

Silent Valley Waste Services
Silent Valley Landfill
Failure Response Plan

REP/115825-00/00 Failure Response Plan

Issue | 23 March 2018

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 115825-00

Ove Arup & Partners Ltd
Admiral House Rose Wharf
78 East Street
Leeds LS9 8EE
United Kingdom
www.arup.com

ARUP

Document Verification

ARUP

Job title		Silent Valley Landfill		Job number	
				115825-00	
Document title		Failure Response Plan		File reference	
Document ref		REP/115825-00/00 Failure Response Plan			
Revision	Date	Filename			
Draft 1	12 Dec 2017	Description	First draft		
			Prepared by	Checked by	Approved by
		Name	Leslie Brown	Jenny Lightfoot	Charlie Martin
		Signature			
Draft 2	10 Jan	Filename			
		Description	Second Draft		
			Prepared by	Checked by	Approved by
		Name	Leslie Brown	Jenny Lightfoot	Charlie Martin
		Signature			
Issue	23 Mar 2018	Filename	Failure Response Plan Report Issue 23_3_18.docx		
		Description			
			Prepared by	Checked by	Approved by
		Name	Leslie Brown	Jenny Lightfoot	Charlie Martin
		Signature			
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			
Issue Document Verification with Document ☒					

Contents

	Page
1 Introduction	1
1.1 Background	1
1.2 Arup appointment	1
2 Hydrogeological assessment	2
2.1 Sources of information	2
2.2 Topography	2
2.3 Geology	2
2.4 Landfill	3
2.5 Hydrogeological Interpretation	4
2.6 Leachate heads	10
2.7 Hydrogeological conceptual model	15
2.8 Requirement for a Failure Response Plan	16
3 Failure Response Plan	20
3.1 Assessment of leachate levels and response zones within the Phase 1 waste mass	20
3.2 Proposal for leachate extraction wells	20
3.3 Extraction well locations and specification	21
3.4 Implementation options	21
4 Conclusions	22
5 References	23

Appendices

Appendix A

Figures

1 Introduction

1.1 Background

Natural Resources Wales (NRW) has applied an Improvement Condition (IC2) to the Silent Valley Landfill permit requiring preparation of a Failure Response Plan relating to the site leachate drainage system, as follows:

Prepare a Failure Response Plan for Silent Valley landfill for implementation if the BSC pipe were to fail. The response plan shall include:

- a) An assessment of leachate levels and response zones within the Phase 1 waste mass;*
- b) proposals to install dedicated leachate extraction wells in the event of a failure to BSC pipe or the branch lines being detected;*
- c) the proposed extraction well locations and their construction specification;*
- d) the response time for their installation, or for pre-emptive installation if necessary.*

1.2 Arup appointment

Arup has been appointed by Silent Valley Waste Services Limited (SVS) to prepare a Failure Response Plan for Silent Valley Landfill that responds to the improvement condition IC2.

Each of the four Failure Response Plan requirements stated in the improvement condition (a-d) relate to the hydrogeological regime of the landfill. Therefore a hydrogeological assessment is presented, which describes the hydrogeological data available and the interpretation thereof to develop a conceptual model. The Failure Response Plan meeting the requirements of a) to d) above follows the hydrogeological assessment.

2 Hydrogeological assessment

2.1 Sources of information

The hydrogeology of Silent Valley Landfill is detailed in the following existing reports:

- Hydrogeological Risk Assessment (Arup, 2004) [1]
- Hydrogeological Risk Assessment (Arup, 2009)[2]
- Investigation into the Western Flank of the Cut-off System, Silent Valley Landfill, (Arup 2011)[3],
- Annual Monitoring Reports (Arup, 2010, 2011, 2012, 2013, 2014, 2015 & 2016)[4][5][6][7][8][9][10]
- Site Closure Report (Arup, 2013A)[11]
- Leachate and Groundwater Monitoring data (Arup, 2010-2017)

The Hydrogeological Risk Assessments (2004 & 2009)[1][2], Site Closure Report (2013)[11] and File Note (Arup 2013) provide the overall conceptualisation of the geological setting and the hydrogeological regime. In compiling this report it is assumed that the reader is familiar with these documents. Particular reference is made to the detailed descriptions of topography, geology, hydrogeology and history of the site that are included in Appendix A1 of the HRA (2004)[1].

Figure 1, Figure 2 and Figure 3 from the Closure Report (Arup, 2013A)[11] are included in **Appendix A** of this report to show the locations of leachate monitoring wells and the groundwater monitoring wells at the site.

2.2 Topography

Silent Valley Landfill Site is located in Cwm Merddog, an eastern tributary valley which joins the Ebbw Fawr at the village of Cwm. It is located at the southern end of Ebbw Vale, to the east of Waunlwyd.

The closed landfill facility is located about half way up the tributary valley. The last phase of landfilling (Phase 1A) had a maximum filling elevation of just over 400mOD. The Nant Merddog, which flows through the valley, has been diverted into a pipeline that passes to the east of the landfill. To the south, the downhill toe of the landfill lies at 310mOD.

2.3 Geology

The geology of the site is presented in Appendix A1 of the HRA (2004)[1] based on published 1:10,560 scale geology map, sheet SO 10 NE, the published geological memoirs, borehole data and mine plans.

The landfill generally lies at elevations below the outcrop of the Brithdir Seam and rests on the Rhondda Beds of the Pennant Sandstone Formation (Carboniferous Upper Coal Measures, Westphalian C and D). The Rhondda Beds consist of an alternating sequence of sandstones, siltstones and mudstones with occasionally thin coal seams. The siltstones and mudstones comprise coloured beds, often referred to as the red beds or Deri Beds.

The dips of the local strata at Silent Valley have been proved by boreholes and by mine workings to form a synclinal fold structure with its axis generally aligned with the valley

floor. The syncline axis plunges southwards by approximately 3° with the dip of strata towards SSE (165°) at 3° to 4° on the western valley side and at a similar dip towards the SSW on the eastern side. Minor faults trending NW-SE are shown on available geological maps (1:10,000 and 1:50,000 scales), which have also been proven in the mine workings and can be inferred from the borehole data. Geological interpretation at Silent Valley has identified a sequence of main sandstone and mudstone/siltstone units, numbered as S0, S1, S2, S3 etc and M0, M1, M2, M3 etc, which were presented in Figure 2A, Figure 2B and Figure 3 (Arup, 2013B)[11], which are included in **Appendix A** of this report.

The valley floor, generally below the elevation at which the Brithdir coal seam crops out, the bedrock is overlain by boulder clay. The thickness of the boulder clay is variable and generally up to 3m thick but locally absent. The boulder clay typically comprises stiff sandy silty clay with a varying content of gravel, cobbles and boulders. The boulder clay will form a natural barrier between landfill and bedrock where present but where absent continuity between landfill and bedrock is possible.

2.4 Landfill

The history of the landfill is presented in Appendix A1 of the HRA (Arup, 2004)[1] and a summary of both the landfill and the drainage system are presented here.

2.4.1 History of landfilling

From the late 1930's to the mid 1950's the site was utilised for spoil deposit by Ebbw Vale steelworks and deposition mainly comprised blast furnace slag. Partial reclamation of the slag for various re-use was undertaken between the early 1960's to the early 1980's. In 1981 the site was purchased by Blaenau Gwent County Borough Council (BGCBC) and in 1983 the Council developed the valley as a landfill site for controlled and special waste. From 1994 the operator responsibility was transferred to Silent Valley Waste Services Limited (SVWS), as the Local Authority Waste Disposal Company. An appropriate waste management licence was issued by BGCBC, which is now regulated by NRW.

As noted above, Silent Valley Landfill has been developed in two phases, Phase 1 under BGCBC up to 1994 and Phase 1A under the control of Silent Valley Waste Services from mid-1994 onwards. In terms of the area of filling there is an overlap of Phase 1A Cells over and on top of Phase 1.

The original southern face to Phase 1 was capped with 0.8m of clay (with a design hydraulic conductivity of 1×10^{-9} m/s) in 2000 and drainage improvements were made. An LLDPE geomembrane system is used for capping at the site. The south eastern corner of Phase 1A was capped with the eastern flank in 2005, western flank in 2009 and the central and northern flanks in 2013. Phase 1 was subsequently re-capped in 2015 when it was discovered that the capping was not performing to specification.

2.4.2 Landfill drainage

The British Steel Corporation originally culverted the Nant Merddog in a 750mm concrete 148m long pipe to enable tipping across the valley floor. This culverting of the Nant Merddog is now referred to as the BSC pipeline. Drawings of the BSC pipeline are presented in the HRA (2004)[1] and are taken from a survey completed by BGCBC 1981. Staff involved with the site during the early 1980s recall that the BSC pipeline incorporated a

herringbone system of underdrains had been constructed on the lower slopes on the east side of the valley. Aerial photographs taken in 1973 show clear evidence that such a sub-surface drainage system was installed. CCTV surveys of the 148m-long BSC pipeline show that the culvert ends in rubble, which extends in height from invert to soffit.

