landfill (Egniol, 2016, 2017, 2018 and 2019). These reports present environmental monitoring data, specifically analytical data for groundwater, leachate and surface water and compares the data with previous monitoring data.
- Leachate level data (October 2016 to May 2020)
- Groundwater level data (April 2017 to November 2019)
- Leachate, groundwater and surface water quality data from limited sample locations from five sampling event between April 2015 and April 2020.

1.5 Guidance

The HRA has been conducted in accordance with relevant Environment Agency (EA) guidance, in particular the following:

- EA, 2018. Groundwater risk assessment for your environmental permit. Available at https://www.gov.uk/guidance/groundwater-risk-assessment-for-your-environmental-permit Last updated 3 April 2018
- EA, 2017a. Protect groundwater and prevent groundwater pollution. Available at https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution Last updated 14 March 2017
- EA, 2017b. Groundwater protection technical guidance. Available at https://www.gov.uk/government/publications/groundwater-protection-technical-guidance/groundwater-protection-technical-guidance Last updated 14 March 2017
- EA, 2016. Landfill developments: groundwater risk assessment for leachate. Available at https://www.gov.uk/guidance/landfill-developments-groundwater-risk-assessment-for-leachate Published 1 February 2016.

1.6 Report Format

This report provides a HRA review for the site. Section 2 provides a summary of the relevant background information (i.e. geography, landfill construction, hydrology and hydrogeology). Section 3 reviews the 2014 to 2020 monitoring data and compares this with previous data.

Section 4 provides an updated CSM, determines whether the assumptions of the 2003 Landsim modelling remain valid and re-assesses the risks to Controlled Waters receptors. Section 5 provides a proposed revised monitoring programme along with associated control and trigger values. Section 6 provides conclusions and recommendations.

2 BACKGROUND INFORMATION

This section gives a brief description of the environmental setting of the site and the landfill design based on information presented in the 2007 HRA (Entec, 2007a), the Stability Risk Assessment (Entec, 2007b) and annual monitoring reports (Egniol, 2016, 2018 and 2019).

2.1 Geography

The site is located approximately 2 km north-west of the town of Menai Bridge, Anglesey and is centred at the approximate National Grid Reference (NGR) 253100 374560 (Figure 1). The site (comprising Areas 2 and 3) is approximately 21ha in area and is part of a larger site totaling 33 ha which includes a civic amenity site, an in-vessel composting facility and a household waste recovery centre (Area 1). The site is a licensed non-hazardous landfill which was used for the disposal of waste from before 1968 until 2007.

The site is surrounded by agricultural grazing land to the north west, south west and north east and Area 1 (the civic amenity site, the in-vessel composting facility and a household waste recovery centre) to the south east with the access road beyond. Prior to the disposition of waste the site use was likely similar to the surround area i.e. rough grazing and wetland.

The site is located on the north-east side of the shallow valley of the Afon Braint. Prior to landfilling natural topography ranged from approximately 65 mAOD in the north-east of the site to 53 mAOD in the south-west. Following landfilling ground level is now up to 68.7 mAOD in Area 2 and 73.2 mAOD in Area 3 (Valley Cell).

2.2 Landfill Description

The landfill comprises of two distinct areas:

- Area 2 located in the south west of the site. This was the first area to be filled and pre-dates 1968. Previous site investigations have indicated that both household and commercial waste were deposited in this area. It is unlined and operates on the dilute and disperse principal. There is an active gas management system in Area 2 but no leachate management system. Infilling of Area 2 was completed in 1998 and capped (with linear low density polyethylene [LLDPE] geomembrane overlain by 750mm thickness topsoil) in 1999/2000.
- Area 3 located in the north east of the site. Waste disposal commenced in this area in 1998 and operated on the principal of engineered containment. This area comprises four lined engineered cells (Cell 1, Cell 2, Cell 3 and Valley Cell). There is a gas and leachate management system in Area 3. The area was closed in 2007 and capped from 2003 to 2007.

Entec (2007b) provide the following details on the construction and leachate management system in Area 3:

- Lining System. The composite basal and sidewall lining system of Area 3 comprises a geosynthetic clay liner (GCL) overlain with a 2mm thick high density polyethylene (HDPE) geomembrane. Adjacent panels of GCL were overlapped and sealed using powdered bentonite. Adjacent panels of HDPE were overlapped and fusion welded.
- Cap. The cap in Area 3 comprises a 1mm LLDPE geomembrane overlain by a geosynthetic drainage layer (GDL) and 800mm thick soil layer. Adjacent panels of LLDPE were overlapped and fusion welded.
- Leachate management system. The leachate drainage blanket to Area 3 consists of a 300m deep layer of 20mm to 40mm low calcareous rounded gravel with a network of 100mm to 200m diameter slotted HDPE pipes leading to a leachate collection point in each cell. Riser pipes from these points allow leachate to be pumped from the cells to the three leachate storage tanks (total capacity of 54000 litres) located to the east of Area 3. Leachate is then tankered off-site to a suitably licensed wastewater treatment plant.

The Site Manager reported that in recent years, leachate has predominantly only been abstracted from Cell 2. This leachate had been tankered off-site but for the last 18 months, on agreement with Natural Resources Wales (NRW), leachate abstracted from Cell 2 has been recirculated into leachate wells in Cell 1 rather than tankered off-site. The site manager estimates that over 1400 m^3 of leachate had been re-circulated over this 18 month period.

The Site Manager reported that the LLDPE geomembrane cap for Cells 2 and 3 had been torn in various places as a result of installation of land drains in the cap. These breaches were repaired in summer 2018.

2.3 Hydrology

The site is located in a marsh / wetland area which has several small streams or drainage ditches which drain towards the main water feature in the area, the Afon Braint watercourse. This is located adjacent to the western site boundary of the site, approximately 50m from Area 2, and flows in a general southerly direction joining the Menai Strait approximately 3.3km south of the site. Under the Water Framework Directive the Braint upper waterbody was classified as “Good” for both chemical and ecological quality in 2018 (Natural Resources Wales, 2020).

Average annual rainfall at Pentraeth, located 3.5km north-west of the site, for the period 2003 to 2019 was 1006 mm (Anglesey History, 2020). Annual rainfall at Pentraeth is compared with Valley (located 24 km west of the site) (from Met Office, 2020) in Figure A below. The long-term record for Valley shows that average annual rainfall over the last 20 years (881 mm) is greater than that over the preceding 20 years (825 mm) and that the seven wettest years in that 40 year period have occurred in the last 20 years. There is anecdotal evidence of an increase in surface water flooding in the vicinity of the site over recent years which could also be an indication of an increase in frequency and intensity of rainfall events.

Monthly rainfall data from the Pentraeth weather station indicates that the wettest months are typically October, November or December and that the driest months are typically April, May or June.

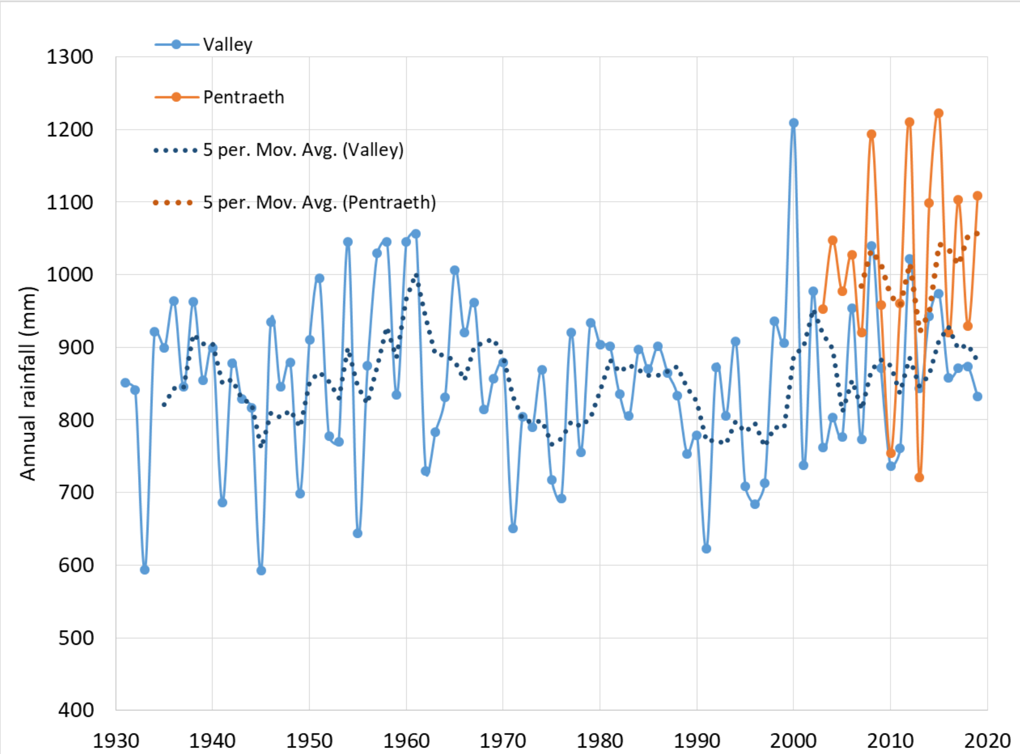

Figure A: Annual rainfall at Pentraeth and Valley weather stations

2.4 Geology

The BGS geological maps for Angelsey (BGS, 1974 and 1980) and BGS geological viewer (BGS, 2020) indicate that the majority of the site is underlain by alluvium overlying Glacial Till, overlying Mica Schist bedrock.

The borehole logs for the site monitoring wells were not available for review but according to Entec (2007a) previous investigation at the site has shown that the Glacial Till is embedded with layers of sand and gravel. The log for a borehole (SH57NW3) located 500m north of the site available on the BGS borehole database (BGS, 2020) (see Appendix 1 for log and Figure

1 for location) indicates that the Glacial Till is 40 m thick at this location and largely comprises sand and gravel layers.

During construction of Cell 3 most of the basal area was reported to have pockets of peat, overlying the glacial drift deposits, which were subsequently removed prior to construction works taking place. The Schist bedrock was not encountered during these works (Entec, 2007b) however it was encountered during the drilling of perimeter monitoring wells BH7 (located to the immediate east of Cell 3) at 2 m below ground level (mbgl) and BH11 (located further east) at 7.4 mbgl (see Figure 2).

2.5 Hydrogeology

The Alluvium and Glacial Till deposits are both classified as Secondary A aquifers[1] and the Mica Schist bedrock is classified as a Secondary B aquifer[2]. Groundwater in the drift deposits flows to the south and west under the landfill (Entec, 2007a) and is assumed to discharge to the nearby Afon Braint watercourse and associated wetland area and ditch system.

According to Entec (2007a, citing Entec, 2003), there are no licensed groundwater abstractions within 2km of the site. One private groundwater abstraction is located within 2km of the site however due to data protection the location of this is unknown (Entec, 2007a).

[1] Secondary A Aquifers (formerly minor aquifers) contain 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

[2] Secondary B Aquifers (formerly non-aquifers) are predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering

3 MONITORING DATA

Leachate, groundwater and surface water monitoring has continued since the last HRA review was conducted in 2007. However, only data from 2014 onwards were available for review. This data is discussed and compared with previous monitoring data in this section. The monitoring locations referred to in this section are shown on Figure 2.

3.1 Leachate Levels

The measurement of leachate levels in Area 2 is not a permit requirement and no leachate level data is available for Area 2 for the period 2014 to 2020.

The site provided leachate level monitoring data for the period June 2017 to May 2020 for the following leachate monitoring wells located in Area 3:

- Cell 1: BHL14 and BHL15
- Cell 2: BHL13, BH next to 38 and BH next to 122
- Cell 3: BHL10, BHMH3A and BHMH3B
- Valley Cell: L16 and L17

The leachate level monitoring data are provided in Table 1 and a hydrograph showing the monitored leachate levels is shown in Figure B below.

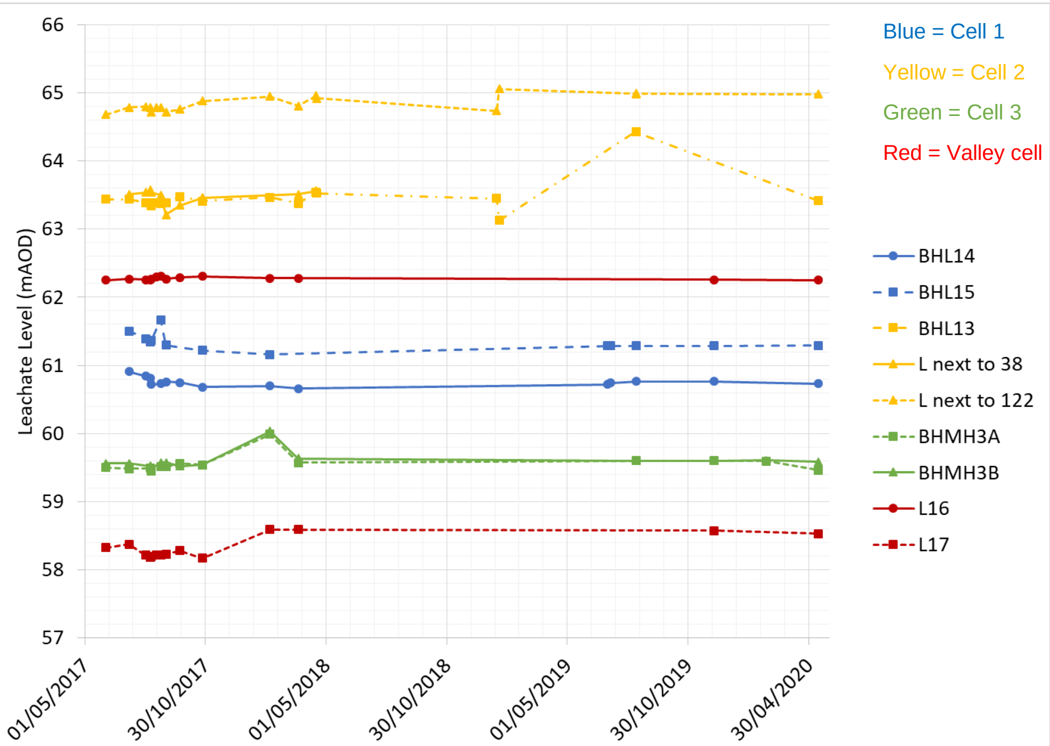

Figure B: Hydrograph of monitored leachate levels (mAOD) in Area 3

The hydrograph shows that the leachate levels have been relatively consistent since 2017. The average depths of leachate above base in each cell are compared with the previous data in Table A below. This shows that the average leachate levels in each cell for the period 2017 to 2020 are 1.8 to 6.5m higher than they were in 2002 to 2007. Whilst this may, in part, be due to different leachate wells being used to monitor leachate levels to the previous monitoring conducted in 2002 to 2007, the data suggest that leachate levels are now significantly greater than they were previously.

