TerraConsult

July 2016
Report No 2570-R01

GIANTS GRAVE LANDFILL SITE

HYDROGEOLOGICAL RISK ASSESSMENT REVIEW

Prepared for

Neath Port Talbot Waste Management Company Ltd

GIANTS GRAVE LANDFILL SITE

HYDROGEOLOGICAL RISK ASSESSMENT REVIEW

July 2016

Carried Out For:

Neath Port Talbot Waste Management Company Ltd

Prepared By:

TerraConsult Ltd
Bold Business Centre
Bold Lane
Sutton
St. Helens
WA9 4TX

Telephone: 01925 291111
Facsimile: 01925 291191
E-mail: mailbox@terraconsult.co.uk

DOCUMENT INFORMATION AND CONTROL SHEET

Document Status and Approval Schedule

Report No	Title
2570-R01	**GIANTS GRAVE LANDFILL SITE HYDROGEOLOGICAL RISK ASSESSMENT REVIEW**

Issue History

Issue	Status	Date		Signature	Date
1		Dec 2015	**Prepared By:** Craig Fannin	*Craig A Fannin*	11/12/2015
			Checked By: Craig Fannin	*John Baxter*	14/12/2015
			Authorised By: John Baxter	*John Baxter*	14/12/2015
2		Jan 2016	**Authorised By:** Craig Fannin	*Craig A Fannin*	18/01/16
3		July 2016	**Authorised By:** John Baxter	*John Baxter*	31/07/16

GIANTS GRAVE LANDFILL SITE

HYDROGEOLOGICAL RISK ASSESSMENT REVIEW

CONTENTS

APPENDICES

DRAWINGS

1. INTRODUCTION

1.1 Background

This document, prepared by TerraConsult (South) Ltd (TCL), who were commissioned by Neath Port Talbot Waste Management Company Limited (NPTWMC) to prepare a Hydrogeological Risk Assessment (HRA) Review for Giants Grave Landfill Site, Neath in line with the requirement to provide periodic hydrogeological risk assessment reviews to demonstrate that the site is continuing to stabilise as expected and is not causing an increasing pollution risk.

1.2 Site Location and History

The Giants Grave landfill is a former landfill site located 2.5km southwest of Neath, comprising a total area of 65ha, of which, 30ha has been landfilled. It is bounded to the north by the main railway line embankment, in the east by the Neath canal, and the tidal River Neath on the west. There is also a small, unnamed tributary to the River Neath on the southern boundary.

The site area originally comprised an area of relatively level salt marsh with tidal creeks on the eastern bank of the River Neath. Salt marshes are still present on the undeveloped areas. The area was first developed between 1884 and 1899 when a north-south bunded valley feature known as 'The Cut' was constructed to aid with navigation of the River Neath. The northern perimeter of the site is bounded by a railway embankment which was also constructed during this period. The Neath Canal forms the eastern perimeter of the site.

The existing landfill cells, located within the eastern half of the site, initially accepted waste in the 1970s and was operated as a land raise above the *in-situ* alluvial sediments. Landfilling initially comprised the disposal of 30,000 tonnes per annum between 1972 and 1984, increasing to 150,000m^3 per year between 1984 and closure in 2003. Giants Grave Landfill site ceased accepting waste during July 2003 and has progressively been capped and restored. A landfill gas extraction system was installed by April 2004.

The site was originally regulated for the disposal of controlled waste under a certificate of deemed planning permission granted by Neath County Council from 1984. The site was then issued with a waste disposal licence in 1993 for the disposal of municipal waste, which was subsequently superseded by a Waste Management Licence (Number EAWML 34060). This was in turn converted into EP EAWML34060 under the Pollution Prevention and Control Regulations (2002) and the Environmental Permitting Regulations (2007). Disposal operations within the existing cells ceased in 2003. A separate permit, HP3535PS, has been issued to continue landfilling in the "Western and Southern extension" to the site, within Landfill Directive cells. However, landfilling operations have not commenced under Permit HP3535PS, although engineering materials have been won from the southern extension area for capping and restoration materials to restore the existing landfill.

The existing cells are physically separated from the undeveloped 'Western Extension' area by the former navigational channel "The Cut". The Cut was developed as a leachate treatment reed bed. Phragmites were planted in the northern 50m of The Cut which then colonised throughout the entire length of the channel. It has now developed into an effective passive treatment system, through which all leachate collected from the landfill is treated.

Leachate is discharged from the reed bed system through a tidally controlled flap valve at the south of The Cut into the River Neath and regulated by the site's Environmental Permit.

There is a smaller area to the south of the existing cells, known as the 'Southern Extension' which is also currently a salt marsh and ponds. Both the Western and Southern extensions are flat lying lands behind the River Neath sea defences to protect against tidal and fluvial flooding.

1.3 Previous Risk Assessments

There have been two Hydrogeological Risk Assessments (HRAs) undertaken for the sites:

- Robert Long Consultancy Ltd (2004) Hydrogeological Risk Assessment. Report: – focussing on proposed extensions
- Jacobs (2010) Hydrogeological Risk Assessment

The 2004 HRA was submitted as part of a PPC Permit application for the continuation of landfilling operations as a physically separate operation from the existing landfill, whilst the 2010 HRA considered the holistic impact of the proposed and existing cells to aid with closure of the existing cells. Prior to 2010, a HRA had not been produced for the existing cells as landfill disposal operations had ceased prior to the application of a PPC Permit.

In addition to the previous HRA reviews, the ongoing monitoring dataset and discussions provided within the recent 2013 and 2014 Annual Monitoring Reviews have also been considered within the preparation of this assessment.

2. SOURCE TERM

2.1 Site Engineering

The existing cells occupy a 30ha area within the eastern sector of the site. These cells have been restored to grassland and form a landraise from 3mAOD to 24mAOD. The base of the landfill is estimated to be around 3mAOD.

The site has progressively been capped in two phases from the summer of 1999 with low permeability clay over the main part of the landfill. It is understood that site derived clays and silts from the western and southern extensions were used as the capping material, however the precise details are not known. Upon closure of the site, in September 2003 a third phase of capping, including the installation of a membrane cap, was undertaken. However the western and southern flanks, have been restored with soils.

Giants Grave Landfill site was designed, constructed, and operated as a 'natural containment site' as the *in-situ* low permeability of the underlying geology, was considered to act as a containment seal. There are no records of an engineered liner or other basal containment systems beneath the landfill and during the licenced operations period it was expected that the alluvium would act as a geological barrier providing a combination of contaminant attenuation, dilution, and dispersal beneath the site.

The leachate and gas management systems were installed in several phases and include in-waste wells, cut-off walls, and interception drain collection systems. All leachate collected from within and around the site is directed to the reed bed treatment system within The Cut.

Leachate is managed by a capping and restoration layer to reduce infiltration and the passive drawdown of leachate by perimeter trammel drains. The trammel drain system installed on the eastern perimeter comprises a permeable geotextile against the landfill and

an outer impermeable, 3m deep cut-off wall and collects leachate moving eastwards from the landfill site. The collected leachate in the eastern drain flows to a channel along the northern edge called the Northern By-pass Drain, which channels leachate and surface water into the north of The Cut for treatment within the reed bed system.

Two trammel drains are understood to be present along the southern edge of the site, with the deeper drain installed to intercept a deeper response zone for any leachate migrating in the downgradient direction through the alluvium. Both drains discharge to The Cut for treatment. The western flank of the site is lined by The Cut, which intercepts any westerly seeping leachate.

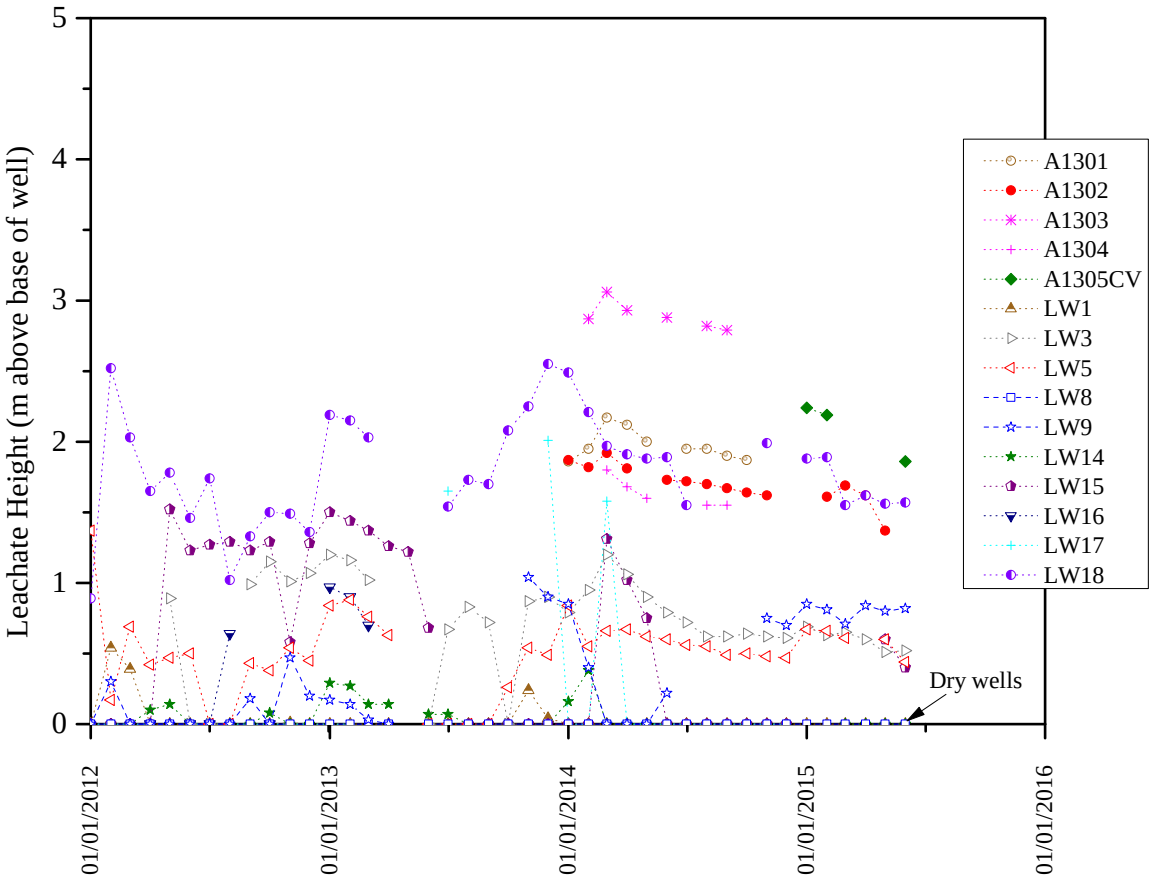
Surface water and leachate generated from infiltration through the cap are directed to the northern by-pass drain via the 'Eastern Ditch', which lies above the eastern trammel drain, and the South East Grip that was installed in 2013. Surface water, and leachate, is passed through the reed bed system within The Cut and is discharged to the River Neath via a flap-valve. There is no longer discharge from the original NE and SE discharge locations from surface water balancing lagoons.

2.2 Leachate Volume

The volume of leachate has been difficult to establish but leachate level data has been monitored on site from 2008. Leachate levels are generally stable with limited fluctuations. In previous years there was evidence to suggest leachate doming within the vicinity of LW8 and LW9, although a central leachate dome is consistent with leachate management by drawdown to perimeter interception channels. As discussed within the 2010 HRA Review, the doming was considered to be an artefact of ponding and increased localised infiltration surrounding leachate wells. However, a scheme to address differential settlement around the site was undertaken in autumn 2010[1] which included the reinstating and sealing around the leachate wells and cap and the re-profiling of the cap to efficiently drain rainfall to prevent ponding. Recently a proportion of the in-waste wells have been reported as dry, and leachate levels within the remaining wells are either at 0.5 - 1m above the base of the well or 1.4 - 2.2m above the base of the well (Figure 1).

[1] C&P Environmental Ltd (2013) Landfill Closure Report

Figure 1 Leachate Height above Base of Well



Given the time period since the site last accepted waste and the 9 year period since the current landform shape was completed and the progressively increased restored surface it is likely that a steady-state has developed between leachate generation and lateral migration to the interception drains. This steady-state is likely to remain stable in future as the collection of leachate is a passive action.

2.3 Leachate Quality

Matrix Substances

A summary of the leachate quality data has been presented below for the monitored locations between 2012 and 2015.

The leachate is consistent with that expected from a typical non-hazardous leachate receiving municipal wastes of the site's age. The leachate is a sodium-bicarbonate-chloride solution with significant potassium, ammoniacal-N and organic components, of which the latter is almost entirely recalcitrant (Table 1). The leachate strength is depleted compared to an operational site with the two primary leachate indicator substances chloride and ammoniacal-N typical at <300mg/l, although outlier concentrations do occur.

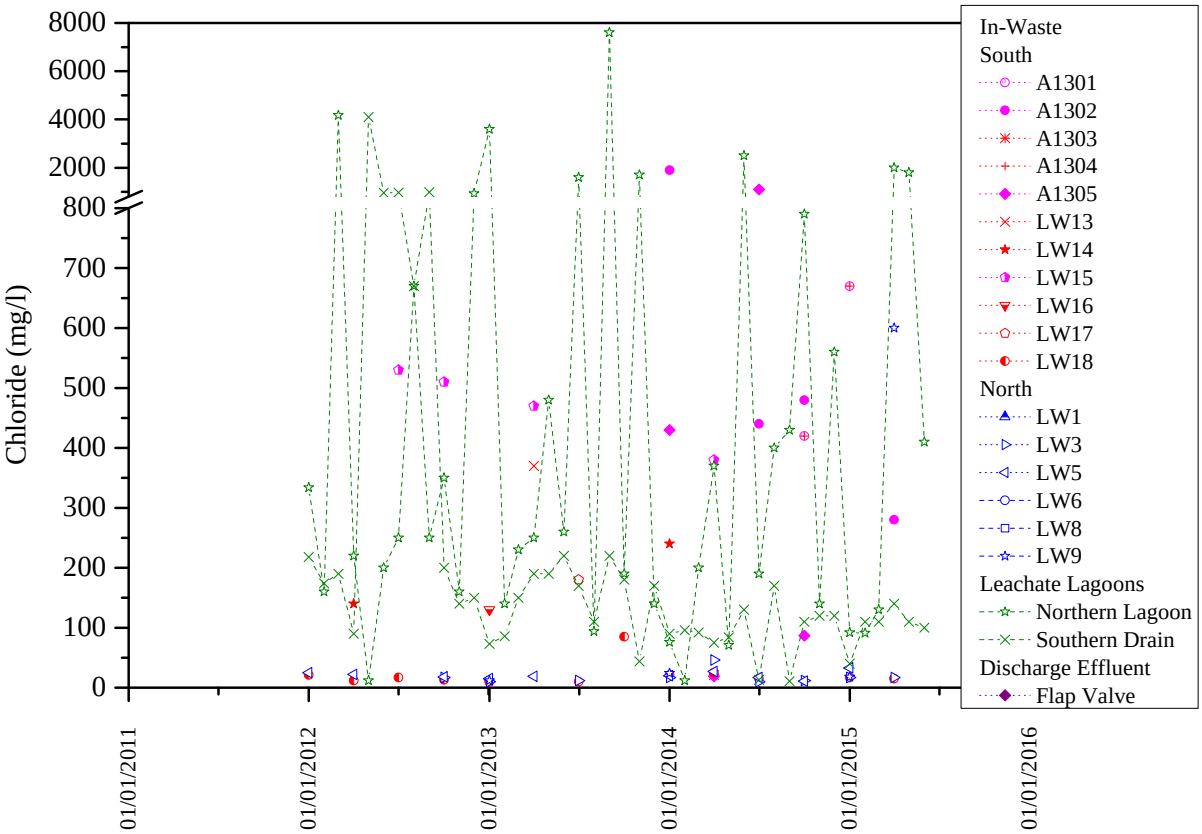
Table 1 Summary of Leachate Matrix Constituents from the 2012-2015 Data

		NH_4-N	NO_3-N	COD	BOD	TOC	Ca	Na	Mg	K	Cl	SO_4	Alk
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
EQS												**400**	
DWS		**0.39**	**50**				**250**	**200**	**50**		**250**	**250**	
LW3	median	3	0.5	19	<3	11	120	21	22	11	17	11	400
	max	10	140.0	78	7	120	230	39	45	25	46	2,200	580
LW5	median	4	0.5	29	6	11	149	29	41	21	20	14	590
	max	30	1.7	320	26	340	170	270	93	160	33	63	690
LW9	median	2	0.5	24	<3	87	115	175	61	122	21	14	465
	max	310	0.5	360	16	180	150	670	200	420	600	390	2,270
LW14	median	14	0.5	112	7	124	185	146	74	65	190	226	1,400
	max	220	0.7	160	10	220	210	210	79	130	240	440	1,800
LW15	median	170	0.1	270	13	220	140	400	85	220	470	<0.5	1,880
	max	210	1.8	320	22	280	210	460	98	380	530	750	1,940
LW18	median	8	0.5	30	<3	16	150	27	26	21	16	51	463
	max	200	1.9	180	110	190	190	36	32	70	85	980	610
A1305	median	3	0.5	159	10	182	135	405	93	280	259	16	1,505
	max	340	1.6	1,000	92	870	160	730	110	420	1,100	64	3,940
A1304	median	185	0.5	490	62	180	120	460	86	380	420	2	2,180
	max	210	1.7	590	76	390	130	740	95	440	670	33	2,400
A1302	median	200	0.5	330	32	490	110	430	73	240	440	38	2,510
	max	2,100	0.9	2,900	240	1,200	140	1,400	86	790	1,900	2,500	7,100
A1301	median	1	0.5	540	69	285	99	550	91	320	545	1	2,290
	max	1,300	0.5	590	76	390	130	740	95	440	670	2	2,400
LW17	max	41	4.5	130	6	250	170	200	35	58	180	190	920
LW16	max	29	0.5	330	<3	230	220	120	97	80	130	3.5	370
LW13	max	100	4.2	130	0.05	53	160	220	78	160	370	130	1,340
A1303	max	1,800	1.8	14	<3	3	130	480	88	390	21	34	280

Chloride concentrations in the leachate wells indicate a weak leachate in the north, where concentrations are at an environmentally insignificant 10 - 50mg/l, with a single outlier occurring in LW9 at 600mg/l. The southern locations typically average below 500mg/l with occasional outliers up to 2000mg/l. Peak chloride concentrations were reported for the A13 series of gas abstraction wells where concentrations oscillated between 259mg/l and 1,900mg/l (*e.g.* at A1302).

However, the most informative information on leachate quality is derived from the leachate intercepted from the perimeter wells (Figure 2) which indicate an overall depleting trend from 200mg/l to 100mg/l between 2012 and 2015 within the southern drain. The leachate collected from the eastern and northern drains collected within the northern lagoon, appear to contain a steady-baseline concentration at ~200mg/l, with peak concentrations between 800 and 7,600mg/l. These peak concentrations are periodic and occur as extended cyclic trends. It is difficult to understand this trend if landfill leachate from a contained site were the only source, it is noted that in other areas dominated by salt marsh conditions, groundwater chloride concentrations can exceed 20,000mg/l due to a combination of saline intrusion and accumulation of evaporite horizons within the alluvium. Notwithstanding the above, the River Neath is tidal and contains marine chloride concentrations of up to 19,000mg/l and therefore chloride the concentrations observed are of no environmental significance.

Figure 2 Leachate Chloride 2012-2015



Pre 2014, ammoniacal-N can be separated into two groups a weaker leachate in the north and a stronger leachate in the south (Figure 3). The first group consists of those with concentrations between 0.1mg/l and 20mg/l with outlying maximum values of up to 310mg/l in LW9 on inconsistent isolated occurrences. The second group consists of the locations with consistently elevated values between 30mg/l and 200mg/l. A third group can be identified post 2013 from monitoring at the A13 series of gas abstraction wells , where concentration values typically fluctuate between 185mg/l to 2,100mg/l, with the highest concentrations identified at A1302. The A13 series are gas wells and the elevated levels monitored within them could be due to condensate.

There is not a simple relationship between elevated chloride and ammoniacal-N either within individual in-waste wells (*e.g.* A1302, Figure 4) or within the northern lagoon (Figure 5). There is limited fluctuation with regards to ammoniacal-N between 0.1 - 250mg/l in the collected leachates, in contrast there have been periodic spikes in chloride of up to 4,000mg/l in the southern drain and 7,600mg/l in the northern drain, which is indicative of a separate chloride influence. Similarly for gas abstraction well A1302, although there are fewer chloride datapoints than for ammoniacal-N, there is not a consistent increase in ammoniacal-N in parallel with chloride and on occasions ammoniacal-N increases independently of chloride. In all likelihood the highest ammoniacal-N concentrations observed are likely to be a consequence of condensate accumulation within abstraction wells (hence ammoniacal-N can spike in the absence of chloride). The relatively elevated ammoniacal-N in the gas abstraction wells could also be indicative of a stratified leachate system with higher ammoniacal-N in the upper waste layers, with the lower concentrations

being representative of the lower waste levels and of the leachate acting on the base of the site.

Figure 3 Leachate Ammoniacal-N 2012 - 2015

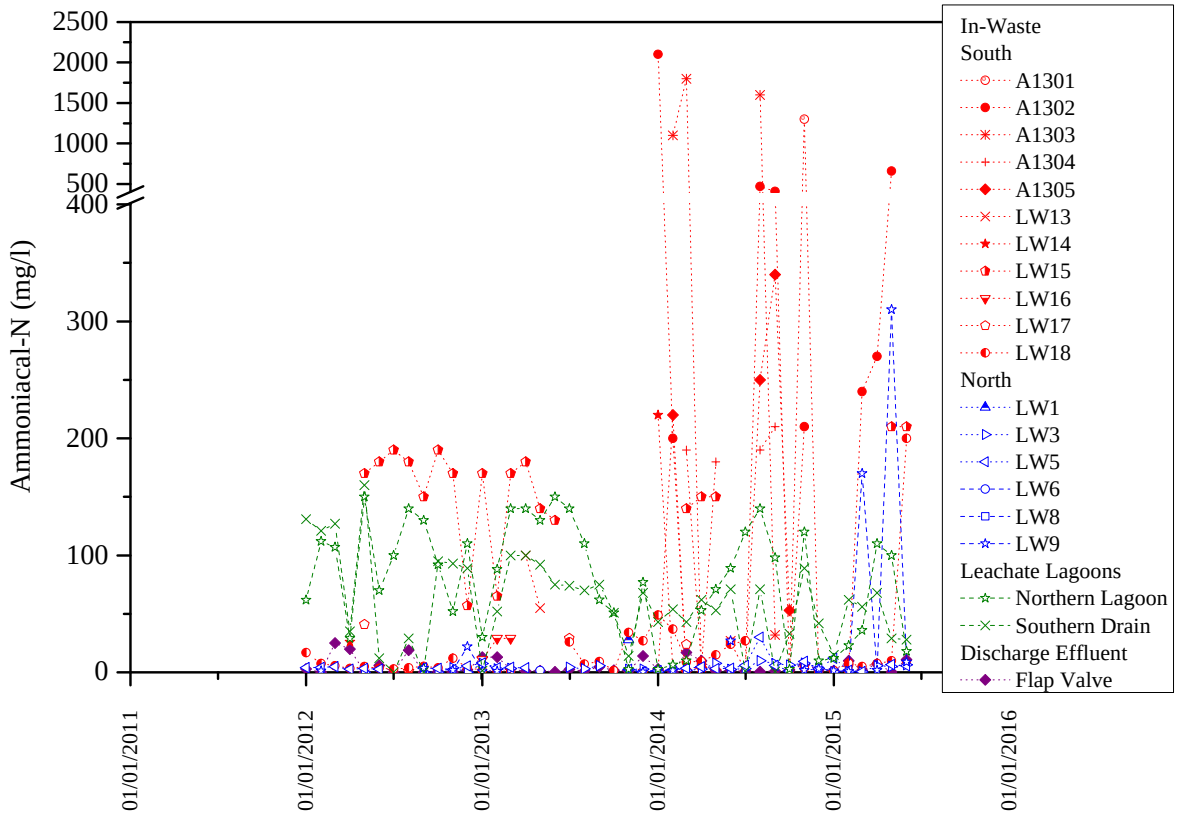


Figure 4 Matrix Constituents for Location A1302

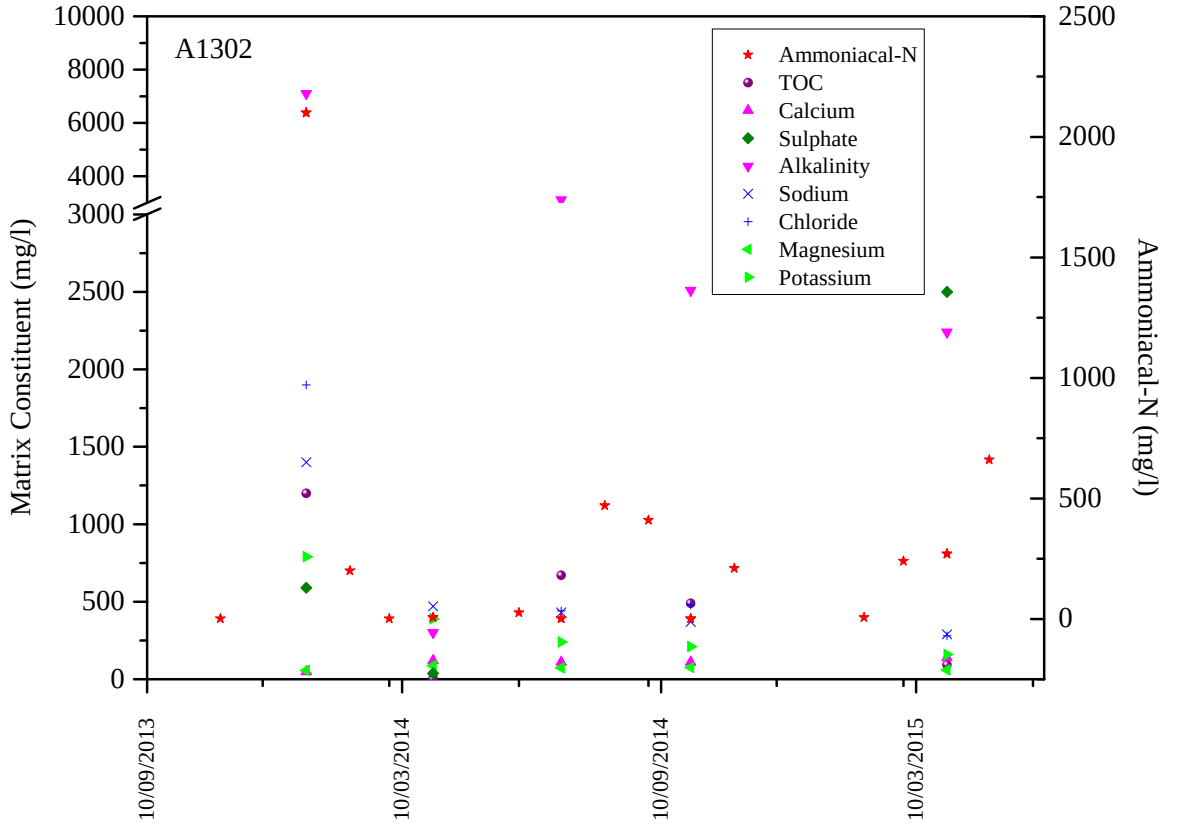
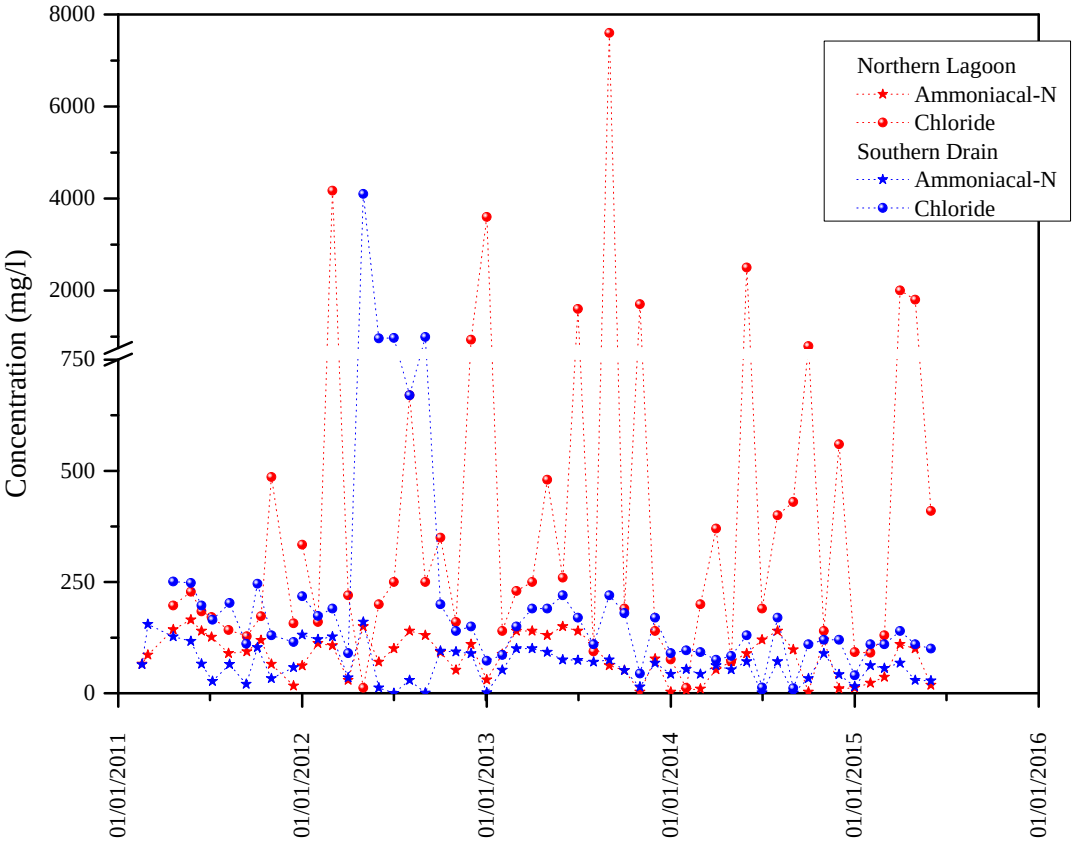


Figure 5 Ammoniacal-N and Chloride for the Northern Lagoon and Southern Drain



Priority Metals

Priority metals are monitored routinely on a monthly basis and are summarised in Table 2.