In 1983 an 800mm diameter Armco pipeline was constructed to the east of the BSC pipeline in order to carry the Nant Merddog around the then footprint of the landfill. As the landfill continued to expand, the Nant Merddog was again diverted in the early 1990s in order to maintain separation from the landfill. This most recent diversion of the Nant Merddog was to a 500mm diameter concrete pipeline that had been constructed around the eastern side of the landfill. This current diversion carries the stream around the landfill and re-joins the original stream course at the toe of Phase 1. As part of measures to manage surface water at the site, various high level springs that emerge on the upper slopes above the landfill north of Phase 1A have been intercepted by ditches and routed to the Nant Merddog to prevent their ingress into the landfill.

Post closure, both the BSC pipeline and the Armco pipeline are open and carry flow to the toe of the landfill. The flow is a combination of groundwater emergent into the landfill and leachate generated in the landfill. Both the BSC pipeline and the Armco pipeline drain to a sump at the downstream toe of the landfill and the combined flow from both are pumped into a concrete lagoon, which discharges to sewer.

A cut-off system has been implemented at the toe of the landfill which comprises of multiple pumping wells with compliance monitoring wells. The cut-off system is designed to prevent leachate for migrating south of the toe via groundwater pathways.

2.5 Hydrogeological Interpretation

2.5.1 Groundwater Flow

The hydrogeological conceptual model presented in the HRA (Arup, 2004 & 2009)[1][2] describes a geological sequence of alternating sandstone, mudstone and siltstone beds (with occasional coal seams) that is overlain by boulder clay. These bedrock stratigraphic sequence was deposited in a Carboniferous fluvial environment with sand deposition in river channels, along with mud and silt (with occasionally rich in organics) deposited in plains during flood events. Typical of such fluvial settings, sediment accumulations can be irregular so that bedded units are variable in their lateral extent.

The laminar, platy nature of sediment that forms mudstone and siltstone gives these beds a particularly low primary hydraulic conductivity and they will form barriers to groundwater flow where present. However, the site investigations have shown that the mudstone/siltstone layers can locally be fractured and as such they may develop local zones where secondary permeability has developed and groundwater flow is greater.

By comparison, sandstones have a higher primary permeability and because of their generally massive bedding and higher competency, they often also have a higher secondary fracture permeability. However, it is important to recognise that even when mudstone and siltstone is fractured, the mechanics of deforming laminar bedded strata generates a poorly developed fracture network with limited connectivity.

On the basis of the above descriptions, the sandstone units are considered to contain the majority of groundwater flow in the sequence and these are constrained by underlying and

overlying mudstones/siltstones. Whilst the mudstone/siltstone are generally barriers to flow they may be leaky where significantly fractured or weathered and on this basis there may be localised hydraulic connectivity between sandstone units, which can be assessed based on groundwater level monitoring.

The boulder clay present in the valley floor will locally confine the bedrock where its cover is thick enough. Areas where thick boulder clay is present will prevent groundwater from emerging but where the cover is thin or absent then groundwater will flow to surface as springs or seepages.

2.5.2 Springs and Seepages

The HRA (Arup, 2004 & 2009)[1][2] and 2013 geological review[12] states that well developed spring lines existed in the natural valley floor. This statement is based on observations from employees at the site over the lifespan of the landfill but also from historical maps and aerial photographs. These springs identify that groundwater was naturally emergent into the valley and that groundwater had a significant contribution to the flow of the Nant Merddog.

Section 2.5.1 above identifies that sandstone units contain the main groundwater flow and as such, springs (turbulent flow) and seepages (low flow) are most likely to occur where sandstone outcrops. Furthermore, the following hydrogeological conditions are likely to exist at each location:

- the topography intersects areas of the aquifer unit that are fractured,
- thinner or absent boulder clay cover, and;
- the hydrostatic head in the aquifer unit lies above ground level.

Due to the low permeability of the mudstone/siltstone, springs are unlikely to form in these units. Although flow may occur as seepages from zones in the units where fracturing and weathering is present.

Given that the site initially received slag waste from the British Steel site which was then placed directly onto the valley floor with the only apparent site preparation being the culverting of the stream channel and side drains, then it is very likely that the groundwater inflows to the landfill mainly occur at the original spring locations and that these inflows contribute directly to the BSC pipeline and tributaries.

2.5.3 Groundwater Levels

The annual monitoring reports for Silent Valley Landfill include groundwater level records for the period January 2010 to June 2017. The monitoring points comprise of twelve (12 No.) groundwater monitoring locations. Of the groundwater monitoring location five (5 No.) are downgradient of the landfill toe (GW6, GW7, GW9, GW10 and GW12) and seven (7 No.) are upgradient of the landfill (EC1, EC2, EC3, EC4, GW2A, GW3A and GW4) (refer to Closure Report[11] Figure 2 for all monitoring well locations). The EC wells refer to groundwater monitoring on the eastern side of the landfill at the eastern cut off system. There have been additional probe holes drilled at Silent Valley but these have not been used for long term monitoring.

Table 1. Groundwater head elevations (mOD)

	GL mOD	RZ Top Btm	GWL mOD	2010	2011	2012	2013	2014	2015	2016	2017
GW6	307.00*	299.50*	Min (m)	300.05	300.24	300.34	300.18	300.36	300.31	300.41	300.65
		293.20*	Max (m)	300.33	300.41	301.03	300.97	300.48	300.58	300.69	301.09
GW7	303.50*	300.70*	Min (m)	300.35	300.86	301.00	300.75	300.79	300.96	300.05	301.21
		290.50*	Max (m)	301.50	301.67	301.72	301.45	301.54	301.77	301.46	301.46
GW9	329.95	313.55	Min (m)	312.97	313.08	313.08	313.33	313.08	313.07	313.00	313.39
		309.55	Max (m)	315.32	314.56	314.56	314.31	314.59	314.00	314.11	314.43
GW10	346.45	338.95	Min (m)	338.97	338.93	338.71	338.88	338.85	338.88	338.91	338.94
		335.45	Max (m)	339.48	339.10	339.95	339.08	339.17	339.14	339.04	339.15
GW12	N/D		Min (m)	314.45	314.47	314.22	314.42	314.42	314.39	314.45	314.52
			Max (m)	315.81	315.07	315.58	315.32	315.97	315.17	315.83	314.78
EC1	371*		Min (m)	357.96	N/D	N/D	N/D	N/D	N/D	N/D	N/D
			Max (m)	359.59	N/D	N/D	N/D	N/D	N/D	N/D	N/D
EC2	372*		Min (m)	366.80	N/D	N/D	N/D	N/D	N/D	N/D	N/D
			Max (m)	367.90	N/D	N/D	N/D	N/D	N/D	N/D	N/D
EC3	374*		Min (m)	357.96	N/D	N/D	N/D	N/D	N/D	N/D	N/D
			Max (m)	357.98	N/D	N/D	N/D	N/D	N/D	N/D	N/D
EC4	377*		Min (m)	363.32	N/D	N/D	N/D	N/D	N/D	N/D	N/D
			Max (m)	363.35	N/D	N/D	N/D	N/D	N/D	N/D	N/D
GW2 A	377*		Min (m)	345.54	345.33	345.38	345.31	345.39	345.49	345.55	N/D
			Max (m)	345.96	345.98	345.75	345.62	345.64	345.60	345.63	N/D
GW3 A	375*		Min (m)	343.21	344.80	344.80	344.88	344.14	344.92	344.92	344.92
			Max (m)	344.84	344.97	344.98	344.93	344.93	345.07	345.01	344.93
GW4	418.46		Min (m)	406.54	406.66	406.96	406.54	406.64	406.63	406.78	407.18
			Max (m)	407.76	407.82	407.82	407.83	407.86	407.65	408.41	407.28

Notes:

- RZ= Response Zone (top and bottom)
- GL= Ground Level
- GWL =Groundwater Level
- * Elevation data measured from topographic plan as no elevation data on logs
- N/D = No Data
- Where ground levels are recorded to nearest metre they have been determined from OS maps
- Lowest recorded level in Red, Highest recorded level in Blue
- Groundwater level data is plotted in Figure 1

All of the groundwater monitoring wells are located around the periphery of the landfill, with no groundwater monitoring wells located within the landfill waste footprint. The response zones for each monitoring well are designed to target particular sandstone units (refer to Figure 2A, Figure 2B and Figure 3 in **Appendix A**) based on the geology intercepted during drilling.

Groundwater wells EC1, EC 2, EC3 and EC4 ceased being monitored at the end of 2010 but all other groundwater monitoring wells are monitored over the full period January 2010 to July 2017. The monitoring frequency varies between quarterly and monthly depending on the year.

All groundwater wells show a seasonal fluctuation, with groundwater heads higher through winter and at their lowest through the summer. The amplitude of seasonal variation varies between boreholes but also varies with each year. The majority of boreholes have a seasonal range of 0.80m to 1.20m, however, GW7 has a seasonal range of 2.35m and GW2A has a seasonal range as low as 0.11m. The downgradient wells may show groundwater levels drawn down by pumping in the cut-off system at the toe of the landfill.

The seasonal groundwater range also varies each year, which is a measure of the amount of rainfall that recharges groundwater. There is no single year in the database that is uniformly high in all groundwater wells but the summers of 2010 and 2011 have the lowest reported groundwater levels. As a general interpretation of the groundwater levels, the aquifer can be characterised as responding to dry summers with a uniform lowering of the groundwater levels to a base level. Groundwater rises occur in all wells in response to recharge events but the rate and extent of rise is different for each well. These characteristics are typical of relatively moderate to low yielding aquifers that are dominated by fracture flow, which corresponds to the geological descriptions provided in the HRA (2004 & 2009)[1][2].