Table A: Summary of Leachate Levels over time

Landfill Cell	Average leachate depth above basal liner	
	2002 to 2007 [1]	2017 to 2020 [2]
Area 3 – Cell 1	1.3	0.5
Area 3 – Cell 2	0.8	3.3
Area 3 – Cell 3a	1.2	2.6
Area 3 – Cell 3b	0.7	
Area 3 – Valley Cell	0.9	0.3

Notes: 1. As reported in Entec, 2007a; 2. See Table 1

Based on the available data, average depth of leachate has decreased in Cell 1 and Valley Cell but has increased by 2.5m in Cell 2 and by 1.4m to 1.9m in Cell 3. It is noted that the average leachate depths in Cell 2 and Cell 3 in 2017 to 2020 are greater than the control and trigger limits of 1.5m and 2.0m, respectively. The Site Manager reported that the abstraction of leachate, which is then either tankered off-site or re-circulated, appears to have very little effect on leachate levels and it has been postulated that there is a breach in the side wall or basal liner in the cells which is allowing groundwater to enter the cells and cause the high leachate levels. However, groundwater levels in the vicinity of Area 3 (see Section 3.3) are generally lower than leachate levels and so it is unlikely that groundwater would enter the landfill even if a breach had occurred. It is possible that the increase in leachate levels was due to breaches in the cap which have now been repaired.

3.2 Leachate Quality

Leachate quality has been monitored on an annual basis from leachate wells L1, L4, L5, L6 and L7 in Area 2 with samples analysed for pH, electrical conductivity, chloride, ammoniacal nitrogen, chemical oxygen demand (COD), biochemical oxygen demand (BOD) and dissolved oxygen. Leachate quality monitoring in Area 3 has been more sporadic with samples obtained for analysis in September and October 2017, April 2018 and April 2020. The analytical suite for samples from Area 3 includes pH, electrical conductivity, chloride, ammoniacal nitrogen, dissolved metals, mecoprop, trichloroethene (TCE) and toluene. The analytical results from 2014 onwards are presented in Table 2.

The measured concentrations of chloride and ammoniacal nitrogen are compared with previous monitoring data in Tables B and C below, respectively. The average concentration of chloride and ammoniacal nitrogen in Areas 2 and 3, averaged over each monitoring period, are also shown graphically in Figures C and D below.

Table B: Summary of chloride concentrations in leachate monitoring wells over time in Areas 2 and 3

Well	No	Min	Mean	Max	No	Min	Mean	Max	No	Min	Mean	Max
Area 2	**1995 to July 2003**				**Aug 2003 to 2007**				**2014 to 2020**			
L1	15	686	2204	4440	15	133	1447	2520	5	88	254	460
L4	8	164	817	1660	14	54	901	1260	5	19	170	479
L5	5	29	41	69	13	14	27	43	4	17	20.3	27
L6	6	42	101	213	13	25	33	46	5	22	26.8	30
L7	8	93	215	402	13	31	56	82	5	17	26.6	42
All Area 2	**62**	**29**	**957**	**4440**	**69**	**14**	**547**	**2520**	**24**	**17**	**103**	**479**
Area 3	**2000 to July 2003**				**Aug 2003 to 2007**				**2017 to 2020**			
Cell 1	2	1600	1866	2120	no data				2	88	944	1800
Cell 2	8	190	2783	3400	no data				3	< 10	937	1500
Cell 3 (LC3B)	4	187	632	1260	6	206	1407	2040	3	< 10	627	990
Valley Cell	no data				no data				2	64	2282	4500
LV	no data				17	408	1122	1720	No data			
All Area 3	**12**	**39**	**2172**	**3400**	**23**	**206**	**1265**	**2040**	**10**	**10**	**1114**	**4500**
All Data	**74**	**29**	**1565**	**4440**	**184**	**14**	**762**	**2520**	**34**	**10**	**400**	**4500**

All concentrations in $mg.L^{-1}$

Table C: Summary of ammoniacal nitrogen concentrations in leachate monitoring wells over time in Areas 2 and 3

Well	No	Min	Mean	Max	No	Min	Mean	Max	No	Min	Mean	Max
Area 2	**1995 to July 2003**				**Aug 2003 to 2007**				**2014 to 2020**			
L1	15	106	468	1110	28	14	194	411	7	17	80.2	151
L4	8	16	146	356	22	1.7	240	117	7	0.79	48.3	133
L5	5	0.3	0.7	1.4	26	0.3	1.1	4.8	5	0.05	1.30	3
L6	7	0.4	14	52	26	0.3	0.8	3	7	0.04	0.18	0.39
L7	8	0.3	22	51	26	0.3	1.8	7.1	7	0.02	0.52	2.04
All Area 2	**63**	**0.3**	**249**	**1110**	**129**	**0.3**	**189**	**411**	**33**	**0.02**	**27.6**	**151**
Area 3	**2000 to July 2003**				**Aug 2003 to 2007**				**2017 to 2020**			
Cell 1	2	1110	1135	1160	no data				2	720	845	970
Cell 2	7	100	658	1620	no data				3	630	847	970
Cell 3 (LC3B)	4	37	174	306	6	62.8	415	634	3	110	277	420
Valley Cell	no data				no data				2	17	28	39
LV	no data				29	140	370	630	no data			
All Area 3	**12**	**37**	**575**	**1620**	**35**	**62.8**	**393**	**634**	**10**	**17**	**512**	**970**
All Data	**75**	**0.3**	**412**	**1620**	**164**	**0.3**	**250**	**634**	**43**	**0.02**	**140**	**970**

All concentrations in $mg.L^{-1}$

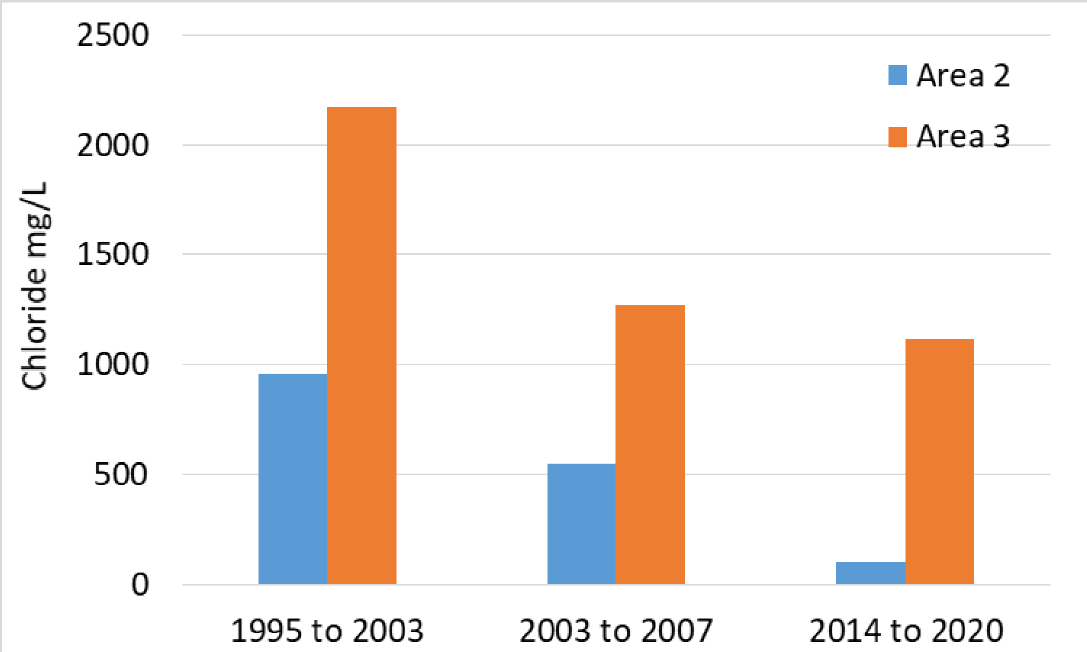

Figure C: Average concentration of chloride in landfill leachate compared for each monitoring period

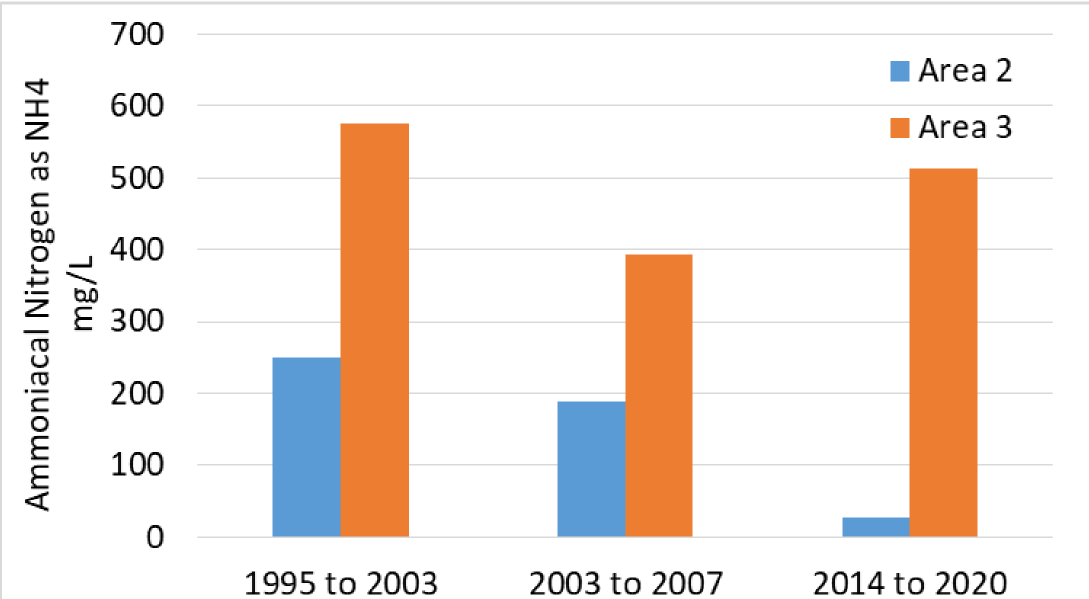

Figure D: Average concentration of ammoniacal nitrogen in landfill leachate compared for each monitoring period

Tables B and C and Figures C and D show that there has been a significant decrease in the concentrations of chloride and ammoniacal nitrogen in the landfill leachate in Area 2 over the lifetime of the landfill. The average concentrations of chloride and ammoniacal nitrogen in Area 2 for the period 2014 to 2020 are almost one order of magnitude below what they were in 1995 to 2003. With the exception of the far west of Area 2 (where L1 and L4 are located), the concentrations of chloride and ammoniacal nitrogen in Area 2 are now similar to background groundwater quality (see Section 3.4).

A more modest decrease in concentrations has occurred in Area 3. The average concentration of chloride in 2017 to 2020 (1114 mg.L^{-1}) is about half what it was in 2000 to 2003 (2172 mg.L^{-1}). The average concentration of ammoniacal nitrogen in 2017 to 2020 (512 mg.L^{-1}) is only slightly less than it was in 2000 to 2003 (575 mg.L^{-1}) and is higher than in 2003 to 2007 (393 mg.L^{-1}). However, it should be noted that there are no data for Cells 1 and 2 (where the highest concentrations of ammoniacal nitrogen have been detected) for the 2003 to 2007 period and so the true average for this period will likely be greater. The data for Cell 3 shows that there has been a decrease in the average concentration of ammoniacal nitrogen from 415 mg.L^{-1} in 2003 to 2007 to 277 mg.L^{-1} in 2017 to 2020. Based on typical concentrations for domestic waste leachate given in Waste Management Paper 26A (DoE, 1993), the current concentrations of ammoniacal nitrogen in Cells 1 and 2 are characteristic of waste with high moisture content, whilst concentrations in Cell 3 are characteristic of aged waste. The concentrations of ammoniacal nitrogen in the Valley Cell are significantly lower (average of 28 mg.L^{-1} for 2017 to 2020).Leachate samples taken from Area 3 in 2017 to 2020 were also analysed for dissolved metals, mecoprop, TCE and toluene (Table 2). The concentrations of these constituents are summarised in Table D below along with the freshwater environmental quality standards (EQS) for comparison. The concentrations of dissolved metals exceed EQS in most samples. The EQS for mecoprop is only exceeded in two samples and the concentrations of TCE and toluene do not exceed EQS.

Entec (2007a) reported a concentration of toluene of 326 µg.L^{-1} in the Area 3 leachate in 2007 whereas the maximum concentration detected in 2017 to 2020 was 10 µg.L^{-1}. Entec (2007a) reported concentrations of mecoprop of 31.8 and 10.2 µg.L^{-1} in the Area 3 leachate in 2007. These concentrations are within the range detected in 2017 to 2020 (0.25 to 75.2 µg.L^{-1}).

Table D: Summary of concentrations of dissolved metals, mecoprop, TCE and toluene in Area 3 for the period 2017 to 2020

Determinant	Units	Area 3 cells 2017 to 2020				EQS [1]	No. exceedances
		No	Min	Mean	Max		
Cadmium	µg.L^{-1}	11	<0.02	0.058	0.33	0.08 – 0.25 [2]	1
Chromium	µg.L^{-1}	11	<0.2	12	57	3.7-4.7 [3]	6
Copper	µg.L^{-1}	11	<0.5	7.2	49	1.0 [4]	6
Iron	µg.L^{-1}	7	2900	6843	13000	1000	7
Lead	µg.L^{-1}	11	<0.2	10	75	1.2 [4]	5
Manganese	µg.L^{-1}	11	22	1774	6200	123 [4]	9
Nickel	µg.L^{-1}	11	0.8	30	170	4 [4]	7
Zinc	µg.L^{-1}	11	<0.5	63	530	10.9 [4]	7
Mecoprop	µg.L^{-1}	11	0.25	16	75.2	18	2
TCE	µg.L^{-1}	6	<1.0	<1.0	<1.0	10	0
Toluene	µg.L^{-1}	11	<1.0	2.2	10	74	0

Notes

1. EQS as an annual average concentration in freshwater from The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015
2. Cadmium EQS is dependent on hardness
3. Values for CrVI and CrIII
4. EQS is the bioavailable concentration

3.3 Groundwater Levels

Groundwater level data were made available for the period January 2017 to December 2019 and are presented in Table 3. A hydrograph showing the monitored groundwater levels with time is shown in Figure E below. This shows that groundwater levels vary seasonally with the highest groundwater levels generally occurring between December and March (coinciding with highest rainfall) and the lowest levels generally occurring between June and August. Seasonal variation is typically 3m, similar to that observed by Entec (2007a).