Table 2 Summary of Leachate Priority Metals from 2012 – 2015

		Cd	Hg	As	Cr	Cu	Pb	Ni	Zn
		µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
EQS				**25**					
DWS		**5**	**1**	**10**	**50**	**2000**	**10**	**20**	**5000**
LW3	median	0.055	<0.05	4	18	3	19	18	40
	max	0.350	<0.05	25	41	7	35	130	1100
LW5	median	0.055	<0.05	6	25	2	0.3	18	11
	max	0.260	<0.05	11	360	11	24	60	150
LW9	median	0.095	<0.05	11	12	8	1	27	20
	max	0.160	<0.1	13	85	13	6	62	47
LW14	median	0.055	<0.05	6	257	4	1	24	15
	max	0.090	<0.05	7	440	6	1	25	20
LW15	median	0.050	0.08	9	63	10	<0.3	29	15
	max	1.100	0.26	17	95	46	1	31	49
LW18	median	0.030	<0.05	5	19	3	<0.3	8	25
	max	0.170	0.11	10	670	16	3	279	300
A1305	median	0.025	0.06	12	65	6	1	32	13
	max	0.030	0.09	22	120	9	3	61	19
A1304	median	0.030	0.05	14	57	8	3	32	10

	max	0.050	0.08	19	77	23	4	57	16
A1302	median	0.030	0.13	23	68	5	2	50	17
	max	0.500	0.50	230	450	28	13	130	180
A1301	median	0.025	0.07	13	44	12	3	39	6
	max	0.030	0.08	19	57	23	4	57	10
LW17	max	<0.02	0.17	14	51	5.4	2.2	15	6
LW16	max	<0.02	<0.05	3.9	42	0.6	<0.3	25	10
LW13	max	0.05	<0.05	8.6	60	0.7	<0.05	59	22
A1303	max	0.04	0.11	20	120	11	<0.3	40	11

Both the hazardous metals cadmium and mercury are at concentrations below their respective 5µg/l and 1µg/l Drinking Water Standard (DWS), with mercury predominantly below detection limits.

Arsenic is below its 25µg/l EQS in the in-waste monitoring points except for one location, A1302, where although median concentrations are reported below the EQS at 23µg/l, arsenic has been reported at up to at 230µg/l. At all other locations, arsenic typically approximates to the 10µg/l DWS (Figure 6). However, it appears that arsenic is being generated by the natural soils within the reed bed, and is not derived from the landfill itself.

Chromium (Figure 7) and nickel (Figure 8) are the only potentially significant non-hazardous constituents within the leachate as they are the only metals consistently in excess of their respective DWS. However, it should be noted that chromium cannot persist as the Cr(VI) form under the methanogenic conditions within the site and will be in the less toxic Cr(III) from. It is highly likely that given the low solubility of all Cr(III) forms under the leachate pH, then the chromium is associated with the suspended solid component, whilst nickel is the most likely non-hazardous metal to be present within a mobile form, namely as an organic colloid.

Zinc is between 0.01 and 0.3mg/l, with a single outlier at 1.1mg/l. This outlier is inconsistent with a soluble form, and is representative of either a particulate or a colloidal form. Significantly, both of these forms would be physically filtered by the clay at the base of the landfill and are of no relevance to seepage, particularly as the leachate source concentrations are below the zinc Drinking Water Standard of 5mg/l.

Both lead (Figure 9) and copper (Figure 10) are typically below their Drinking Water Standard of 0.01mg/l and 2mg/l respectively. However outlier lead concentrations are reported as above the DWS for LW5 and A1302. Median concentrations are within the DWS. LW3 is the only location where the median concentration is in excess of the lead DWS (at 19µg/l) however, this concentration is only double the DWS and the peak concentration of 35µg/l is not significant for a landfill leachate.

Figure 6 Leachate Arsenic 2012-2015

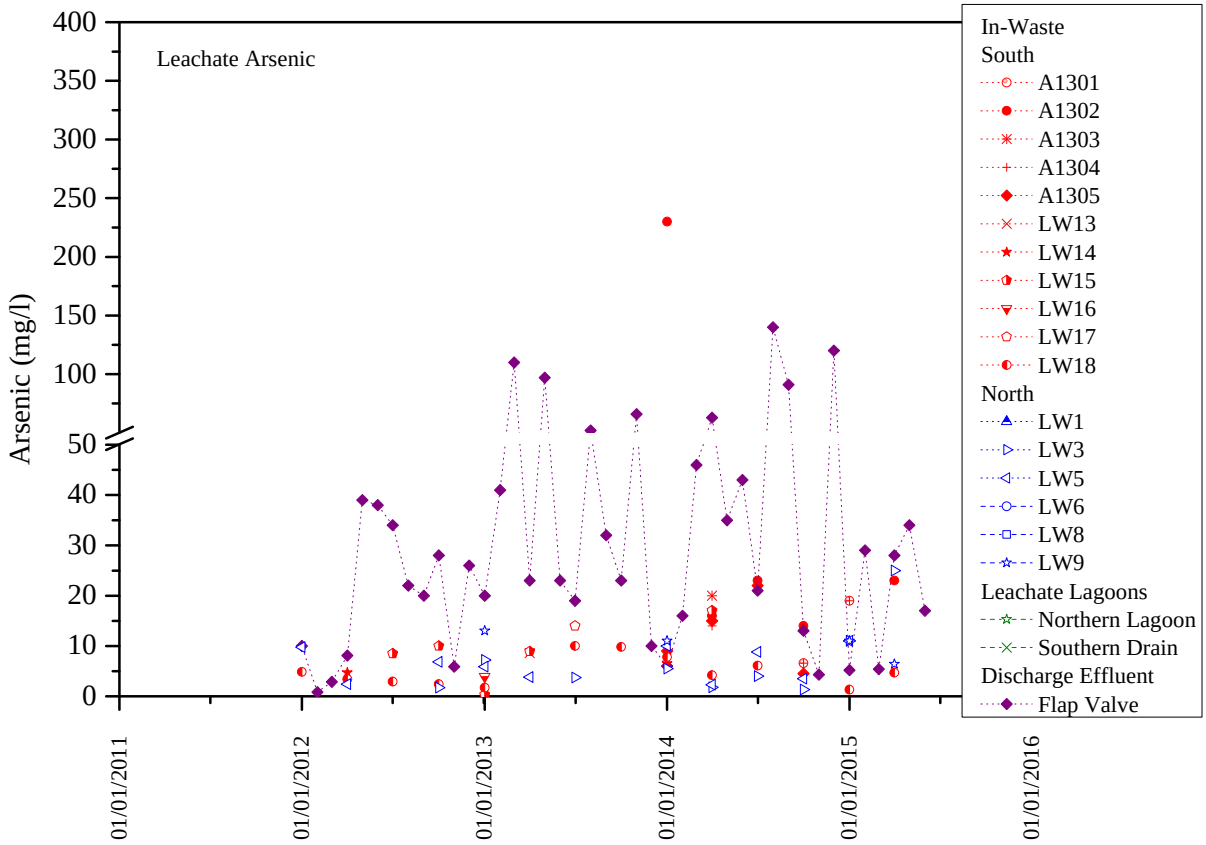


Figure 7 Leachate Chromium 2012-2015

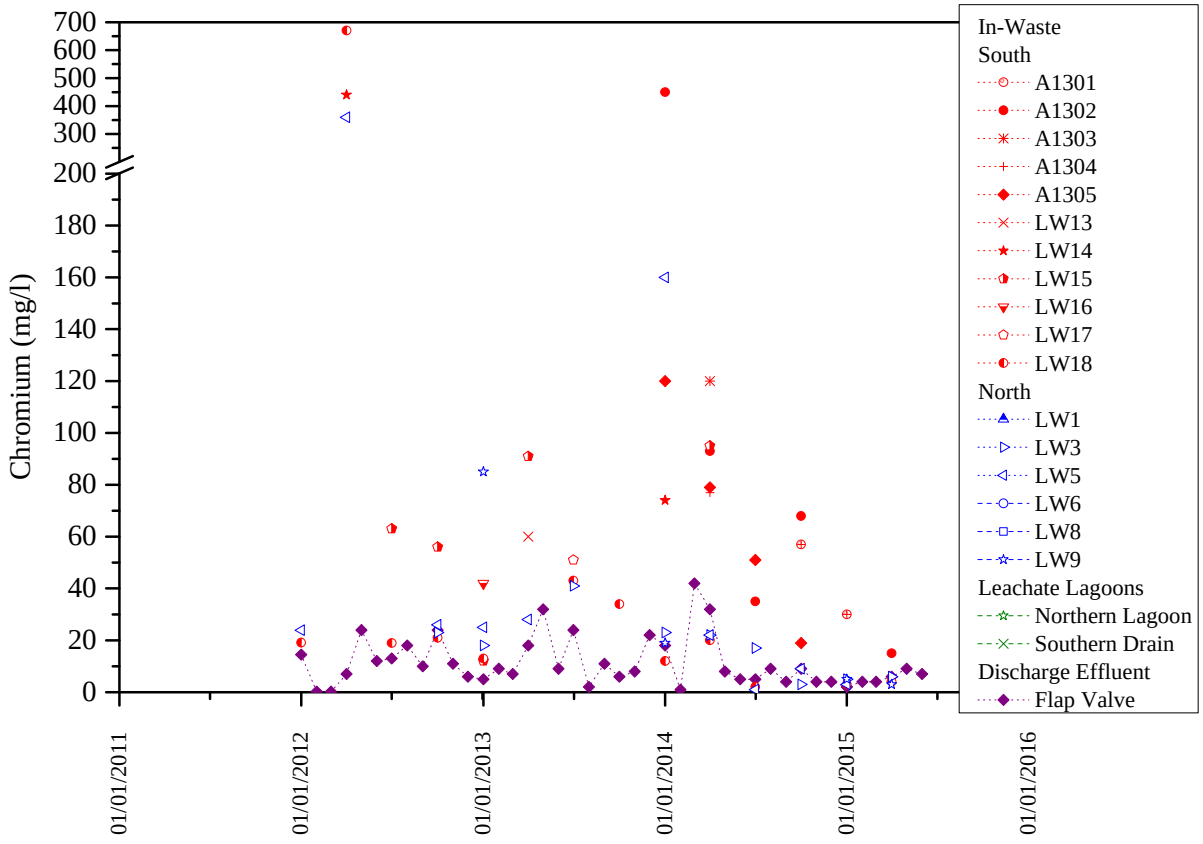


Figure 8 Leachate Nickel 2012-2015

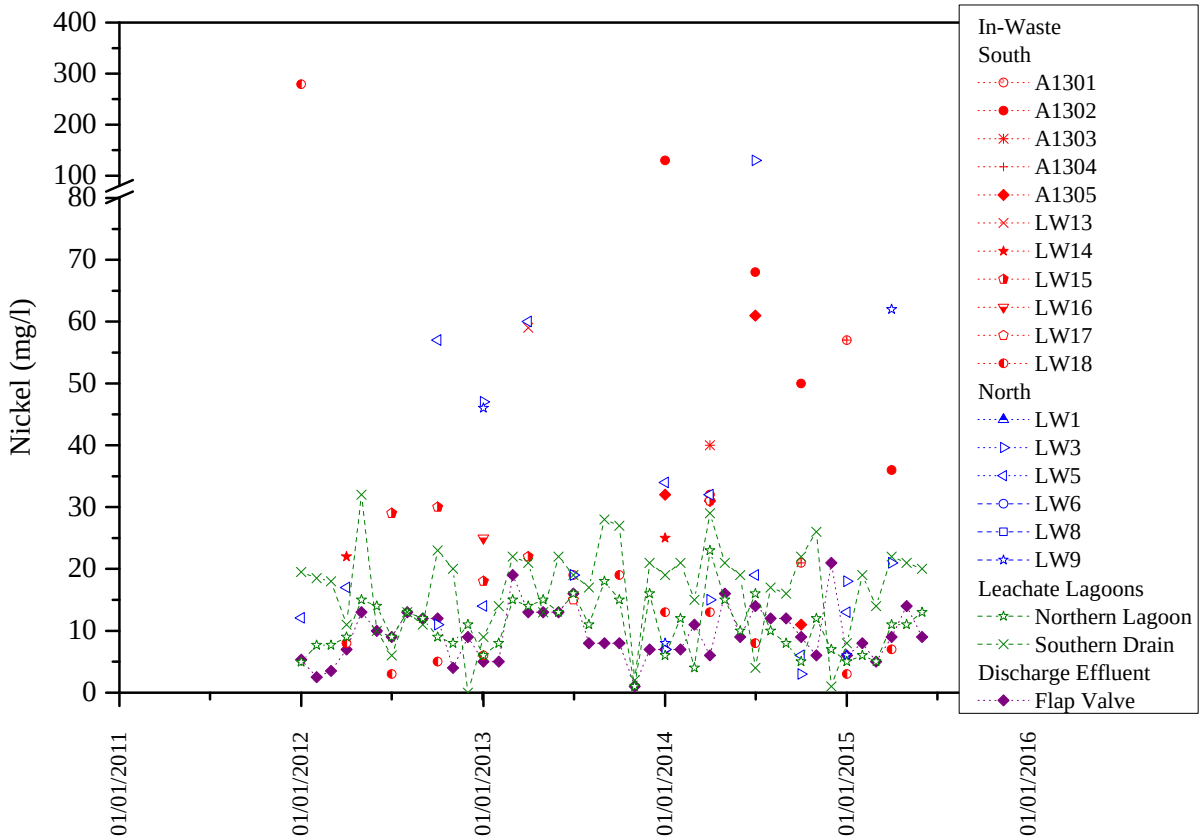


Figure 9 Leachate Lead 2012 - 2015

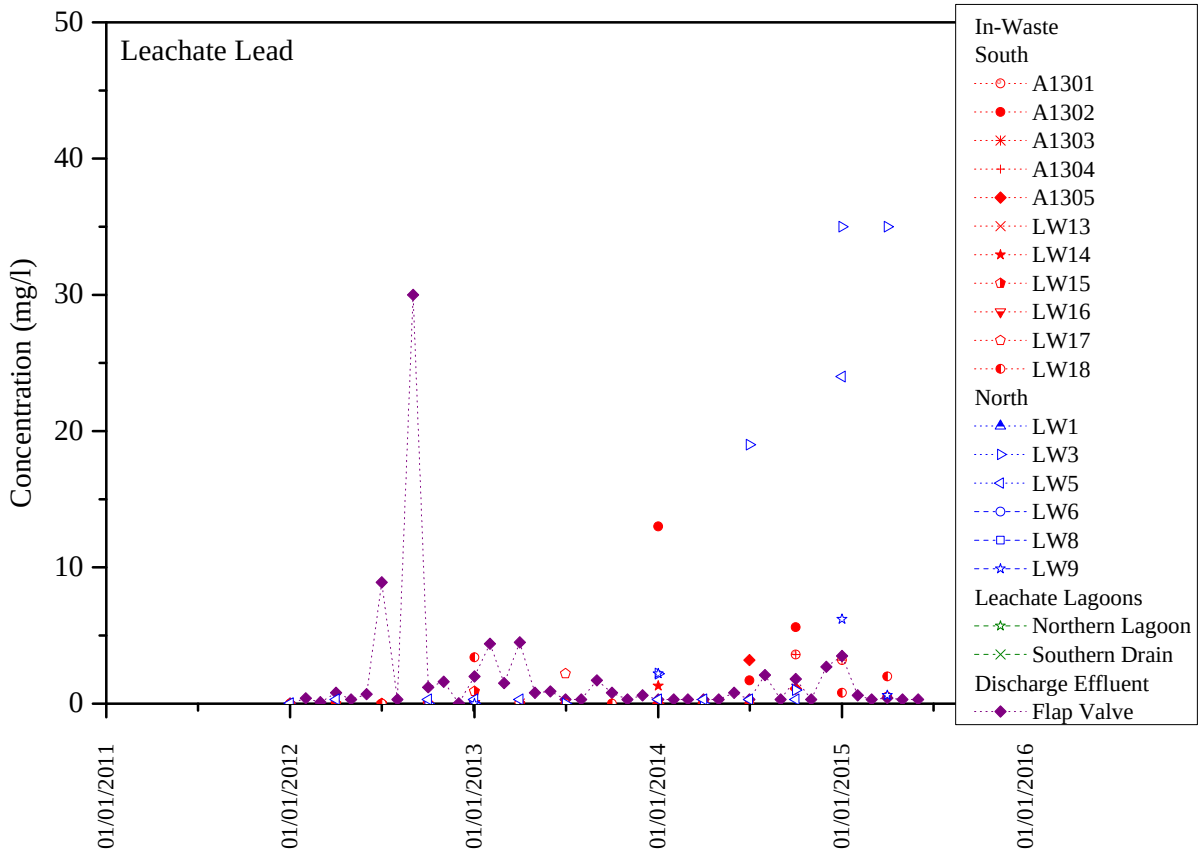
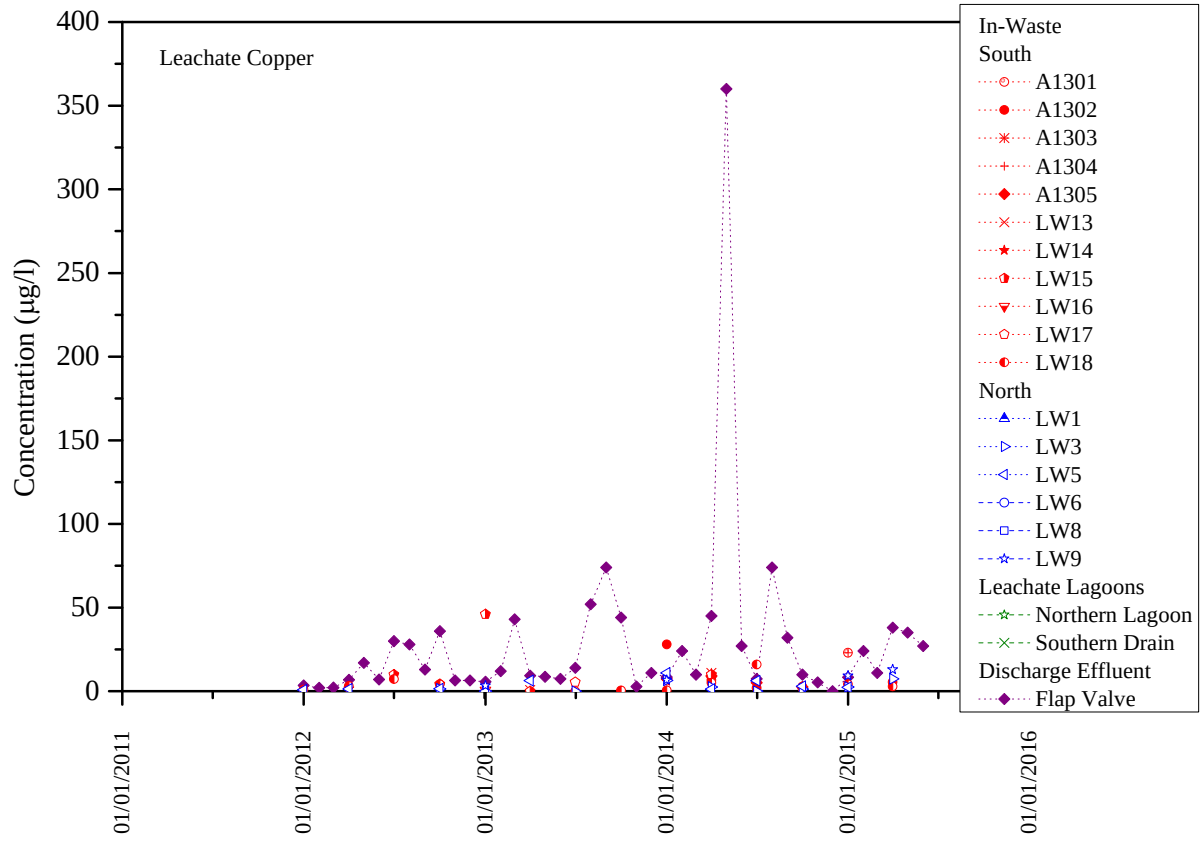


Figure 10 Leachate Copper 2012 - 2015



Organic Substances

The organic compounds within the leachate are dependent on the maturity of the methanogenic conditions produced within the landfill.

Table 3 Summary of Max Leachate Organic Substances Identified as Present (2012-2015)

	EQS AA	EQS 95th %ile	Unit	LW3	LW5	LW15	LW18	A1305	A1302	A1301
Cyanide (Total)	1	5	µg/l	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Naphthalene	1.2	N/A	µg/l	0.1	0.1	2.9	3.6	0.1	0.6	1.0
Benzo(a)pyrene	0.05	0.1	µg/l	<0.01	<0.01	<0.010	2.4	0.03	<0.01	0.01
Phenol	7.7	46	µg/l	<0.5	<0.016	<0.5	8.4	<0.5	<5	0.6
Mecoprop	18	187	µg/l	0.04	0.2	5.3	<0.04	0.7	4.4	34.0

Shaded cells exceed the EQS for the annual average

The non-hazardous herbicide mecoprop was identified in all wells except LW18, with the highest concentration of 34µg/l in well A1301. No BTEX were recorded as present but benzo(a)pyrene was present at a maximum of 2.4µg/l in LW18.

Phenol and mecoprop exceed the EQS for the annual average but do not exceed the 95th percentile upper limit to the EQS. Naphthalene and benzo(a)pyrene are above EQS levels within the leachate.

2.4 Leachate Summary

The leachate composition is relatively consistent with the previously assessed leachate inventory for persistent pollutants (0). The leachate does not appear to contain excessively high concentrations of hazardous and non-hazardous persistent pollutants. The majority of substances are typically reported at concentrations that approach their relevant water quality standards, with the occasional outlier within an order of magnitude of their respective water quality standards.

Average ammoniacal-N concentrations are consistent with previous assumptions; however there are a number of peaks in excess of those previously appreciated for the leachate. It is likely that this apparent change reported for the 2012 - 2015 period is associated with the periodic upper range in concentrations reported for the A13 gas abstraction borehole series installed in 2013. However, when the site is considered holistically, such as within the perimeter collection systems, leachate concentrations do not vary significantly from the average concentration and the holistic ammoniacal concentration is within the 100 - 250mg/l range.

Although chloride also appears to be elevated, average concentrations are below that previously assessed with maximum concentrations at 10% of that in the River Neath. This concentration is considered to be consistent with the salinity expected for a salt marsh system which is naturally adapted to saline conditions in excess of the leachate salinity.

Table 4 Previously Assessed Leachate Inventory

Parameter	2010Summary	2012-2015 Summary
	Mean – max (mg/l)	Mean – max (mg/l)
Ammoniacal-N	103 - 770	90 - 2,100
Chloride	318 – 1,203	190 - 1,900
Potassium	108 - 458	131 - 790
Arsenic	0.0075 - 0.021	0.012 - 0.025*
Chromium	0.014 - 0.047	0.067 - 0.67
Copper	0.057 - 1.25	0.006 - 0.046
Lead	0.017 - 0.26	0.003 - 0.035
Nickel	0.022 - 0.11	0.033 - 0.28
Zinc	0.22 - 3.33	0.059 - 1.1
Cadmium	0.0012 - 0.011	0.0001 - 0.0011
Mercury	0.0016 - 0.043	0.0001 - 0.0005
Phenols	0.32 - 0.87	0.15 - 8.4
Naphthalene	0.0016 - 0.006	0.0011 - 0.0036

*Excluding maximum outlier of arsenic at 0.23mg/l

3. PATHWAYS

3.1 Geology

The area has been significantly modified since the turn of the previous century by a combination of the two canals and the railway line in addition to the late 20th century disposal operations. The eastern and northern boundaries of the landfill comprise of sandy silts and silty clays containing occasional brick and sandstone fragments, which could be attributed to the construction of the canal and the railway embankment.

Anecdotal evidence also suggests that early tipping occurred right up to the edge of the canal, with uncontrolled filling and fly-tipping outside of the operators control occurring on both canal banks. In addition, the Made Ground at the northern boundary also includes the plinth through which monitoring boreholes were installed.

