



TerraConsult

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WITHYHEDGE LANDFILL SITE

HYDROGEOLOGICAL RISK ASSESSMENT REVIEW

Prepared for

Resources Management UK Ltd t/a Potters Waste Management

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November 2018

Carried Out For:

Resources Management UK Ltd t/a Potters Waste Management

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WITHYHEDGE LANDFILL SITE

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CONTENTS

APPENDICES

DRAWINGS

1. INTRODUCTION

1.1 Background

This document, prepared by TerraConsult Ltd (TCL) was commissioned by Resources Management (UK) Limited (RML) to prepare a Hydrogeological Risk Assessment Review (HRAR) for Withyhedge Landfill Site (the Site). The most recent Hydrogeological Risk Assessment Review (HRAR) was produced in February 2012.

A varied permit referenced EPR/MP3330WP was issued on the 29th September 2014 following the full transfer of the permit EPR/GP3630HT from SITA UK Ltd to Resources Management UK Limited.

A variation notice prior to the previous HRAR (18th May 2011) allowed the operator to change the waste types accepted in the valley area (located in-between the two phases at site). Phase 1 is classified as non-hazardous but historically accepted a restricted number of hazardous wastes including asbestos and Phase 2 is a non-hazardous landfill.

A requirement by virtue of improvement condition S1.3.7a (EPR/GP3630HT/V002) was to submit a Hydrogeological Risk Assessment (HRA) as the permit boundary has been revised to include all phases of the site, Phase 1 (the unlined dilute and disperse area) and Phase 2 (an engineered and lined site). That 2012 review[1] provided an assessment of discharge from the site as a whole and included an updated quantitative modelling exercise. It was also stated in the 2012 HRA[1] *"that previous HRA's have been produced for both Phase 1 and Phase 2 by Golders and accepted by the Agency".*

This review provides an update and appraisal (where applicable) of monitoring data since the submission of the 2012 HRAR however all data will be collated if available. As part of the preparation the following key documents and data sources have been consulted in the preparation of this review including:

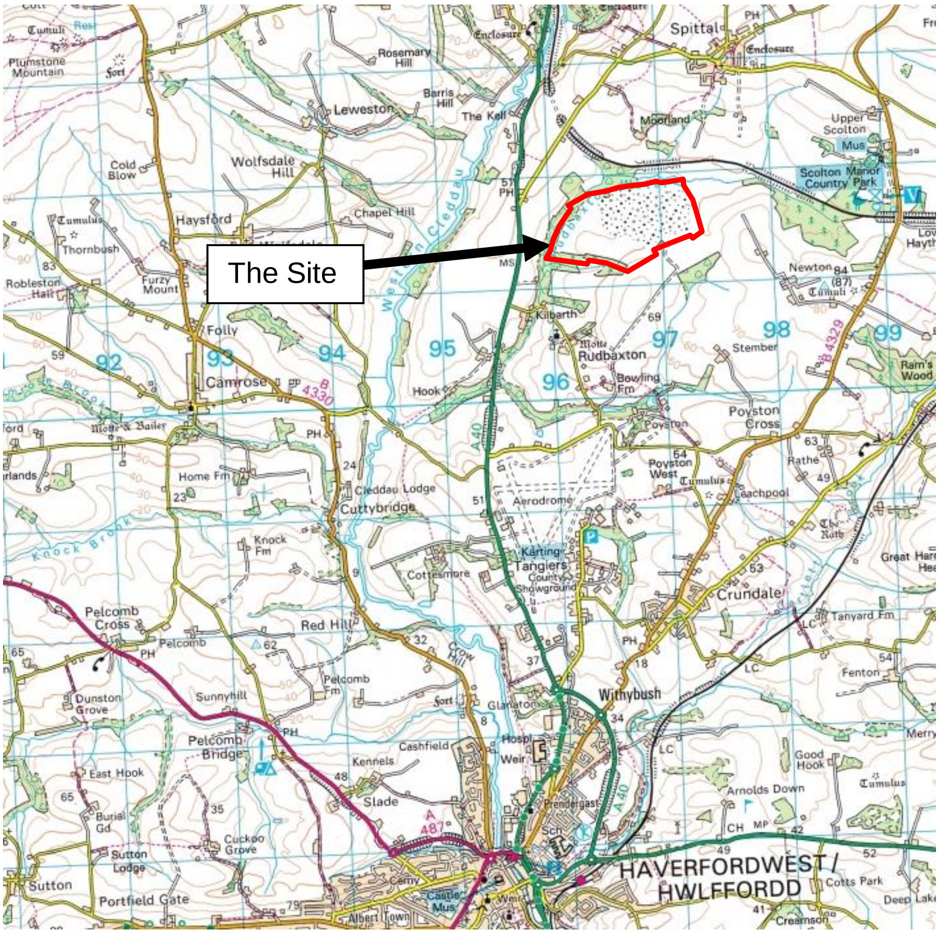
- TerraConsult, January 2018, (Ref 2932/R/005/01) Withyhedge Landfill Site 2017 Annual Review Condition 4.2.2 Section a) of Environmental Permit EPR/MP3330WP (with reference to EPR/GP3630HT/V002)
- TerraConsult, March 2017, (Ref 2932/R/003/1) Withyhedge Landfill Site 2016 Annual Review Condition 4.2.2 Section a) of Environmental Permit EPR/MP3330WP (with reference to EPR/GP3630HT/V002)
- ExCal Ltd. June 2016 /KE 240-01-08/Rev 1/Annual Report (1st January 2015 – 31st December 2015)
- SUEZ, February 2012, Withyhedge Landfill Site, Consolidated Hydrogeological Risk Assessment Review (WH/CHRA/ v2.0)
- Golder Associates, November 2007 – Hydrogeological Risk Assessment, Withyhedge Landfill Phase 1 (report reference 07514290132.500)
- Golder Associates, June 2005 – Section B Hydrogeological Risk Assessment Withyhedge Landfill Phase 2 (report reference 04529421.502/A.0)
- AIG Consulting Ltd, 2003, Withyhedge Landfill Site, Hydrogeological Risk Assessment Review Report No: 5605/HRA v1 Date: November 2003