Figure 3 shows the interpreted groundwater piezometry at the site in August 2019. This shows that groundwater flow is to the south-west in the north of the site and to the north-west in the south-east of the site, roughly reflecting natural topography. The interpreted groundwater levels and groundwater piezometry for August 2019 are very similar to that shown by Entec (2007a) for August 2007 indicating that groundwater levels and flow have not changed significantly.

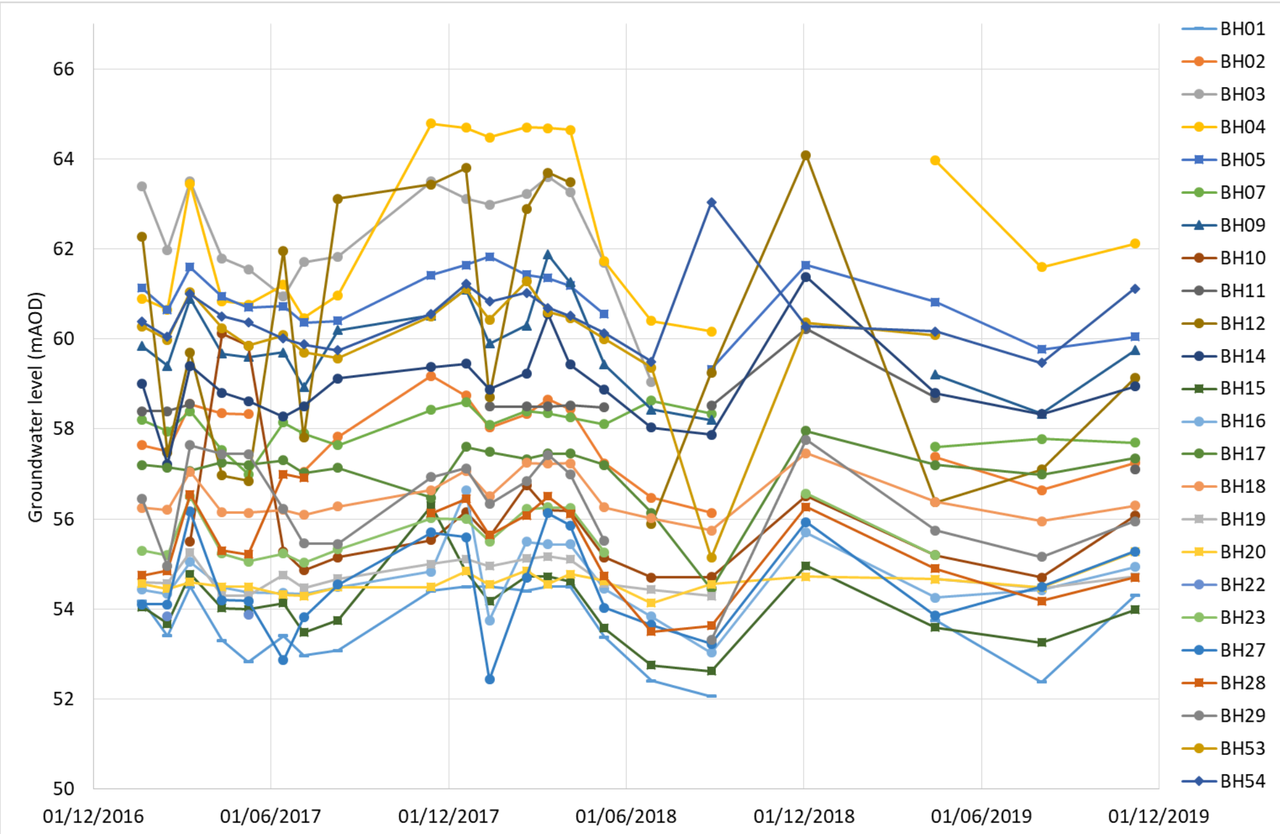

Figure E: Hydrograph of monitored groundwater levels at the site

3.4 Groundwater Quality

Groundwater quality has been monitored on an annual basis in four perimeter groundwater monitoring wells (BH1/88[3], BH2/88[3], BH22[4] and BH96B) since 2014. BH1/88 is cross-hydraulic gradient of the landfill and is therefore assumed to represent background groundwater quality. BH2/88, BH22 and BH96 are down-hydraulic gradient of the landfill. The analytical results are presented in Table 4. The concentrations of chloride and ammoniacal nitrogen are compared with previous data in Table E below.

Table E: Summary of concentrations of chloride and ammoniacal nitrogen in perimeter groundwater monitoring wells over time

Well	1989 to 2007				2014 to 2020			
	No	**Min**	**Mean**	**Max**	**No**	**Min**	**Mean**	**Max**
Chloride (mg.L^{-1})								
BH1/88	109	4	17	147	7	8.2	15.3	38
BH2/88	66	18	198	600	7	13	38.7	50
BH22	21	45	220	420	2	85	86.5	88
BH96B	64	3.1	61	163	6	7.6	15.6	25
Ammoniacal nitrogen (mg.L^{-1})								
BH1/88	110	<0.3	0.60	4.2	7	<0.015	0.34	1.8
BH2/88	66	<0.3	0.9	3.5	7	0.041	0.13	0.433
BH22	23	<0.3	27	90	2	7.3	7.45	7.6
BH96B	62	<0.3	1	3.4	6	<0.2	0.85	1.8

These results indicate that the highest concentrations of chloride and ammoniacal nitrogen are recorded in BH22 located to the south of the site whilst the lowest concentrations are generally recorded in BH1/88, which can be considered to represent background groundwater quality.

The average concentrations of chloride and ammoniacal nitrogen in the down-gradient locations have decreased significantly since the 1989 to 2007 monitoring period. The concentrations of chloride and ammoniacal nitrogen in BH96 and ammonical nitrogen in BH2/88 are now similar to background (BH1/88). The concentrations of chloride and ammoniacal nitrogen in BH22 when last monitored in April 2018 were still elevated relative to background. This well is located in a boggy area and has become silted up and so it no longer functionable.

[3] Note that there are two BH1s and two BH2s at the site. BH1/88 and BH2/88 are used to distinguish from wells BH01 and BH02

[4] Note that BH22 is located in the wetland is now silted up and so can no longer be sampled

3.5 Surface Water Quality

Surface water has been sampled from the following locations on an annual basis since 2014:

- SW1 Drain and tributary of Afon Briant, upstream of the site;
- SW2 Water entering Afon Briant from the drain (SW1);
- SW3 Afon Briant to west of the site;
- SW4 Drain from wetland to Afon Briant, downgradient of the site;
- SW5 Central part of wetlands;
- SW6 Drain entering the site from east, an upstream monitoring point;
- SW7 A stream entering the site from the drain (SW6), an upstream monitoring point;
- SW8 At the culvert exit, downstream of the site;
- SW9 Drainage ditch draining from wetland towards Afon Briant, a downstream monitoring point;
- SW10 Briant Afon at the point of entry from drainage ditch (SW9), a downstream monitoring point.

Monitoring points SW1, SW2, SW3, SW6 and SW7 are up-stream of the site and therefore represent background surface water quality.

The analytical results for the sampling conducted since 2014 are shown in Table 5. The results for chloride and ammoniacal nitrogen are summarised and compared with previous data in Table F below.

Table F: Summary of concentrations of chloride and ammoniacal nitrogen in surface water samples over time

Well	1994 to 2007				2014 to 2020			
	No	Min	Mean	Max	No	Min	Mean	Max
Chloride (mg.L^{-1})								
SW1*	54	19	32	150	7	24	26.9	30.7
SW2*	108	9	28	79	6	23	25.4	28.1
SW3*	106	3.6	27	49	7	18	25.6	34
SW4	51	24	104	301	7	24	52.2	100
SW5	85	43	647	2200	2	41	47.5	54
SW6*	100	21	37	60	7	14	22.3	31.7
SW7*	55	17	33	49	6	21	31.5	61
SW8	97	20	53	122	7	33	42.9	54
SW9	94	35	77	253	7	41	46.4	57
SW10	95	15	30	75	7	21	28.1	52
Ammoniacal nitrogen (mg.L^{-1})								
SW1*	52	<0.1	1.0	5.1	7	0.0015	0.13	0.34
SW2*	109	<0.1	1.2	30	6	0.037	0.73	3.6

SW3*	107	<0.1	0.8	30	7	0.06	0.17	0.44
SW4	51	<0.2	3.1	23	7	0.1	0.23	0.5
SW5	85	<0.4	146	441	2	0.87	4.04	7.2
SW6*	101	<0.1	1	11	7	0.01	0.10	0.2
SW7*	55	<0.1	0.5	2.1	6	0.05	1.79	10
SW8	97	<0.1	2.7	17	7	0.02	2.09	5.6
SW9	94	<0.1	0.8	18	7	0.12	0.47	0.97
SW10	95	<0.1	0.4	1.1	7	0.047	0.20	0.34

* Upstream sample location

The previous (1994 to 2007) data showed that the concentrations of chloride and ammoniacal nitrogen were significantly elevated at downstream locations SW4 and SW5 relative to upstream. The 2014 to 2020 monitoring has shown that there has been a marked decrease in the concentrations of these constituents at SW4 and SW5. The concentrations of these constituents in April 2020 were similar to those in the upstream samples.

It is noted that since 2016 there has been an increasing trend in the concentrations of ammoniacal nitrogen at SW8 (see Table 1), with the most recent sample from April 2020 recording a concentration of 5.6 $mg.L^{-1}$. This is still significantly lower than the historic maximum of 17 $mg.L^{-1}$ recorded at this location.

3.6 Summary

In summary, the main points to note from the recent site data (2014 to 2020) are as follows:

- Leachate levels have increased in Cells 2 and 3 of Area 3. Average leachate depths (above base) have increased by 2.5m in Cell 2 and 1.4m to 1.9m in Cell 3 relative to the 2003 to 2007 period;
- Leachate quality has continued to improve in Area 2, with average concentrations of chloride and ammoniacal nitrogen almost one order of magnitude lower than they were in the 1995 to 2003 monitoring period. In Area 3 the average concentrations of chloride are approximately half what they were in 1995 to 2003, but a slower decline is noted for ammoniacal nitrogen;
- Groundwater elevations and flow direction in the vicinity of the site largely remain the same as the 2003 to 2007 monitoring period; and
- Groundwater and surface water quality shows a general improvement down hydraulic gradient of the site since the 2003 to 2007 monitoring period.

4 HYDROGEOLOGICAL RISK ASSESSMENT UPDATE

The original HRA (Entec, 2003) was undertaken using LandSim which is a probabilistic software package designed on behalf of the Environment Agency to assess risk to Controlled Waters from landfills (Golder Associates, 2003). LandSim allows a variety of landfill designs to be modelled, including those used at Penhesgyn landfill.

This section uses the monitoring data from 2014 to 2020 to assess whether the conceptual site model (CSM) and assumptions used for the original 2003 HRA remain valid and to re-assess the risk to Controlled Waters. Whilst the original HRA is no longer available, there is sufficient information presented in the 2007 HRA (Entec, 2007a) on the assumptions used to allow a reasonable assessment to be made.

The various components of the CSM used as the basis of the 2003 HRA, and how these have changed based on recent data, are discussed below.

4.1 Source

Landfill leachate is considered the source. In the 2003 LandSim modelling the source concentrations were modelled using a probabilistic triangular distribution based on measured minimum, average and maximum concentrations in leachate for the period 1995 to 2003. The same source term was used for Area 2 and Area 3.

The measured minimum, average and maximum concentrations in leachate at the site for each modelled constituent are compared for the monitoring periods 1995 to 2003, 2003 to 2007 and 2014 to 2020 in Table G below. This shows that the average concentrations in 2014 to 2020 are substantially lower than those modelled in the original (2003) HRA.

Table G: Comparison of leachate source term concentrations in mg.L^{-1}

Determinant	2003 source term (data from 95 to 03)	2007 source term (data from 03 to 07)	2020 source term (data from 14 to 20)
Chloride	29 – **1565** – 4440	14 – **762** – 2520	<10 – **400** – 4500 [1]
Ammoniacal nitrogen	0.3 – **412** – 1620	0.3 – **250** – 634	<0.02 – **140** – 970 [2]
Copper	0.03 – **0.05** – 0.10	<0.05 – **0.069** – 0.57	<0.0005 – **0.0076** – 0.049
Zinc	0.06 – **0.16** – 1.1	0.007 – **0.297** – 1.96	<0.0005 – **0.063** – 0.53
Mecoprop	0.001 – **0.019** – 0.14	0.010 – **0.113** – 0.333	0.00025 – **0.016** – 0.0752
Toluene	0.01 – **0.0233** – 0.58	0.326	<0.001 – **0.0022** – 0.01
1,1,1-TCA	0.001 – **0.0086** – 0.086	< detection limit	No data available

Notes:

Source terms presented as minimum – **average** – maximum

1. Refer to Table B for detailed chloride data
2. Refer to Table C for detailed ammoniacal nitrogen data

As described in Entec (2007a) the 2003 LandSim model assumed a declining source term with the decline in source concentrations modelled using the following equation:

$$C_t = C_0\, exp(-\lambda t)$$

Where:

C_t = concentration at time t ($mg.L^{-1}$)

C_0 = starting concentration ($mg.L^{-1}$) (average concentration used as source term in 2003 HRA)

t = Time (years)

λ = HER (W_t * W_n)

HER = average effective rainfall into each cell - assumed to be 50mm/y for first 250 years (Entec, 2007a)

W_t = average waste thickness (m), Areas 2 and 3 are assumed to be 12 m and 10 m, respectively (Entec, 2007a).