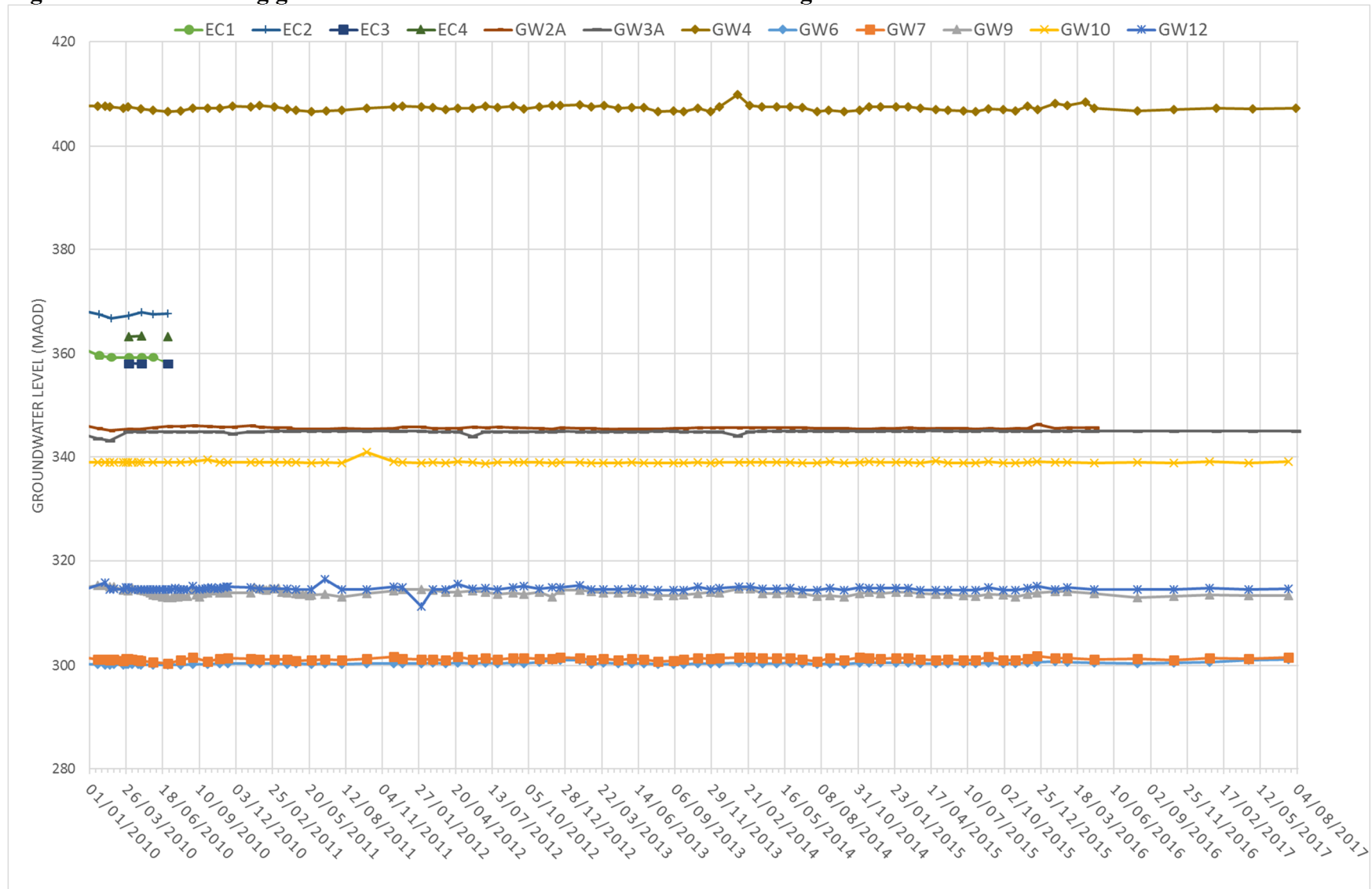
On the basis of the cross sections presented in **Appendix A** (Arup 2013B[3], Figure 2B) downgradient groundwater monitoring wells GW6, GW7 and GW9 have their target zone set in sandstone unit S1, whilst, GW10 and GW12 are located in a higher sandstone units (S3). The groundwater level data for the toe of the landfill shown in **Appendix A** (Arup 2013B[3], Figure 2B) indicates that there are distinct groundwater tables in each sandstone unit, with only the lowest units (S0 and S1) being fully saturated.

Owing to the geometry of the sandstone units and the valley topography (pre-landfill) then sandstone units S0 and S1 are unlikely to crop out into base of the landfill. However, sandstone units S2, S3 S4 and S5 will likely crop out into the base of the landfill. Sandstone units S2, S3, S4 and S5 also have the potential to be the pathways for springs and seepages that have been recorded pre-landfilling. Due to the geology geometry the springs on the western valley sides will be sourced by recharge to the west and springs on the eastern side of the valley floor from recharge in the west.

Unlike sandstone units S0 and S1 which are fully saturated at the toe of the landfill and have limited outcrop below the landfill footprint, the sandstone units S2, S3, S4 and S5 all outcrop below the landfill and are unlikely to be fully saturated in the valley sides. Unit S2 is likely to be saturated further north in the valley but partially unsaturated to the south, which means that although it forms a hydraulic trap under the northern part of the landfill, in the south it does not and could receive leachate. Owing to the geology geometry S3, S4 and S5 are likely to be free draining into the landfill and as such leachate is unlikely to escape from the footprint unless there is a pathway to unit S2.

raises the potential for leachate to drain into their unsaturated zones if they are within the waste footprint.

Figure 1. Chart showing groundwater elevations as recorded in monitoring wells



2.6 Leachate heads

The location of the nine leachate monitoring wells at Silent Valley Landfill are shown in Figure 2 of the Closure Report (Arup, 2013)[11]. The level of leachate in the landfill is measured as the head above the landfill base and these data are summarised below in Table 2.

Table 2. Heads in the leachate monitoring wells

	Landfill Base (mOD)		2010	2011	2012	2013	2014	2015	2016	2017
L1	336.8	Min (m)	0.70	0.00	0.00	0.14	0.00	N/D	N/D	N/D
		Max (m)	0.82	0.54	0.17	0.79	0.61	N/D	N/D	N/D
LC1A	358.13	Min (m)	0.00	0.77	0.76	0.29	0.28	0.32	0.35	1.04
		Max (m)	2.00	0.95	0.96	1.03	0.4	0.41	0.43	1.07
LC2A	363.38	Min (m)	3.16	2.93	2.97	1.56	1.48	1.56	0.96	1.91
		Max (m)	3.84	3.25	3.2	2.16	2.19	2.29	2.18	2.02
LC4A	373.98	Min (m)	1.70	1.92	1.96	0.11	0.17	0.26	0.28	0.29
		Max (m)	1.95	2.06	2.11	0.16	0.26	0.26	0.35	0.35
LC5A	349.98	Min (m)	1.69	2.32	2.08	2.12	2.2	3.89	4.13	4.91
		Max (m)	5.62	6.33	3.00	2.45	3.95	4.96	4.96	5.07
BH1	346.57	Min (m)	N/D	N/D	N/D	7.83	8.75	6.85	6.55	6.48
		Max (m)	N/D	N/D	N/D	8.77	9.07	7.35	7.58	6.60
BH2	326.58	Min (m)	N/D	N/D	N/D	9.53	10.46	8.43	9.25	9.37
		Max (m)	N/D	N/D	N/D	10.44	10.73	10.62	10.62	9.69
BH3	318.71	Min (m)	N/D	N/D	N/D	5.31	6.17	5.53	6.28	6.38
		Max (m)	N/D	N/D	N/D	6.52	6.26	6.54	6.87	6.65
BH4	316.61	Min (m)	N/D	N/D	N/D	2.08	2.40	-0.88	1.95	3.03
		Max (m)	N/D	N/D	N/D	2.77	2.89	1.52	3.12	3.19

Notes:

- N/D = No Data
- Lowest recorded level in Red, Highest recorded level in Blue
- The landfill base in L1, LC1A, LC2A, LC4A, LC5A, BH3 and BH4 is measured from boreholes logs
- For BH1 and 2 the landfill base is not identified on borehole logs and leachate head is calculated above base of the well
- L1, which is located on the BSC pipe, was not measured in 2015, 2016 or 2017

The leachate monitoring wells provide location where the level of leachate in the landfill can be monitored. All data since 2010 is plotted in Figure 2 below. Owing to the significant elevation range across the landfill more detailed plots of leachate head are provided in Figure 3 for the northern part of the landfill and Figure 4 for the southern part of the landfill. All data on leachate levels is presented in the quarterly and annual monitoring reports. These reports also provide details on the monitoring wells including changes in their construction.