Beneath the made ground the natural sequence consists of:

Strata	Age	Description	Depth bgl
Alluvium	Recent	Clay, silt, and sand beds	0 to >12.9m
Upper Coal Measures	Carboniferous	Sandstone, siltstone, and mudstone	>12.9m

Detailed cross sections were presented within the 2010 HRA review as Jacobs Drawing B1404900/H/Figure3 and Drawing B1404900/H/Figure4.

Bedrock Geology

The bedrock geology was not encountered in ground investigations due to the extensive thickness of alluvial sediments at the site and hence has been inferred from geological maps. The bedrock consists of the South Wales Upper Coal Measures Formation, (previously the Upper Pennant Measures). The upper beds of this stratum comprise of fine grained sandstone, siltstone and mudstone flood plain deposits with occasional fluvial channel deposits.

Superficial Geology

The site lies upon natural marine and estuarine alluvium. The alluvium consists of interbedded clay, silt, and sand beds which have been proven to at least 12.5m thick (at BH49W). However the full thickness of the alluvium was not proven during investigations.

The alluvium can be summarised as:

- Silty sandy clay/clay under the base of the site, thinning to the west beneath the western extension area;
- Sandy and clayey silt present at shallow depths, thinning to the west beneath the western extension area;
- Silty clayey sand present beneath the clay and silt across the whole site at shallow depths, thinning to the west beneath the western extension area;
- Sand commonly present below the silty clayey sand, at greater thicknesses and shallower depths beneath the western extension area;

An average of 5m of cohesive alluvium (*i.e.* silty sandy clay), is likely to be continuous directly beneath the landfill, and would form a significant geological barrier underlying the original landfill cells. This horizon thins towards the west, to a more granular material; suggesting that a proportion of the western extension would be underlain by a more permeable strata than in the east.

Field and laboratory tests demonstrate that the cohesive alluvium had a hydraulic conductivity range of $1.7x10^{-10}$m/s to $6.2x10^{-8}$m/s, averaging at $1.1x10^{-8}$m/s. The granular alluvium was more permeable, with a hydraulic conductivity between $3.3x10^{-8}$m/s and $1.5x10^{-4}$m/s. Average laboratory permeabilities for the granular material of $3.2x10^{-5}$m/s are consistent with field tests at $5.9x10^{-5}$m/s.

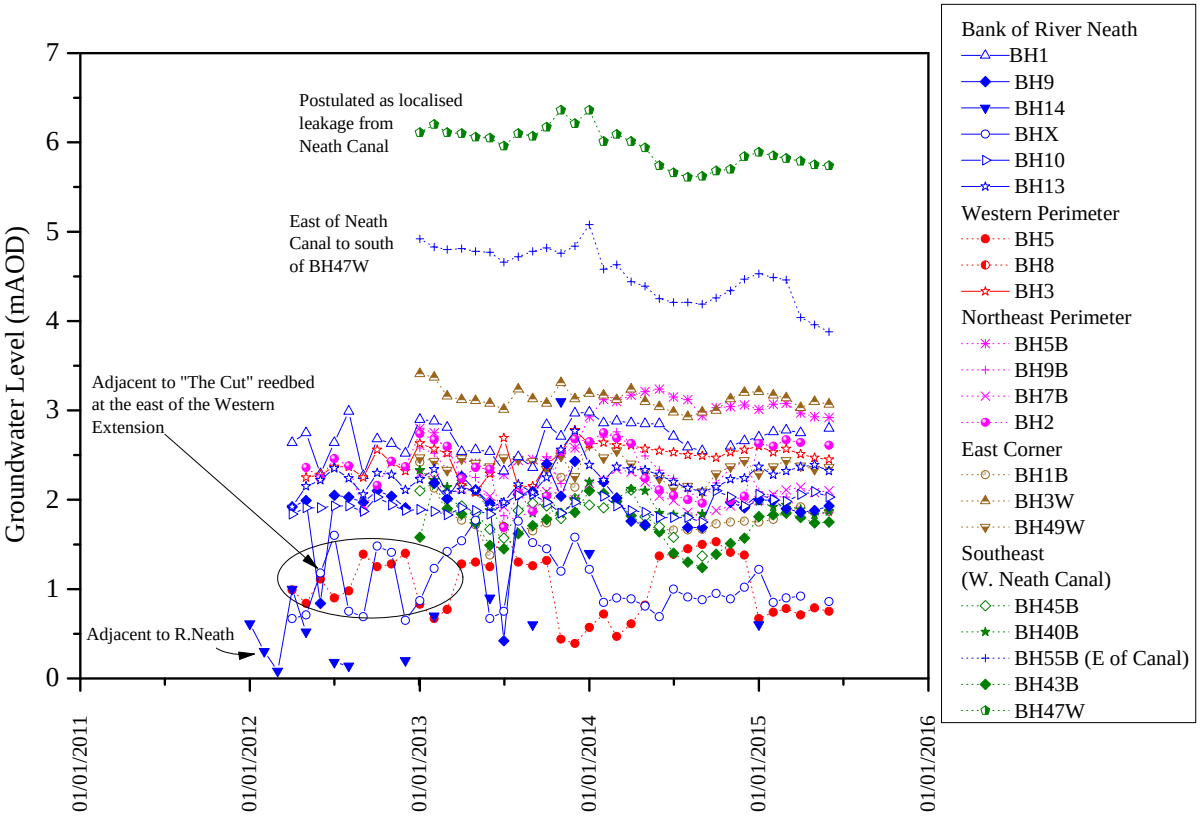
3.2 Hydrogeology

Groundwater is controlled by a general gradient from the terrestrial recharge zone to the north and east towards the estuary, however there is a tidal influence on groundwater which cyclically alters the hydraulic gradient and complicates interpretations, particularly during summer periods when the terrestrial recharge is limited (Figure 11). There are however minor local variations, such as in the east where there are local groundwater mounds complicate flow patterns; such as in the vicinity of BH47W where there is a suspected breech in the lining of the canal.

The variation between minimum and maximum levels is most notable in the north western section of the western extension, *i.e*. at the edge of the River Neath, which is presumed to be the most influenced by tidal fluctuations.

Groundwater levels within the superficial deposits demonstrate the hydraulic gradient to the western side of the site, is towards the River Neath and broadly follows the topography. Local discrepancies include a domed groundwater high at BH47W, which is suspected to be due to leakage from the canal. There is another but more diffuse, high at BH1 on the bank of the River Neath, where the tidal drainage channel to the north catches the ebb tide.

Figure 11 Groundwater Level



3.3 Hydrology

There are various types of waterways which surround the site:

- The western edge of the site is bounded by the River Neath which flows north-south before turning slightly to form the south west boundary of the southern extension. Water quality in the river is monitored to the north and south of the site.
- The Neath Canal forms the eastern boundary. The canal is no longer used for navigation. Stretches to the north are however navigable and there are licenced abstractions to the south of the site. Water quality is also monitored to the north and south of the site.
- There is a tidal drainage channel to the north of the site, which was constructed against the northern perimeter bund and the railway embankment.

Surface water and above ground leachate seepages are intercepted and collected in the Eastern Ditch. Water flows north in the eastern ditch, and further Leachate Treatment Lagoon via the Northern By-pass Drain. . The eastern trammel drain lines below the aforementioned Eastern drainage ditch and intercepts leachate at depth on the eastern edge.

4. RECEPTORS

4.1 Introduction

There are two potential receptor types usually considered with respect to landfills for the permanent disposal of wastes, namely the groundwater beneath or downgradient of a landfill site and any hydraulically connected surface water bodies.

With regards to the Giants Grave landfill site, there are no water abstractions downgradient of the site and the permitted area includes landfills to the south and west of the current landfill. Therefore there is not the potential for groundwater abstraction between the current operations and the River Neath estuary.

Notwithstanding this, the environmental water quality data is discussed within this section in terms of saline intrusion, background soil leaching to comment on historical industrial activities which could have affected the alluvium within the River Neath floodplain in order to distinguish the impact of the landfill on the water environment.

4.2 Groundwater Quality

The groundwater quality data is illustrative of the transition the terrestrial and estuarine system, where the composition is increasingly trending towards a marine composition due to saline intrusion (Table 5 and Figure 12 from the tidal River Neath.

Table 5 Summary of the Median Groundwater Matrix Chemistry

	NH_4-N	COD	BOD	TOC	Ca	Mg	Na	K	Cl	SO_4	Alk
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
DWS	**0.39**				**250**	**50**	**200**	**12**	**250**	**250**	
North											
BH1	0.45	665	35	2	330	560	3,600	230	7,000	1,000	570
BH3	0.24	11	<3	3	130	53	41	37	16	68	510
BH9B	1.45	113	10	14	135	240	1,900	120	3,900	790	465
BH1B	0.94	160	18	64	50	34	320	33	245	30	845
Central											
BH5	0.10	20	<3	4	105	14	17	9	14	37	280
BH8	1.70	24	<3	14	130	56	81	37	220	82	570
BH9	0.27	170	10	3	150	315	2,350	151	5,100	850	415
BH43B	68.00	71	5	23	120	66	135	79	140	9	995
BH45B	12.00	57	4	45	73	52	249	71	107	1	885
South											
BH14	0.22	30	<3	10	160	95	500	86	570	388	570
BHX	0.19	21	<3	6	110	52	160	50	96	135	580
BH12	1.47	43	4	13	98	44	100	25	140	39	540
BH15	0.57	52	<3	23	25	29	450	56	240	98	1,050

The saline intrusion has resulted in elevated sodium, chloride (Figure 13), magnesium and sulphate concentrations within groundwater in excess of that within the site's leachate, with the strongest saline influence apparent at BH1, BH9B and BH9. BH1 and BH9 are located directly adjacent to the River Neath in the Western Extension, whereas BH9B is adjacent to the tidal channel in the north. There is also a lesser estuarine influence apparent at BH14, where the chloride is exceeding the DWS in the absence of ammoniacal-N (the only viable potential leachate indicator substance at the site). BH14 is located adjacent to the River Neath in the Southern Extension below the Flap Valve discharge point.

Figure 12 Groundwater Matrix constituents at All Locations

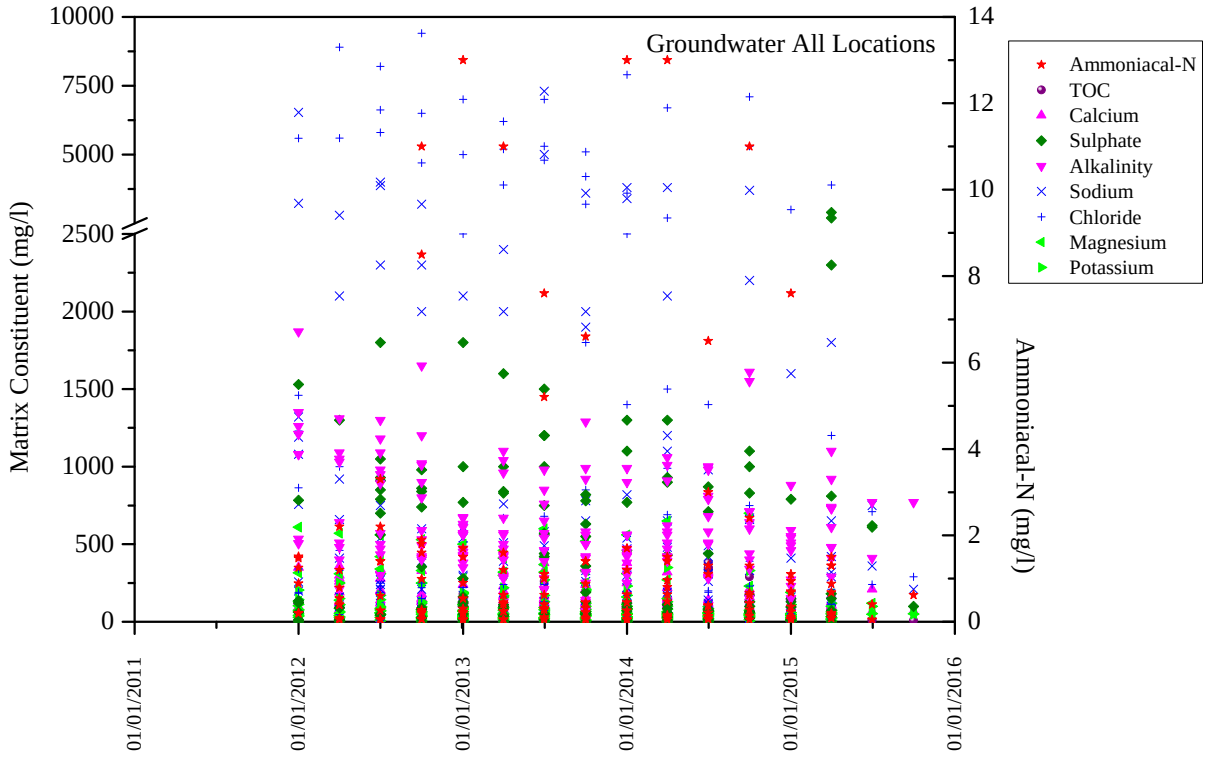
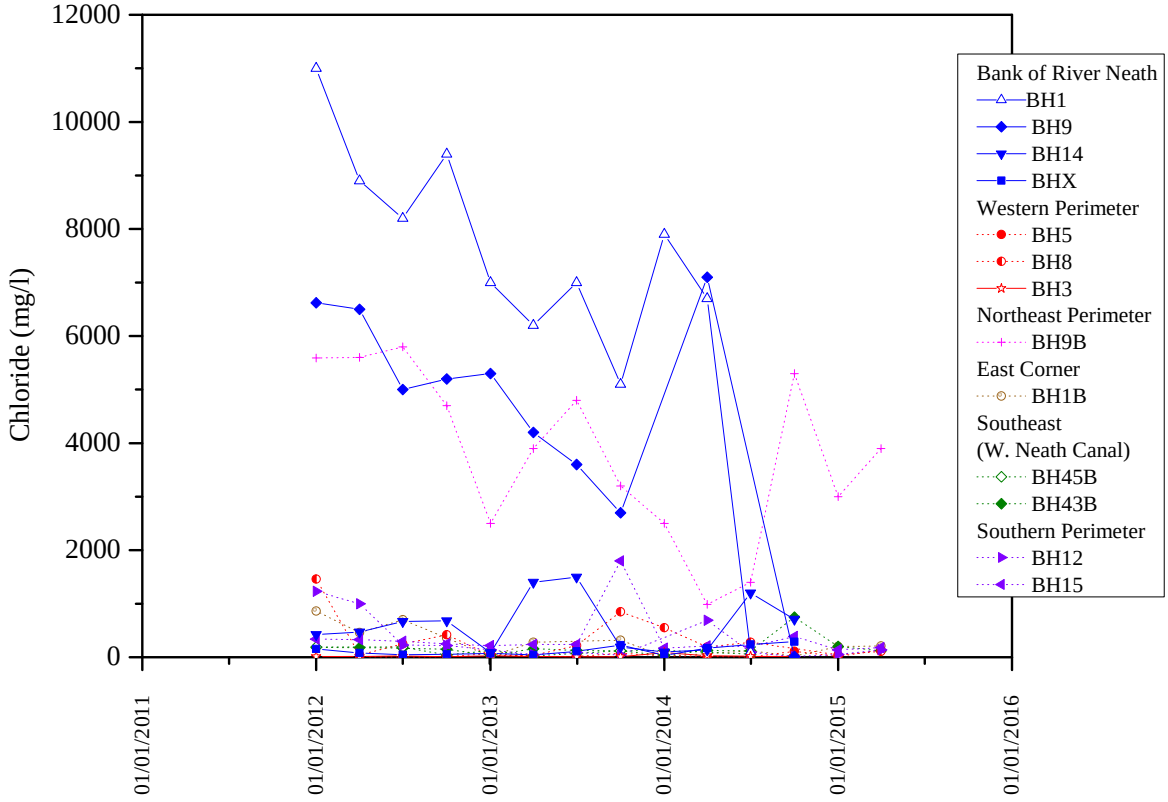


Figure 13 Groundwater Chloride



The saline intrusion to the south and west of the landfill, *i.e.* on the downgradient edge of the site is demonstrative that the groundwater within the superficial deposits should properly be described as transitional waters and part of the river estuary system. Consequently given

the primarily low permeability properties beneath the landfilled area and the saline intrusion into the granular alluvium, the superficial deposits are considered to act as a pathway towards the estuarine system and not as part of a viable groundwater resource.

As noted above, marine waters contain elevated sodium, chloride, potassium, magnesium and sulphate compared to most terrestrial waters, except where there are evaporitic beds or confined water mineralisation. Landfill leachates can be characterised as sodium-chloride-bicarbonate solutions with elevated ammoniacal-N, potassium, magnesium and dissolved organic carbon compared to most terrestrial waters. Therefore as the majority of these substances are expected to increase in concentration towards the River Neath, which will itself be at a higher concentrations than the source leachate, there is only one leachate primary constituent of potential environmental significance, namely ammoniacal-N.

Ammoniacal-N in the groundwater (Figure 14) can be broadly characterised as occurring in three groups, namely:

i. No obvious ammoniacal-N influence, where the concentrations are below 0.39mg/l DWS.
ii. A second group where although average ammoniacal-N slightly exceeds 0.39 and is in the 0.4 - 2mg/l range, peak concentrations are in excess of 10mg/l; and
iii. A third group containing consistently elevated ammoniacal-N, namely at BH43B (~68mg/l) and BH45B (~12mg/l) which could possibly be attributed to a leak in the base of the eastern drain as discussed in more detail below.

The first two groups are not considered to be environmentally significant, particularly for a biologically active area, for example salt marshes can be demonstrated as capable of not only tolerating, but treating a full strength non-hazardous landfill[2], in addition to what can be demonstrated for the site specific leachate within “The Cut” reed bed.

[2] Fannin et al (2009) Wetland system for primary treatment of landfill leachate *Waste and Resource Management* 162 75 - 83

Figure 14 Groundwater Ammoniacal-N

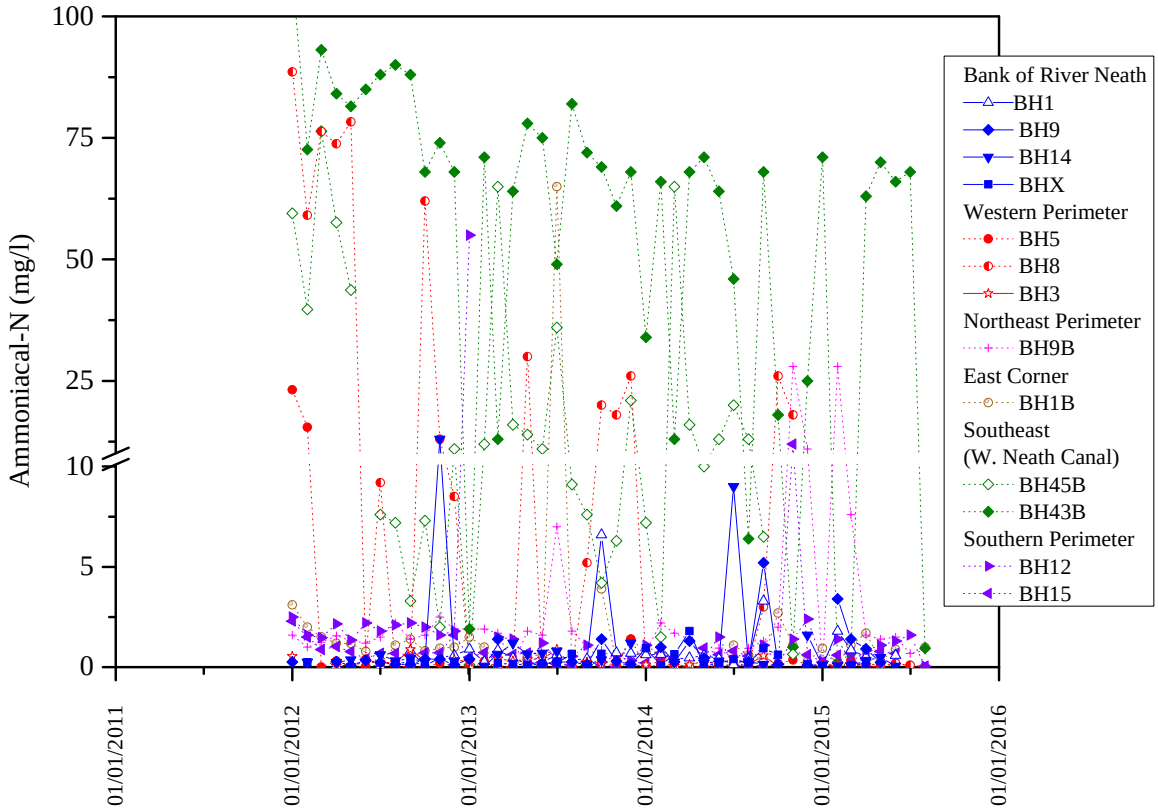
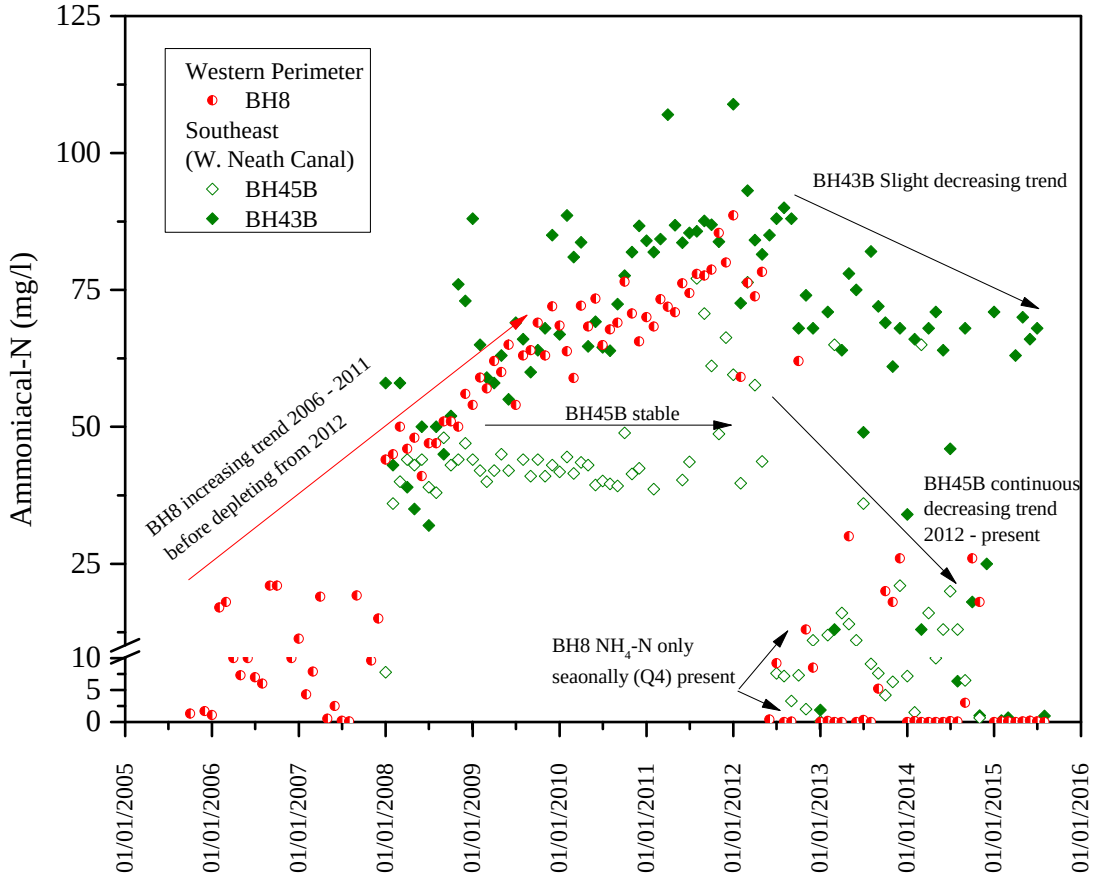


Figure 15 Long Term Groundwater Ammoniacal-N For BH8, BH43B and BH45B



Elevated ammoniacal-N was first observed as an increasing trend at BH8 immediately to the west of The Cut which continued between 2006 and 2012 (at 89mg/l), before depleting significantly to negligible concentrations (<0.3mg/l) in 2012, except for seasonal (winter) peaks in the following years (Figure 15).

This increasing trend was identified in the 2010 HRA. Supporting investigation associated with data available from 2008 from additional monitoring points has demonstrated a similar increase in almost identical increase in ammoniacal-N at BH43B, but slightly lower concentrations at BH43B (*i.e.* at 75 - 95mg/l) from 2010 - 2013 on the opposite (eastern) perimeter of the site. Elevated ammoniacal-N is also apparent at BH45B to the south of BH43B. The ammoniacal-N at BH45B has, similar to BH8 followed a depleting trend and returned to negligible concentrations during the first half of 2015.

In contrast to BH8 and BH45B, ammoniacal-N has depleted at a slower rate at BH43B, which may be indicative that the ammoniacal-N source is in the vicinity of BH43B, whilst BH8 and BH45B are representative of an ammoniacal-N plume which has essentially dispersed towards background concentrations, with only the occasional identification during periods of wet weather conditions and elevated groundwater.

However, as the ammoniacal-N has been observed at the end of the growing season, when groundwater saturation levels are likely to rise the potential for the development of anaerobic conditions with either seasonal vegetation dieback or following localised flooding of ponds cannot be discounted. It is noted in the 2010 HRA that BH8 is located in the vicinity of a former tidal creek and therefore likely to be low lying, and hence subject to seasonal flooding, although this could also form a preferential pathway between BH45B and BH8. If such a channel does exist it is indicative of good containment properties beneath the landfill, otherwise ammoniacal-n would be permanently present in the groundwater. Therefore in all likelihood there could have been an outbreak incident in the vicinity of BH43B, however, as this 'event' appears to be depleting it is considered that any impact will be less significant in future.

Significantly monitoring at BH12 to the south of BH45B at the edge of the southern extension demonstrates that any plume that developed had been completely dispersed or attenuated to background concentrations by the edge of the landfilled area.

Priority Metals

In addition to the matrix constituents, hazardous and non-hazardous metals are also monitored within the groundwater (Table 6). These substances are reported at concentrations consistent with the site setting, *i.e.* a river alluvium within a long term industrialised zone, with upriver recharge dominated by run-off from a 19th - 20the century coal mining area. There is little to no evidence of a relationship between elevated metal concentration and ammoniacal-N, and in all likelihood the metal concentrations are associated with the background sediment quality.

Cadmium and mercury are below their respective DWS, and in the case of mercury concentrations are below detection limits, except for the occasional unsustained outlier. Significantly cadmium appears to be associated with the River Neath sampling locations (Figure 16) and hecne it is suspected that either the reported data has not been properly background corrected for analytical interference during the testing of such a high salinity groundwater or if real there is no association with the landfill.

Interpretation of the non-hazardous metal and metalloids is skewed by historical data which has characteristics of total metal concentration due to suspended solids in the 3003 - 2008 period. More recent data demonstrates that the historically high concentrations are not continuous through the dataset. However, the over-riding characteristic is that there appears to be high concentrations associated with the River Neath sampling locations. In addition in the recent dataset (2012 - 2015), elevated metal concentrations appear as outliers except in high salinity zones as illustrated by the distinction between median and maximum concentrations.

Lead and nickel are the least significant metals within the groundwater. Lead is consistently below detection limits, whilst nickel only exceeds 10g/l on an intermittent basis, whilst consecutive concentrations in excess of 20μg/l are only occur on a single occasion (Figure 17).