Wn = water content of waste under free draining conditions (assumed to be 10%, Entec, 2007a)

Entec (2007a) used this equation to determine what the source term concentrations of chloride and ammoniacal nitrogen were predicted to be in 2007. Comparison of these predicted concentrations with the average measured concentrations for the period 2003 to 2007 showed that the LandSim model under-predicted the rate of source decline and was therefore conservative.

This exercise has been repeated using the equation above to predict leachate concentrations 17 years after 2003 (i.e. 2020). These predicted concentrations are compared with the measured concentrations in Areas 2 and 3 for the period 2014 to 2020 in Table H below. This shows that the measured concentrations are significantly lower than the predicted concentrations in Area 2 indicating that the LandSim model has under-predicted source decline for this area and is therefore conservative.

In Area 3, the predicted concentrations of chloride are similar to the measured concentrations, but the predicted concentrations of ammoniacal nitrogen are about half the average measured concentrations indicating that the LandSim model may have over-predicted source decline of ammoniacal nitrogen in this area.

Table H: Comparison of leachate source term concentrations

Area	Determinant	Starting concentration (2003) ($mg.L^{-1}$)	Predicted concentration (2020) ($mg.L^{-1}$)	Average measured concentration (2014 to 2020) ($mg.L^{-1}$)
2	Chloride	1000	492	103
	Ammoniacal nitrogen	250	123	27.6
3	Chloride	2200	940	1114
	Ammoniacal nitrogen	600	256	512

4.2 Receptors

Potential Controlled Waters receptors are described below:

- **Groundwater**. The Alluvium and Glacial Till deposits that underlie the site are classified as Secondary A aquifers and the Mica Schist bedrock is classified as a Secondary B aquifer. These are considered plausible Controlled Waters receptors.
- **Groundwater abstractions**. According to Entec (2007a) there are no licensed groundwater abstractions within 2km of the site. One private groundwater abstraction is located within 2km of the site however due to data protection the location of this is unknown (Entec, 2007). As discussed above, groundwater is considered to flow to the south-west and discharge to the Afon Braint or associated wetland and drains. Given that there are no buildings located between the site and this watercourse there is unlikely to be any groundwater abstractions potentially impacted by groundwater migration from the site. A number of springs and wells are located in the vicinity of the site as marked on the OS map however none of these are located directly down-hydraulic gradient of the site and are therefore not considered to be plausible receptors.
- **Surface water**. Afon Braint is located approximately 50m west of the landfill and joins the Menai Strait 3.3km south of the site. Afon Braint is considered a plausible receptor.

Thus, both groundwater and surface water are considered plausible receptors, with the Afon Braint considered as the key Controlled Waters receptor. The receptors therefore remain unchanged from the original 2003 HRA.

4.3 Pathways

Plausible migration pathways are described below:

- **Leaching of contaminants from waste**. In Area 2 there is no barrier between the waste and the groundwater so any leachate produced will migrate downwards to the water table. Areas 2 and 3 were capped in 2007 which will significantly reduce the amount of infiltration to the waste and thus reduce the generation of leachate.

- **Migration of leachate through the liner (Area 3)**. The basal and sidewall liners in Area 3 comprise a GCL overlain by a 2mm thick HDPE liner with welded seams constructed in accordance with the Construction Quality Assurance (CQA) plan. The leachate monitoring for 2017 to 2020 indicates that the average depth of leachate in the cells ranges from 3.0 to 7.3m and is above the control and trigger levels of 1.5m and 2.0m, respectively, and is presumably above the leachate levels assumed in the 2003 HRA. The leachate levels are above groundwater levels and there is therefore a potential for leakage of leachate to groundwater through any breaches that occur in the basal or sidewall liner. However, the fact that leachate levels have remained relatively stable over the last three years suggests that no significant breaches have occurred.

- **Migration through groundwater**. Area 2 is an unlined landfill and therefore any leachate produced is assumed to infiltrate downwards to groundwater where it will be diluted. In Area 3 any leachate that migrates through the liner will mix with and be diluted by groundwater. Once in the groundwater in the alluvium / Glacial Till any contaminants will then migrate with the groundwater flow to the south-west where it discharges to the Afon Braint or associated wetland and drainage ditches. Contaminants in groundwater will be subject to natural attenuation processes (sorption and biodegradation). The groundwater monitoring conducted in 2017 to 2019 suggests that groundwater levels and flow direction remain largely the same as previous years despite a possible increase in rainfall and flood event frequency (Section 2.3).

4.4 Risk Assessment

Comparison of the monitoring data for the period 2014 to 2020 with previous data has shown that the assumptions of the 2003 HRA remain valid with the following possible exceptions:

- Leachate levels in Area 3 are now higher than assumed for the 2003 HRA;
- The source concentrations of ammoniacal nitrogen in Area 3 have not declined as predicted in the 2003 HRA; and
- The source concentrations of chloride and ammoniacal nitrogen in Area 2 have declined more rapidly than predicted in the 2003 HRA.

Based on the above it is reasonable to conclude that the 2003 LandSim model over-predicted risk for Area 2 but that risk may have been under-predicted for Area 3. However, when considering the risk for Area 3 it is important to account for the fact that the leachate in Area 3 is contained due to the presence of a low permeability liner. The high leachate levels in Area 3 demonstrates that the liner is working effectively and preventing migration of leachate to groundwater. This is supported by the groundwater and surface water monitoring that shows that groundwater and surface water quality are improving and that discernible impacts from the landfill are localised. Based on the available data it is reasonable to conclude that the risks to Controlled Waters are still low despite the higher leachate levels and slow rate of decline of ammoniacal nitrogen in leachate in Area 3.

5 REQUISITE MONITORING

A programme for post-closure (Aftercare Phase) monitoring was proposed by Entec in the 2007 HRA (Entec, 2007a). This comprised leachate, groundwater and surface water monitoring at the site. Entec also set control and trigger values for comparison with the monitoring data.

Almost thirteen years have passed since the site was closed and this presents a good opportunity to review the monitoring requirements along with the control and trigger values. The proposed monitoring regime and control and trigger values are presented in the following sections.

5.1 Monitoring Regime

5.1.1 Leachate Monitoring

The post-closure monitoring proposed by Entec was for monthly monitoring reducing to quarterly after one year. Since 2014, leachate quality monitoring at the site has been conducted on an annual basis and this is considered a reasonable frequency on which to continue. As far as possible this should be conducted in April (as previous years) to coincide with the groundwater and surface water monitoring and when groundwater levels are between winter highs and summer lows. It is proposed that leachate level monitoring occurs in Area 2 on an annual basis and in Area 3 on a quarterly basis.

The proposed leachate monitoring schedule is presented in Table I below.

Table I: Proposed leachate monitoring schedule

Monitoring location	Frequency	Measurement/ determinant
Area 2 (level & quality) - L1, L4, L5, L6, L7	Annually	Leachate level and total depth (mbtoc and mbgl)*, pH, electrical conductivity, chloride, ammoniacal nitrogen, COD, BOD
Area 3 (level) - Cell 1 (BHL14, BHL15) - Cell 2 (BHL13, L nr 38, L nr 122) - Cell 3 (BHL10, BHMH3A, BHMH3B) - Valley Cell (L16, L17)	Quarterly	Leachate level and total depth (mbtoc and mbgl)*
Area 3 (quality) - Cell 1 (BHL13) - Cell 2 (BHL14) - Cell 3 (BHMH3A) - Valley Cell (BH60)	Annually	pH, electrical conductivity, chloride, ammoniacal nitrogen, COD, BOD

* mbtoc = metres below top of casing, mbgl = metres below ground level

5.1.2 Groundwater monitoring

As with the leachate monitoring, groundwater monitoring should be conducted on an annual basis and preferably in April as with previous rounds (and when groundwater levels are typically highest). The proposed groundwater monitoring schedule is presented in Table J below. Note that BH22 has become silted up and is no longer operational and so it is proposed that BH19 is sampled instead.

Table J: Proposed groundwater monitoring schedule

Monitoring location	Frequency	Measurement/ determinant
BH01 to BH31, BH50 to BH54, BH1/88, BH2/88, BH96B	Annually	Groundwater level (m below top of casing)
BH1/88, BH2/88, BH19, BH96B	Annually	pH, electrical conductivity, chloride, ammoniacal nitrogen, COD, BOD, dissolved oxygen

5.1.3 Surface water monitoring

As with the leachate and groundwater monitoring, surface water monitoring should be conducted on an annual basis and preferably in April as with previous rounds. The proposed surface water monitoring schedule is presented in Table K below.

Table K: Proposed surface water monitoring schedule

Monitoring location	Frequency	Measurement/ determinant
SW1 to SW10	Annually	pH, electrical conductivity, chloride, ammoniacal nitrogen, COD, BOD, dissolved oxygen

5.2 Control and Trigger Levels

Control and Trigger Levels were set in 2003 as part of the environmental permit for the site and were revised during the 2007 HRA update. A breach of the control and/or trigger levels initiates a contingency plan to investigate the causes of the breach and assess its likely impact and take appropriate action to mitigate the impact if required.

Given that 13 years has passed since the previous HRA, a review (and update where required) of these control and trigger values is warranted to ensure that they are still effective for helping to manage risks from the site.

5.2.1 Leachate

The control and trigger levels proposed by Entec (2007a) are compared with maximum concentrations/levels from the 2014 to 2020 monitoring for Areas 2 and 3 in Table L below.

Table L: Existing leachate control and trigger levels compared with recent site data

Parameter	Units	Control Level	Trigger Level	Maximum measured 2014 to 2020	
				Area 2	Area 3
Chloride	$mg.L^{-1}$	4440	4884	479	4500
Ammoniacal Nitrogen	$mg.L^{-1}$	1710	1800	151	970
Mecoprop	$mg.L^{-1}$	0.33	0.67	no data	0.075
Toluene	$mg.L^{-1}$	1.3	2.6	no data	0.01
1,1,1-Trichloroethane	$mg.L^{-1}$	0.086	0.17	no data	no data
Leachate Level	m (above base of cell)	1.5	2	N/A	8.33

Given that the leachate concentrations of chloride and ammoniacal nitrogen in Area 2 are now considerably lower than in Area 3 it would be more appropriate to have separate control and trigger values for these constituents for Areas 2 and 3. For Area 2 it is proposed that the control and trigger values are based on the mean concentration at L1 for the period 2014 to 2020 plus two and three standard deviations, respectively. For Area 3 it is proposed that the control and trigger values are based on the mean concentration in the Area 3 leachate wells for the period 2014 to 2020 plus two and three standard deviations, respectively.

Given that the measured concentrations of mecoprop and toluene in Area 3 in 2014 to 2020 were generally below EQS these are not considered constituents of potential concern. Likewise, 1,1,1-trichloroethane, although not included in the analytical suite for samples taken from 2014 onwards, was below the limit of detection in the 2003 to 2007 monitoring (Entec, 2007a) and so is not considered a constituent of potential concern. As such, these constituents have not been included in the proposed monitoring schedule and control and trigger values have not been derived.

Leachate levels in Cells 2 and 3 of Area 3 have consistently exceeded the 2 m trigger value in recent years. The reason for the high levels of leachate in these cells is unknown but the site have reported that the leachate abstraction has negligible effect on leachate levels (see Section 3.1). The monitoring data shows continued improvement in groundwater and surface water quality down-hydraulic gradient of the landfill and this would suggest that the higher leachate levels in Cells 2 and 3 are not resulting in significant impact to water quality. Given the practical difficulties in reducing leachate level in Cells 2 and 3 and the lack of impact to water quality it is proposed that the control and trigger levels for leachate level in Cells 2 and 3 are increased to 3.5m and 4m, respectively. The control and trigger levels for Cell 1 and Valley Cell are proposed to remain at 1.5 m and 2 m, respectively.

The proposed control and trigger levels for leachate are presented in Table M below.

Table M: Proposed leachate control and trigger levels

Parameter	Units	Control Level		Trigger Level	
		Area 2	Area 3	Area 2	Area 3
Chloride	$mg.L^{-1}$	617	4220	799	5673
Ammoniacal Nitrogen	$mg.L^{-1}$	171	1271	217	1642
Leachate Level - Cell 1 - Cell 2 - Cell 3 - Valley Cell	m (above base of cell)	-	 1.5 3.5 3.5 1.5	-	 2 4 4 2

5.2.2 Groundwater

Entec (2007a) set control and trigger levels for chloride, ammoniacal nitrogen, cadmium and mecoprop in groundwater for four downgradient monitoring wells, namely BH2/88, BH8/88, BH22 and BH96B. Given that the measured concentrations of cadmium and mecoprop in the Area 3 leachate in 2014 to 2020 were generally below EQS these are not considered constituents of potential concern and have not been included in the proposed groundwater monitoring schedule. As such, control and trigger levels have not been derived for these constituents.

Well specific control and trigger values have been derived for chloride and ammoniacal nitrogen for wells BH2/88 and BH96B. Monitoring wells BH8/88 and BH22 have been lost or silted up and are therefore no longer available. The well specific control and trigger values have been calculated as the mean concentration in the well for the period 2014 to 2020 plus two and three standard deviations, respectively. The proposed control and trigger levels for groundwater are presented in Table N below. The existing control and trigger levels for these wells derived by Entec (2007a) are shown in brackets for comparison. As shown, the proposed values are less than the existing values reflecting the general improvement in groundwater quality at the site.

Table N: Proposed groundwater control and trigger levels

Parameter	Units	Control Level		Trigger Level	
		BH2/88	BH96B	BH2/88	BH96B
Chloride	$mg.L^{-1}$	63 (225)	28 (225)	75 (250)	34 (250)
Ammoniacal Nitrogen	$mg.L^{-1}$	0.42 (3.6)	2.3 (3.8)	0.56 (4.8)	3.0 (5.1)

Values in brackets are existing values derived by Entec (2007a)

5.2.3 Surface Water

Entec (2007a) set control and trigger levels for chloride, ammoniacal nitrogen, cadmium and mecoprop at downstream monitoring points SW9 and SW10. As discussed above, cadmium and mecoprop are no longer considered constituents of potential concern and therefore control and trigger values have not been derived for these determinants.