[1] SUEZ (February 2012). Withyhedge Landfill Site, Consolidated Hydrogeological Risk Assessment Review (WH/CHRA/ v2.0)

1.2 Site Location and History

The Site is located approximately 5.5 km north of Haverfordwest in Pembrokeshire at National Grid Reference (NGR) SM968213 and is shown on Figure 1. The Site is bound to the north and west by Rudbaxton Water and to the south and east by agricultural land. As stated in the Golder's 2005 HRA '*The catchment of Rudbaxton Water comprises a shallow valley, of which the site is located on the south-eastern flank. The valley slopes gently towards the south west. The elevation of the site is at approximately 70 m AOD in the east and approximately 50 m AOD in the west. Rudbaxton Water is at an elevation of approximately 30 to 35 m AOD'.*

Figure 1 Site Location



The site boundary encompasses an area which is divided into Phase 1 (approx. 17.8 ha) and Phase 2 (approx. 34.1 ha). Access to the Site is off the A40.

Before development of the landfill, the Site had been in use for agricultural purposes. According to the 2007 HRAR[2], "*the Site was run by Pembrokeshire County Council under a Resolution and accepted waste from 1985. Planning consent and a Waste Management Licence was awarded to RML in January 1996 (WML SWW/163/L) under the Waste Management Licensing Regulations (1994)".*

[2] Golder Associates Ltd (November 2007). Hydrogeological Risk Assessment, Withyhedge Landfill Phase 1 (report reference 07514290132.500)

"The Site operated as a non-hazardous waste landfill, and has not accepted hazardous waste since 16 July 2004. Phase 1 accepted its final waste in December 2006. A PPC Permit has been granted for landfilling in the area to the west of the existing Site (Phase 2). Phase 1 has a total of fifteen cells. Much of the Site operated on a dilute and disperse basis (Cell 1-10 and 12), however, four of the landfill phases (Cell 11, 13, 14 and 15) have been engineered with artificially established mineral barriers. The exact layout of Cells 1 to 10 and 12 is unknown."

It has been previously reported that the site occupies the void space left by the removal of superficial deposits and mudstone bedrock as each landfill cell is constructed. Clays are preserved for engineered cell lining systems and other material is retained for daily cover, inert fill and capping soils[3].

1.3 Risk Assessment Objectives

This report has been prepared in response to the PPC Permit requirement to undertake a HRAR in accordance with condition 3.1.6 of the permit. The review covers the entire site as per the most recent HRAR (i.e. Phase 1 and Phase 2, Area A-E).