Table 6 Summary of the Median Groundwater Priority Metals 2012-2015

		As	Cd	Hg	Cr	Cu	Ni	Zn	Pb
		μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l
EQS		**25**	**0.2**	**0.05**	**32**	**5**	**20**	**40**	**7.2**
DWS		**10**	**5**	**1**	**50**	**2000**	**20**	**5000**	**10**
North									
BH1	Median	41	0.16	<0.01	19	28	11	15	<0.3
	Max	140	1.40	<0.05	40	330	23	170	0.6
BH3	Median	3	0.03	<0.01	17	6	6	9.5	<0.3
	Max	55	0.14	<0.05	38	8	9	170	0.8
BH1B	Median	13	0.09	<0.01	18	17	7	37	3.5
	Max	43	0.83	<0.5	970	89	31	230	14
BH9B	Median	42	0.12	<0.01	14	41	9	10	<0.3
	Max	96	0.25	<0.05	990	210	14	130	20
Central									
BH5	Median	4	0.05	<0.01	7	10	4	9	<0.3
	Max	9	0.22	<0.05	17	46	11	72	24
BH8	Median	9	0.24	<0.01	23	14	11	15	3.3
	Max	166	2.70	<0.05	59	140	37	250	78
BH9	Median	29	0.12	<0.01	15	23	6	11	<0.3
	Max	180	0.21	0.21	36	160	9	44	1.4
BH43B	Median	14	0.06	<0.01	37	4	11	16	1.4
	Max	130	0.45	<0.05	790	49	28	87	40
BH45B	Median	6	0.08	<0.01	25	4	7	11.5	1.7
	Max	68	0.09	<0.05	55	9	12	35	4.3
South									
BH14	Median	19	0.65	<0.01	18	32	12	130	<0.3
	Max	34	1.90	0.05	64	110	88	270	1.7
BHX	Median	57	0.06	<0.01	15	67	6	17	<0.3
	Max	180	0.88	0.02	38	1,200	20	230	9.7
BH12	Median	9	0.09	<0.01	17	6	6	23	0.45
	Max	50	0.22	0.05	70	65	23	140	1.6
BH15	Median	19	<0.02	<0.01	20	8	2	7	0.9
	Max	34	0.17	0.27	61	31	14	76	12

Figure 16 Groundwater Cadmium

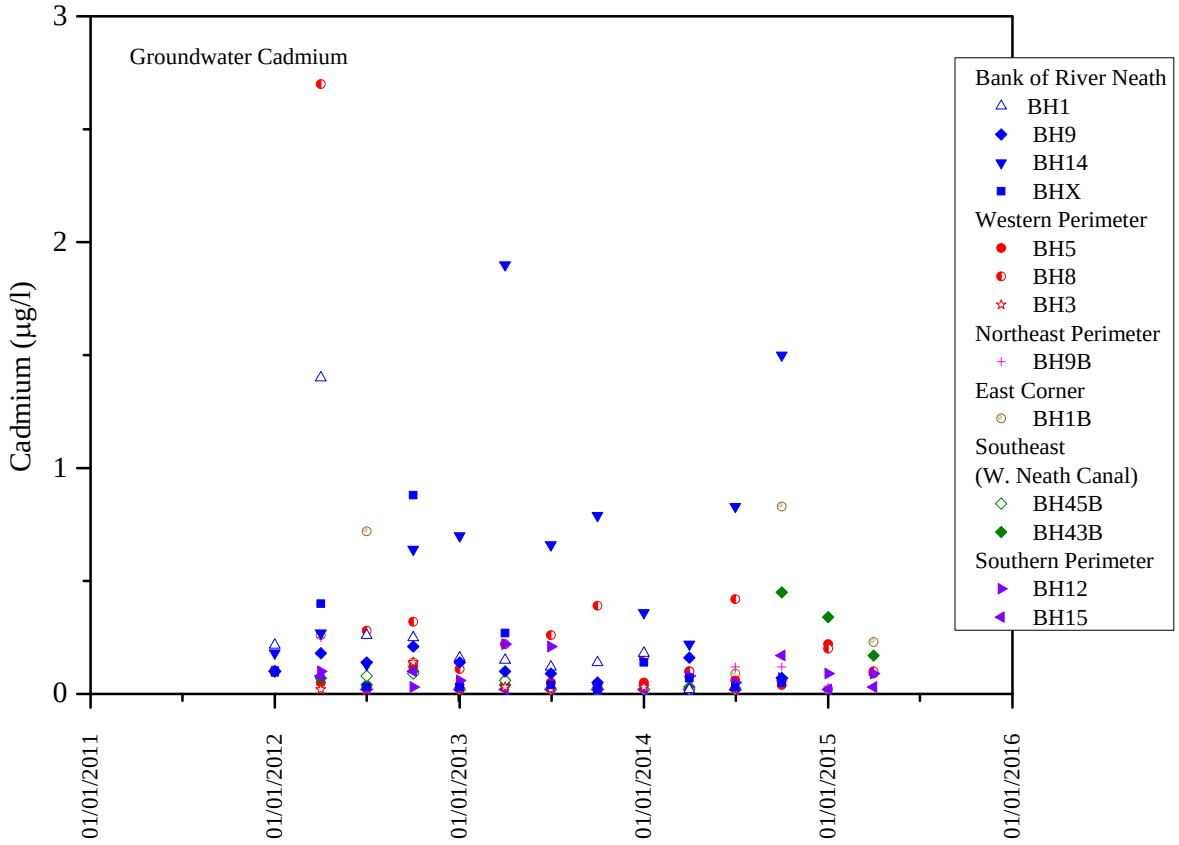
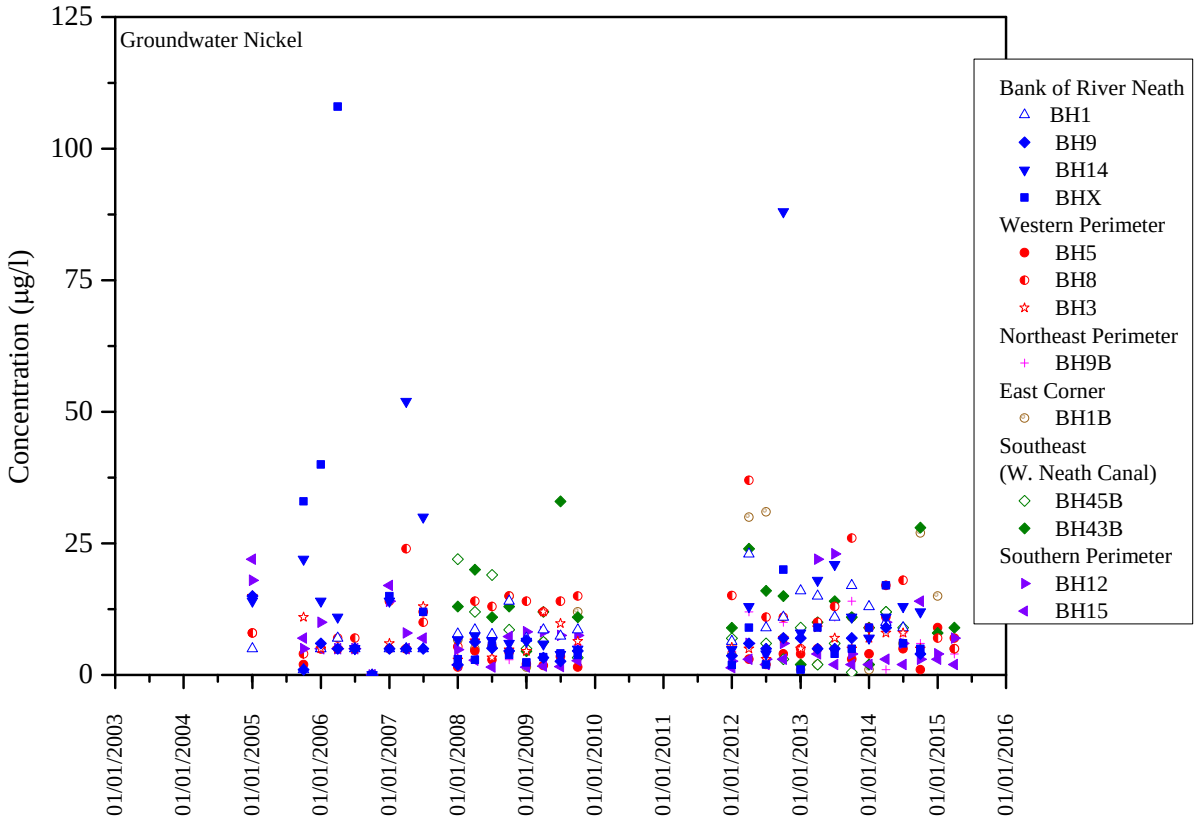


Figure 17 Groundwater Nickel



Chromium is generally <75µg/l, however elevated concentrations occur, such as in 2005 it appears to be almost ubiquitous which implies a laboratory or other procedure / interference bias. However there appears to be a slight recent bias towards the east of the site where chromium is in the 40 - 70µg/l range (Figure 18).

This eastern chromium bias is not repeated for zinc, where the bias is skewed towards the River Neath (Figure 19). This bias is stronger for copper (Figure 20), however, copper analysis can be significantly compromised by high salinity interference.

It is considered that as there no increasing trends in metal concentration and different metals are identified in different locations, whilst there is also no apparent correlation between ammoniacal-N concentrations (*i.e.* evidence of a leachate influence) and the metals, then it is considered that the analysis undertaken to date is representative of the background system within the capabilities of current technologies to routinely analyse high or variable strength solutions.

Where a correlation can be inferred is restricted to chromium at BH45B and BH43B between 2012 and 2015. However, there is no evidence of chromium migration and if the source is leachate and not background, the impact is highly localised and there is no (and unlikely to be) off-site impact.

Figure 18 Groundwater Chromium

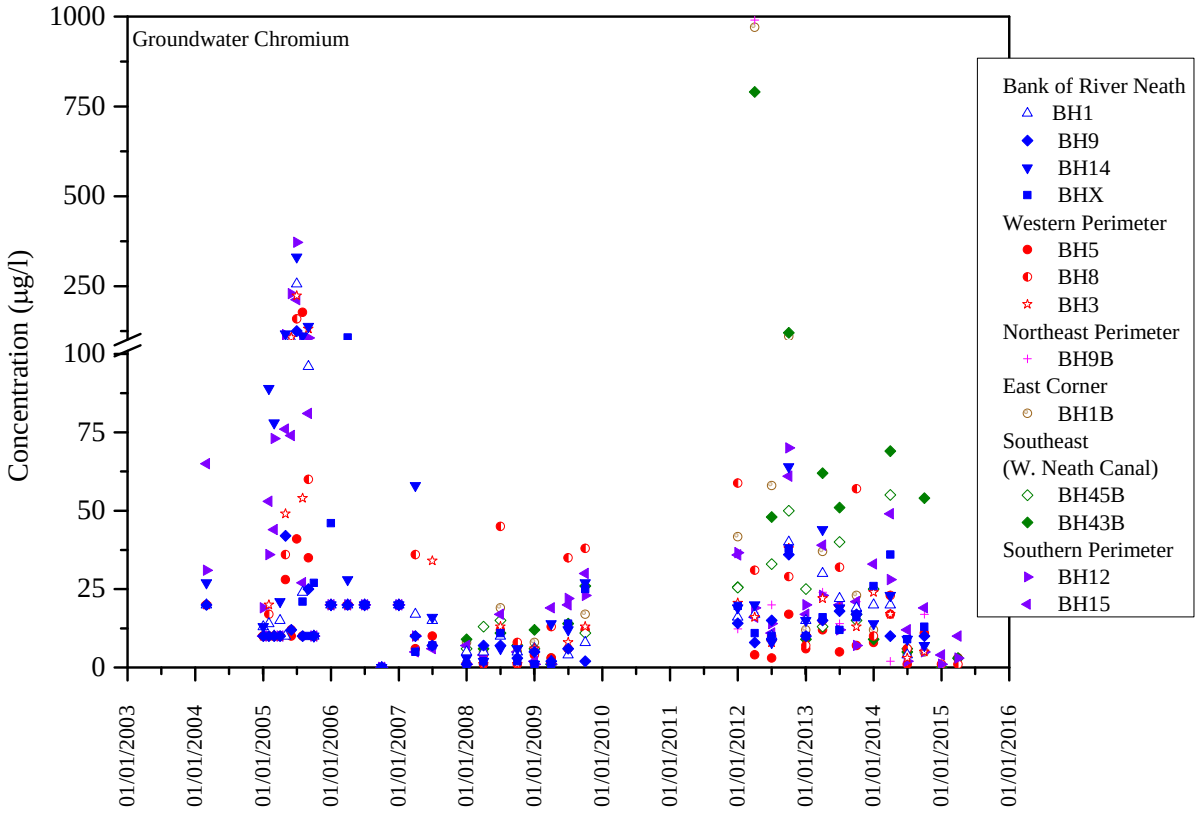


Figure 19 Groundwater Zinc

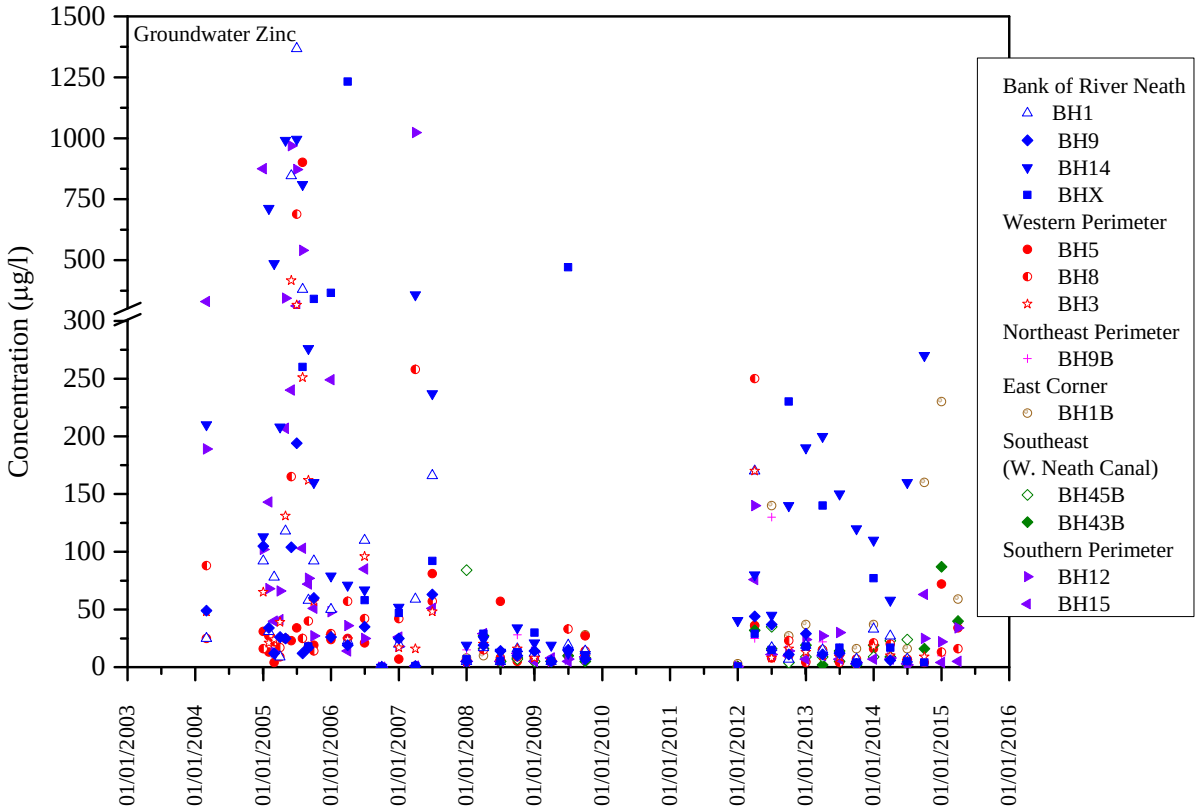
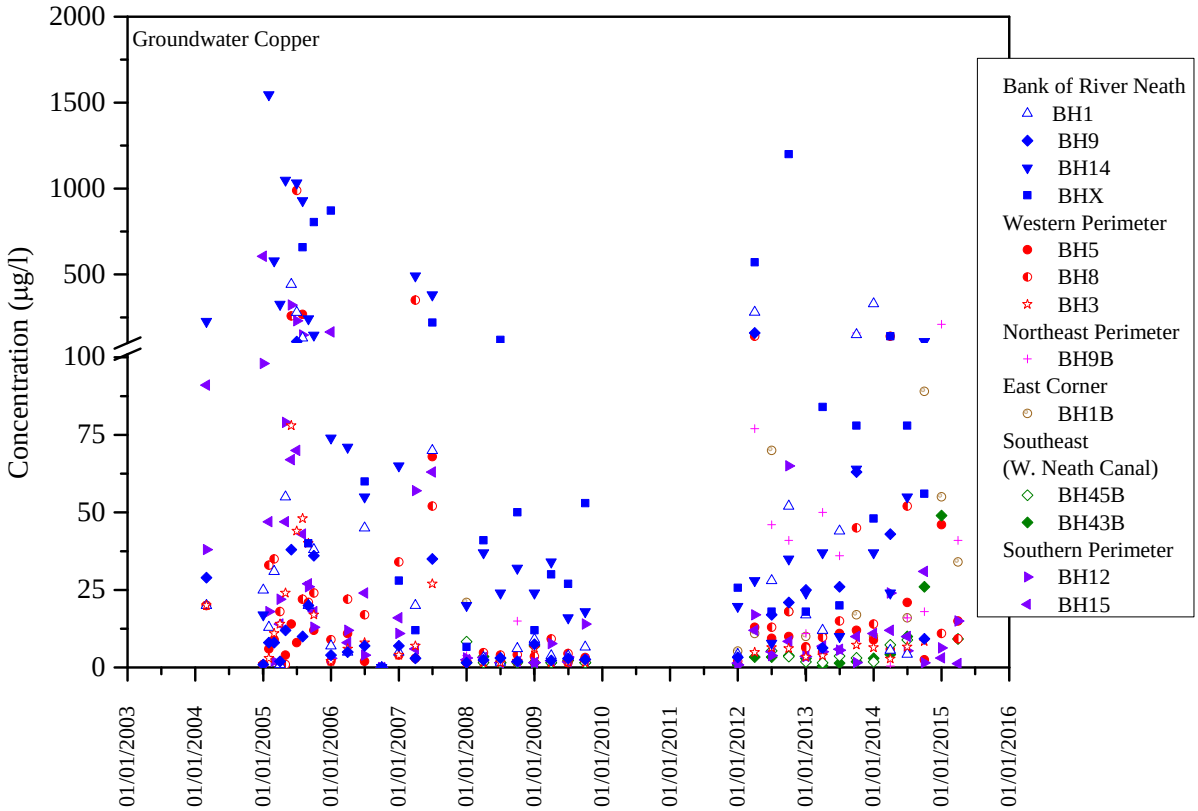


Figure 20 Groundwater Copper



Arsenic is also exhibiting contradicting data, although here is an apparent increasing trend at BH8 associated with the increase in ammoniacal-N in 2008 and 2009, this trend does not occur for BH45B and BH43B (Figure 21). If the increasing arsenic is associated with landfill leachate, a consistent response would be expected at BH43B, where there is an identical increase in ammoniacal-N at this time and as such there cannot be a correlation between sources.

It is also noted that the groundwater arsenic is in excess of leachate arsenic and therefore there must be an alternative source unrelated to the landfill (Figure 22). A potential source, as the site setting is adjacent to a steel works, down river of a major coal production area, and bounded by a railway and canal. All of these sources would have used coal and hence it is likely that ash and other arsenic forms (such as iron-arsenic minerals) have accumulated within the salt marsh. Such tidal areas are known to develop sulphate reducing conditions and hence any dissolved iron and arsenic could readily precipitate from solution and accumulate within the alluvium.

Figure 21 Groundwater Arsenic

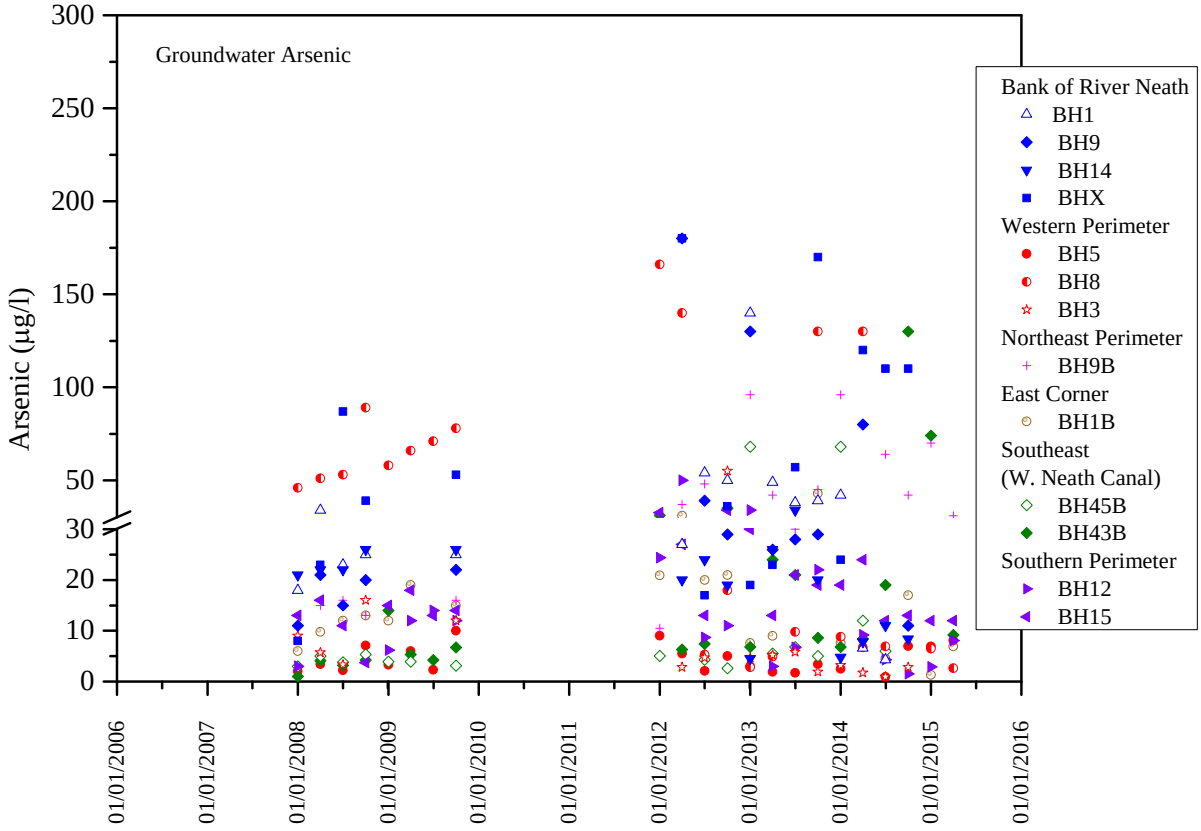
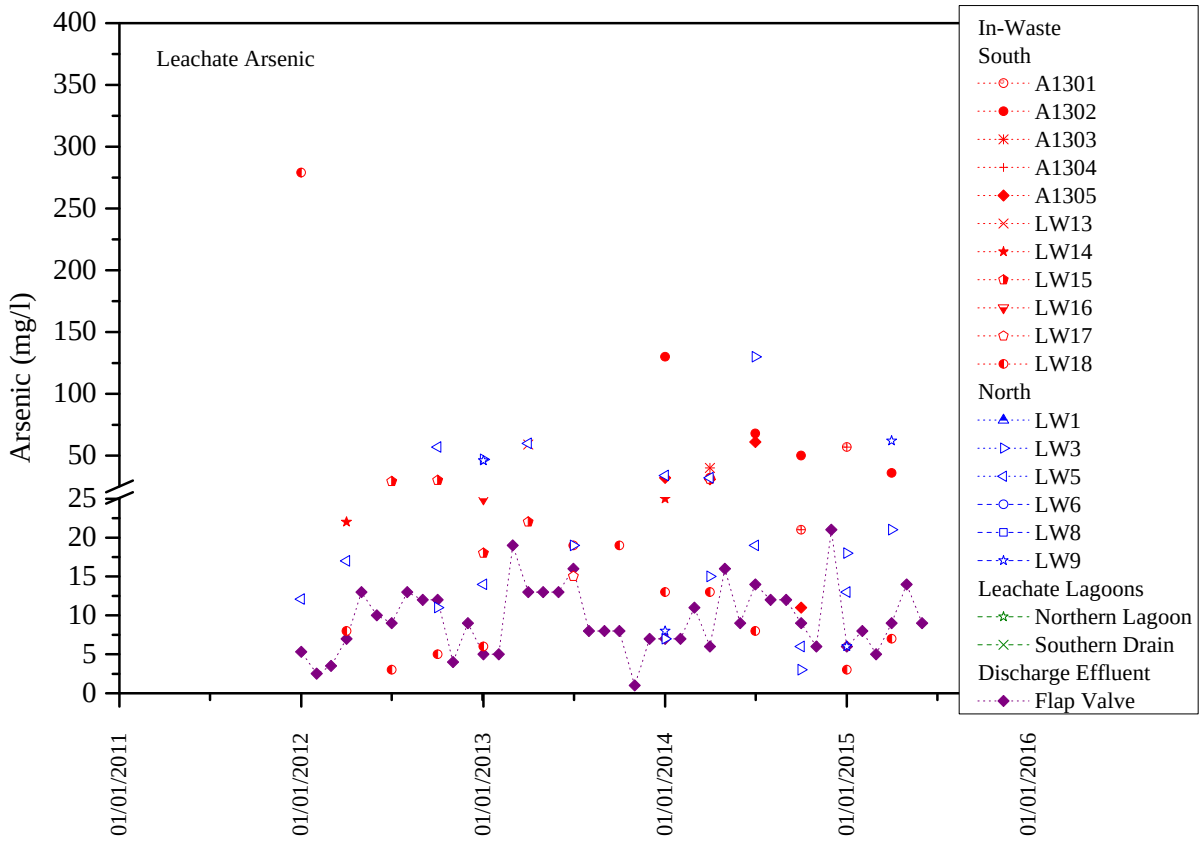


Figure 22 Leachate Arsenic



Organic Substances

Annual organic screens are undertaken as part of the routine monitoring schedule. The organic screens consistently demonstrate that there are a limited number of substances present above detection limits (Table 7).

The data demonstrates that there are minor amounts of the PAHs naphthalene and benzo[a]pyrene reported within the groundwater. However neither substance can be correlated with the elevated ammoniacal-N identified at BH43B, BH45B or BH8 and therefore it is unlikely that the source is from the landfill.

Phenol and 3,4-methylphenol are highly soluble hydrolysis products which can be rapidly degraded under both aerobic and anaerobic conditions with half-life's of hours to days. They are usually only discernible within the early stages of waste disposal within a cell where the development of a microbial population has not yet developed and hence phenols are observable whilst there is sufficient freshly disposed putrescible waste for hydrolysis rates to exceed biodegradation rates. Therefore it is surprising that phenol and methylphenol associated with landfill leachate could be discernible in the groundwater, as such a causal relationship between the landfill and the 270µg/l phenol and 730µg/l methylphenol observed at BH9B in October 2014 cannot be substantiated, particularly as phenols have not been reported at BH45B, BH43B and BH8, the locations containing elevated ammoniacal-N.