The control and trigger values for chloride and ammoniacal nitrogen derived by Entec (2007a) were based on the concentrations at upstream locations (SW6 and SW3, respectively) plus a fixed concentration which ranged from 75 to 150 $mg.L^{-1}$ for chloride and 0.4 to 3.0 $mg.L^{-1}$ for ammoniacal nitrogen, depending on location and whether it was a control or trigger level. For consistency with groundwater, the proposed control and trigger values for chloride and ammoniacal nitrogen at SW9 and SW10 are based on the mean concentration at these locations plus two and three standard deviations, respectively. The proposed control and trigger values, along with the existing levels (in brackets) for comparison, are shown in Table O. As shown, the proposed values are less than the existing values reflecting the general improvement in surface water quality at the site.

Table O: Proposed surface water control and trigger levels

Parameter	Units	Control Level		Trigger Level	
		SW9	SW10	SW9	SW10
Chloride	$mg.L^{-1}$	58 (SW6 + 75)	50 (SW3 + 75)	64 (SW6 + 150)	61 (SW3 + 100)
Ammoniacal Nitrogen	$mg.L^{-1}$	1.0 (SW6 + 1.0)	0.42 (SW3 + 0.4)	1.3 (SW6 + 3.0)	0.53 (SW3 + 1.0)

Values in brackets are existing values derived by Entec (2007a)

5.3 Contingency Plan

As proposed by Entec (2007a) it is proposed that breach of control levels only leads to action once they have been exceeded for three separate monitoring rounds. Exceedance of a trigger value on a single occasion will require enaction of the contingency plan. The outline course of action and suggested response times are summarised in Table P below. This is based on a slightly modified version of that presented by Entec (2007a).

Table P: Proposed Contingency Plan

Action	Response time
1. The monitoring technician shall inform the Site Manager	Immediately
2. Inform NRW	In accordance with the requirements of Schedule 5 of the Permit
3. Increase monitoring frequency at the affected monitoring points to monthly	For 3 months
4. Review exiting monitoring data	1 month
5. Investigate the reason for exceedance /review performance of leachate collection system/pumps/ ambient conditions/other relating factors	3 months
6. If a fault is identified on the leachate extraction system, refer to Leachate Action Plan (Section 7.0 of LMP). Where breaches of the leachate control levels are on-going due to elevated levels, a remedial leachate action plan will be agreed with NRW within 3 months.	3 months
7. Re-evaluate risks and assessment criteria in consultation with NRW.	12 months

6 CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

The following conclusions can be drawn from the work presented herein:

- Leachate quality continues to improve in Area 2. The average concentrations of chloride and ammoniacal nitrogen for the period 2014 to 2020 are almost one order of magnitude lower than they were in the 1995 to 2003 monitoring period and are only elevated with respect to background groundwater quality in the far west. The decline in concentrations is more rapid than predicted by the LandSim modelling conducted in 2003.
- In Area 3 the average concentration of chloride in leachate for the period 2017 to 2020 is approximately half what it was in 1995 to 2003 in line with the 2003 LandSim predictions. There does not yet appear to have been a significant decline in concentrations of ammoniacal nitrogen in Area 3. This will continue to be assessed with the proposed annual monitoring programme.
- Leachate levels have increased in Cells 2 and 3 of Area 3. Average leachate depths (above base) have increased by 2.5m in Cell 2 and 1.4m to 1.9m in Cell 3 relative to the 2003 to 2007 period and exceed the control and trigger values of 1.5m and 2.0m, respectively. It is possible that this is due to breaches in the landfill cap which has now been repaired. The site is currently only abstracting leachate from Cell 2 which is recirculated into Cell 1.
- Groundwater and surface water quality down-hydraulic gradient of the site continues to improve. The concentrations in groundwater and surface water are now similar to background with the exception of localised impacts at BH22 and SW8.
- Groundwater elevations and flow direction in the vicinity of the site remain largely the same as the 2003 to 2007 monitoring period.
- It has been concluded that the assumptions used for the 2003 LandSim modelling remain valid and suitably conservative with the exception of the higher leachate levels and slow decline of ammoniacal nitrogen observed in Area 3. However, the continued improvement in groundwater and surface water quality at the site indicates that the leachate in Area 3 is well contained and it is concluded that the risks to Controlled Waters receptors remain low.

6.2 Recommendations

The following recommendations are made:

- Regular monitoring of leachate, groundwater and surface water is continued as detailed in Section 5. As discussed, it is recommended that BH19 is used as a groundwater sampling point in place of BH22 which has silted up and is no longer functionable.
- The control and trigger values for leachate level are exceeded in Cells 2 and 3. At present the liner provides an effective containment barrier for the leachate. However, over time liner degradation may result in breaches occurring and leakage of leachate to groundwater. Reducing the head of leachate in the landfill cells will reduce the leakage rate and impact to groundwater should this occur. It is therefore recommended that options for reducing leachate head are assessed and, where possible, implemented.

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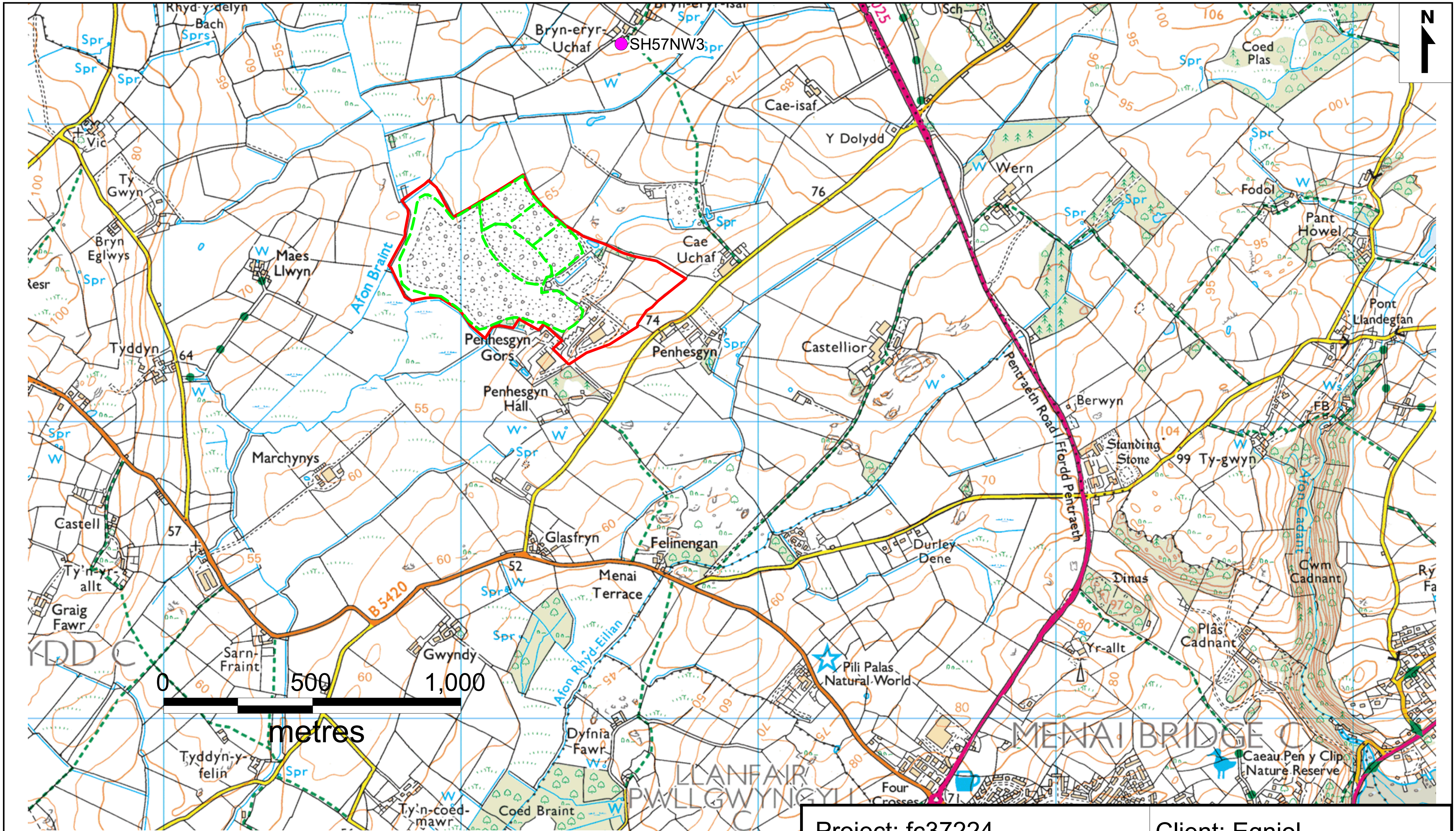
FIGURES



- Site boundary
- Landfilled area
- Borehole on BGS database

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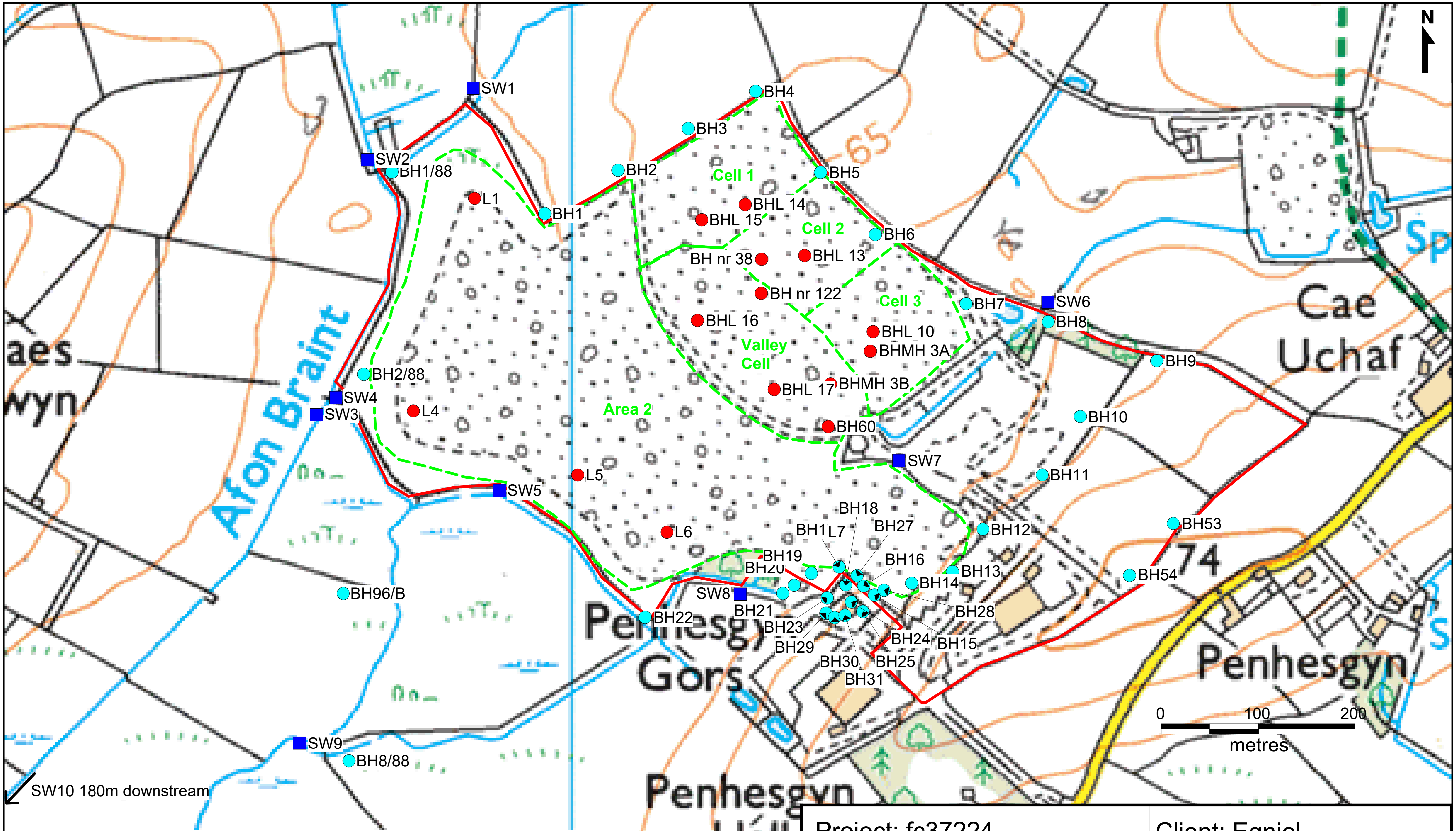
Project: fc37224 Penhesgyn Landfill	Client: Egniol Environmental Ltd
Figure 1	Site location
Scale: as shown	
Date: 15/05/20	



- Site boundary
- Landfill cell/area
- Gas/groundwater monitoring well
- Leachate monitoring well
- Surface water sampling location