Figure 2. Chart showing leachate elevations as recorded in monitoring wells

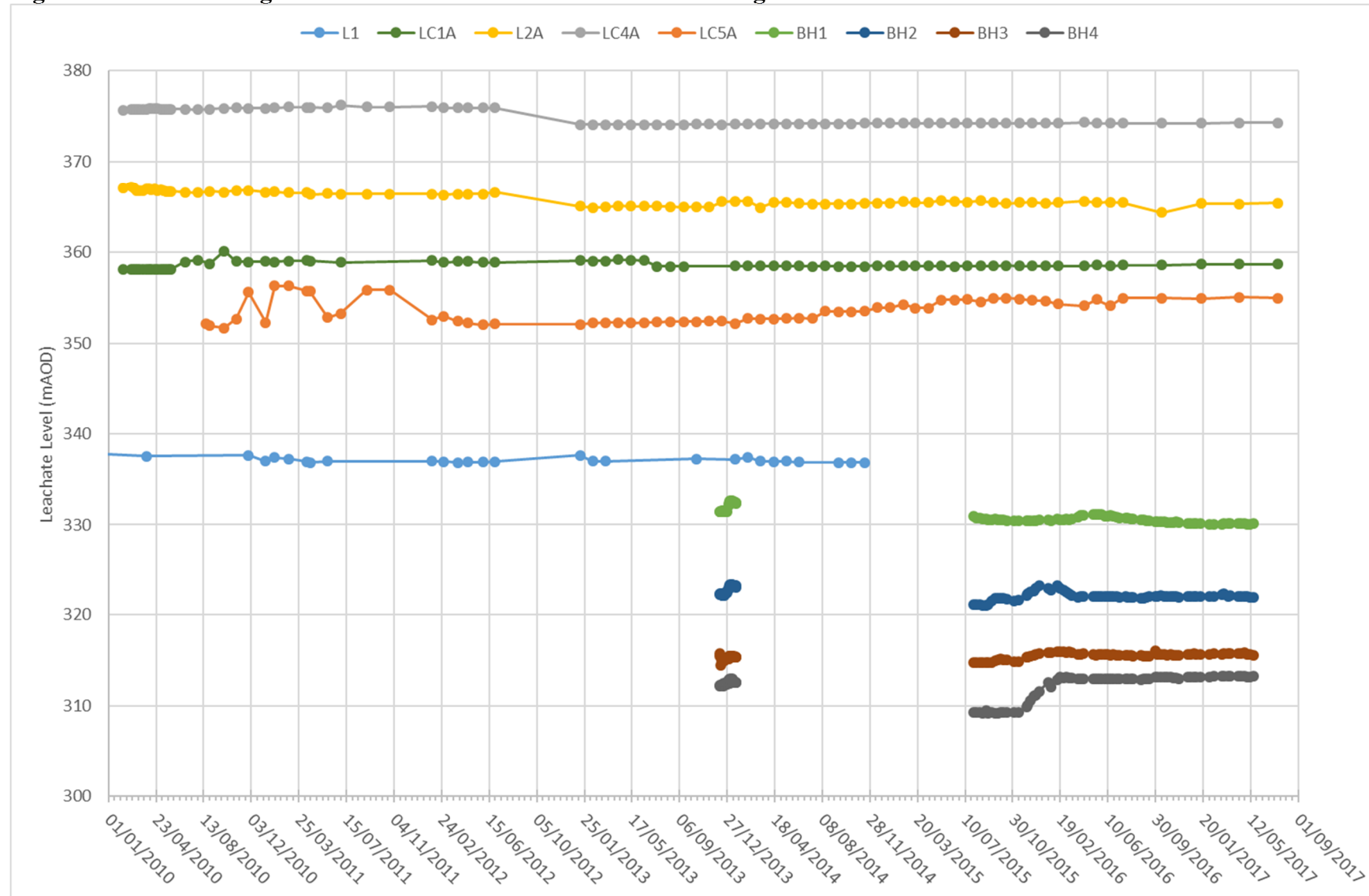


Figure 3. Chart showing leachate elevations as recorded in monitoring wells in the northern part of Silent Valley Landfill

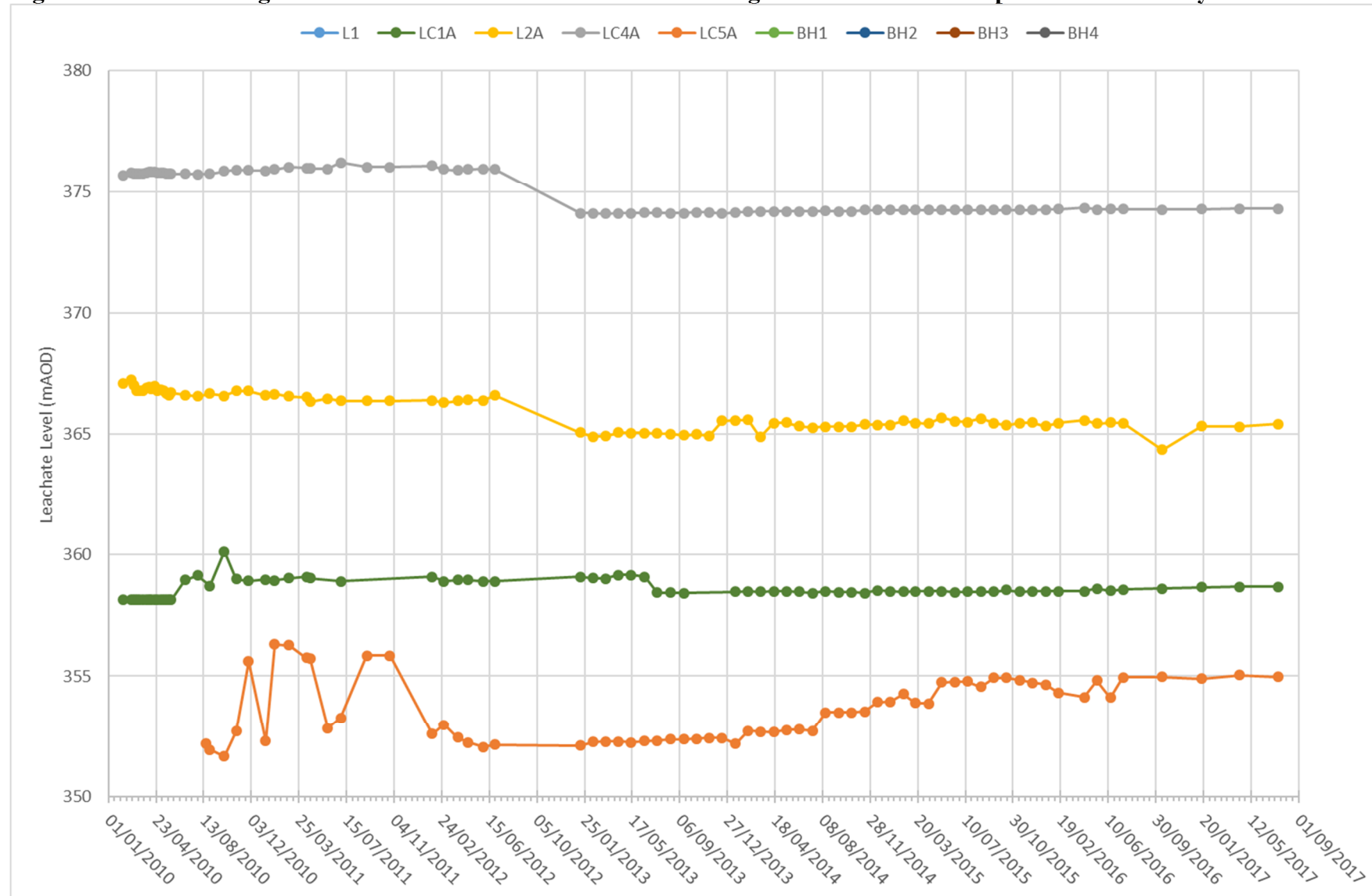
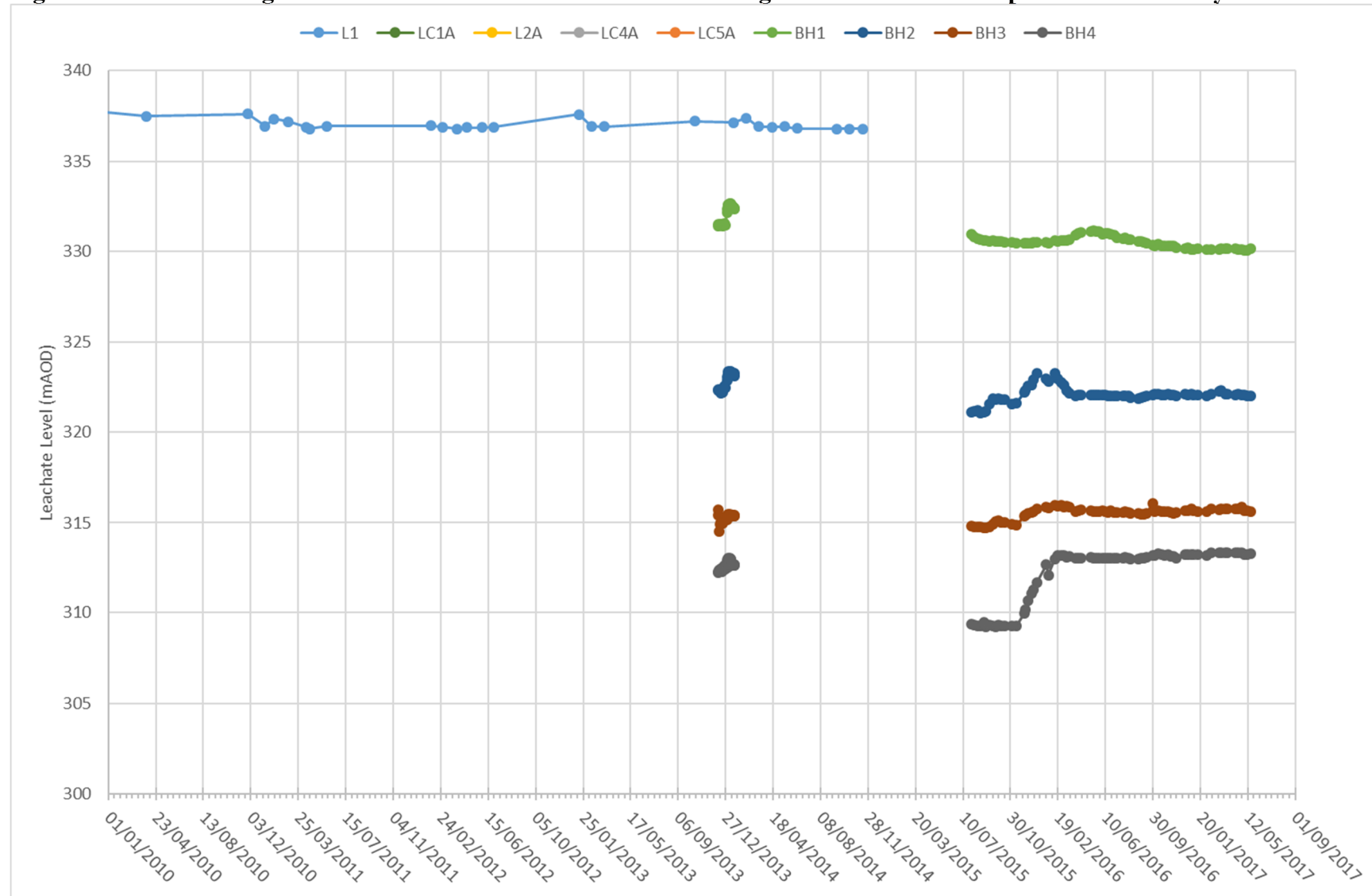