The phenol and methylphenol at BH9B in October 2014 does however correlate with elevated TOC (290mg/l) and BOD (46mg/l) and a pike in ammoniacal-N (from 1.3 to 11mg/l) with an estuarine chloride of (5,300mg/l) and it is therefore likely to be associated with saline intrusion or other non-landfill source containing degradable organic matter. If the source had

been leachate, then ammoniacal-N would be expected to be at least an order of magnitude higher to be associated with such a high chloride. However irrespective of the source, ammoniacal-N and phenol concentrations at BH9B have continued to deplete on each successive monitoring event and as such the depletion is also demonstrative that the source is not an uncontrolled landfill leachate.

The herbicide mecoprop has been identified at four locations BHX, BH8, BH43B and BH45B at concentrations marginally above the 0.1μg/l DWS for a herbicide, however, peak concentrations of 2μ/l are not environmentally significant for coastal or transitional waters, where the good standards for rivers, lakes and transitional waters is an annual average of 18μg/l.

The TPH analysis has reported concentrations slightly above detection limits. However, this analysis is not specific to refined petroleum hydrocarbons as it is based on a solvent extraction then reporting of the amount of material extracted. In organic rich waters, such as the biologically active salt marsh environment, in all likelihood the analysis is reporting natural organic matter including solid / colloidal organic matter rather than a petroleum spillage.

Table 7 Summary of Maximum Present Organic Substances in Groundwater

	Naphthalene	Benzo(a) Pyrene	Phenol	3,4 - Methylphenol	Mecoprop	TPH (Aliphatic) total	TPH (Aromatic) total
		ug/l	mg/l	ug/l	ug/l	mg/l	mg/l
BH1	<0.05	0.04	0.001	<1	<0.04		
BH3	0.11	<0.10	0.110	<1	<0.04	0.21	0.08
BH9	0.48	<0.01	0.001	<1	<0.04		
BH14	0.22	0.12	<0.005	<1	<0.04	0.04	0.03
BHX	0.05	0.10	<0.0005	<1	0.17	0.01	
BH1B	0.04	<0.01	0.016	<1	<0.04		0.01
BH5	0.12	0.04	0.001	<1	<0.04	0.01	
BH8	0.08	<0.10	<0.016	<1	2.00		
BH9B	0.24	<0.01	0.270	730	<0.1	0.15	0.02
BH12	2.40	0.15	<0.016	<1	<0.04	0.02	
BH15	3.30	0.25	<0.016	<1	<0.04	0.06	
BH43B	<0.01	<0.01	<0.016	<1	1.80		0.07
BH45B	<0.01	<0.01	<0.016	<1	0.51	0.04	

*Shaded cells are above the DWS and display outliers
**Outlier in October 2014 of 730μg/l removed from table, all the other data points at <1μg/l

4.3 Comparison with Permit Limits

Permit limits have been proposed within the 2010 HRA, the majority of substances have been below these limits between 2012 and June 2015, although there are a number of outliers where limits have been exceeded (Table 8).

The Permit Limits were derived using a statistical methodology with the purpose of benchmarking the groundwater chemistry for key determinands which can then be used to identify whether there has been a detrimental change in groundwater quality.

A review of the data demonstrates that phenol has only exceeded the 2010 proposed limits on two occasions, of these, phenol at BH1B was reported at the detection limit and the exceedances at BH9B have been discussed as a single event which does not appear to be

related to landfill leachate migration. This same event caused the exceedance of ammoniacal-N identified for BH9B.

The only other ammoniacal-N exceedance was reported for BH45B occurred in March 2012, *i.e.* at the end of the 'sustained period' of elevated ammoniacal-N. It is therefore representative of a historic event which time series analysis demonstrates is no longer occurring.

It is noted that the only two locations where elevated mercury have been identified BH12 and BH15. With regards to BH12 the elevated ammoniacal-N is reported at one of the limits of detection used (<0.05µg/l) and are not associated with elevated ammoniacal-N and therefore it is unlikely to be related to leachate migration. Similarly the 0.27µg/l mercury reported in October 2013 and 0.18µg/l reported in April 2015 are associated with 0.22mg/l and 0.68mg/l respectively. Not only is this an inverse relationship, but ammoniacal-N concentrations are not significant given the site's setting. It is therefore considered that the mercury concentrations observed are not related to landfill leachate.

Arsenic is more difficult to interpret as superficially there is an apparent correlating relationship between elevated arsenic and elevated ammoniacal-N, however, as discussed above there is a more complex relationship whereby the peak arsenic concentrations are not associated with elevated ammoniacal-N, and of the two locations where ammoniacal-N concentrations increased in parallel (*i.e.* BH8 and BH453B), the increase in arsenic only occurred at BH8. With regards to the recent period elevated arsenic appears to have a greater correlation with the edge of the River Neath than with the western edge of the landfill (Figure 23). It is therefore considered that the primary source of the arsenic in groundwater is redox cycling of sediment iron-arsenic oxide and sulphide minerals independent of the influence of the landfill site.

The use of the current Permit Limits as spot checks that identify pollution caused by the Giant's Grave landfill is therefore flawed and inappropriate. However, the limits can be used as a marker to undertake a more detailed evaluation of the holistic dataset include complementary substances and time series analysis to determine if there are increasing trends which could be attributable to leakage from the landfill which could cause pollution.

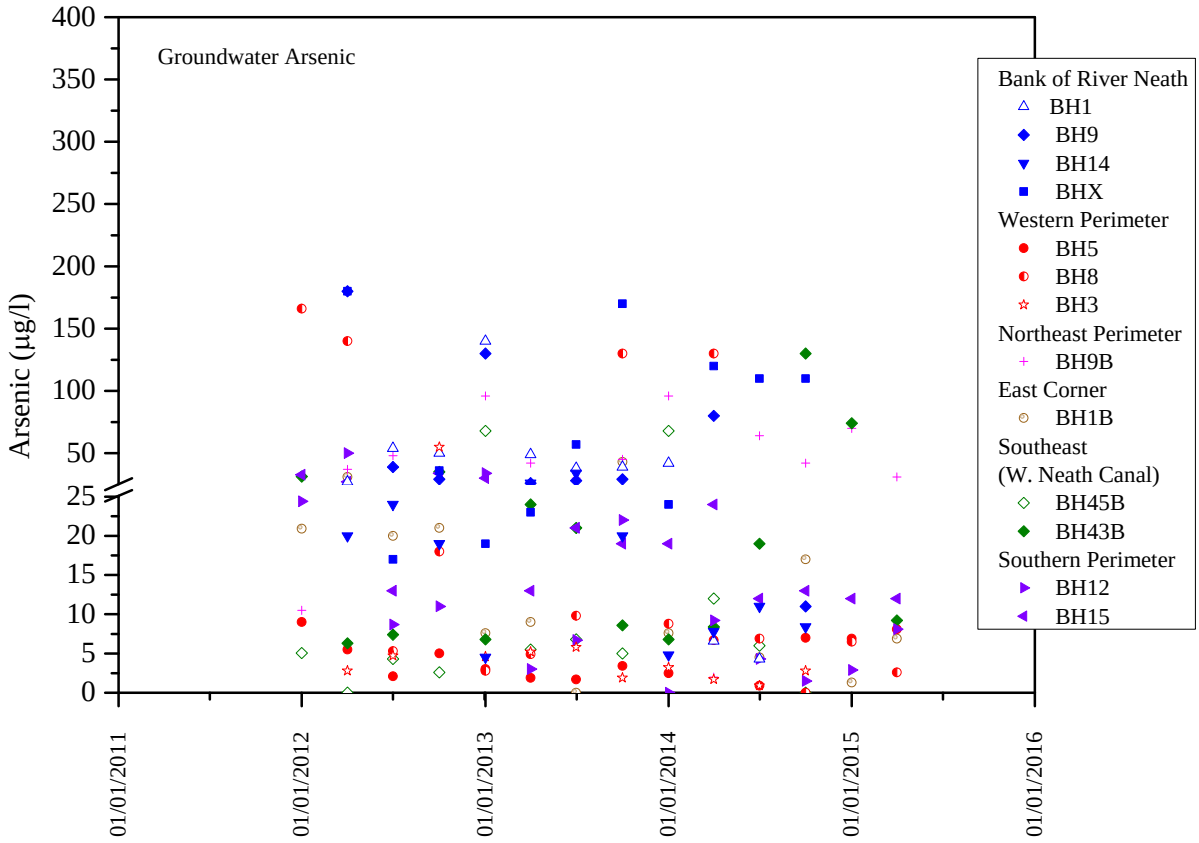
Significantly, the monitoring data demonstrates a continued improvement in groundwater quality between 2012 and 2015 which is indicative that there is not a continuous or worsening leakage from the site.

Table 8 Comparison of Maximum Concentration of 2012-2015 with 2010 Proposed Limits

Borehole	Location	NH_4-N		Mercury		Arsenic		Phenol	
		Limit	Max	Limit	Max	Limit	Max	Limit	Max
		mg/l		µg/l		µg/l		mg/l	
BH1B		3.1	1.5	0.01	<0.05	34.28	43	0.015	0.016
BH5		23.2	1.4	0.01	<0.05	19.02	9	0.015	0.0006
BH8		88.6	76.3	0.01	<0.05	254	166	0.015	<0.016
BH9B		1.6	11	0.01	<0.05	13.8	96	0.015	0.27
BH12		2.5	2.4	0.01	0.05	107	50	0.015	<0.016
BH15		2.3	1.6	0.01	0.27	1516	34	0.015	<0.016
BH43B		108.9	93.1	0.01	<0.05	98.5	130	0.015	<0.016
BH45B		59.5	76.4	0.01	<0.05	6.22	68	0.015	<0.016

shaded cells exceed proposed Permit Limits

Figure 23 Groundwater Arsenic



Surface water

Surface water monitoring is undertaken on a monthly basis from the River Neath and the Neath Canal to the north and south of the site. The results are summarised in Table 7.

Table 9 Summary of Surface Water Monitoring points 2012 - 2015

		Ammoniacal-N		Chloride		Nickel	Phenols
		Limit	Conc^n	Limit	Conc^n		
		mg/l	mg/l	mg/l	mg/l	µg/l	mg/l
River Neath North	Min	0.4	0.05	24,074	38	3	<0.0005
	Median		0.23		10,050	10	<0.0005
	Max		1.7		20,000	92	<0.016
River Neath South	Min	0.5	0.05	53,031	460	3	<0.0005
	Ave		0.27		10,050	10	<0.0005
	Max		1.9		21,000	80	<0.016
Neath Canal North	Min	1	<0.05	27	7	<1	<0.0005
	Median		0.2		15	3	<0.0005
	Max		1.9		250	9	<0.016
Neath Canal South	Min	0.5	<0.05	25	7	1	<0.0005
	Median		0.2		15	3	<0.0005
	Max		2.1		450	30	<0.016

The data confirms the seawater influence on the River Neath as median chloride concentrations of 10,000mg/l are at 50% of seawater concentrations, with the reported chloride being dependent on the precise part of the tidal cycle sampled (Figure 24). In contrast the Neath Canal is consistent with a terrestrial water, with chloride typically negligible at <30mg/l, although isolated outlier concentrations are apparent, for these to be

related to leachate would require a significant turn-over of the canal volume and hence would be apparent in both the north and south sampling locations (Figure 25).

Figure 24 Surface Water chloride

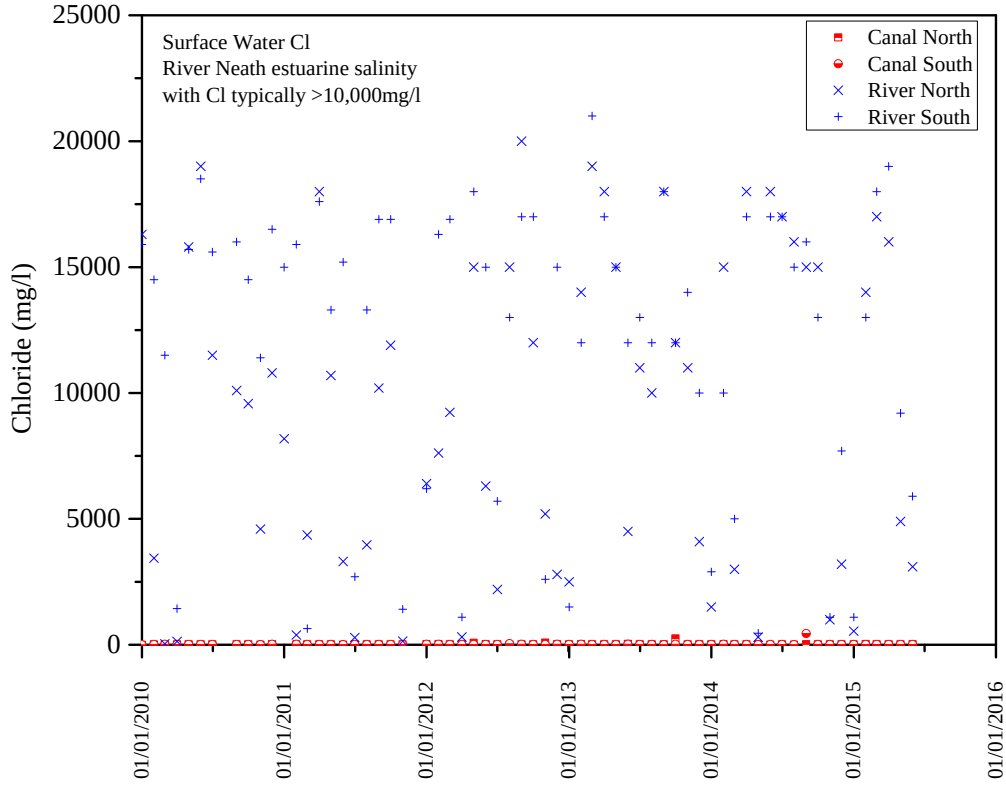
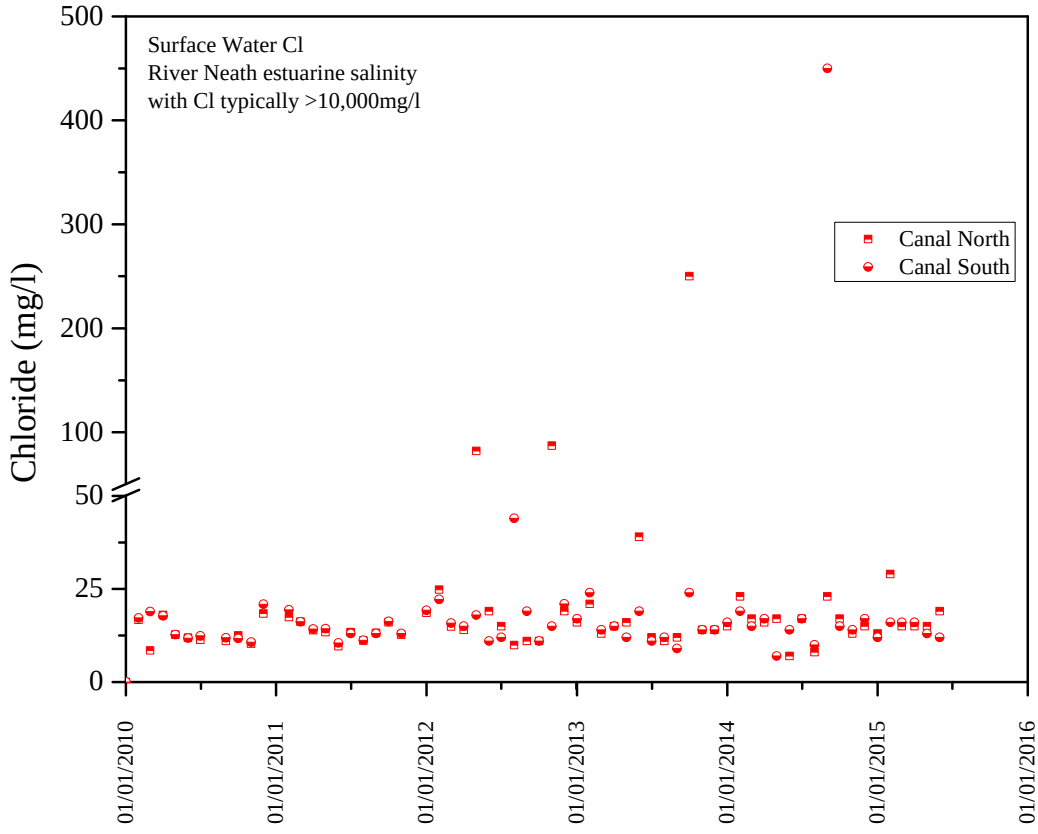


Figure 25 Neath Canal Chloride



There appears to have been a step change in the ammoniacal-N concentrations reported for both the River Neath and the Neath Canal. Prior to mid 2012, ammoniacal-N was predominantly reported at the detection limit (<0.2mg/l), however from mid 2012, there has been a wider distribution in reported ammoniacal-N concentrations from <0.01 - 2mg/l (Figure 26).

Significantly ammoniacal-N is greater in the River Neath than the Neath Canal and there is no significant difference in reported concentrations at either water body between the northern and southern sampling points. Such an influence on the River Neath ammoniacal-N both to the north and south of the site cannot be due to the landfill and therefore it is considered that the data is representative of the background system within the context of analytical capabilities.

With regards to the Neath Canal there does not appear to be a relationship between elevated ammoniacal-N and chloride which would be expected if there was a pollution linkage with the landfill site (Figure 27). There is however an elevated BOD in the 10 - 50mg/l range which is in excess of that reported for groundwater (Figure 28).

Therefore given that ammoniacal-N is essentially a closed and static water system (as the canal is no longer used), the most likely source of ammoniacal-N is from algal growth and dieback cycles leading to the consumption and release of ammonium. The inclusion of algae within samples could also account for the occasional BOD spike identified within the canal.

Figure 26 Surface Water Ammoniacal-N

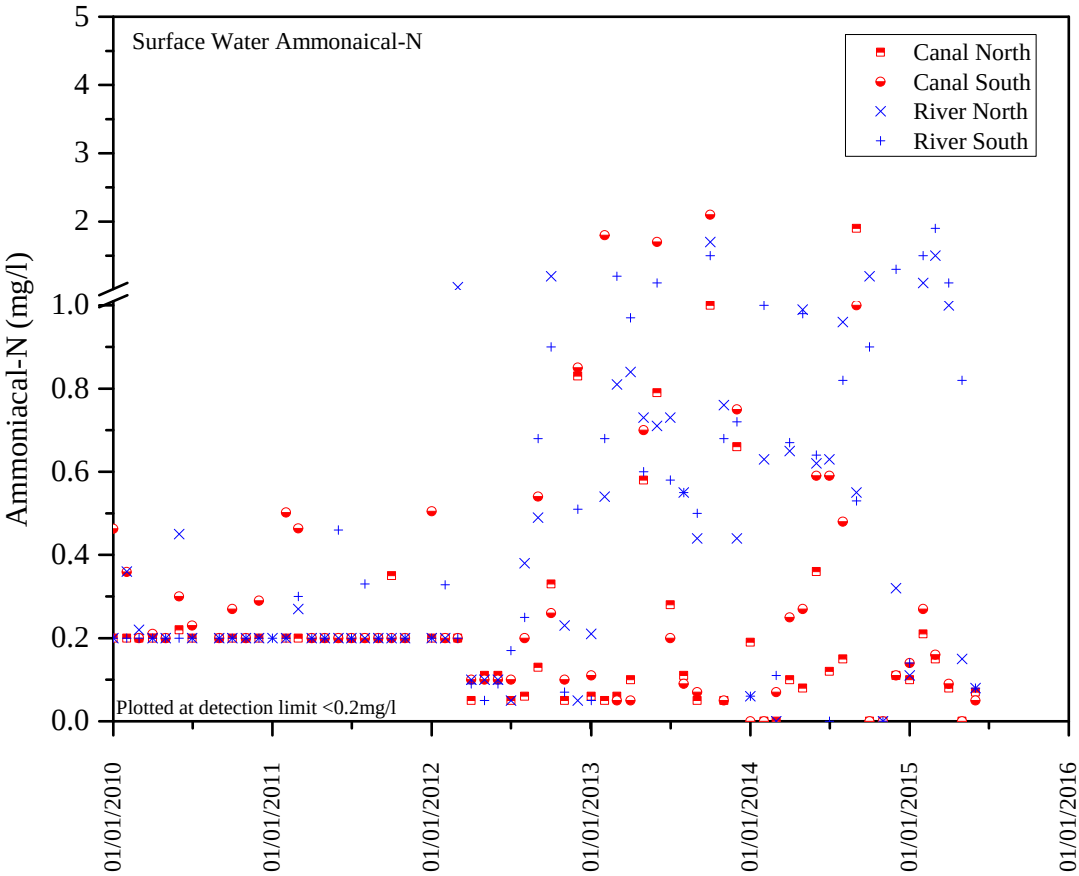


Figure 27 Neath Canal Chloride and Ammoniacal-N

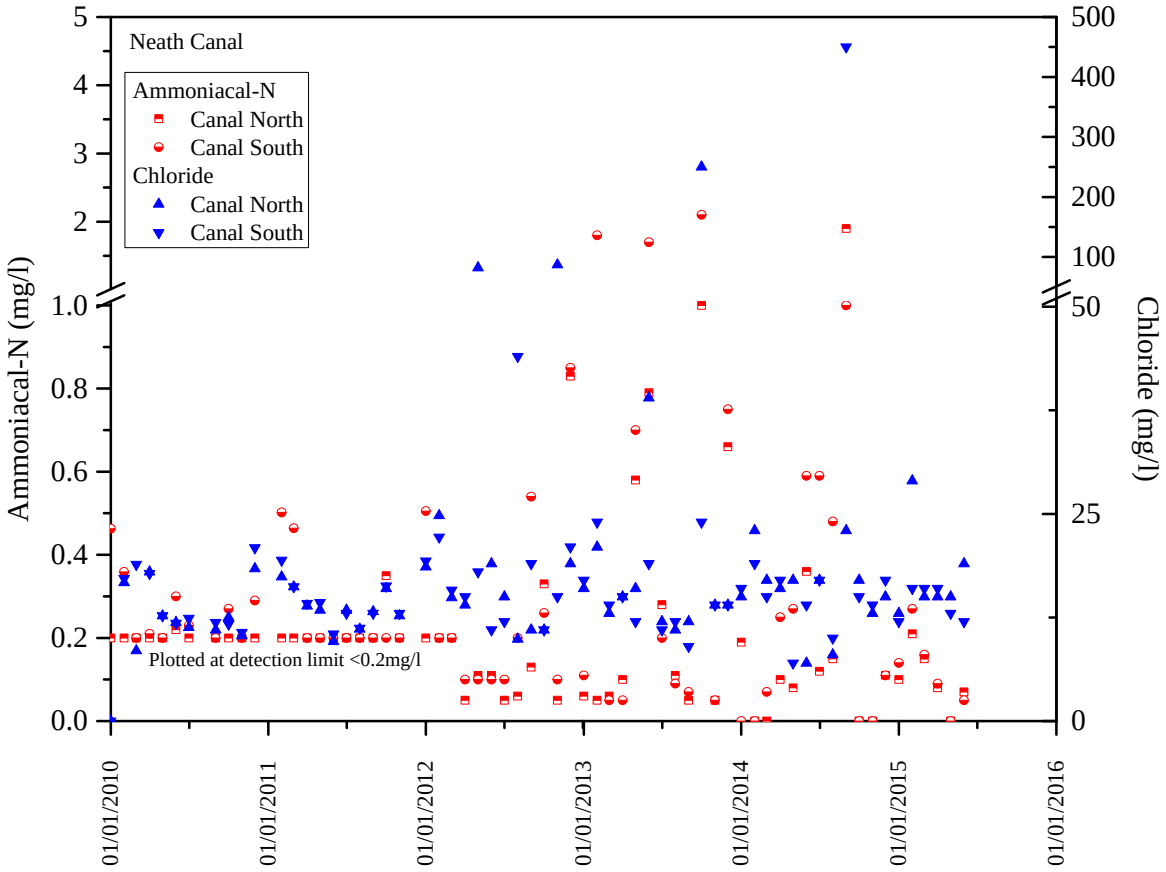
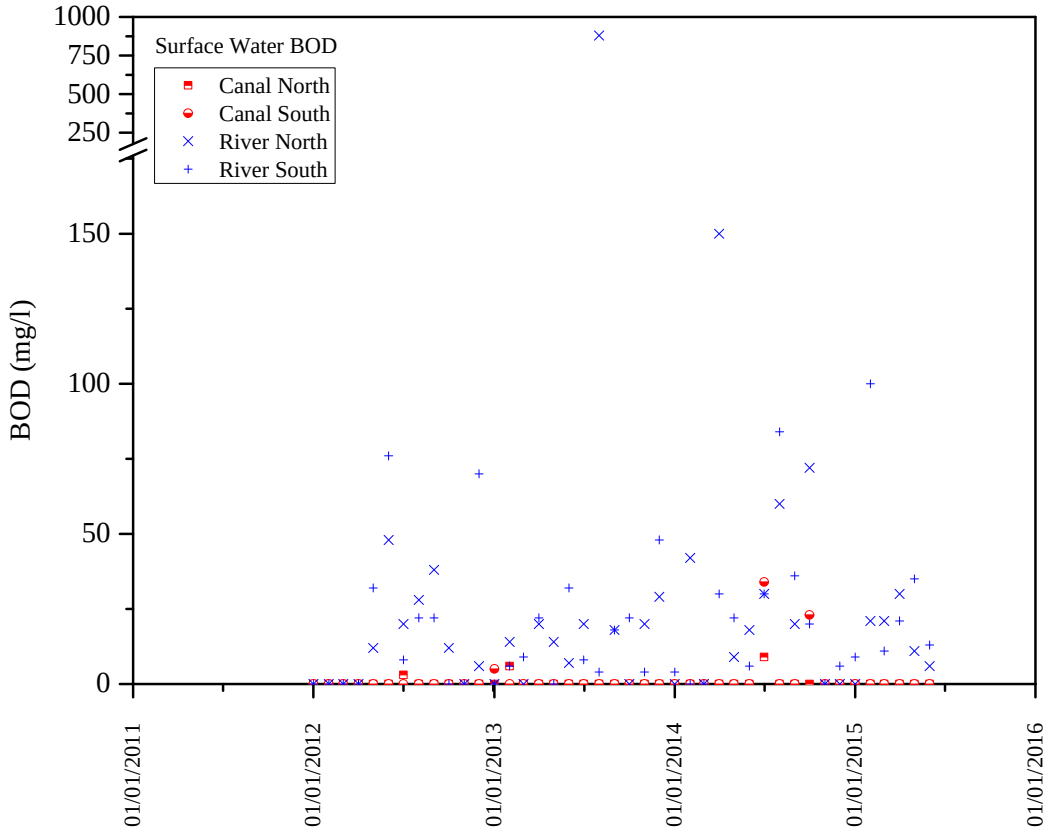
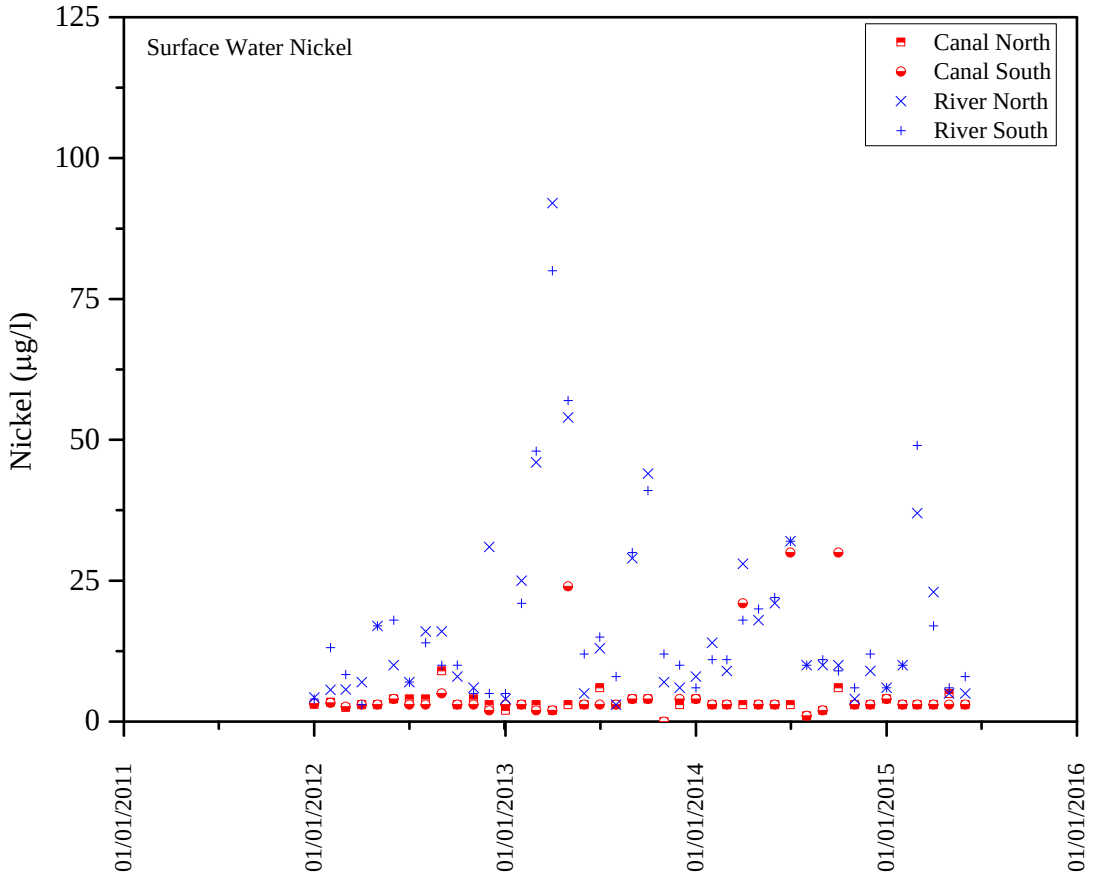


Figure 28 Surface Water BOD



Nickel concentrations are typically low in both the canal and the river (Figure 29). With regards to the canal, elevated nickel appears to occur as isolated outliers, whilst there is a constant nickel background with the River Neath at a level which can exceed groundwater concentrations. This bias within the River Neath therefore implies a background nickel contribution and that the Giant's Grave landfill is having no effect on environmental nickel concentrations.