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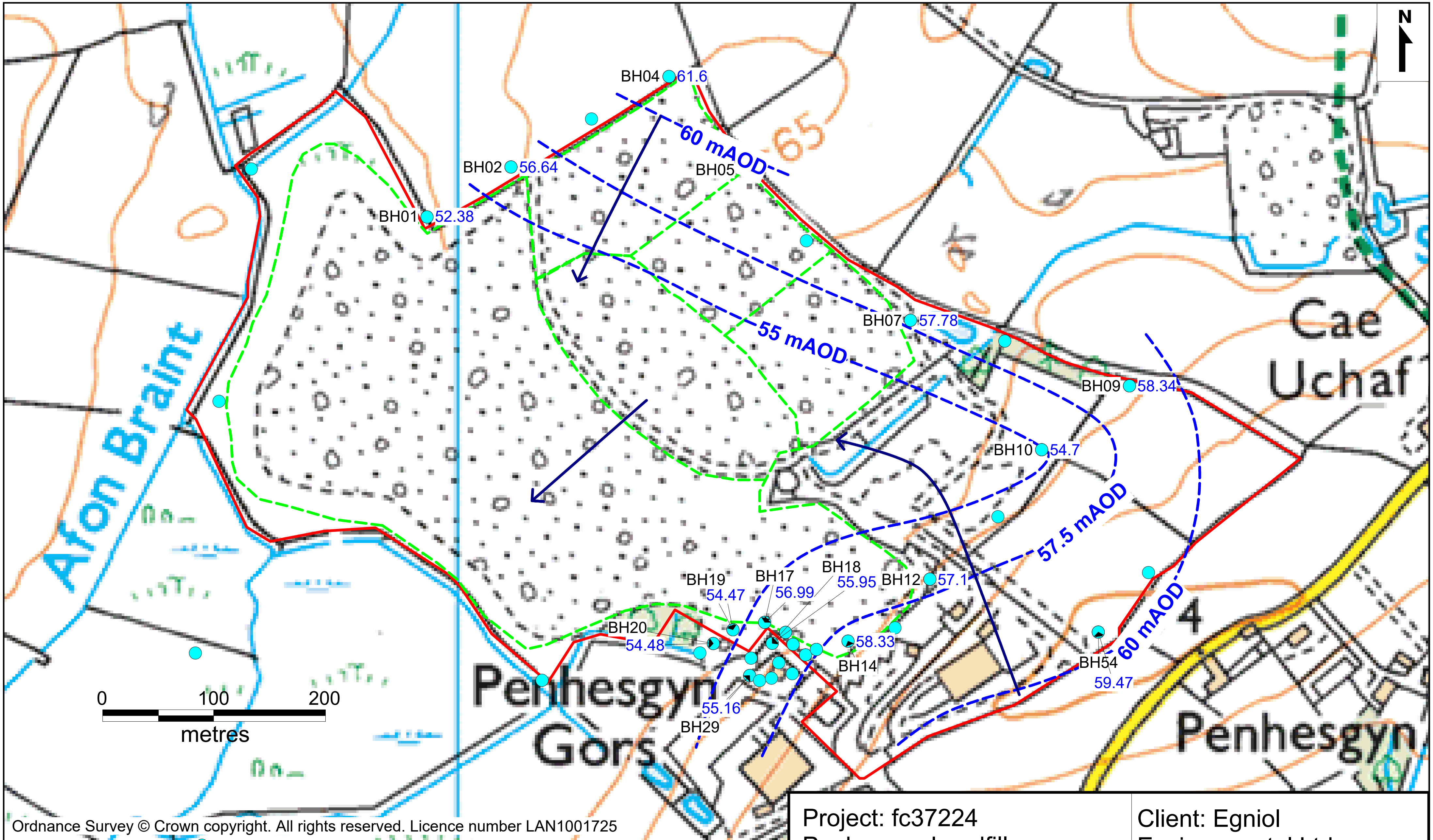
Figure 2	Monitoring locations
Scale: as shown	
Date: 15/05/20	



Site boundary
Landfilled areas
Groundwater monitoring well
54.48 Groundwater level on 02/08/2019 (mAOD)
Piezometric contour
Groundwater flow direction

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Project: fc37224
Penhesgyn Landfill

Client: Egniol Environmental Ltd

Figure 3

Scale: as shown

Date: 15/05/20

Groundwater piezometry (August 2019)

TABLES

Table 1: Leachate Level Data Area 3

Well Number	Date	Depth to Base mbtoc	Depth to Leachate mbtoc	Ground Level mAOD	Head works height m above ground level	Top of casing (toc) mAOD	Depth of leachate above base (m)	Leachate Level mAOD
CELL 1								
BHL 14	07/07/2017	9.64	9.12	68.88	1.15	70.03	0.52	60.91
BHL 14	02/08/2017	9.64	9.19	68.88	1.15	70.03	0.45	60.84
BHL 14	08/08/2017	9.64	9.22	68.88	1.15	70.03	0.42	60.81
BHL 14	10/08/2017	9.64	9.31	68.88	1.15	70.03	0.33	60.72
BHL 14	24/08/2017	9.64	9.3	68.88	1.15	70.03	0.34	60.73
BHL 14	01/09/2017	9.64	9.27	68.88	1.15	70.03	0.37	60.76
BHL 14	22/09/2017	9.64	9.28	68.88	1.15	70.03	0.36	60.75
BHL 14	26/10/2017	9.64	9.35	68.88	1.15	70.03	0.29	60.68
BHL 14	05/02/2018	9.64	9.33	68.88	1.15	70.03	0.31	60.7
BHL 14	20/03/2018	9.64	9.37	68.88	1.15	70.03	0.27	60.66
BHL 14	01/07/2019	9.64	9.31	68.88	1.15	70.03	0.33	60.72
BHL 14	05/07/2019	9.64	9.29	68.88	1.15	70.03	0.35	60.74
BHL 14	13/08/2019	9.64	9.265	68.88	1.15	70.03	0.375	60.765
BHL 14	09/12/2019	9.64	9.264	68.88	1.15	70.03	0.376	60.766
BHL 14	15/05/2020	9.64	9.3	68.88	1.15	70.03	0.34	60.73
BHL 15	07/07/2017	9.1	8.32	68.52	1.3	69.82	0.78	61.5
BHL 15	02/08/2017	9.1	8.43	68.52	1.3	69.82	0.67	61.39
BHL 15	08/08/2017	9.1	8.48	68.52	1.3	69.82	0.62	61.34
BHL 15	10/08/2017	9.1	8.45	68.52	1.3	69.82	0.65	61.37
BHL 15	24/08/2017	9	8.15	68.52	1.3	69.82	0.85	61.67
BHL 15	01/09/2017	9.1	8.52	68.52	1.3	69.82	0.58	61.3
BHL 15	26/10/2017	9.1	8.6	68.52	1.3	69.82	0.5	61.22
BHL 15	05/02/2018	9.1	8.66	68.52	1.3	69.82	0.44	61.16
BHL 15	01/07/2019	9.1	8.534	68.52	1.3	69.82	0.566	61.286
BHL 15	05/07/2019	9.1	8.534	68.52	1.3	69.82	0.566	61.286
BHL 15	13/08/2019	9.1	8.534	68.52	1.3	69.82	0.566	61.286
BHL 15	09/12/2019	9.1	8.536	68.52	1.3	69.82	0.564	61.284
BHL 15	15/05/2020	9.1	8.53	68.52	1.3	69.82	0.57	61.29
CELL 2								
BHL 13	02/06/2017	9	6.05	68.64	0.85	69.49	2.95	63.44
BHL 13	07/07/2017	9	6.05	68.64	0.85	69.49	2.95	63.44
BHL 13	02/08/2017	9	6.1	68.64	0.85	69.49	2.9	63.39
BHL 13	08/08/2017	9	6.1	68.64	0.85	69.49	2.9	63.39
BHL 13	10/08/2017	9	6.15	68.64	0.85	69.49	2.85	63.34
BHL 13	17/08/2017	9	6.1	68.64	0.85	69.49	2.9	63.39
BHL 13	24/08/2017	9	6.11	68.64	0.85	69.49	2.89	63.38
BHL 13	01/09/2017	9	6.1	68.64	0.85	69.49	2.9	63.39
BHL 13	22/09/2017	9	6.01	68.64	0.85	69.49	2.99	63.48
BHL 13	26/10/2017	9	6.08	68.64	0.85	69.49	2.92	63.41
BHL 13	05/02/2018	9	6.02	68.64	0.85	69.49	2.98	63.47
BHL 13	20/03/2018	9	6.11	68.64	0.85	69.49	2.89	63.38
BHL 13	16/04/2018	9	5.95	68.64	0.85	69.49	3.05	63.54
BHL 13	17/04/2018	9	5.96	68.64	0.85	69.49	3.04	63.53
BHL 13	14/01/2019	9	6.04	68.64	0.85	69.49	2.96	63.45
BHL 13	18/01/2019	9	6.36	68.64	0.85	69.49	2.64	63.13
BHL 13	13/08/2019	9	5.055	68.64	0.85	69.49	3.945	64.435
BHL 13	13/08/2019	9	5.06	68.64	0.85	69.49	3.94	64.43
BHL 13	15/05/2020	9	6.07	68.64	0.85	69.49	2.93	63.42
L NEXT TO 122	02/06/2017	10.5	6.5	70.33	0.85	71.18	4	64.68
L NEXT TO 122	07/07/2017	10.5	6.39	70.33	0.85	71.18	4.11	64.79
L NEXT TO 122	02/08/2017	10.5	6.38	70.33	0.85	71.18	4.12	64.8
L NEXT TO 122	08/08/2017	10.5	6.39	70.33	0.85	71.18	4.11	64.79
L NEXT TO 122	10/08/2017	10.5	6.46	70.33	0.85	71.18	4.04	64.72
L NEXT TO 122	17/08/2017	10.5	6.4	70.33	0.85	71.18	4.1	64.78
L NEXT TO 122	24/08/2017	10.5	6.4	70.33	0.85	71.18	4.1	64.78
L NEXT TO 122	01/09/2017	10.5	6.46	70.33	0.85	71.18	4.04	64.72
L NEXT TO 122	22/09/2017	10.5	6.42	70.33	0.85	71.18	4.08	64.76
L NEXT TO 122	26/10/2017	10.5	6.3	70.33	0.85	71.18	4.2	64.88
L NEXT TO 122	05/02/2018	10.5	6.23	70.33	0.85	71.18	4.27	64.95
L NEXT TO 122	20/03/2018	10.5	6.37	70.33	0.85	71.18	4.13	64.81
L NEXT TO 122	16/04/2018	10.5	6.22	70.33	0.85	71.18	4.28	64.96
L NEXT TO 122	17/04/2018	10.5	6.26	70.33	0.85	71.18	4.24	64.92
L NEXT TO 122	14/01/2019	10.5	6.44	70.33	0.85	71.18	4.06	64.74
L NEXT TO 122	18/01/2019	10.5	6.12	70.33	0.85	71.18	4.38	65.06
L NEXT TO 122	13/08/2019	10.5	6.185	70.33	0.85	71.18	4.315	64.995
L NEXT TO 122	13/08/2019	10.5	6.19	70.33	0.85	71.18	4.31	64.99
L NEXT TO 122	15/05/2020	10.5	6.2	70.33	0.85	71.18	4.3	64.98
L NEXT TO 38	07/07/2017	8.52	6.3	69.01	0.8	69.81	2.22	63.51
L NEXT TO 38	02/08/2017	8.52	6.27	69.01	0.8	69.81	2.25	63.54
L NEXT TO 38	08/08/2017	8.52	6.23	69.01	0.8	69.81	2.29	63.58
L NEXT TO 38	10/08/2017	8.52	6.27	69.01	0.8	69.81	2.25	63.54
L NEXT TO 38	24/08/2017	8.52	6.31	69.01	0.8	69.81	2.21	63.5
L NEXT TO 38	01/09/2017	8.52	6.6	69.01	0.8	69.81	1.92	63.21
L NEXT TO 38	22/09/2017	8.52	6.46	69.01	0.8	69.81	2.06	63.35
L NEXT TO 38	26/10/2017	8.52	6.35	69.01	0.8	69.81	2.17	63.46
L NEXT TO 38	20/03/2018	8.52	6.3	69.01	0.8	69.81	2.22	63.51
L NEXT TO 38	16/04/2018	8.52	6.25	69.01	0.8	69.81	2.27	63.56
L NEXT TO 38	17/04/2018	8.52	6.26	69.01	0.8	69.81	2.26	63.55
CELL 3								
BHL 10	08/08/2017	9.45	8.3	67.97	?	?	1.15	?
BHL 10	10/08/2017	9.45	9.27	67.97	?	?	0.18	?