Figure 4. Chart showing leachate elevations as recorded in monitoring wells in the southern part of Silent Valley Landfill



During the period of leachate level monitoring there have been ongoing works as part of the landfill closure, which include capping. Capping progressed as a series of phases and as part of these works the headworks of leachate wells were raised so that they can continue to be monitored. The leachate head database takes into account to raised headworks and revised elevation of the monitoring locations. The effect of the landfill capping is clearly observed in the LC series of monitoring wells as a reduction in the previously clear seasonal response of the wells after 2012. Noticeably all wells (with the exception of LC5A) also show a reduction and stabilisation in leachate level after capping which is directly caused by recharge to the landfill from rainfall being cut-off. The leachate level in monitoring well LC5A is anomalous compared to the other wells. The steady rise in recorded level can be a characteristic of a malfunctioning well with a blocked screen. The anomalous leachate level in LC5A have been flagged from the monitoring data and is currently being investigated are part of the ongoing site operations.

The data show that the leachate heads vary through each year. In most wells the variation is less than 1m (except LC5A). There are a number of trends apparent in the leachate head database. The main general trend being that the highest recorded leachate heads in all wells occurred in 2010, 2011 and 2012, which is prior to completion of the landfill capping. There have been some increases in leachate levels since 2012 but these have been at a reduced scale from what was observed between 2010-12.

It is worth noting that when interpreting these leachate head data that the whilst maximum head values provide information on any connectivity with recharge inputs it is the minimum leachate heads for each year provide a good indication on long term trends. These lowest annual heads provide an indication of any change to the base leachate levels, and these give indication on any changes to how leachate migrates through the landfill drains, providing indication on if the pathways to discharge remain consistent or have reduced or increased in flow rate. A rise in base leachate levels can indicate a reduction in flow path capacity, such as from blockage.

The leachate wells can be considered into two main groups, those leachate wells where the annual minimum heads since capping was completed have generally:

- generally remained the same with no consistent rise in heads (LC1A, LC2A, LC4A, BH1, BH2, BH3 and BH5)
- increased in head consistently over a number of years(LC5A)

(Note, leachate well L1 is not included in this assessment as it is no longer monitored).

Of these data, only leachate well LC5A has had a continuous rise in the minimum leachate head. Over the last 7 years the leachate head has risen from 1.61m (2010) to 4.91m (2017), with the peak head in 2017 reaching 5.07m. Between 2013 and 2015 leachate heads in LC5A were rising at 1m/yr but have remained stable since 2015. In the last 4 years, leachate well LC5A is the only well in the monitoring network to have a leachate head over 3m, being continuously over 3m for the last 3 years.

The HRA (2004)[1] states: *‘Combined with the steep valley topography and the presence of underdrains and pipelines, the effect of this will be rapid drainage of leachate, with little opportunity for the build-up of leachate heads.’* The monitoring data from the annual reports supports this statement for all wells in the database with the exception of LC5A, which has seen a steady rise in leachate levels over the monitoring period (**Figure 2**). Currently it is considered that the results of the monitoring of leachate head in LC5A are not representative of the actual leachate head in this location due to fouling or blockage within the monitoring well.

As also noted earlier, leachate heads for the data period show a change in trend between the first two years and the latter five. The first two years have lower base levels but with significant peak events in 2011 and 2012, whilst the latter five years are much less responsive but with a trending increase in head, which is solely driven by the increasing leachate head in LC5A (as discussed above). All other leachate monitoring wells remain relatively stable. The change in base level coincides with the scheduling of the closure plan and are related to final works capping and sealing Phase 1A which sealed the landfill from recharge inputs from rainfall.

2.7 Hydrogeological conceptual model

The hydrogeological conceptualisation was presented as part of the HRA (2004)[1], which provides a thorough review of geological and hydrogeological data up to 2004. This conceptualisation remains valid and in this report has been updated with groundwater and leachate monitoring data for the period 2010-2017. For completeness the 2004 summary conceptual model is presented below in full.

The site is contained within the steep-sided Cwm Merddog valley. Steep hydraulic gradients towards the valley floor can be expected as a result of this topographical situation. The underlying strata contain alternating beds with a regular occurrence of mudstone bands which form effective aquicludes. This inhibits the percolation of groundwater to deeper levels. Combined with a dip out of the hillside, the geological and topographical situation favours a flow of groundwater from the hillside/natural strata and into the landfill, rather than vice versa.

The use of steelworks slag for daily cover and cell construction has resulted in a relatively permeable landfill. Together with a natural lining of low permeability boulder clay and steep underlying topography, this mitigates against the development of leachate heads and favours the rapid transmission of leachate out of the site. This is a further factor which discourages the loss of leachate into the underlying strata.

This hydrogeological regime, and the relatively high rainfall which the site experiences, results in a large volume of dilute leachate, the majority of which is collected in the lagoon and discharged to sewer. Monitoring of the leachate flows at the downhill toe of the site has demonstrated seasonal variation with a high percentage of base flow originating from a natural groundwater catchment, consistent with the hydrogeological regime anticipated from the site topography and geology. It is concluded from this, that groundwater mainly flows into rather

than out of the site and the only significant receptor of potentially contaminated groundwater is the Nant Merddog.

As presented in **Section 2.5 Groundwater levels** and **Section 2.6 Leachate heads** the data collected 2010-2017 generally supports the 2004 hydrogeological conceptualisation. Based on the groundwater level data the seasonal groundwater responses are typical of fracture flow aquifers. Furthermore, the groundwater levels recorded in the monitoring wells indicate a steep hydraulic gradient from north to south which, considering the geomorphology of the original valley of steep valley sides and shallow valley floor, would generate groundwater inflows to the valley floor and the landfill.

2.8 Requirement for a Failure Response Plan

In the existing environment the leachate heads within the landfill are the balance between input to the landfill (from leachate generation and groundwater) and outflow from the landfill as leachate and groundwater combined. The balance between input and output is reflected in the leachate head. Since the capping of the landfill has been completed the leachate heads have become stable (see note on LC5A above) and the quantity of discharge from the landfill toe has reduced (refer to Annual Monitoring Reports).

Within the landfill the leachate head is a measure of how quickly the leachate and groundwater drains through the waste mass and to the landfill toe. The flow paths to the landfill toe comprise of the drains (BSC, Armco and the full drainage network) which have a very high hydraulic conductivity of an open channel but also the waste matrix itself, which has a lower permeability (calculated to be 1×10^{-5} m/s in HRA, 2004[1]). The efficiency of leachate movement through the waste mass is a combination of these two hydraulic conductivities. Although there are many pathways through the waste mass the efficiency of the drains mean that these carry the majority of the leachate. If the drainage system becomes blocked, then there will be greater reliance on the hydraulic conductivity of the waste mass.

Blockage of drain pathways may occur in a number of ways but the main concerns are from collapse or from precipitate clogging the drainage. Collapse may come from structural failure of the pipe and lead to waste entering the drain and either fully or partially sealing it. In this case the flow path will be constricted and the water level upstream of the blockage will cause leachate levels to rise. As leachate levels rise the flow will find pathways around the blockage through the waste but it will lead to a localised build-up of leachate head which would extend radially upstream from the collapse. Blockage by precipitate has been observed in locations from camera surveys of the BSC, and may also be the cause of anomalous heads in leachate monitoring well LC5C. Where leachate seeps into pipes/drains/wells there is a risk that oxidation from contact with air causes precipitate and encrusting on surfaces. If wide spread this encrusting can block tributaries and small scale pathways into drains and lead to leachate heads in the waste to rise.