Figure 29 Surface Water Nickel



Reed Bed Discharge

Leachate is treated within "The Cut" reed bed system before discharge to the River Neath. The primary function of the reed bed is to reduce ammoniacal-n from the influent leachate to below 190mg/l. The treatment process is highly effective and ammoniacal-N is maintained below 40mg/l and concentrations, particularly in summer are in the <0.1 - 5mg/l range (Figure 30). There does not appear to be a direct relationship with leachate generation which has a slight seasonal bias and is likely influenced by surface run-off from the landfill flanks which are collected within surface water channels before being directed to the reed bed.

The non-hazardous metals and metalloids are also consistently below their respective Permit Limits (Figure 31), except for the occasional outlier. Arsenic appears the most variable and highest persistently concentrated substance. The most significant recent outliers are for copper at 360µg/l and 140µg/l in May and December 2014 respectively, however, these elevated concentrations were not continuous across successive monitoring events and are not indicative of a process failure within the reed bed. There is also no apparent correlation between each metal indicative of a higher concentrated leachate pulse passing through the cut.

Figure 30 Treated Leachate Discharge - Ammoniacal-N

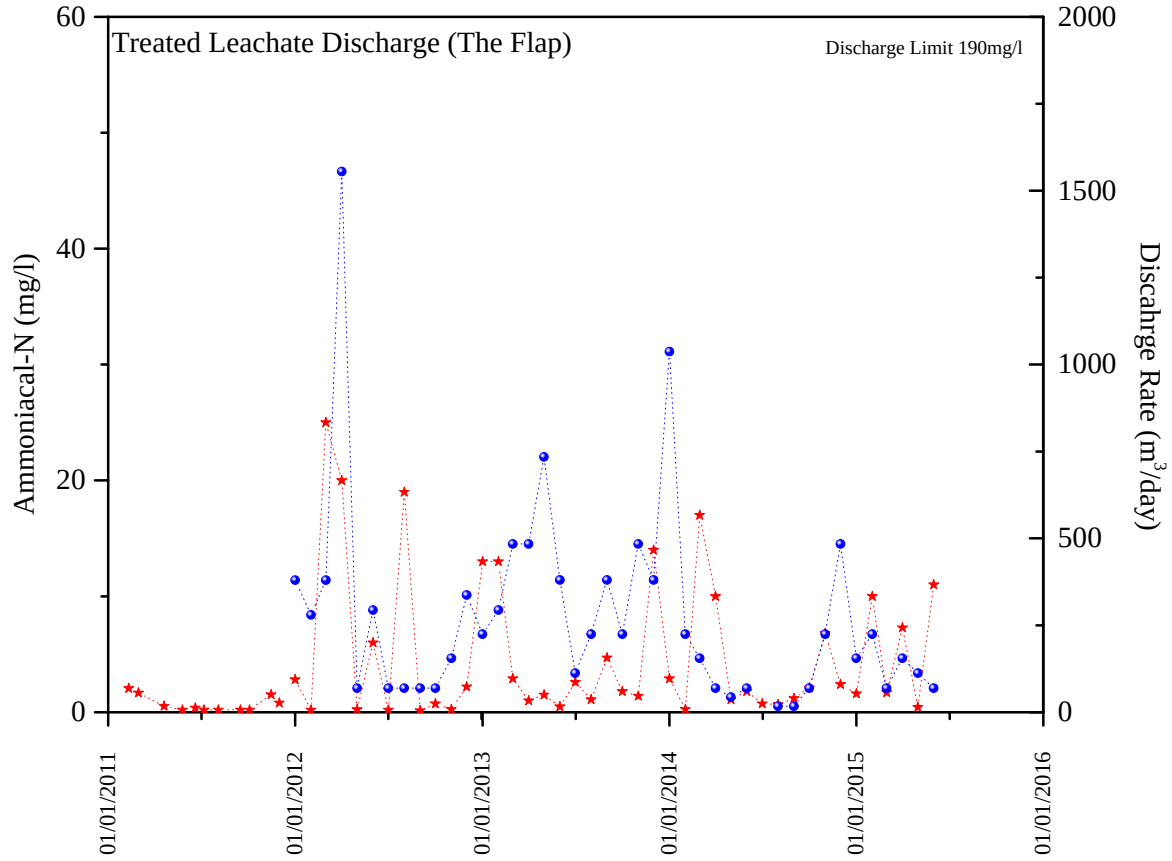
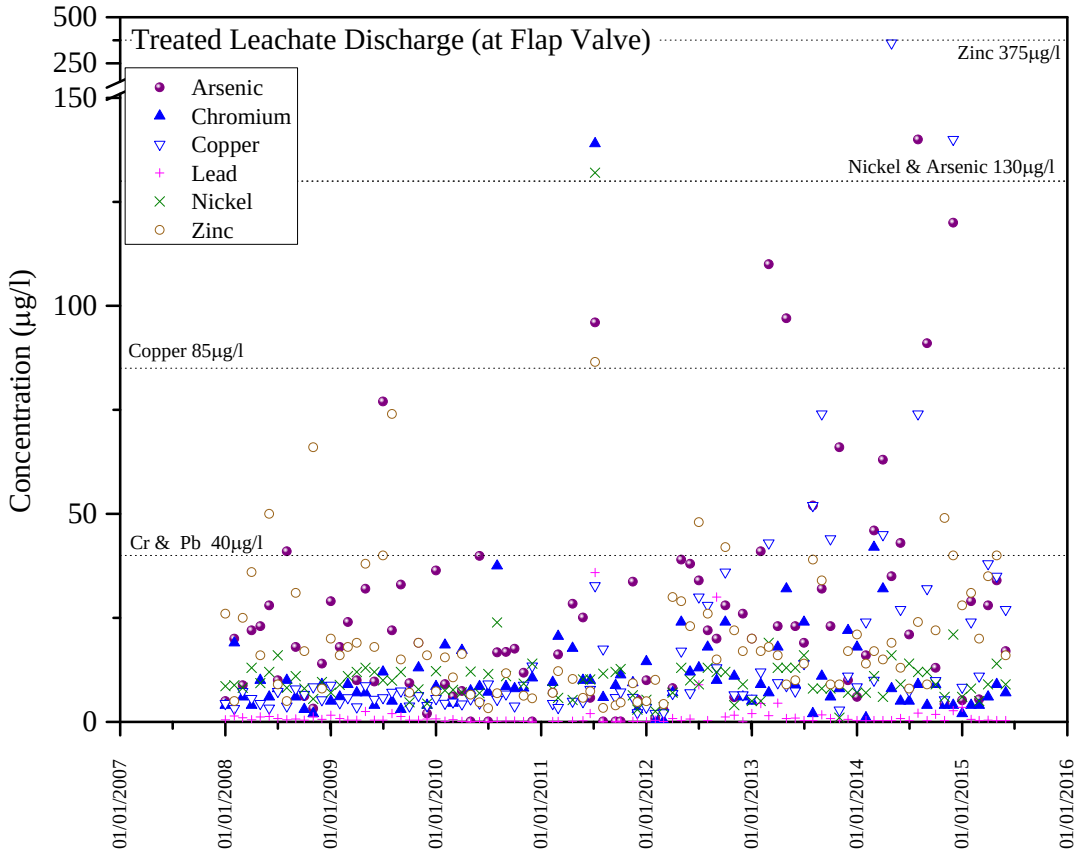


Figure 31 Treated Leachate Discharge - Non-hazardous metals & Metalloids



5. CONCEPTUAL SITE MODEL

A simple conceptual model has been constructed for the site (Figure 32), based on the relationship

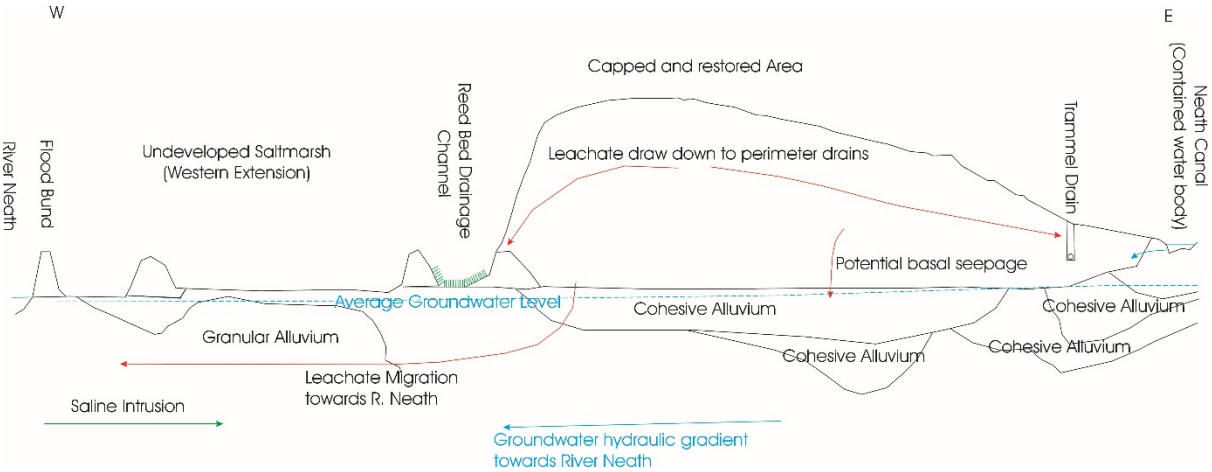
Source → Pathway → Receptor

Where:

- The Source is leachate within the landfill;
- The Pathway is the natural strata beneath the landfill and the groundwater; and
- The Receptor is the River Neath

This landfill is in the aftercare period, where levels are actively maintained. Leachate is managed by limiting infiltration through the restored surface and contained by underlying cohesive sediments. The potential for leachate accumulation within the site is managed by the passive drawdown into perimeter interception drains. These perimeter drains in combination with the capped surface prevent lateral outbreak of leachate migration, and the collected leachate is discharge via a reed bed treatment system.

Figure 32 Schematic Conceptual Model



The Neath Canal is an enclosed water system with an artificially maintained water level which would act against a hydraulic gradient from the direction of the landfill. The River Neath is therefore the primary receptor adjacent to the site.

There are two potential pollution migration pathways, namely via basal seepage or lateral seepage. The potential for lateral seepage is low to negligible due to the surface drainage channels which direct leachate to the reed bed. Therefore the only viable pollution route is vertical leakage through the cohesive alluvium and into the granular alluvium towards the River Neath.

In a terrestrial system, the granular alluvium would usually be classified as an aquifer and the cohesive alluvium as non-productive strata (*i.e.* a geological barrier). The geological barrier properties of the cohesive alluvium are demonstrated as there is not the continuous leakage of a polluting leachate from the landfill site as demonstrated by the localised and temporal distribution of ammoniacal-N. There has only been one credible uncontrolled leakage event, which is the identical appearance of ammoniacal-N in 2006 at BH43B and BH8. This event appears to be localised to the vicinity of BH43B where ammoniacal-N

concentrations are following a slow depleting trend in contrast to other locations where there has been rapid ammoniacal-N depletion. Consequently it must be assumed that whatever the source of the 2006 ammoniacal-N outbreak that the management controls implemented, which may include surface sealing / profiling and interception drain maintenance had had a mitigating effect by the 2012.

It is also apparent that the cohesive alluvium has the necessary hydraulic containment as well as attenuation properties necessary to prevent contamination migration downgradient of the site, except for where there is a preferential conduit. Notwithstanding the above, the alluvium is also considered as a source of the persistent leachate constituents including chloride, arsenic and other non-hazardous metals, such as zinc, chromium and copper. Significantly this source appears to have a greater influence on the groundwater quality and biochemistry than the landfill, particularly where concentrations are greater outside of the site than within the leachate.

Outside of the cohesive alluvium there is the potential for mixing with the groundwater flux within the granular alluvium and then dispersion and attenuation before mixing within the River Neath. This mixing will occur in two stages, the first of which is mixing with an increasingly saline water within the saline intrusion zone of the granular alluvium and the second within the river itself.

6. RISK ASSESSMENT

6.1 Justification for Modelling Approach and Software

There is not a substantive change to the site compared to the September 2010 HRA as the current restoration landform was completed in 2007. No new landfill cells have been constructed within either the western or southern extension areas and therefore there has not been a change in the pollution load or construction of new engineering cells.

Conceptually there has therefore been no change to the site or the setting with the only substantive change between the 2010 HRA and at present is the additional stabilisation period for the landfill since 2010.

In 2010 the site was modelled using the Risk Assessment Model (RAM) developed by ESI Ltd. The model was selected in preference to LandSim and ConSim as neither model could conceptualise the site setting to the same degree as the RAM which has the capability of considering multiple pathways. RAM is a quasi-two dimensional model that allows the stochastic assessment of leaching, retardation and degradation of contaminants along the migration pathway to a receptor.

Model parameters are appended.

6.2 Modelling Conclusion

The 2010 HRA predicted that the hazardous substances modelled (*i.e.* mercury, malathion and toluene) as well as the non-hazardous substances arsenic, mecoprop and toluene would be completely retarded (*i.e.* concentrations predicted at <0.001μg/l, reducing to $<10^{-36}$μg/l) within the alluvium.

The model demonstrated that mixing within the granular alluvium along with attenuation and dispersion within this unit was sufficient to prevent pollution. There was an even higher degree of protection when the cohesive alluvium was also considered (Table 10).

These conclusions were drawn for a contaminant transport model in which the modelled leachate head was representative of a conservative approximation of the existing leachate, in which the leachate was assumed as ranging between 5.1mAOD and 12.71mAOD with a most likely elevation of 7.46mAOD.

Table 10 RAM Predicted Concentrations for Priority Pollutants (2010 HRA) in the Alluvium

Determinand	Alluvium Pathways Modelled	
	Cohesive & Granular	Granular Only
	mg/l	mg/l
Mercury	No breakthrough	
Malathion	No breakthrough	$4x10^{-38}$
Toluene	No breakthrough	$1x10^{-29}$
Phenol	$1x10^{-8}$	$9x10^{-6}$
Mecoprop	$3x10^{-34}$	$4x10^{-38}$
Arsenic	No breakthrough	$1x10^{-24}$

Modelling for ammoniacal-N, chloride and arsenic also considered the two components of the alluvium assuming groundwater mixing in a 1m deep zone as well as the impact to the River Neath (Table 11).

The model did not predict a significant difference for chloride which is consistent with expectations for a non-hazardous substance. The model also demonstrates that attenuation within the cohesive alluvium is the primary mechanism for preventing ammoniacal-N migration and that this level of protection was considered to be as effective as dilution within the low flow conditions for the River Neath.

Table 11 RAM Predicted Concentrations for Primary Leachate Non-hazardous Constituents within the Alluvium and the River Neath

Receptor	Pathway	Ammoniacal-N	Chloride	Arsenic
		mg/l	mg/l	mg/l
Alluvium	Granular Only	103	279	$1x10^{-24}$
	Cohesive & Granular	0.04	303	No breakthrough
River Neath	Granular Only	0.05	0.35	$6x10^{-37}$
	Cohesive & Granular	$5x10^{-6}$	0.96	No breakthrough

It is noted that the model predicts a lesser impact on the groundwater for all substances than actually present within the both the alluvium groundwater monitoring points and the River Neath. In addition it is nonsensical to model substances such as chloride into an estuarine system where there is a salinity gradient increasing away from the site.

The model does, however, give a reasonable estimation of the impact observed within BH8, however, the BH8 data was used to calibrate the model. The model conclusions can

therefore be considered as representative of the potential impact directly on the River Neath if the ammoniacal-N at BH8 was ubiquitous across the entire downgradient edge of the site.

Although peak ammoniacal-N concentrations are reported above the modelled maximum (of 568mg/l) at 2,100mg/l, these peak concentrations are not sustained and are localised within the waste mass and therefore not representative of the holistic site leachate. It is this holistic leachate, which is likely to be consistent with the average concentrations observed which could have a non-localised environmental impact.

Significantly since the 2010HRA was undertaken, the monitoring data demonstrates that the average leachate ammoniacal-N concentration has reduced from the modelled average ammoniacal-N concentration of 275mg/l to the recent average concentration of 90mg/l (between 2012 and 2015).

It is therefore considered that the Giant's Grave landfill site does not require further detailed hydrogeological modelling and that the modelling carried out to date is demonstrative of a localised impact, which does not occur across an extended area or the potential to discernibly impact the primary receptor at the site, namely the River Neath estuarine system.

Further modelling is therefore not recommended.

7. REVIEW OF TECHNICAL PRECAUTIONS

The Giants Grave landfill site is a historic site operated to the standards of the time during the period prior to the introduction of the requirements of the Landfill and Groundwater Directives. Consequently the site has not been engineered to modern standards.

Notwithstanding the above technical precautions have been implemented coincident with the level of risk posed by a site of its age and pollution potential. These controls are passive and include:

- a surface profile designed to shed incidental rainfall;
- restoration soil and capping layers designed to limit infiltration into the waste mass;
- a passive drainage system designed to intercept and collect the leachate that is generated; and
- an underlying low permeability *in-situ* geological barrier.

The leachate generation and migration controls are therefore passive with limited potential for failure. Where failure may have occurred, there has been a localised impact within the immediate vicinity of the site which has not translated to a continuous migration plume outside of the immediate area of the site. This impact is no longer occurring.

The site is considered to be in a low risk environment with respect to its setting, that is persistent pollutants do not appear to be accumulating in the groundwater above background levels for a river alluvium in an industrialised area. The impact that has been observed is associated with a non-persistent substance (*i.e.* ammoniacal-N) which will act as a nutrient within a salt marsh system and does not cause a risk to the salt marsh ecology.

8. REQUISITE SURVELLIANCE

8.1 Monitoring Schedule

Monitoring is required to ensure that the landfill continues to stabilise as expected and to demonstrate that the leachate management system continues to operate and does not become compromised resulting in increased pollution of groundwater and surface waters.

Monitoring is therefore undertaken on the routine basis from within the landfill site (Table 12), as part of the leachate interception and treatment system (Table 13), groundwater (Table 14) and surface water (Table 15).

Table 12 Leachate Monitoring Schedule

Location	Parameter	Frequency
LW1, 5, 8,9, 14, 14, 15, 17, 18	Level/Dip Base level	Monthly
LW5, 8, 9, 15, 17	Temp, pH, EC, DO NH_4-N, NO_3	Monthly
3, 16, A1301 - A1304 A1305CV	COD, BOD, TOC Na, K, Ca, Mg Cl, SO_4, Alkalinity Fe, Mn Cr, Cu, Ni, Zn, Pb Cd, Hg Phenol	Quarterly
	Ba, B, F, PO_4, NO_2 Sb, Se, V, U Mecoprop Phenols (Phenol, 2-methylphenol, 4-methylphenol) PAH (Benzo(a)pyrene, Naphthalene) VOC (Benzene, Toluene, Ethylbenzene, o-Xylene, m/p-Xylene) Speciated TPH CWG	Annually

Table 13 Leachate Treatment Monitoring Schedule

Location	Parameter	Frequency
Vee-notch Weir	Flow Measurement	Monthly
Discharge Flap	NH_4-N Fe Cr, Cu, Ni, Zn, Pb As, Cd	Monthly
Leachate Lagoons	NH_4-N, NO_3, COD Cl Ni Phenol	Monthly

Table 14 Groundwater Monitoring Schedule

Location	Parameter	Frequency
BH1B, 3W, 4, 5B 6, 7, 7B, 8, 9B, 12, 15 40B, 43B, 45B	Water Level	Monthly
North BH9B East BH1B, 43B, 45B South BH12, 15 West BH5, 8	Temp, pH, EC, DO NH_4-N, NO_3	Monthly
	BOD, COD, TOC Na, K, Ca, Mg Cl, SO_4, Alkalinity Fe, Mn Cr, Cu, Ni, Zn, Pb, As Cd, Hg Phenol	Quarterly
	Ba, B, F, PO_4, NO_2 Sb, Se, V, U Mecoprop Phenols (Phenol, 2-methylphenol, 4-methylphenol) PAH (Benzo(a)pyrene, Naphthalene) VOC (Benzene, Toluene, Ethylbenzene, o-Xylene, m/p-Xylene) Speciated TPH CWG	Annually

Table 15 Surface Water Monitoring Schedule

Location	Parameter	Frequency
Canal South Canal North River North River South	Temp, pH, EC, DO Suspended Solids NH_4-N, NO_3, COD, BOD Ni Phenol	Monthly

The monitoring suites are prescriptive and wide ranging which contain the likely leachate indicators as well as a series of substances. It appears that the monitoring schedules have been developed to be all inclusive, which is useful whilst data is being collected in order to understand the background system and the developmental status of the leachate. However, this information gathering period has occurred and the holistic evaluation of the data demonstrates that the monitoring schedule is primarily identifying false positives unrelated to leachate migration.

Within this there are also Permit Limits set which have no purpose, for example setting chloride concentrations at seawater levels within the River Neath.

8.2 Recommendations

The modelled assessment, which demonstrated that the site was unlikely to cause a future unacceptable detrimental impact on the environment, was undertaken assuming leachate elevations within the current range. As the leachate controls are passive and a steady-state system has developed it is considered appropriate that leachate level limits are based on the existing steady-state condition.

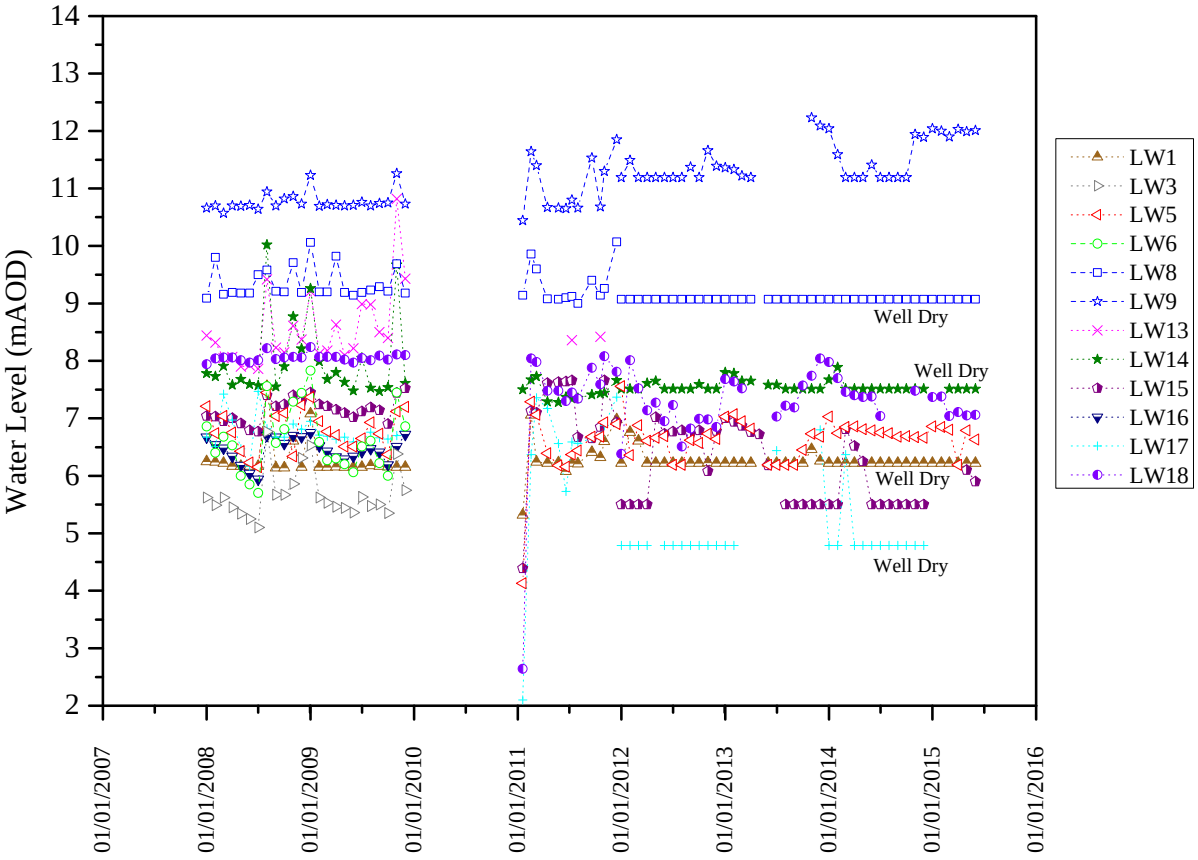
Therefore it is recommended that leachate level limits are revised in accordance with the steady-state that has developed and set as a mAOD limit, representative of the 'domed' leachate profile that has developed with a draw down towards the perimeter drains. As such this does include a philosophy change from a limit set at a height above an arbitrary elevation.