Table 1: Leachate Level Data Area 3

Well Number	Date	Depth to Base mbtoc	Depth to Leachate mbtoc	Ground Level mAOD	Head works height m above ground level	Top of casing (toc) mAOD	Depth of leachate above base (m)	Leachate Level mAOD
BHL 10	24/08/2017	9.45	9.28	67.97	?	?	0.17	?
BHL 10	01/09/2017	9.45	9.28	67.97	?	?	0.17	?
BHMH 3A	02/06/2017	13.5	10.86	68.56	1.8	70.36	2.64	59.5
BHMH 3A	07/07/2017	13.5	10.88	68.56	1.8	70.36	2.62	59.48
BHMH 3A	08/08/2017	13.5	10.87	68.56	1.8	70.36	2.63	59.49
BHMH 3A	10/08/2017	13.5	10.91	68.56	1.8	70.36	2.59	59.45
BHMH 3A	24/08/2017	13.5	10.85	68.56	1.8	70.36	2.65	59.51
BHMH 3A	01/09/2017	13.5	10.85	68.56	1.8	70.36	2.65	59.51
BHMH 3A	22/09/2017	13.5	10.8	68.56	1.8	70.36	2.7	59.56
BHMH 3A	26/10/2017	13.5	10.82	68.56	1.8	70.36	2.68	59.54
BHMH 3A	05/02/2018	13.5	10.37	68.56	1.8	70.36	3.13	59.99
BHMH 3A	20/03/2018	13.5	10.79	68.56	1.8	70.36	2.71	59.57
BHMH 3A	13/08/2019	13.5	10.761	68.56	1.8	70.36	2.739	59.599
BHMH 3A	09/12/2019	13.5	10.76	68.56	1.8	70.36	2.74	59.6
BHMH 3A	26/02/2020	13.5	10.765	68.56	1.8	70.36	2.735	59.595
BHMH 3A	15/05/2020	13.5	10.9	68.56	1.8	70.36	2.6	59.46
BHMH 3B	02/06/2017	16.02	13.02	70.57	2.01	72.58	3	59.56
BHMH 3B	07/07/2017	16.02	13.02	70.57	2.01	72.58	3	59.56
BHMH 3B	08/08/2017	16.02	13.06	70.57	2.01	72.58	2.96	59.52
BHMH 3B	10/08/2017	16.02	13.1	70.57	2.01	72.58	2.92	59.48
BHMH 3B	24/08/2017	16.02	13.01	70.57	2.01	72.58	3.01	59.57
BHMH 3B	01/09/2017	16.02	13.01	70.57	2.01	72.58	3.01	59.57
BHMH 3B	22/09/2017	16.02	13.06	70.57	2.01	72.58	2.96	59.52
BHMH 3B	26/10/2017	16.02	13.04	70.57	2.01	72.58	2.98	59.54
BHMH 3B	05/02/2018	16.02	12.55	70.57	2.01	72.58	3.47	60.03
BHMH 3B	20/03/2018	16.02	12.95	70.57	2.01	72.58	3.07	59.63
BHMH 3B	13/08/2019	16.02	12.979	70.57	2.01	72.58	3.041	59.601
BHMH 3B	09/12/2019	16.02	12.98	70.57	2.01	72.58	3.04	59.6
BHMH 3B	26/02/2020	16.02	12.975	70.57	2.01	72.58	3.045	59.605
BHMH 3B	15/05/2020	16.02	12.995	70.57	2.01	72.58	3.025	59.585
VALLEY CELL								
L16	02/06/2017	9.88	9.8	70.8	1.25	72.05	0.08	62.25
L16	07/07/2017	9.88	9.78	70.8	1.25	72.05	0.1	62.27
L16	01/08/2017	9.88	9.79	70.8	1.25	72.05	0.09	62.26
L16	08/08/2017	9.88	9.8	70.8	1.25	72.05	0.08	62.25
L16	10/08/2017	9.88	9.78	70.8	1.25	72.05	0.1	62.27
L16	17/08/2017	9.88	9.75	70.8	1.25	72.05	0.13	62.3
L16	24/08/2017	9.88	9.74	70.8	1.25	72.05	0.14	62.31
L16	01/09/2017	9.88	9.78	70.8	1.25	72.05	0.1	62.27
L16	22/09/2017	9.88	9.76	70.8	1.25	72.05	0.12	62.29
L16	26/10/2017	9.88	9.74	70.8	1.25	72.05	0.14	62.31
L16	05/02/2018	9.88	9.77	70.8	1.25	72.05	0.11	62.28
L16	20/03/2018	9.88	9.77	70.8	1.25	72.05	0.11	62.28
L16	09/12/2019	9.88	9.795	70.8	1.25	72.05	0.085	62.255
L16	15/05/2020	9.88	9.8	70.8	1.25	72.05	0.08	62.25
L17	02/06/2017	13.75	13.2	69.98	1.54	71.52	0.55	58.32
L17	07/07/2017	13.75	13.15	69.98	1.54	71.52	0.6	58.37
L17	01/08/2017	13.75	13.31	69.98	1.54	71.52	0.44	58.21
L17	08/08/2017	13.75	13.34	69.98	1.54	71.52	0.41	58.18
L17	10/08/2017	13.75	13.33	69.98	1.54	71.52	0.42	58.19
L17	17/08/2017	13.75	13.3	69.98	1.54	71.52	0.45	58.22
L17	24/08/2017	13.75	13.3	69.98	1.54	71.52	0.45	58.22
L17	01/09/2017	13.75	13.29	69.98	1.54	71.52	0.46	58.23
L17	22/09/2017	13.75	13.24	69.98	1.54	71.52	0.51	58.28
L17	26/10/2017	13.75	13.35	69.98	1.54	71.52	0.4	58.17
L17	05/02/2018	13.75	12.93	69.98	1.54	71.52	0.82	58.59
L17	20/03/2018	13.75	12.93	69.98	1.54	71.52	0.82	58.59
L17	09/12/2019	13.75	12.95	69.98	1.54	71.52	0.8	58.57
L17	15/05/2020	13.75	12.99	69.98	1.54	71.52	0.76	58.53

Table 2: Leachate Quality Data for Areas 2 and 3

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Sample ID	Date Sampled	pH	Electrical Conductivity	Chloride as Cl	Ammoniacal Nitrogen, as N	Chemical Oxygen Demand	Biochemical Oxygen Demand	Dissolved Oxygen	Cadmium (dissolved)	Chromium (dissolved)	Copper (dissolved)	Iron (dissolved)	Lead (dissolved)	Manganese (dissolved)	Nickel (dissolved)	Zinc (dissolved)	MCPP (Mecoprop)	Trichloroethene	Toluene	Methane (dissolved)
		pH units	µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Area 2																				
L1	14/03/2014	7.01	3340		117		6.49	0.3												
L1	14/04/2015	7.93	4700		151		6.92	0.3												
L1	26/04/2016	7.2	3450	442	73.4	110	6.6	1.9												
L1	26/04/2017	7.1	3710	460	96	6.2	92	8.8												
L1	09/04/2018	7.1	2640	120	68	22	16	8.8												
L1	09/04/2019	7.1	1000	88	17	40	2.5	3.2												
L1	30/04/2020	7.1	1600	160	39	61	23													
L4	14/03/2014	7.47	1850		54.8		3.35	0.3												
L4	14/04/2015	8.16	3580		133		10	0.3												
L4	26/04/2016	7.3	2960	479	86.9	164	11.1	2.1												
L4	26/04/2017	7.5	1540	190	14	2.6	42	7.8												
L4	09/04/2018	7.6	2090	140	47	86	14	6.1												
L4	09/04/2019	6.7	760	19	0.79	34	3.6	2												
L4	30/04/2020	6.6	820	24	1.5	29	17													
L5	14/03/2014	7.63	537		0.629		17.4	10.1												
L5	14/04/2015																			
L5	26/04/2016	7.4	367	27	0.05	11	2.9	9.4												
L5	26/04/2017																			
L5	09/04/2018	8.1	642	19	1.5	10	17	9.4												
L5	09/04/2019	6.9	690	17	1.3	170	6.6	2.4												
L5	30/04/2020	7	800	18	3	43	17													
L6	14/03/2014	7.19	688		0.239		5.55	7.9												
L6	14/04/2015	7.84	667		0.2		1	4.57												
L6	26/04/2016	7	800	30	0.04	12	2	4.8												
L6	26/04/2017	7.1	995	24	0.12	1.4	10	10.5												
L6	09/04/2018	7.3	719	29	0.21	10	14	8.2												
L6	09/04/2019	6.7	940	29	0.072	16	2.5	2.7												
L6	30/04/2020	6.9	980	22	0.39	31	17													
L7	14/03/2014	7.53	630		0.2		20.3	0.3												
L7	14/04/2015	7.4	661		2.04		3.94	0.3												
L7	26/04/2016	6.9	758	25	0.02	12	2	6												
L7	26/04/2017	7.2	994	21	0.056	1.1	10	11.2												
L7	09/04/2018	7.6	679	17	0.063	10	15	7.2												
L7	09/04/2019	7.1	1500	42	1.2	2900	11	2.1												
L7	30/04/2020	7.2	1200	28	0.065	23	7.7													
Area 3																				
BHL 14 (Cell 1)	09/10/2017	8	16600	1800	720	6200	240		0.33	57	49	13000	75	1500	170	530	75.2		2.1	
BHL 14 (Cell 1)	30/04/2020	8	17000	88	970				< 0.02	4.3	< 0.5		27	22	7.7	2	1.7	< 1.0	3.8	
BHL 13 (Cell 2)	18/09/2017	7.7	10000	1300	970	590	56		<0.03	25	2.8	3300	2.5	330	33	29	6.9		<1	23000
BHL 12 (Cell 2)	09/04/2018	7.8	7790	<10	630				<0.03	17	0.8	3200	2.1	260	15	13	5.9	<1	10	
BHL 13 (Cell 2)	30/04/2020	7.8	12000	1500	940				< 0.02	0.9	< 0.5		0.3	40	1.2	< 0.5	1.5	< 1.0	< 1.0	
BHL 10 (Cell 3)	09/10/2017	7.2	5540	880	110	1200	360		0.07	2.7	14	13000	5.5	3600	28	62	5.47		<1	
BHMH 3a (Cell 3)	09/04/2018	7.3	6530	<10	300				0.04	9.7	2	2900	1.2	6200	21	26	4	<1	<1	
BHMH 3A (Cell 3)	30/04/2020	7.4	7700	990	420				< 0.02	0.3	< 0.5		0.2	3600	0.8	< 0.5	2.2	< 1.0	< 1.0	
BHL 11 (Valley Cell)	09/10/2017	6.9	1170	64	17	44	6.2		<0.03	0.72	5.1	9100	0.29	3200	1	11	0.25		<1	
BH 60 (Valley Cell)	30/04/2020	7.4	1300	4500	39				< 0.02	< 0.2	< 0.5		< 0.2	210	1.1	2	0.93	< 1.0	< 1.0	
BHNT	18/09/2017	7.8	14800	3300	700	650	33		<0.03	16	3.1	3400	1.2	550	47	16	71		<1	700

Table 3: Groundwater Level Data

firth consultants

Groundwater Level in mbgl

Well Number	GL mAOD	20/01/2017	15/02/2017	10/03/2017	12/04/2017	09/05/2017	14/06/2017	05/07/2017	09/08/2017	13/11/2017	19/12/2017	12/01/2018	19/02/2018	13/03/2018	05/04/2018	10/05/2018	27/06/2018	28/08/2018	03/12/2018	15/04/2019	02/08/2019	06/11/2019
BH01	54.5	0.32	1.1	0	1.2	1.67	1.1	1.53	1.42	0.1	0	0	0.1	0	0	1.12	2.09	2.44		0.75	2.12	0.2
BH02	59.5	1.86	2	0.95	1.15	1.17	N/A	2.45	1.67	0.32	0.76	1.47	1.17	0.84	1.06	2.26	3.03	3.36		2.12	2.86	2.25
BH03	63.6	0.2	1.62	0.1	1.81	2.05	2.66	1.89	1.77	0.1	0.48	0.61	0.38	0	0.33	1.91	4.56					
BH04	65.4	4.5	4.75	1.95	4.56	4.63	4.2	4.93	4.43	0.61	0.71	0.92	0.7	0.72	0.75	3.67	5	5.23		1.43	3.8	3.28
BH05	65	3.87	4.36	3.4	4.06	4.3	4.27	4.64	4.6	3.58	3.36	3.17	3.57	3.65	3.81	4.45		5.67	3.36	4.18	5.23	4.95
BH07	58.8	0.6	0.85	0.4	1.27	1.8	0.66	0.9	1.16	0.38	0.2	0.71	0.4	0.45	0.54	0.69	0.17	0.46		1.2	1.02	1.1
BH09	63.5	3.66	4.1	2.6	3.83	3.9	3.8	4.57	3.3	2.98	2.4	3.6	3.2	1.62	2.24	4.07	5.07	5.3		4.29	5.16	3.75
BH10	63.2			7.7	3.08	3.35	7.92	8.34	8.05	7.67	7.04	7.6	6.45	7.01	7.02	8.05	8.5	8.49	6.69	8	8.5	7.13
BH11	64	5.6	5.6	5.45								5.5	5.5	5.5	5.47	5.52		5.48	3.78	5.31		6.9
BH12	65	2.72	7.53	5.3	8.03	8.15	3.04	7.19	1.88	1.57	1.2	6.29	2.12	1.3	1.52		9.11	5.75	0.91	8.63	7.9	5.87
BH14	64	5	6.78	4.6	5.19	5.38	5.73	5.49	4.88	4.62	4.55	5.12	4.76	3.45	4.57	5.13	5.97	6.13	2.62	5.2	5.67	5.05
BH15	60.9	6.85	7.23	6.12	6.88	6.91	6.77	7.42	7.15	4.6	6.06	6.73	6.17	6.18	6.28	7.33	8.15	8.28	5.94	7.31	7.65	6.92
BH16	58.9	4.47	4.56	3.85	4.42	4.53	4.54	4.57	4.41	4.07	2.27	5.15	3.41	3.46	3.46	4.45	5.07	5.87	3.2	4.65	4.48	3.97
BH17	59.2	2	2.05	2.13	1.94	2	1.9	2.18	2.06	2.73	1.6	1.71	1.87	1.75	1.75	2	3.06	4.75	1.24	2	2.21	1.85
BH18	59	2.75	2.8	1.95	2.85	2.86	2.8	2.91	2.72	2.36	1.93	2.5	1.75	1.77	1.76	2.74	2.98	3.25	1.54	2.62	3.05	2.7
BH19	57	2.41	2.43	1.74	2.7	2.7	2.24	2.53	2.33	2	1.89	2.05	1.88	1.83	1.9	2.44	2.57	2.71		2.34	2.53	2.28
BH20	57	2.44	2.55	2.4	2.5	2.5	2.68	2.71	2.51	2.51	2.16	2.46	2.15	2.45	2.22	2.37	2.87	2.45	2.28	2.34	2.52	1.73
BH22	54		0.17			0.12																
BH23	59	3.7	3.8	2.5	3.77	3.94	3.77	3.97	3.67	2.98	3	3.5	2.78	2.74	2.75	3.74			2.43	3.8		
BH27	59.4	5.3	5.3	3.23	5.2	5.22	6.54	5.59	4.86	3.7	3.8	6.97	4.7	3.27	3.54	5.37	5.75	6.17	3.47	5.55	4.9	4.12
BH28	62.5	7.75	7.65	5.95	7.2	7.29	5.5	5.59		6.37	6.05	6.86	6.42	6	6.38	7.77	9	8.87	6.23	7.6	8.32	7.8
BH29	60	3.55	5.05	2.36	2.56	2.56	3.78	4.54	4.55	3.07	2.87	3.67	3.16	2.57	3	4.49		6.69	2.24	4.25	4.84	4.05
BH30	?	2.9	2.6																			
BH31	?	2.42	2.67	2.34	2.6	2.6	2.6	2.52	2.29	2.17	2.18	2.4	2.25	2.17	2.2	2.6	2.54		1.71	2.53	2.51	1.8
BH50	?	0	0	0.1					0.36		0	0	0	0	0							
BH51	?	0.3	0.82	0	0.2	0.36	0.35	1.33	1.26	0.1	0.68	0.75	0.5	0.4	0.51	0.61	0.7	1.09		0.8	1.29	
BH52	?				1.25	1.41	0.2	0.61		0												
BH53	73	12.72	13.02	11.95	12.76	13.15	12.92	13.3	13.43	12.5	11.89	12.57	11.72	12.4	12.53	13	13.63	17.86	12.64	12.92		
BH54	77	16.62	16.95	16	16.5	16.64	16.99	17.12	17.25	16.44	15.78	16.17	15.97	16.31	16.49	16.87	17.5	13.97	16.72	16.83	17.53	15.88