Whilst blockage from collapse may lead to a rapid build-up of leachate heads on the upstream site it is likely to be localised. Blockage of pathways from encrusting

by precipitate may cause more widespread rise in leachate heads but the response will be gradual and over a number of years.

The Failure Response Plan is a strategy to implement management of leachate heads in the event that a continued rate of rise occurs that could pose a threat to landfill stability or risk deterioration of the water environment.

A number of options have been considered to manage leachate levels including abstraction wells, additional drains in the embankment at the landfill toe and directional drilling. Of these three options, the implementation of additional drains and directional drilling have the potential to be successful but there are significant unknowns on how these would be implemented without risking slope stability at the landfill toe. In this regard there would need to be greater geotechnical understanding of the ground conditions prior to these being designed.

Utilising abstraction wells is a common methodology to manage leachate levels and can be undertaken relatively rapidly assuming quick mobilisation. On this basis this section considers the use of leachate abstraction wells only.

This section provides:

- methodology for implementation of a Failure Response Plan
- a design for the extraction well(s)
- identifies risks associated with their installation.

Methodology

In the event of failure of the BSC pipe, Armco pipe or interconnected drains then there may be a rise in leachate heads upgradient of the failure. The Failure Response Plan must prevent unacceptable build-up of leachate head in the event of a drainage system failure but the implementation of the Plan itself must not have negative impacts. Unacceptable build up is defined as head levels that would cause engineering issues with the integrity of the landfill or cause environmental concerns. For example, a leachate head would be considered unacceptable if it increased the uplift pressure on the landfill toe to raise concern of failure or if increased leachate heads became higher than the groundwater levels in the base of the valley floor and caused an inversion of flow causing leachate to drain to the aquifer rather than the current scenario where groundwater is emergent.

The hydrogeological assessment provided above in Section 2 has summarised the groundwater system at Silent Valley and identified that sandstone units S2, S3, S4 and S5 are likely to crop out below the landfill. In particular, S2 underlies the base of the landfill for a significant part of the valley floor. Although boulder clay is likely to be thickest in the floor of the valley (rather than its sides) there are likely to be areas where the cover is thin or absent. In this regard S2 has the potential to receive leachate. Sandstone units S2, S3, S4 and S5 are less at risk as the hydraulic gradients indicate these to be free draining into the landfill footprint. Only sandstone unit S2 has a significant capacity to carry groundwater (and leachate) downgradient in the valley past the valley toe. With regard to build up of leachate heads, the higher the leachate head then the increased downward gradient to groundwater. As groundwater is emergent into the valley floor from S2 it is

recommended that leachate heads are restricted in the landfill to 3m, which is the estimated groundwater head in the valley floor.

Based on the above assessment a number of measures are recommended for the implementation of a Failure Response Plan:

1. The failure response plan will limit leachate heads in the landfill to an agreed level above the landfill base.
2. Implementation of the Failure Response Plan will be triggered by a continued rise in leachate levels that risks exceeding the maximum allowable leachate level or by exceedance of the maximum allowable leachate level.
3. The initial response of the Failure Response Plan will be increased frequency of monitoring at the locations in question and if necessary installation of additional monitoring wells to determine the extent where leachate heads have become elevated.
4. The enhanced monitoring will be assessed to determine the cause of the rise in leachate head and measure the rate of rise.
5. If required leachate extraction well(s) will be implemented in order to reduce and manage the leachate heads. In the interim monitoring wells can be implemented for interim pumping before the abstraction wells come on line.

On this basis, regular monitoring of leachate heads across the landfill is key to ensuring that leachate heads remain controlled. The current monitoring data identifies that all leachate monitoring wells have leachate heads less than 3m (with the exception of LC5A). Leachate wells BH1, BH2, BH3 and BH4 show that the leachate level along the BSC drain has remained stable since capping.

In terms of the monitoring network it is recommended that additional wells are installed perpendicular to the BSC drain set back at c.50m from the landfill toe, allowing access via the already constructed roads. These monitoring wells would provide data on leachate heads along the length of the toe, which from a geotechnical standpoint would allow calculation of uplift potential.

Extraction Well Design

The leachate extraction well design comprises of 150mm HDPE slotted pipe with plain riser, screen (gravel pack) and bentonite seals as well as base cap, top cap, headworks. The diameter of the well will allow use of a 100mm diameter pump, which will be required considering the significant lift (up to 50m) to surface. The well will be installed below the base of the landfill so that a sump can be installed as part of the design to collect and pump leachate.

It is recommended that the sump extends three meters beyond the base of the landfill through the underlying boulder clay and into the bedrock. Using a basal sump in the well below the base of the landfill will allow the extraction well to collect leachate. Importantly a sump will also provide longevity to the life of a well by allowing sediment to collect without impacting on performance and also allow rehabilitation by cleaning. As the extraction well required a sump below the leachate level it will also require a basal seal to prevent connectivity in the well annulus between aquifer and landfill. During construction, the action of drilling

through the base of the landfill has the risk of causing a temporarily increase in the connectivity between landfill and groundwater.

Risk

It is critical that implementation of the Failure Response Plan does not cause increased environmental risk from the landfill.

As groundwater is emergent into the base of the landfill and contributes to the volume of leachate generation it is a critical aspect of the hydrogeological regime at the landfill and has implications for the Failure Response Plan. Where the groundwater level lies above the valley floor then the leachate is contained in a hydraulic trap and is prevented from draining to ground. It is paramount that the Failure Response Plan does not impact on the groundwater levels, either by:

- lowering groundwater levels during leachate extraction and thereby allowing leachate to drain to ground or,
- Allowing increased groundwater inflow into the landfill and causing the leachate heads to increase.

In this regard, extraction wells should only be installed where there is a clear requirement for leachate levels to be lowered and controlled.

Other Options

As part of the review of leachate control measures that may be applicable we reviewed the following options in addition to the installation of pumping wells:

- Installation of Counterfort Drains
- Installation of Horizontal Wells
- Installation of Vertical Pumping wells in to the waste body.

With regards to Counterfort Drains it was considered that the inherent risks associated with the excavation in to the waste body at the toe of the landfill were too great to pursue this option. The landfill form is generally at a slope of 1/3, however there are limited locations where the slope is steeper and therefore excavating into this slope was considered to present too much of instability and therefore this option was not pursued.

The base of the Phase 1 area of the landfill is understood to comprise slag deposits from the time when the landfill received wastes from the British Steel site. In the lower reaches of the landfill this slag has fused and presents a significant obstruction within the waste body, albeit generally nearer the base, and therefore there is a significant risk of failure to progress this type of control and so this was discounted as an option.

3 Failure Response Plan

3.1 Assessment of leachate levels and response zones within the Phase 1 waste mass

An assessment of leachate levels in the waste mass has been undertaken in **Section 2.6 Leachate heads** of this report. The assessment concludes that in general the waste mass is of high hydraulic conductivity and that in the last four years, leachate heads have remained below 3m in all monitoring locations except LC5A.

At LC5A there has been a steady increase in leachate heads. Over the last 7 years the leachate head has shown a rise in annual minimum levels from 1.69m (2010) to 4.91m (2017), with peak heads in 2017 reaching 5.07m. It is noted that pre-closure (2010-2011) LC5A showed significant short term peak rises in leachate head but that since closure these short term events have ceased and a gradual increase of 1m/year occurred between 2013 to 2015. Since 2015 leachate heads have remained stable.

3.2 Proposal for leachate extraction wells

The objective of leachate extraction wells is to manage leachate levels in the waste mass in the event of failure of the BSC and Armco pipes and connecting drains. Indication of failure in the BSC pipe may arise through reduction of water emergent from the drain at the toe of the landfill or from the localised build-up of leachate heads in monitoring wells distributed across the landfill.

Due to the general high hydraulic conductivity of the waste mass it is likely that failure of the BSC or branch drains will lead to bypass flow propagating through the waste mass itself and only cause a localised rise in leachate heads around the failure. Nonetheless, a Failure Response Plan is required to ensure that the extent of the leachate rise is monitored, identified and managed.

The number of monitoring wells across the landfill will be increased to provide an increased dataset that can be assessed for leachate rise. Additional monitoring wells will be located at regular spacing either side of the BSC and Armco pipes but with increased coverage across the landfill

As discussed in Section 2.8 the Failure Response Plan must be implemented to control leachate heads but to not increase risk to the environment. There is a risk to the environment during the installation of the extraction wells that a good seal between the landfill will not be achieved as well as concerns from long term degradation. As monitoring wells do not require a sump and have a narrower construction they have a significantly lower risk of potentially impacting the groundwater regime below the site. As such, having an increased monitoring network to detect build-up of leachate heads is recommended rather than pre-emptively implementing a network of extraction wells, which would have a greater risk to the environment and may indeed not be used.

3.3 Extraction well locations and specification

The extraction wells will comprise of 150mm installed screen, riser and sump, which will allow the use of 4" submersible pumps. In order to install the 150mm riser the borehole will need to be drilled at a diameter of at least 200mm. Installing a 3m sump on each extraction well will allow collection of leachate and pumping to the surface for treatment. A 3m sump will also provide some resilience for the extraction well and allow it to remain operational for a longer period with the inevitable build-up of solids in the base.