The objective of the leachate level monitoring programme would therefore be to demonstrate the continuation of the observed steady-state does system and as such the following limits, based on a measureable increase above recent data (Figure 33) for key locations are proposed (Table 16):

Table 16 Proposed Leachate Limits

Location	Limit
	mAOD
LW1	6.4
LW5	7.3
LW8	10.2
LW9	12.3
LW14	8.0
LW15	7.5
LW17	7.5
LW18	8.2

Figure 33 Recent Leachate Elevations



Given the complexities of the monitoring schedule is proposed that the routine leachate and groundwater schedules are reduced to a more manageable schedule which is targeted towards identifying leachate migration, which in the case of Giant's Grave, can only be related to ammoniacal-N, although chloride and potassium are recommended as supporting determinands to demonstrate that results are not due to a localised dilution incident as shown in Table 17 and Table 18.

Table 17 Leachate Monitoring Schedule

Location	Parameter	Frequency
LW1, 5, 8,9, 14, 14, 15, 17, 18	Level/Dip Base level	Monthly
LW5, 8, 9, 15, 17	Temp, pH, EC, NH_4-N, Cl, K	Quarterly
3, 16, A1301 - A1304 A1305CV	COD, BOD, TOC Na, Ca, Mg SO_4, Alkalinity Fe, Mn Cr, Cu, Ni, Zn, Pb, As Cd	Annually
	Hazardous Substances	Every four years

Table 18 Proposed Groundwater Monitoring Schedule

Location	Parameter	Frequency
BH1B, 3W, 4, 5B 6, 7, 7B, 8, 9B, 12, 15 40B, 43B, 45B	Water Level	Monthly
North BH9B East BH1B, 43B, 45B South BH12, 15 West BH5, 8	Temp, pH, EC NH_4-N, K, Cl	Monthly
	BOD, COD, TOC Na, K, Ca, Mg Cl, SO_4, Alkalinity Fe, Mn Cr, Cu, Ni, Zn, Pb, As Cd, Hg	6-monthly
	Hazardous Substances	Every two years

With regards to the current set of limits, it is recommended that limits are only set for ammoniacal-N as a demonstration that there is not an adverse change or increase which could be related to leachate migration or outbreak. It is apparent that groundwater arsenic, mercury and phenol can only be used as spot measurements if in collaboration with ammoniacal-N, otherwise the data collected is only identifying a localised variation unrelated to leachate migration.

Limits should be retained for ammoniacal-N, however, the use of any limits at Giants Grave should be used with care, with the primary function to trigger an investigation which can confirm a leachate outbreak requiring an engineering solution or a background effect within a biologically active system which includes both aerobic and anaerobic processes where ammoniacal-N cycling can occur.

Similarly there is no point in setting a permit limit for chloride at any location where the primary influence on chloride is seawater, this includes the River Neath. The 2010 proposed Permit Limits of 0.4mg/l and 0.5mg/l for ammoniacal-N to the north and south of the site are inappropriate as background concentrations frequently exceed 3mg/l. However, even in the event that there could be a leachate impact on the river, it is highly unlikely that there is sufficient leachate within the site to cause a discernible increase in concentration. Similarly any permit limit which takes into account background concentrations must be set above 2mg/l.

At Giant's Grave chloride can be used as marker for a leachate outbreak only at the Neath Canal, however, even in this case, the impact of concern is ammoniacal-N leading to eutrophication. Unfortunately the primary cause of eutrophication in semi-static water bodies such as unused canals is algal growth and dieback leading to a depletion in dissolved oxygen concentrations. As such given the canal is an independent hydraulic unit, the current Permit Limits cannot be used for identifying a leachate outbreak as the majority of exceedances would be from natural sources. However, a leachate impact could be hypothesised in the event that the canal increased in chloride, potassium and ammoniacal-N at concentrations inconsistent with mixing with seawater. Such a Permit Limit should exceed 2.5mg/l ammoniacal-N. However, even in this case a causal relationship with a landfill leachate should be determined to prevent false positives due to background processes being misinterpreted as a leachate spillage incident.

9. CONCLUSIONS

The Giants Grave landfill site is a historic site when ceased to accept wastes for disposal in 2003, prior to the requirement for the site to operate under a Pollution Prevention and Control Permit. Since this date, the site has been restored and a passive leachate management system with integrated leachate treatment has been implanted.

A Permit has been issued for the continuation of landfill operation at the site in two physically separated phases which must be engineered to Landfill and Groundwater Directive standards. However, operations within these phases have not commenced.

The site is located within a salt marsh environment, which has been impacted by historical industrialisation. There is not a discernible impact on groundwater downgradient of the site with respect to persistent pollutants which can be attributed to leachate seepage or outbreak. Where an impact can be inferred, this impact is associated with the non-persistent pollutant ammoniacal-N and the impact is not continuous downgradient of the site. Significantly, the ammoniacal-N concentrations observed are not toxic to a salt marsh or reed bed ecology.

It is considered that the site is continuing to stabilise and that any impact the site has had on the environment has peaked and that there will be continued improvement to the environment overtime as the site continues to stabilise.

It is considered that the Giant's Grave landfill site does not require further detailed hydrogeological modelling and that the modelling carried out to date is demonstrative of a localised impact, which does not occur across an extended area or the potential to discernibly impact the primary receptor at the site, namely the River Neath estuarine system.

It is recommended that the monitoring schedule is simplified and targeted towards the identification of leachate impacts on the environment, such as an uncontrolled leachate outbreak. As part of this simplification it is also recommended that leachate level height monitoring is based on an absolute elevation (mAOD) representative of the steady-state that has developed. This recommendation is also based on the conclusions from risk assessment.

Appendix A

2010 RAM Model Input Parameters

B1404900 TASK H: RAM data input for HRA of existing landfill

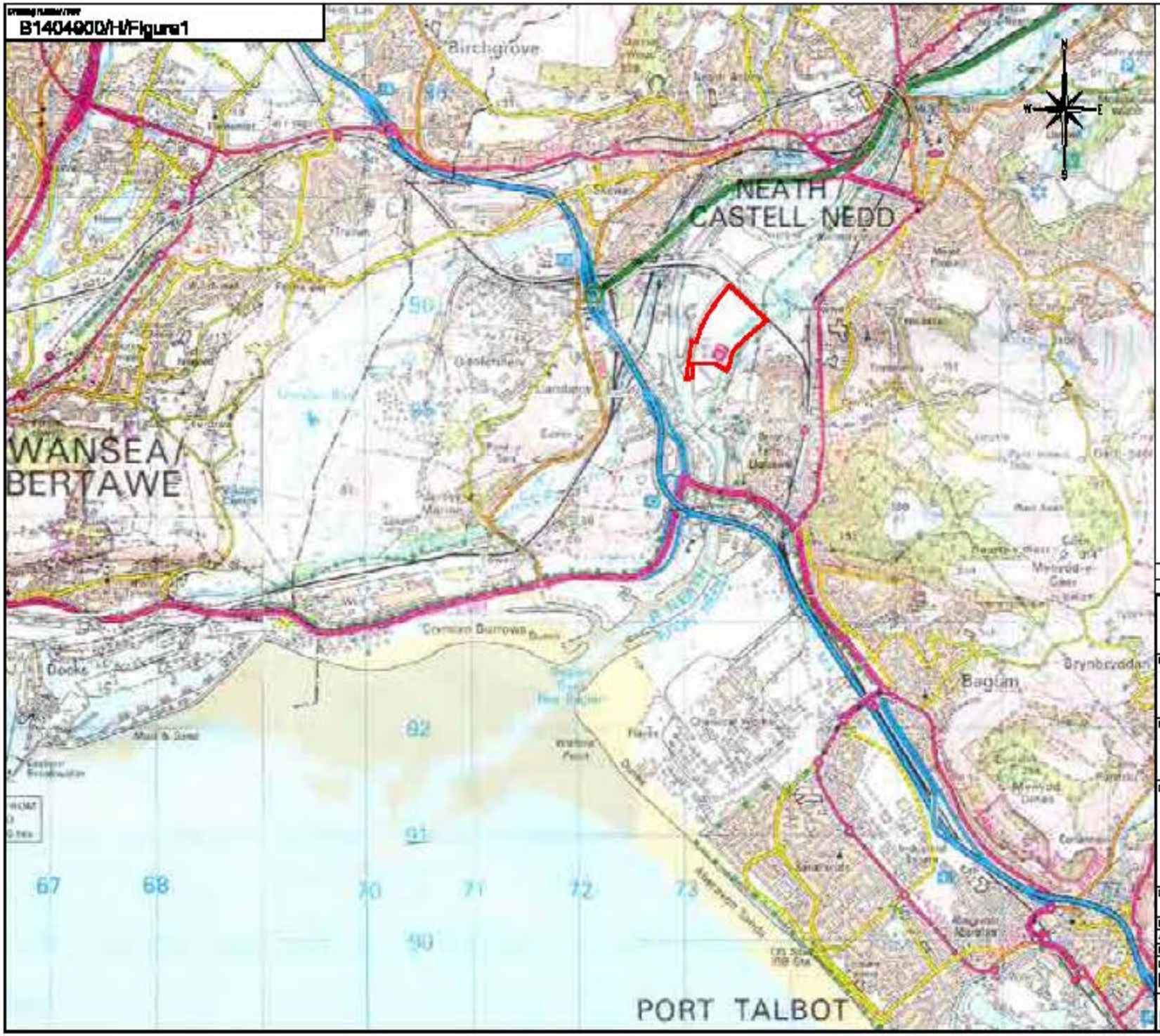
PARAMETER	UNIT	VALUE	COMMENTS
Control			
Advanced level			
Probabilistic			
Receptors			
User Defined Receptor 1: River Neath			Based on average groundwater direction it is estimated that this receptor is at a distance of 470m from the center of the landfill, receptor for non-hazardous pollutants
Q_Dilute (Receptor 1)	m^3/s	0.72	95th percentile Q of EA station 58002 - Neath at Resolven (0.72 m3/s), a few km upstream of the site (source: http://www.ceh.ac.uk/data/nrfa/uk_gauging_station_network.html) - this is a conservative assumption.
User Defined Receptor 2: Granular Alluvium at site boundary			Receptor for hazardous substances. Alluvial deposits at the site are classified as a minor aquifer, and not considered a sensitive receptor (high salinity and no groundwater abstractions / supplies within 2 km of the site). Groundwater contour maps suggest that regional groundwater gradient is westward towards the River Neath.
Contaminant Information			
Ammoniacal Nitrogen as N (NH4-N)			
Target concentration	mg/l	0.614	Coastal and Estuarine EQS for unionised Ammonia (NH3 as N) was converted to Ammoniacal Nitrogen as NH3-N
Target concentration	mg/l	0.686	Freshwater EQS for for unionised Ammonia (NH3 as N) was converted to Ammoniacal Nitrogen as NH3-N
Koc	L/kg	-	Not applicable - inorganic species
Arsenic			
Target concentration	mg/l	0.025	Coastal and Estuarine EQS
Target concentration	mg/l	0.05	Freshwater EQS
Koc	L/kg	-	Not applicable - inorganic species
Chloride			
Target concentration	mg/l	-	No value for saltwater EQS
Target concentration	mg/l	250	Freshwater EQS
Koc	L/kg	-	Not applicable - inorganic species
Malathion			
Target concentration	mg/l	0.000001	MRV published by the Environment Agengy (Horizontal Guidance Note H1 - Annex (j) v 2.0 April 2010)
Koc	L/kg	Not defined	Value of Kd is used
Mecoprop			
Target concentration	mg/l	0.00004	MRV published by the Environment Agengy (Horizontal Guidance Note H1 - Annex (j) v 2.0 April 2010)
Koc	L/kg	Not defined	Value of Kd is used
Mercury			
Target concentration	mg/l	0.00001	MRV published by the Environment Agengy (Horizontal Guidance Note H1 - Annex (j) v 2.0 April 2010)
Koc	L/kg	-	Not applicable - inorganic species
Phenol			
Target concentration	mg/l	0.0001	MRV published by the Environment Agengy (Horizontal Guidance Note H1 - Annex (j) v 2.0 April 2010)
Koc	L/kg	Not defined	Value of Kd is used
Toluene			
Target concentration	mg/l	0.004	MRV published by the Environment Agengy (Horizontal Guidance Note H1 - Annex (j) v 2.0 April 2010)
Koc	L/kg	Uniform (35, 259)	End values based on: U.S. EPA chemical factsheet on Toluene (as part of "National Primary Drinking Water Regulations" by EPA; available on http://www.epa.gov/ogwdw000/pdfs/factsheets/voc/tech/toluene.pdf); U.S. EPA chemical summary for Toluene (EPA, 1994 - available at http://www.epa.gov/chemfact/); and"Screening Level Ecological Risk Assessment Protocol fro hazardous Waste Combustion Facilities - Vol 2 _ Appendix A" (U.S. EPA, 1999)
Source Concentrations (Historical Waste)			
Source data options		Pore water concentrations	
Source type		Declining source	
Historical waste Source Field Capacity		Uniform (0.2-0.4)	Low end value from Hall et al. (2006), as reported in Slack et al. (2006). However, as suggested by Slack et la. (2006) this is particularly variable and a uniform distribution (0.2-0.4) is assumed.
Source Geometry			
Source length	m	410	
Source width	m	650	
Source area	m^2	266500	
Source thickness	m		Not used in calculation
Source volume	m^3	3212000	Volume of waste was estimated with LSS software taking into account site topography and a plane at 3 mAOD, which is thought to be the base of the waste.
Source Concentrations			
Ammoniacal Nitrogen as N (NH4-N)	mg/l	Triangular (16.85, 275, 568.18)	Based on measured leachate concentrations for the period 1999-2003.
Arsenic	mg/l	Triangular (0, 0.0075, 0.021)	Based on measured leachate concentrations for the period 2003-2010
Chloride	mg/l	Triangular (5, 318, 1203)	Based on measured leachate concentrations for the period 2003-2010
Malathion	mg/l	Uniform (0, 0.00028)	Based on measured leachate concentrations for the period 2003-2010
Mecoprop	mg/l	Uniform (0.002, 0.09)	This determinand is currently not monitored. Based on range of values for typical MSW landfills across Europe as reported in Christensen et al. (2001), Biogeochemistry of landfill leachate plumes, Applied Geochemistry 16: 659-718
Mercury	mg/l	Triangular (0, 0.0016, 0.043)	Based on measured leachate concentrations for the period 2003-2010
Phenol	mg/l	Triangular (0, 0.32, 0.87)	Based on measured leachate concentrations for the period 2003-2010
Toluene	mg/l	Triangular (0, 0.0013, 0.0048)	Based on measured leachate concentrations for the period 2003-2010
Hydrogeological Units			Based on geological sections and groundwater levels no unsaturated zone below the landfill is assumed.
Historical Waste			Saturated waste
Unit thickness	m	Triangular (0, 4, 8)	Based on geological sections of Jacobs HRA 2010 and site topography - saturated waste thickness ranges
Log hydraulic conductivity	log m/s	Uniform (-2.2218, -6.6989)	ConSim help file range for silt to coarse sand. Compares favourably with range of hydraulic conductivities for aged domestic waste as shown in Powrie W. et al. (Factors affecting the hydraulic conductivity of waste. In: International Worshop "Hydro-Physico-Mechanics of Landfills, Grenoble I University, France, 2005)
Hydraulic conductivity	m/s	3.46E-05	POWER (10, avge Log_Hydraulic_Conductivity)
Head	m	Triangular (5.10, 7.46, 12.71)	Values in mAOD - based on summary statistics of leachate level monitoring data.
Hydraulic gradient	dimensionless	-	Not defined - vertical flow only.
Porosity	fraction	Uniform (0.3, 0.5)	Based on literature review (Landfill Technology by J Crawford & P Smith) values for waste (used in LandSim). Hall et al. (2006) suggest 0.4 (in Slack et al., 2006). Range is considered conservative.
Velocity	m/s	-	Not defined. Velocity is calculated from the water balance
Tortuosity	dimensionless	Not defined	-
Cohesive Alluvium			Saturated clay/silt of estuarine origin. Based on groundwater levels it is assumed these material are mostly saturated below the landfill site.
Unit thickness	m	Triangular (0, 5, 8)	Inferred from geological sections of Jacobs HRA 2010
Log hydraulic conductivity	log m/s	Triangular (-9.770, -7.967,-7.209)	Results of laboratory falling head tests on cohesive alluvium samples (clay, silt/clay) from the following sources:Steve bennett (1995), Exploration Associates (1997) and Robert Long Consultancy (2004). Values are: minimum, likest (average) and maximum.
Hydraulic conductivity	m/s	Constant (1.08E-8)	Average K results of laboratory falling head tests on cohesive alluvium samples (clay, silt/clay) from the following sources:Steve bennett (1995), Exploration Associates (1997) and Robert Long Consultancy (2004). Values are: minimum, likest (average) and maximum.
Head	m	Triangular (0.04, 2.28, 6.93)	Values in mAOD - based on summary statistics of groundwater level monitoring data. Assumed same head range as underlying granular alluvium.
Hydraulic gradient	dimensionless	-	Not defined - vertical flow only assumed
Porosity	fraction	Triangular (0.01, 0.05, 0.1)	Based on likely range of effective porosity for fine-grained alluvial deposits. Ranges is considered enough conservative
Velocity	m/s	Calculated by RAM	-
Tortuosity	dimensionless	-	Not defined
Granular Alluvium			Saturated sand of estuarine origin
Unit thickness	m	Triangular (2, 10, 12)	Base of alluvium not reached during site investigations. However in BH7B granular thickness drilled was 3m (total drilled thickness of alluvium was 10m). In BH47W the granular thickness is at a minimum (about 2m) as confined between cohesive horizons. An assumed triangular range of 2-10-12m seems reasonably conservative.
Log hydraulic conductivity	log m/s	Triangular (-6.287, -4.23, -3.824)	Based on field falling head tests on granular alluvium (sand) from the following sources: Robert Long Consultancy (2004) and WS Atkins (1990). Values are: minimum, likest (average) and maximum.
Hydraulic conductivity	m/s	5.89E-05	Average K (field values) calculated from the corresponding LogK value. Laboratory values are considered not reliable because 2-3 order of magnitude less. Furthermore laboratory values are inconsistent with expected travel times at BH8, compatible with landfilling history.
Head	m	Triangular (0.04, 2.28, 6.93)	Values in mAOD - based on summary statistics of groundwater level monitoring data.
Hydraulic gradient	dimensionless	Triangular (0.0026, 0.003158, 0.014)	Measured groundwater gradient beneath entire site (based on Jacobs HRA 2010 average groundwater contour map)
Porosity	fraction	Triangular (0.05, 0.1, 0.25)	Based on likely range of effective porosity for medium-coarse grained alluvial deposits. Range is considered enough conservative.
Velocity	m/s	Calculated by RAM	-
Tortuosity	dimensionless	Not defined	-
Attenuation Parameters			
General Properties			
Dry bulk density			
Historical Waste	kg/m^3	Uniform (600, 650)	Range based on reconstituted dry density values of landfilled MSW waste (602 kg/m3) as reported in Reddy et al. (2008, abstract available at: http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=ASCECP000309040970000018000001&idtype=cvips&gifs=yes&ref=no) and Beaven and Powrie (1995) in Slack et al. (2006), which report a value of 0.65 Kg/l for municipal landfill waste (MSW).
Saturated Cohesive Alluvium	kg/m^3	Uniform (1060, 1430)	Range based on lab dry density values as reported in Steve bennett (1995), Exploration Associates (1997) and Robert Long Consultancy (2004).
Saturated Granular Alluvium	kg/m^3	Uniform (1310, 1530)	Range based on lab dry density values as reported in Steve bennett (1995), Exploration Associates (1997) and Robert Long Consultancy (2004).
foc			
Historical Waste	fraction	Not defined	Retardation is not modelled for Historical Waste.
Saturated Cohesive Alluvium	fraction	Not defined	Not needed as Kd values are entered directly.
Saturated Granular Alluvium	fraction	Not defined	Not needed as Kd values are entered directly.
Contaminant Specific Parameters			
Ammoniacal Nitrogen as N (NH4-N)			
kd (Historical Waste)	l/kg	Constant (0)	No retardation assumed
kd (Saturated Cohesive Alluvium)	l/kg	Uniform (2.8, 4.1)	Values from laboratory test (Robert Long Consultancy, 2004)

kd (Saturated Granular Alluvium)	l/kg	Triangular (0, 0.4, 0.9)	Values from Buss et al. (2004) - A review of ammonium attenuation in soil and groundwater, Quat. J. Eng Geol & Hydrog., v. 37: 347-359. Laboratory value (average kd of 2.6) was measured in a single shallow sample (clayey-silt sand at 0.7-0.9 mbgl) above groundwater. The laboratory value may not be representative of more well sorted sand at depth in the aquifer (refer to Jacobs geological sections), furthermore it is outside the kd literature range for sands and gravels. Average kd of 0.4 produces more realistic travel times to BH8, compatible with landfill history.
Half life (Historical Waste)	days	-	No decay assumed.
Half life (Saturated Cohesive Alluvium)	days	Triangular (365, 3650, 36500)	Low range (1 year) value based on Buss. et. al. for aerobic degradation in unsaturated and saturated zones for sands & gravels. Upper range (100 years) considers the possibility that more anaerobic conditions may exist around the landfill and is deemed as sufficiently conservative. In general, field monitoring of NH4 in groundwater does not suggest that much attenuation is present along the main groundwater flow direction, towards BH8. Likest half-life of 10 years produce a reasonable calibration to NH4-N as observed in 2008-09 at BH8.
Half life (saturated granular alluvium)	days	Triangular (365, 3650, 36500)	Low range (1 year) value based on Buss. et. al. for aerobic degradation in unsaturated and saturated zones for sands & gravels. Upper range (100 years) considers the possibility that more anaerobic conditions may exist around the landfill and is deemed as sufficiently conservative. In general, field monitoring of NH4 in groundwater does not suggest that much attenuation is present along the main groundwater flow direction, towards BH8. Likest half-life of 10 years produce a reasonable calibration to NH4-N as observed in 2008-09 at BH8.
Arsenic			
kd (all units)	l/kg	Triangular (25, 30, 250)	Low-upper range from ConSim help files. Likest value has been extrapolated for an average groundwater pH of 7.53 based on suggested pH-dependant values from U.S.EPA (1996) as reported in "Screening Level Ecological Risk Assessment Protocol for hazardous Waste Combustion Facilities, Volume 2 Appendix A" (U.S. EPA, 1999)
Half life	days	-	No decay assumed
Chloride			
kd (all units)	l/kg	Constant (0)	No retardation assumed
Half life	days	-	No decay assumed
Malathion			
kd (all units)	l/kg	Constant (0.981)	Based on correlation equation with Koc that is cited in U.S. EPA (1993) in U.s.EPA (1999) for an assumed organic carbon fraction of 0.01 in soil. It is considered a conservative value.
Half life	days	Uniform (2, 20)	Based on different literature sources. Lower limit based on degradation in saline estuarine seawater overlying natural sediment at pH 7.3-7.7 (as reported in Evaluation on Malathion - Department for Environment, Food and Rural Affairs, UK, August 1995). Upper range based on degradation hald life in subsoild under landfills (Kjeldsen et al. - Sorption and degradation of chlorophenols, nitrophenols and organophosphorus pesticides in the subsoil under landfills -- laboratory studies, Journal of Contaminant Hydrology, Volume 6, Issue 2, September 1990, Pages 165-184).
Mecoprop			
kd (all units)	l/kg	Uniform (0, 0.296)	Based on Janniche (2010) - Fate of herbicides in deep subsurface limestone and sandy aquifers - PhD Thesis Technical University of Denmark.
Half life	days	Uniform (3, 9)	Johnson et. al. 2007 (proposed EQS for WFD Annex VIII substances: mecoprop)
Mercury			
kd (all units)	l/kg	Uniform (450, 3845)	Based on ConSim help files
Half life	days	-	No decay assumed
Phenol			
kd (all units)	l/kg	Uniform (0.096, 0.22)	Based on Klecka et al. (1990) - Natural Bioremediation of Organic Contaminants in Groundwater: Cliffs Dows Superfund Site, Ground Water, 28 (4): 534-543
Half life	days	Uniform (3, 150)	Lower limit based on on Klecka et al. (1990) - Natural Bioremediation of Organic Contaminants in Groundwater: Cliffs Dows Superfund Site, Ground Water, 28 (4): 534-543. Upper limit based on half-life determined from anaerobic soil columns loaded with anaerobic leachate (Journal of Contaminant Hydrology, Volume 6, Issue 2, September 1990, Pages 165-184).
Toluene			
kd (all units)	l/kg	Uniform (0.520, 3.92)	Range based on different sources: (i) kd (0.520 l/kg) between soil and groundwater in an Italian aquifer material characterized by a low organic carbon content (foc = 0.00262) (Ruffino et al., 2009); (ii) soil-water partition coefficient (1.4) as reported in "Screening Level Ecological Risk Assessment Protocol for hazardous Waste Combustion Facilities, Volume 2 Appendix A" (U.S. EPA, 1999). (iii) foc values are unnown at Giants Grave landfill site - for foc values of river sediments (sand, silt) of 0.0057-0.029 (Domenico & Swartz, 1990) and Log koc values of 2.13 l/kg for toluene (ASTM, 1998) equivalent to koc of 135 l/kg (compare well with koc of 140 ml/g - geometric mean of measured values obtained from U.S. EPA, 1996), we obtain a kd of 0.76-3.92 l/kg.
Half life	days	Uniform (7, 70)	Based on estimated biodegradation rates in groundwater (7-28 days) as reported in "Handbook of Environmental Biodegradation Rates" (Howard et al., 1991) - cited in "Toxicological profile for Toluene" (publicatio of the U.S. Department of Health and Human Services, 2000) available at http://www.atsdr.cdc.gov/ToxProfiles/tp56.pdf. Degradation of Toluene is in agreement with Christensen et al. (2001), which stated that "The degradability of toluene and xylenes obseved in plumes has been supported by experimental evidence from field and laboratory experiments...". However, the upper end of the range has been modified taking into account potentia unaerobic conditions developed below the landfill - based on Figures provided by Hutchins ("Biodegradation of Monoaromatic Hydrocarbons by Aquifer Microorganisns Using Oxygen, Nitrate or Notrous Oxydes as the Terminal Electron Acceptor" in: Applied and Environmental Microbyology, Vol. 57 (8), Aug. 1991, p. 2403-2407) Toluene half-life is estimated as 70 days under anaerobic conditions.
Water Balance			It is conservatively assumed that there is a pathway between the Historical Waste and the River Neath, although anedoctal evidence suggests that the Canal is lined. Cells hilighted in blue are used in the pathway worksheet.
Water Balance landfill			
Effective rainfall (=Q_recharge+Q_lateral flow)			Estimation of effective rainfall = infiltration through cap + runoff.
Annual rainfall	mm/yr	995	Long-term annual average from Met Office Numbles Head Sation (2627E 1870N) about 6km southwest of the site.
Evapotranspiration	dimensionless	456	Potential evapotranpiration from MAFF (1975) - cited in HRA 2004 (Robert Long Consultancy Limited, 2004).
Effective rainfall	***mm/yr***	***539.0***	-
Effective rainfall	m/s	1.71E-08	-
Area landfill	m2	266500	Based on Jacobs 2009 Env Monit Plan
Q_effective rainfall	*m3/s*	*4.6E-03*	-
Q_recharge			This term corresponds to the flow through the base of the landfill and is assumed to be equivalent to the flux through the cohesive alluvium) and is assumed to equate the volumetric recharge flux.
Average head in Historical Waste	m	7.46	Value in mAOD - based on summary statistics of leachate level monitoring data.
Average head in Granular Alluvium	m	2.28	Value in mAOD - based on summary statistics of groundwater level monitoring data.
Average thickness Cohesive Alluvium	m	5	Based on geological sections Jacobs HRA 2010
Hydraulic gradient Historical Waste-Granular Alluvium	dimensionless	1.04	Calculated as: (Average head Historical Waste - Average head Granular Alluvium)/ Average thickness Cohesive Alluvium
Average Hydraulic Conductivity (K) Cohesive Alluvium	m/s	1.08E-08	Based on laboratory falling head tests - as previously detailed
qrecharge	m/s	1.12E-08	Recharge through the base of the landfill, calculated as: Hydraulic conductivity Cohesive Alluvium * Hydraulic gradient between landfill lechate and granular alluvium.
qrecharge	***mm/yr***	***352.8***	Equivalent to 35% of annual rainfall and 65% of effective rainfall.
Area landfill	m2	266500	Based on Jacobs 2009 plans
Total Q_recharge (= Total Q_path)	*m3/s*	*2.98E-03*	-
v_Historical Waste	*m/s*	*2.80E-08*	velocity of water moving laterally in the Historical Waste
v_Cohesive Alluvium	*m/s*	*2.24E-07*	velocity of groundwater in cohesive alluvium, estimated based on an average effective porosity of 0.05
Infiltration Area Cohesive Alluvium	*m2*	*195000*	Inferred infiltration area of cohesive alluvium, based on Jacobs HRA 2010 sections & plans
Qpath Cohesive Alluvium	*m3/s*	*2.18E-03*	Qpath in cohesive allluvium is proportional to the inferred infiltration area of the cohesive alluvium.
Q_runoff+Q_leachate control (lateral flow)			This term corresponds to lateral flow component of the landfill towards the leachate collection system, surface drainage netwrok and Neath Canal.
qrunoff+qleachate control	***mm/yr***	***186.2***	Calculated as: Effective rainfall - qrecharge. Equivalent to 19% of annual rainfall and 35% of effective rainfall.
Aquifer flow			
Q_aquifer (Q_Granular Alluvium)			Flow in the granular alluvium
Hidraulic gradient (i)	dimensionless	0.003158	Average hydraulic gradient
Average Hydraulic Conductivity (K) Granular Alluvium	m/s	5.89E-05	Average hydraulic conductivity data from field tests
v_Granular Alluvium	*m/s*	*1.86E-06*	velocity of groundwater in Granular Alluvium, based on an average effective porosity of 0.1
Infiltration Area Granular Alluvim	*m2*	*71500*	Inferred infiltration area of granular alluvium, based on Jacobs HRA 2010 sections & plans
Qpath Granular Alluvium	*m3/s*	*8.0E-04*	Qpath in granular allluvium is proportional to the inferred infiltration area of the cohesive alluvium.
Pathways			
Path 1: Historical Waste - Cohesive Alluvium - Granular Alluvium - River Neath			
Historical waste (source term)		No processes	
Q_path	m^3/s	2.18E-03	Equivalent to recharge through the base of the landfill through Cohesive Alluvium
Q_decline	m^3/s	2.18E-03	Assumed equivalent to Q_Path
Cohesive Alluvium			
Velocity	m/s	2.24E-07	Based on water balance calculations.
Dispersivity	m	0.5	10% of pathway length (travel distance)
Travel distance	m	5	Average unit thickness
Mixing depth	m	undefined	
Mixing width	m	undefined	
Q_Dilute	m^3/s	0	Calculated by RAM. No dilution is assumed in this unit.
Granular Alluvium			
Velocity	m/s	1.86E-06	Calculated by RAM on Hydrogeology worksheet
Dispersivity	m	23	10% of pathway length (travel distance)
Travel distance	m	230	Distance to River Neath from the upper part of landfill western slope, along main groundwater direction (in direction of BH8)
Mixing depth	m	1	In absence of vertical dispersion data it is set to the effective saturated thickness (average thickness multiplied by effective porosity of 0.1= 10m X 0.1 = 1m).
Mixing width	m	600	Dimension of source measured perpendicular to main groundwater flow direction. Based on Jacobs HRA 2010 average groundwater contour plan and NH4-N average contour plan. It does accounts for reduced aquifer width (below landfill and perpendiculat to main groundwater flow direction) because of dilution of tidal water ingressing from the northwest corner of the site (see NH4-N contour plan).
Q_Dilute	m^3/s	1.12E-04	Calculated by RAM.
River Neath			
Q_Dilute	m^3/s	0.72	Set previously to 95th percentile Q of EA station 58002 - Neath at Resolven
Path 2: Historical Waste - Cohesive Alluvium - Granular Alluvium - Granular Alluvium			
Historical waste (source term)		No processes	
Q_path	m^3/s	2.18E-03	Equivalent to recharge through the base of the landfill through Cohesive Alluvium
Q_decline	m^3/s	2.18E-03	Assumed equivalent to Q_Path
Cohesive Alluvium			
Velocity	m/s	2.24E-07	Based on water balance calculations.
Dispersivity	m	0.5	10% of pathway length (travel distance)