Groundwater Level in mAOD

Well Number	20/01/2017	15/02/2017	10/03/2017	12/04/2017	09/05/2017	14/06/2017	05/07/2017	09/08/2017	13/11/2017	19/12/2017	12/01/2018	19/02/2018	13/03/2018	05/04/2018	10/05/2018	27/06/2018	28/08/2018	03/12/2018	15/04/2019	02/08/2019	06/11/2019
BH01	54.18	53.4	54.5	53.3	52.83	53.4	52.97	53.08	54.4	54.5	54.5	54.4	54.5	54.5	53.38	52.41	52.06		53.75	52.38	54.3
BH02	57.64	57.5	58.55	58.35	58.33		57.05	57.83	59.18	58.74	58.03	58.33	58.66	58.44	57.24	56.47	56.14		57.38	56.64	57.25
BH03	63.4	61.98	63.5	61.79	61.55	60.94	61.71	61.83	63.5	63.12	62.99	63.22	63.6	63.27	61.69	59.04					
BH04	60.9	60.65	63.45	60.84	60.77	61.2	60.47	60.97	64.79	64.69	64.48	64.7	64.68	64.65	61.73	60.4	60.17		63.97	61.6	62.12
BH05	61.13	60.64	61.6	60.94	60.7	60.73	60.36	60.4	61.42	61.64	61.83	61.43	61.35	61.19	60.55		59.33	61.64	60.82	59.77	60.05
BH07	58.2	57.95	58.4	57.53	57	58.14	57.9	57.64	58.42	58.6	58.09	58.4	58.35	58.26	58.11	58.63	58.34		57.6	57.78	57.7
BH09	59.84	59.4	60.9	59.67	59.6	59.7	58.93	60.2	60.52	61.1	59.9	60.3	61.88	61.26	59.43	58.43	58.2		59.21	58.34	59.75
BH10			55.5	60.12	59.85	55.28	54.86	55.15	55.53	56.16	55.6	56.75	56.19	56.18	55.15	54.7	54.71	56.51	55.2	54.7	56.07
BH11	58.4	58.4	58.55								58.5	58.5	58.5	58.53	58.48		58.52	60.22	58.69		57.1
BH12	62.28	57.47	59.7	56.97	56.85	61.96	57.81	63.12	63.43	63.8	58.71	62.88	63.7	63.48		55.89	59.25	64.09	56.37	57.1	59.13
BH14	59	57.22	59.4	58.81	58.62	58.27	58.51	59.12	59.38	59.45	58.88	59.24	60.55	59.43	58.87	58.03	57.87	61.38	58.8	58.33	58.95
BH15	54.05	53.67	54.78	54.02	53.99	54.13	53.48	53.75	56.3	54.84	54.17	54.73	54.72	54.62	53.57	52.75	52.62	54.96	53.59	53.25	53.98
BH16	54.43	54.34	55.05	54.48	54.37	54.36	54.33	54.49	54.83	56.63	53.75	55.49	55.44	55.44	54.45	53.83	53.03	55.7	54.25	54.42	54.93
BH17	57.2	57.15	57.07	57.26	57.2	57.3	57.02	57.14	56.47	57.6	57.49	57.33	57.45	57.45	57.2	56.14	54.45	57.96	57.2	56.99	57.35
BH18	56.25	56.2	57.05	56.15	56.14	56.2	56.09	56.28	56.64	57.07	56.5	57.25	57.23	57.24	56.26	56.02	55.75	57.46	56.38	55.95	56.3
BH19	54.59	54.57	55.26	54.3	54.3	54.76	54.47	54.67	55	55.11	54.95	55.12	55.17	55.1	54.56	54.43	54.29		54.66	54.47	54.72
BH20	54.56	54.45	54.6	54.5	54.5	54.32	54.29	54.49	54.49	54.84	54.54	54.85	54.55	54.78	54.63	54.13	54.55	54.72	54.66	54.48	55.27
BH22		53.83			53.88																
BH23	55.3	55.2	56.5	55.23	55.06	55.23	55.03	55.33	56.02	56	55.5	56.22	56.26	56.25	55.26			56.57	55.2		
BH27	54.1	54.1	56.17	54.2	54.18	52.86	53.81	54.54	55.7	55.6	52.43	54.7	56.13	55.86	54.03	53.65	53.23	55.93	53.85	54.5	55.28
BH28	54.75	54.85	56.55	55.3	55.21	57	56.91		56.13	56.45	55.64	56.08	56.5	56.12	54.73	53.5	53.63	56.27	54.9	54.18	54.7
BH29	56.45	54.95	57.64	57.44	57.44	56.22	55.46	55.45	56.93	57.13	56.33	56.84	57.43	57	55.51		53.31	57.76	55.75	55.16	55.95
BH53	60.28	59.98	61.05	60.24	59.85	60.08	59.7	59.57	60.5	61.11	60.43	61.28	60.6	60.47	60	59.37	55.14	60.36	60.08		
BH54	60.38	60.05	61	60.5	60.36	60.01	59.88	59.75	60.56	61.22	60.83	61.03	60.69	60.51	60.13	59.5	63.03	60.28	60.17	59.47	61.12

Table 4: Groundwater Quality Data

firth consultants

Sample ID	Date Sampled	pH	Electrical Conductivity	Chloride as Cl	Ammoniacal Nitrogen, as N	Chemical Oxygen Demand	Biochemical Oxygen Demand	Dissolved Oxygen
		pH units	µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l
BH1/88	14/03/2014	6.7	169	14.4	0.2			5.44
BH1/88	14/04/2015	7.98	148	13.2	0.2			1.32
BH1/88	26/04/2016	6.8	166	13	0.02	10	2.9	5.6
BH1/88	12/04/2017	6.4	127	8.2	0.044	1.6	26	11.1
BH1/88	09/04/2018	7	168	10	0.093	140	25	4.8
BH1/88	09/04/2019	7.1	730	38	0.015	440	1	8.2
BH1/88	30/04/2020	6.8	170	10	1.8	160	31	
BH2/88	14/03/2014	7.35	709	43	0.2			5.84
BH2/88	14/04/2015	8.11	764	40.9	0.433			3.97
BH2/88	26/04/2016	8	956	45	0.07	5	2.9	7.3
BH2/88	12/04/2017	7.4	909	50	0.052	1.7	10	10.1
BH2/88	09/04/2018	7.5	807	41	0.043	11	5.1	9
BH2/88	09/04/2019	6.6	170	13	0.099	690	28	1.4
BH2/88	30/04/2020	7.5	710	38	0.041	23	32	
BH22	14/03/2014							
BH22	14/03/2015							
BH22	26/04/2016							
BH22	12/04/2017	7.4	1240	88	7.3	8.6	34	10.8
BH22	09/04/2018	7.7	974	85	7.6	28	49	10
BH22	09/04/2019							
BH22	30/04/2020							
BH96B	14/04/2015	7.77	688	13.1	0.352			2.14
BH96B	14/03/2014	7.41	692	7.6	0.2			1.6
BH96B	26/04/2016	7.1	787	25	0.5	8	2.9	3.8
BH96B	12/04/2017	7.2	850	18	1.7	1.8	10	7
BH96B	09/04/2018							
BH96B	09/04/2019	7.1	640	19	1.8	590	10	2.3
BH96B	30/04/2020	7.2	770	11	0.52	470	21	

Table 5: Surface Water Quality Data

Sample ID	Date Sampled	pH	Electrical Conductivity	Chloride as Cl	Ammoniacal Nitrogen, as N	Chemical Oxygen Demand	Biochemical Oxygen Demand	Dissolved Oxygen
		pH units	µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l
SW1	14/03/2014	8.02	440	28.9	0.2		1	11.2
SW1	14/04/2015	8.21	469	30.7	0.229	7	1	11.9
SW1	26/04/2016	7.5	350	27	0.09	12	2.9	8.9
SW1	26/04/2017	8.1	493	26	0.0015	2.5	10	11.3
SW1	09/04/2018	7.4	332	24	0.34	19	7.3	10.2
SW1	09/04/2019	8.2	480	27	0.015	13	1.7	11
SW1	30/04/2020	8.3	510	25	0.044	13	2.2	
SW2	14/03/2014	7.59	263	28.1	0.2		1	8.87
SW2	14/04/2015	7.95	275	26.4	0.22	14.4	1	11.4
SW2	26/04/2016	7.5	322	26	0.07	12	2.9	10.4
SW2	26/04/2017							
SW2	09/04/2018	8.1	530	26	3.6	10	6.9	10
SW2	09/04/2019	7.8	310	23	0.037	32	1.9	11
SW2	30/04/2020	7.9	330	23	0.27	19	2	
SW3	14/03/2014	7.59	278	28.2	0.2		1	10.8
SW3	14/04/2015	7.86	293	27.2	0.204	7	1	11.3
SW3	26/04/2016	7.5	369	26	0.06	10	2.9	10.2
SW3	26/04/2017	7.9	332	18	0.089	2.4	13	10.7
SW3	09/04/2018	7.1	630	34	0.44	140	71	3.4
SW3	09/04/2019	7.7	290	22	0.062	19	1.7	10
SW3	30/04/2020	7.8	350	24	0.16	22	3.8	
SW4	14/03/2014	7.16	439	48.8	0.2		7.55	7.51
SW4	14/04/2015	7.7	564	48.4	0.2	46.4	3.24	6.29
SW4	26/04/2016	6.8	735	71	0.5	55	29.4	0.8
SW4	26/04/2017	7.1	736	26	0.12	1	34	8.2
SW4	09/04/2018	7.9	331	24	0.35	18	7.3	9.8
SW4	09/04/2019	6.8	540	47	0.1	51	1.6	2.6
SW4	30/04/2020	7.9	850	100	0.16	55	11	
SW5	14/03/2014							
SW5	14/04/2015							
SW5	26/04/2016							
SW5	26/04/2017							
SW5	09/04/2018							
SW5	09/04/2019	7.3	980	41	7.2	3700	17	1
SW5	30/04/2020	7.6	710	54	0.87	370	20	
SW6	14/03/2014	7.72	501	31.7	0.2		7.03	9.39
SW6	14/04/2015	7.98	393	25.3	0.2	8.04	1	12.1
SW6	26/04/2016	7.7	626	16	0.01	62	2.9	9.2
SW6	26/04/2017	7.8	461	18	0.093	2	10	7.8
SW6	09/04/2018	7.7	357	14	0.082	19	6.4	5.5
SW6	09/04/2019	7.9	600	27	0.035	9	1	11
SW6	30/04/2020	8.1	540	24	0.091	29	6.6	
SW7	14/03/2014	7.77	520	31.9	0.2		1	9.65
SW7	26/04/2016	7.3	476	23	0.05	23	6.8	7.2
SW7	26/04/2017	7.7	721	31	1.2	1.9	10	11
SW7	09/04/2018	7.6	500	21	0.27	81	70	10.2
SW7	09/04/2019	7.1	790	61	10	2100	20	1
SW7	30/04/2020	7.7	600	30	0.69	48		
SW8	14/03/2014	7.67	573	38.7	0.863		1	4.38
SW8	14/04/2015	7.89	611	38.3	0.72	7	1	9.62
SW8	26/04/2016	7.6	642	33	0.02	28	4.1	10.1
SW8	26/04/2017	7.5	754	54	1.5	2.7	10	10.5
SW8	09/04/2018	7.5	681	34	1.6	10	8.5	9.9
SW8	09/04/2019	7.5	720	48	4.3	8.8	2.4	6.6
SW8	30/04/2020	7.7	740	54	5.6	29		
SW9	14/03/2014	7.72	580	45.1	0.571		1	10
SW9	14/04/2015	8.16	652	49.5	0.556	16	2.66	11.8
SW9	26/04/2016	7.3	749	41	0.5	10	<2.9	4
SW9	26/04/2017	7.5	750	42	0.28	2.8	12	8.6
SW9	09/04/2018	7.6	663	41	0.27	10	5.3	9.4
SW9	09/04/2019	7.9	640	49	0.97	8.7	2.9	11
SW9	30/04/2020	7.8	710	57	0.12	31	4.5	
SW10	14/03/2014	7.68	277	27.8	<0.2		1	9.82
SW10	14/04/2015	7.85	287	26.8	0.227	7.33	1	10.5
SW10	26/04/2016	7.3	727	52	0.3	11	7.2	6.9
SW10	26/04/2017	7.7	338	21	0.18	1.5	10	11
SW10	09/04/2018	7.5	333	24	0.34	21	7.3	10
SW10	09/04/2019	7.8	300	21	0.047	17	1	10
SW10	30/04/2020	7.9	340	24	0.12	7.6	4.5	

APPENDIX 1
BGS Borehole Logs

DRILLING LOG

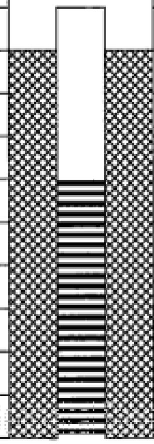
LOG NUMBER 3GS 320

DRAGON DRILLING (WATER & ENERGY) LIMITED
GRAIG LELO INDUSTRIAL ESTATE
CORWEN
LL21 9SD
TEL: 01824 707777

SITE: Bryn Eryr, Penraeth JOB REF NUMBER: 2143 SITE BH NUMBER: 1 BGS NUMBER: SN 19/337 GRID REF: SH53547527 DATE: 12/08/209

OPERATION	SIZE (MM)	FROM DEPTH (M)	TO DEPTH (M)	TOTAL
Set up				1
Symmetrix Drilling	198	G. L	30	30
	140	0	40.5	40.5
Open Hole Drilling	110	40.5	90	49.5
Mud Drilling				
CFA Drilling				

DEPTH (M)	DESCRIPTION		MATERIAL & DEPTH (M)
G.L - 1	Soil		Thermal Grout GL – 90m
1 - 12	Shale, gravel and brown clay		
12 - 14	Orange sand		Loop installed to -90m
14 - 28	Sandy clay and wet gravel		
28 - 29	Wet orange sand		Loop diameter – 40mm
29 - 31	Gravel with very dirty water		
31 - 40	Very wet glacial drift gravel		
40 - 90	Grey / green schist		
	Water strike depths -		



PREDICTED DEPTH (M)	ACTUAL DEPTH (M)	LOOP INSTALLED TO (M)	PRESSURE TESTED	LOOP WEIGHT	BENTONITE (KG)	TRANFER MEDIA (KG)	LOOP CAPS	THERMAL GROUT (MBGL)
90	90	90	Yes – 5 bar	1m	4	16	Yes	90 – G. L

DRILLING FOR: Ground source heating

NAME: Mal Macdonald (LEAD DRILLER)