3.4 Implementation options

Due to the depth of the waste (up to 50m in locations) the time taken to drill through the waste for a leachate extraction well is estimated at:

- two weeks per well using cable tool percussive drilling,
- four days for a rotary drilling rig (such as ODEX) or sonic drilling

Notably, drilling of monitoring wells, which are narrower, will require less time than an abstraction well.

On this basis it is feasible for four extraction wells installed by rotary or sonic drilling to be installed and operational within 6-8 weeks from mobilisation (it is currently understood that it will be possible to procure pumps, hosing, power and disposal points in this time frame).

4 Conclusions

In response to the IC2, this report presents hydrogeological assessment and Failure Response Plan.

Based on the assessments undertaken it is recommended that the Failure Response Plan comprises of a series of steps that are triggered based on regular monitoring of leachate heads.

Priority should be placed on extending the monitoring of leachate heads across the landfill to ensure that those locations (if any) that require control of leachate levels are identified.

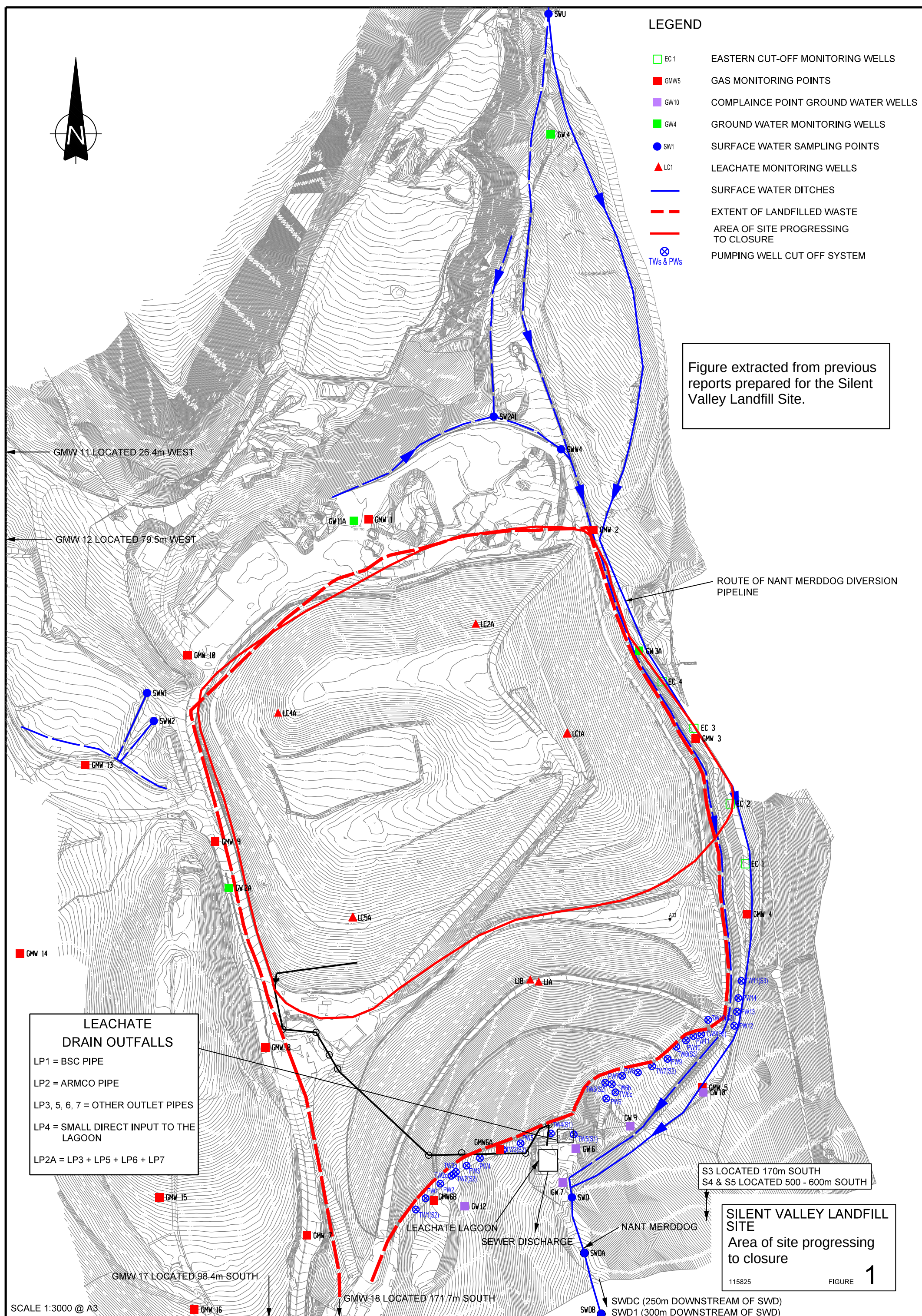
Where areas are identified as having leachate heads that cause environmental or structural concern then extraction wells shall be installed that will enable the leachate level to be lowered and managed.

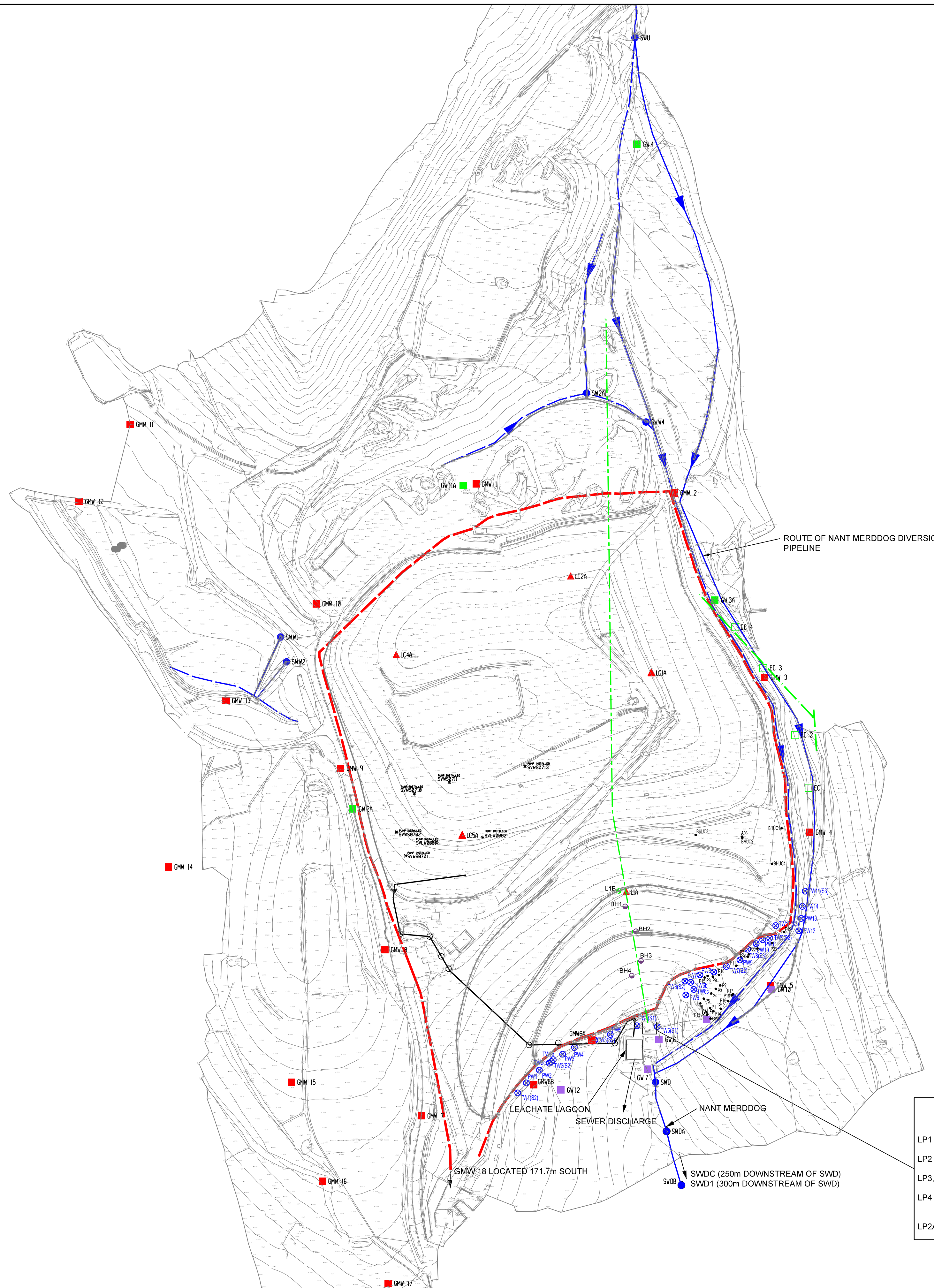
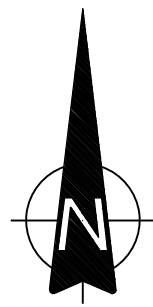
5 References