Travel distance	m	5	Average unit thickness
Mixing depth	m	undefined	
Mixing width	m	undefined	
Q_Dilute	m^3/s	0	Calculated by RAM. No dilution is assumed in this unit.
Granular Alluvium			
Velocity	m/s	1.86E-06	Based on water balance calculations.
Dispersivity	m	11.5	10% of pathway length (travel distance)
Travel distance	m	115	Distance to BH8 from the upper part of the landfill western slope, along the main groundwater flow direction.
Mixing depth	m	1	In absence of vertical dispersion data it is set to the effective saturated thickness (average thickness multiplied by effective porosity of 0.1= 10m X 0.1 = 1m).
Mixing width	m	600	Dimension of source measured perpendicular to main groundwater flow direction. Based on Jacobs HRA 2010 average groundwater contour plan and NH4-N average contour plan. It does accounts for reduced aquifer width (below landfill and perpendiculat to main groundwater flow direction) because of dilution of tidal water ingressing from the northwest corner of the site (see NH4-N contour plan).
Q_Dilute	m^3/s	1.12E-04	Calculated by RAM.
Granular Alluvium (receptor)			
Q_Dilute	m^3/s	0	-
Path 3: Historical Waste - Granular Alluvium - River Neath			Based on Jacobs HRA 2010 geological section B-B, on the western side of the landfill the underlying alluvium is granular and there is no cohesive alluvium between the landfill and the aquifer.
Historical waste (source term)		No processes	
Q_path	m^3/s	8.00E-04	Equivalent to recharge through the base of the landfill through Granular Alluvium
Q_decline	m^3/s	8.00E-04	Assumed equivalent to Q_Path
Granular Alluvium			
Velocity	m/s	1.86E-06	Based on water balance calculations.
Dispersivity	m	23	10% of pathway length (travel distance)
Travel distance	m	230	Distance to River Neath from the upper part of landfill western slope, along main groundwater direction (in direction of BH8)
Mixing depth	m	1	In absence of vertical dispersion data it is set to the effective saturated thickness (average thickness multiplied by effective porosity of 0.1= 10m X 0.1 = 1m).
Mixing width	m	600	Dimension of source measured perpendicular to main groundwater flow direction. Based on Jacobs HRA 2010 average groundwater contour plan and NH4-N average contour plan. It does accounts for reduced aquifer width (below landfill and perpendiculat to main groundwater flow direction) because of dilution of tidal water ingressing from the northwest corner of the site (see NH4-N contour plan).
Q_Dilute	m^3/s	1.12E-04	Calculated by RAM.
River Neath			
Q_Dilute	m^3/s	0.72	Set previously to 95th percentile Q of EA station 58002 - Neath at Resolven
Path 4: Historical Waste - Granular Alluvium - Granular Alluvium			Based on Jacobs HRA 2010 geological section B-B, on the western side of the landfill the underlying alluvium is granular and there is no cohesive alluvium between the landfill and the aquifer.
Historical waste (source term)		No processes	
Q_path	m^3/s	8.00E-04	Equivalent to recharge through the base of the landfill through Granular Alluvium
Q_decline	m^3/s	8.00E-04	Assumed equivalent to Q_Path
Granular Alluvium			
Velocity	m/s	1.86E-06	Based on water balance calculations.
Dispersivity	m	11.5	10% of pathway length (travel distance)
Travel distance	m	115	Distance to BH8 from the upper part of the landfill western slope, along the main groundwater flow direction.
Mixing depth	m	1	In absence of vertical dispersion data it is set to the effective saturated thickness (average thickness multiplied by effective porosity of 0.1= 10m X 0.1 = 1m).
Mixing width	m	600	Dimension of source measured perpendicular to main groundwater flow direction. Based on Jacobs HRA 2010 average groundwater contour plan and NH4-N average contour plan. It does accounts for reduced aquifer width (below landfill and perpendiculat to main groundwater flow direction) because of dilution of tidal water ingressing from the northwest corner of the site (see NH4-N contour plan).
Q_Dilute	m^3/s	1.12E-04	Calculated by RAM.
Granular Alluvium (receptor)			
Q_Dilute	m^3/s	0	-
Simulation Parameters			
Reporting Timeslices		1, 10 , 100, 1000, 10000	RAM default, for long term prediction of emissions
Monte Carlo Analysis			
Reported percentile	%	95	
no. of simulations		10000	
Named Constants			
s_per_year		31557600	
s_per_day		86400	
Laplace Transform Solution Parameters			
sigma		0	RAM default
nu		1	RAM default
nsum		16	RAM default
omega		11	RAM default

Drawings

B1404900/H/Figure1



Key

Environmental Permit Number EAWML 34060 Boundary

1	08/10/09	[illegible]	GA		
Rev	Issue date	Purpose of revision	Drawn	Checked	Approved

JACOBS

[illegible]

Client

NEATH PORT TALBOT WASTE MANAGEMENT COMPANY

Project

GIANTS GRAVE

Drawing title

SITE LOCATION PLAN

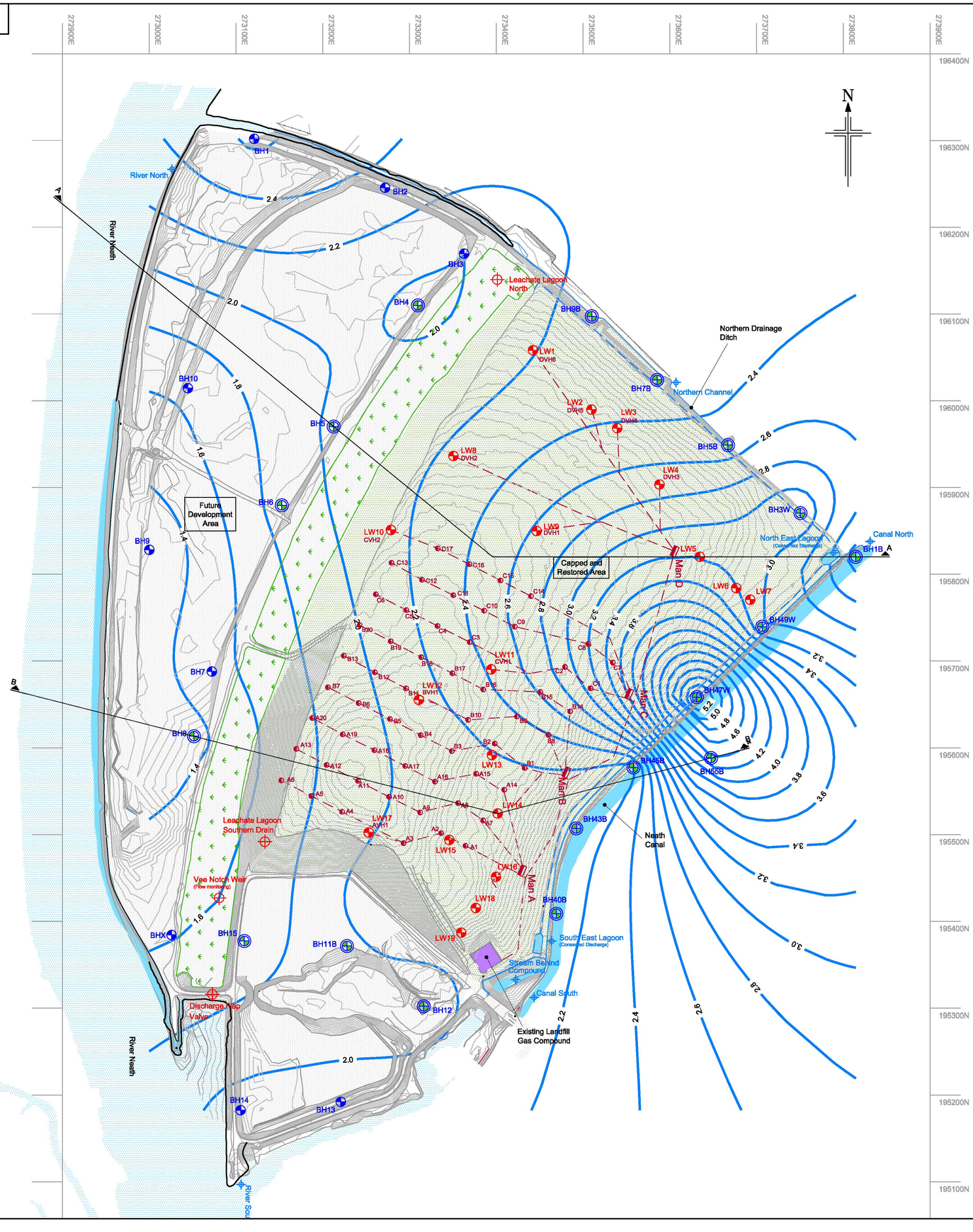
Drawing status

Scale	1:50,000 @ A4	DO NOT SCALE
Jacobs no.	B1404900	
Client no.		

Drawing number: B1404900/H/Figure1 — Rev: 0

Drawing number / Rev

B1404900/H/Figure 6



Legend

- Surface Water Monitoring Point
- Groundwater and Gas Monitoring Borehole
- Groundwater Monitoring Borehole
- Leachate Monitoring Point
- Leachate Well
- Gas Well
- Former Surface Water Monitoring Point
- Gas Manifold
- Waterways
- Reed Bed System
- Capped and Restored Area
- Future Development Area
- Surface Water Drainage Ditches
- Line of Geological Section

Notes

1. Only installations which have provided data are shown.
2. Contours produced using surfer 8 software.

Rev	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'v'd
0	July 2010	Drawing Created	GB	FF		

JACOBS

Churchill House, Churchill Way, Cardiff, CF10 2HH
Tel:+44(0)29 2035 3200 Fax:+44(0)29 2035 3222
www.jacobs.com

Client

Neath and Port Talbot Waste Management Ltd.

Project

Giants Grave Landfill Site

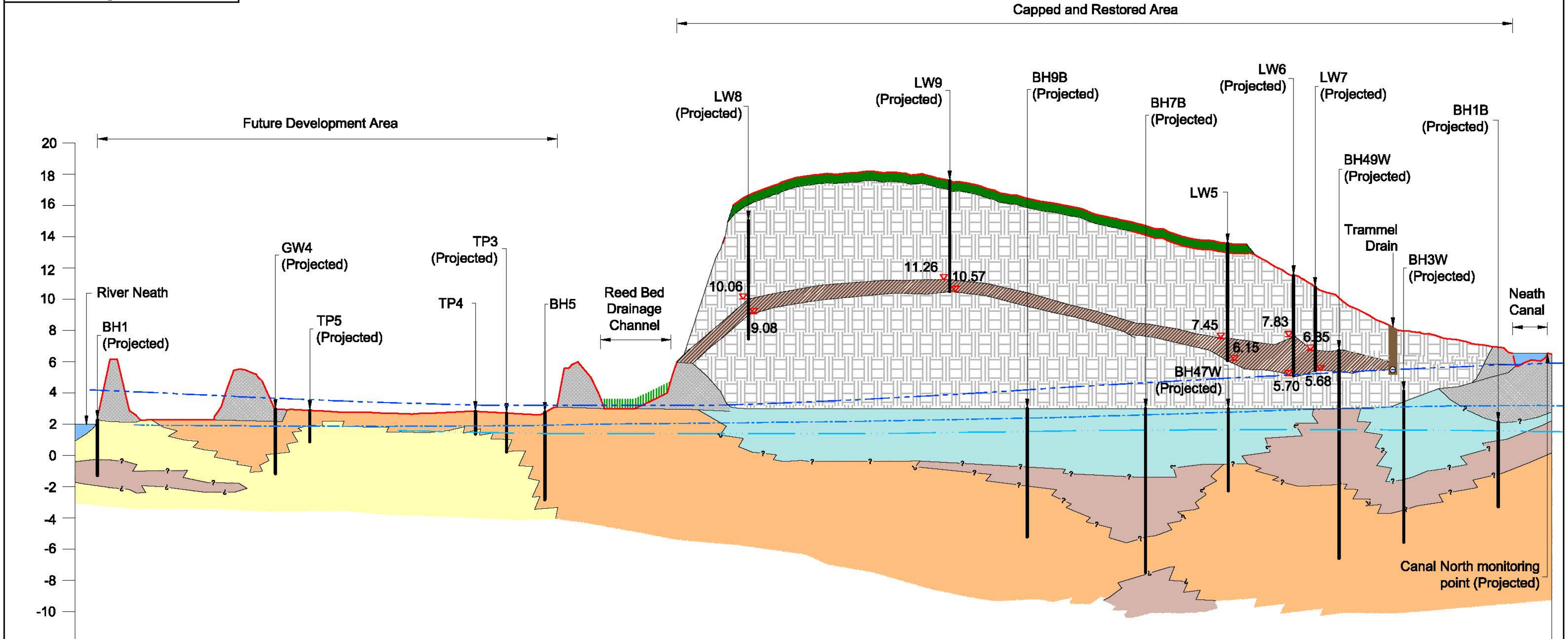
Drawing title

Average Groundwater Levels (2005-2009)

Drawing status

Scale	1:2500 @ A1	DO NOT SCALE
Jacobs No.	B1404900	
Client no.		
Drawing number	B1404900/H/Figure 6	Rev 0

Drawing number / Rev
B1404900/H/Figure 3 - Rev 0



Level (mAOD)	Chainage (m)
2.90	127.1
2.26	153.9
2.30	169.7
2.31	185.4
2.27	200.5
5.45	213.4
5.22	227.8
2.94	247.6
2.89	263.6
2.79	279.5
2.76	295.4
2.70	311.4
2.66	327.3
2.75	345.5
2.84	363.7
2.77	378.8
2.68	394.0
2.60	409.1
6.00	433.8
3.00	450.6
3.00	468.0
3.49	480.5
5.00	493.8
9.00	506.9
13.00	520.0
16.70	543.8
17.32	560.3
17.85	576.9
18.05	593.4
18.05	605.6
18.22	621.3
18.12	636.1
18.03	654.0
17.51	673.9
17.16	693.9
16.68	710.8
16.30	729.1
16.05	744.2
15.67	759.4
15.25	774.6
14.90	789.8
14.46	804.9
13.95	823.6
13.73	837.3
13.47	859.5
12.83	878.7
12.08	894.3
11.17	909.9
10.41	925.5
9.57	941.1
8.78	956.7
8.44	972.3
8.02	993.5
7.68	1009.0
7.52	1020.7
7.10	1032.4
6.06	1045.8

SECTION A-A

SCALE - H 1:2500, V 1:250

Notes:

1. Geological features based on individual borehole and trial pit logs.
2. Where no log information is available, geological features are inferred.
3. Surface water levels are inferred and not based on any specific measurement in time.

Legend

- Surface water body
- Capping
- Waste
- Made Ground
- Silty-Sandy Clay/Clay
- Sandy-Clayey Silt/Silt
- (Slightly) Silty-Clayey Sand
- Sand
- 10.06 / 9.08 Maximum and Minimum leachate level (mAOD) between 2008 and 2009
- Reed bed
- Maximum Groundwater Levels
- Average Groundwater Levels
- Minimum Groundwater Levels
- Observed geological boundary
- Inferred geological boundary

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
0	June 2010	DRAFT	GB	FF		

This drawing is not to be used in whole or part other than for the intended purpose and project as defined on this drawing. Refer to the contract for full terms and conditions.

JACOBS

Client: Neath Port Talbot Waste Management Company Ltd.

Project: Giants Grave Landfill Site

Drawing title: Geological Section A-A

Drawing status: DRAFT

Scale: AS SHOWN @ A3 — DO NOT SCALE

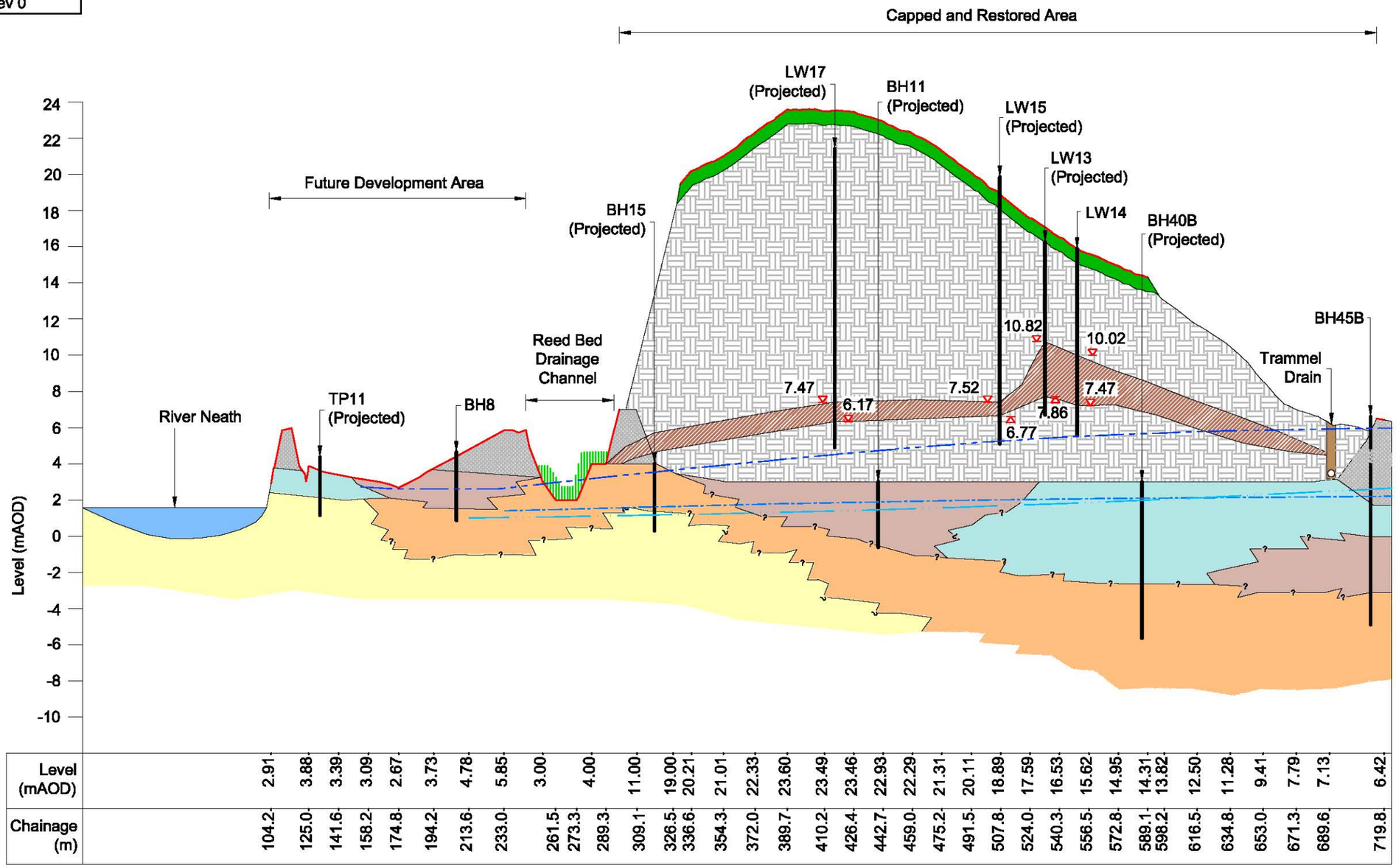
Jacobs No.: B1404900

Client no.:

Drawing number: B1404900/H/Figure 3

Rev: 0

Drawing number / Rev
B1404900/H/Figure 4 - Rev 0



Level (mAOD)	2.91	3.88	3.39	3.09	2.67	3.73	4.78	5.85	3.00	4.00	11.00	19.00	20.21	21.01	22.33	23.60	23.49	23.46	22.93	22.29	21.31	20.11	18.89	17.59	16.53	15.62	14.95	14.31	13.82	12.50	11.28	9.41	7.79	7.13	6.42
Chainage (m)	104.2	125.0	141.6	158.2	174.8	194.2	213.6	233.0	261.5	273.3	289.3	309.1	326.5	336.6	354.3	372.0	389.7	410.2	426.4	442.7	459.0	475.2	491.5	507.8	524.0	540.3	556.5	572.8	589.1	598.2	616.5	634.8	653.0	671.3	689.6	719.8

Notes:

1. Geological features based on individual borehole and trial pit logs.
2. Where no log information is available, geological features are inferred.
3. Surface water levels are inferred and not based on any specific measurement in time.

Legend

- Surface water body
- Capping
- Waste
- Made Ground
- Silty-Sandy Clay/Clay
- Sandy-Clayey Silt/Silt
- (Slightly) Silty-Clayey Sand
- Sand
- 10.06 / 9.08 — Maximum and Minimum leachate level (mAOD) between 2008 and 2009
- Reed bed
- Maximum Groundwater Levels
- Average Groundwater Levels
- Minimum Groundwater Levels
- Observed geological boundary
- Inferred geological boundary

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Appv'd
0	June 2010	DRAFT	GB			

JACOBS
95 Bothwell St, Glasgow, G2 7HX
Tel:+44(0)141 204 2511 Fax:+44(0)141 226 3109
www.jacobs.com

Client: Neath Port Talbot Waste Management Company Ltd.

Project: Giants Grave Landfill Site

Drawing title: Geological Section B-B

Drawing status: DRAFT

Scale	AS SHOWN @ A3	DO NOT SCALE
Jacobs No.	B1404900	
Client no.		

Drawing number: B1404900/H/Figure 4 — Rev: 0







TerraConsult

Leaders in waste management environmental & ground engineering consultancy

TerraConsult (South) Limited
Dugard House
Peartree Road
Colchester, Essex
CO3 0UL

Tel: +44 (0) 1206 585600

TerraConsult Limited
Bold Business Centre
Bold Lane, Sutton
St. Helens
WA9 4TX

Tel: +44 (0) 1925 291111
Fax: +44 (0) 1925 291191

Email: mailbox@terraconsult.co.uk
Website: www.terraconsult.co.uk

smas worksafe contractor www.smasltd.com

bsi. ISO 9001 Quality Management

FS 573193

bsi. ISO 14001 Environmental Management

EMS 573194

smas worksafe consultant www.smasltd.com

TerraConsult