- [1] Silent Valley Landfill, Hydrogeological Risk Assessment, Arup, November 2004
- [2] Silent Valley Landfill, Hydrogeological Risk Assessment (Revision May 2009), Arup, June 2009
- [3] Silent Valley Landfill, Investigation into the Western Flank of the Cut-off System, Arup, August 2011
- [4] Silent Valley Landfill, Annual Monitoring Report 2010, Arup, January 2011
- [5] Silent Valley Landfill, Annual Monitoring Report 2011, Arup, January 2012
- [6] Silent Valley Landfill, Annual Monitoring Report 2012, Arup, January 2013
- [7] Silent Valley Landfill, Annual Monitoring Report 2013, Arup, January 2014
- [8] Silent Valley Landfill, Annual Monitoring Report 2014, Arup, January 2015
- [9] Silent Valley Landfill, Annual Monitoring Report 2015, Arup, January 2016
- [10] Silent Valley Landfill, Annual Monitoring Report 2016, Arup, January 2017
- [11] Silent Valley Landfill, Section A Closure Report, Arup, June 2013
- [12] Silent Valley Landfill, Review of Geology South of Landfill Site, Arup, May 2013

Appendix A

Figures





LEGEND	
	EASTERN CUT-OFF MONITORING WELLS
	GAS MONITORING POINTS
	COMPLAINEE POINT GROUND WATER WELLS
	GROUND WATER MONITORING WELLS
	SURFACE WATER SAMPLING POINTS
	LEACHATE MONITORING WELLS
	SURFACE WATER DITCHES
	EXTENT OF LANDFILLED WASTE
	PUMPING WELL CUT OFF SYSTEM

SCALE 1:2500 @ A1

SILENT VALLEY LANDFILL

SITE PLAN

ENVIRONMENTAL MONITORING

PROGRAMME

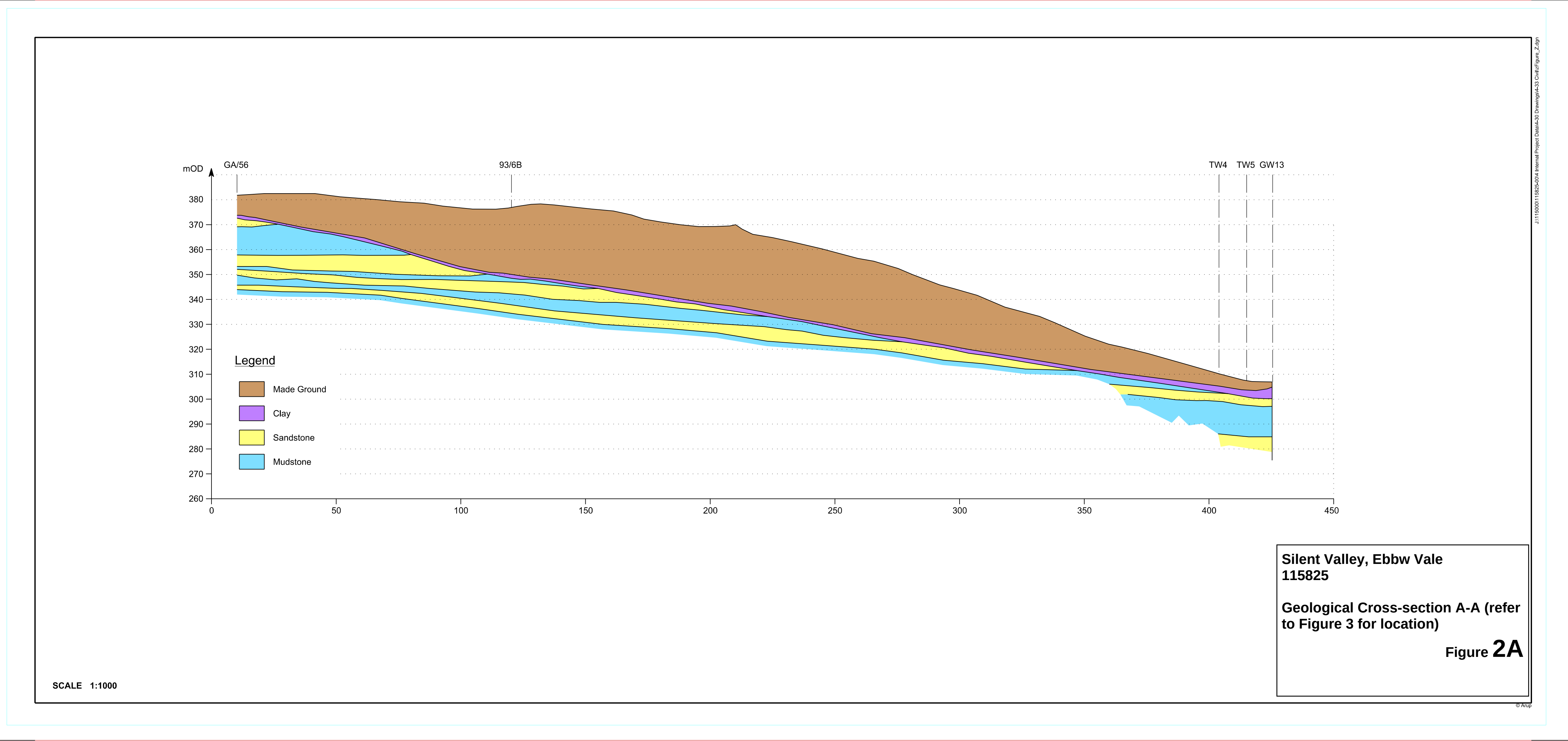
115825-00

FIGURE

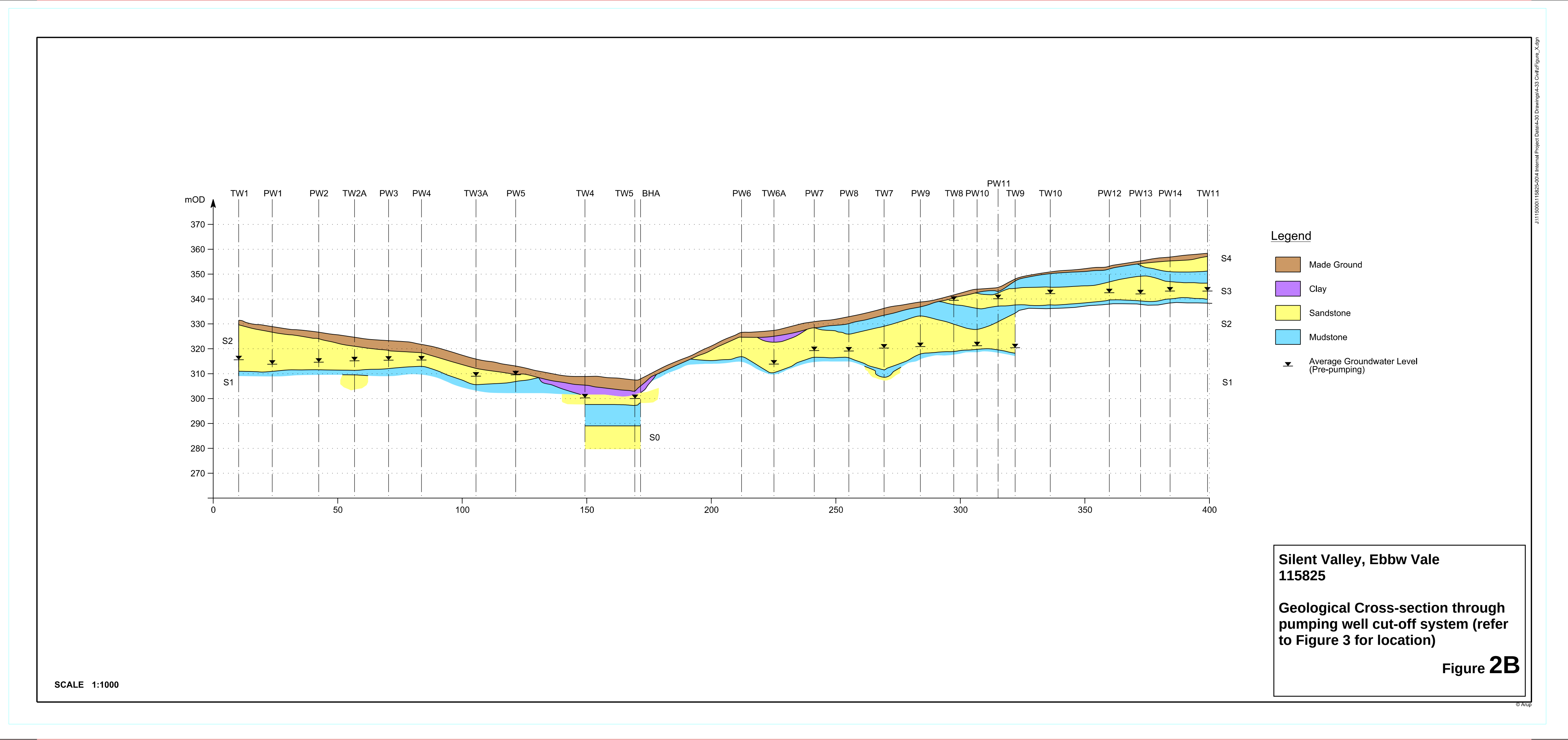
2

LEACHATE
DRAIN OUTFALLS
LP1 = BSC PIPE
LP2 = ARMCO PIPE
LP3, 5, 6, 7 = OTHER OUTLET PIPES
LP4 = SMALL DIRECT INPUT TO THE
LAGOON
LP2A = LP3 + LP5 + LP6 + LP7

Extract from previous report



Extract from previous report



Extract from previous report