These reviews, were originally required on a 4-yearly cycle through the life of the Permit, however, this frequency has subsequently been increased to a 6-year cycle. Based on the information reviewed, the first HRA was undertaken in 2003 by AIG Consulting Ltd[4].

HRA reviews are required to validate the assumptions used within the original HRA and to demonstrate that pollution is not, or is unlikely to occur. Where changes from the original assumptions are identified, then the HRA review provides a vehicle to demonstrate that any changes from the original conceptualisation of the site do not increase the potential for pollution to occur either due to an unforeseen circumstance or from a change in the management philosophy to increase the sustainability of the operations.

This HRA review has therefore been prepared based on sections which detail the as-built landfill, the monitoring undertaken as well as any improved knowledge of the geological / hydrogeological system obtained since the previous reviews were undertaken. Where discrepancies, which may have an impact on pollution potential are identified, then numerical re-modelling should be considered. However, the results of the data (and where appropriate) modelling exercise are used as the basis for recommendations for the ongoing operation, monitoring and compliance at the site.

The HRAR does not include review of previous correspondence between the operator and regulator, additionally TerraConsult Ltd has not independently verified monitoring information supplied by the client or data contained within previous HRAR's.

This HRAR does not attempt to address unresolved matters in relation to previously submitted Improvement Conditions (or address matters of partially approved Improvement Conditions) as referred to in previous CAR report (e.g. ID 5091, dated 13th March 2013). Previously established and proposed trigger limits (and the associated monitoring information) in this regard are outdated.

[3] Golder Associates Ltd (June 2005). Section A Environmental Setting and Installation Design (ESID) Withyhedge Landfill Phase 2 (report reference 04529421.501/A.0

[4] AIG Consulting Ltd (November 2003). Withyhedge Landfill Site, Hydrogeological Risk Assessment Review Report No: 5605/HRA v1

2. SOURCE TERM

2.1 General Engineering

Phase 1 (Cell 1-10 and 12)

The 2003 permit application report[4] detailed the following (also referred to in Golders 2007[2]) *"Waste within Phase 1 Cells 1 to 10 was deposited by Preseli Pembrokeshire District Council (PPDC), prior to RML operating the Site. AIG Consultants (2003) report "It is believed that PPDC commenced landfilling in the south eastern part of the "existing site" on a dilute and disperse basis, with infilling being undertaken beneath a Somerset Litter Net to form a series of east-west orientated unconfined "cells" approximately 30 m in width. Within the "existing site" it is believed that the base of the waste mass placed by PDCC to be at elevations of between 47 and 48 m OD, although no accurate records of landfill engineering by PPDC during the early phases of installation development are available".*

It was also stated "*The base of the cells are therefore likely to lie on the Mydrim Shale. It is reported by RML that the southern area of Cells 1 to 10 was clay lined. However, the clay was not engineered to a permeability specification and no Construction Quality Assurance (CQA) was undertaken prior to waste deposition. The permeability of the clay base is therefore unknown. The northern area is believed to also be lined with clay, however to a much smaller thickness (maximum of 300 mm) and this was also not engineered to a permeability specification or subject to CQA."*

Phase 1 (Cell 11, 13-15)

These cells provide engineered containment, for further detail see section 2.2.

Phase 2 (Cell 1-4)

These cells provide engineered containment, for further detail see section 2.2.

2.2 Site Engineering

An account taken from previous reports[2,3,4,5,15,16,19] is provided here for completeness to avoid significant cross referencing with other documents, most detail has been obtained from AIG 2003 and Golders 2007. A summary of engineering details are given at Table 1, a simplified plan showing the Cell layout is given in Figure 2.

At the time of writing of the previous HRAR[1], Phase 1 had been completed and Phase 2 had been developed up to the completion of Area A. Since that production of that 2012 HRAR the valley between Phase 1 and 2 has been engineered and infilling has commenced.

Phase 1 (Cell 11)

Cell 11 is a rectangular shape cell located along the northern boundary of Phase 1. "The basal liner comprises 1 m thick engineered clay with a maximum permeability of 1 x 10^{-9} m/s. A 5m high clay bund was constructed along the northern edge[5] (referenced in Golders 2007) and confirmed by Golders in 2011" [6].

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[5] CL Associates (1995). Withyhedge Landfill Earthworks Construction of Base Seal and Peripheral Bund for Cell 11, 6770/13, September 1995 – Referenced in Golders 2007

[6] Golder Associates Ltd (2011). Withyhedge Leachate Management System Review, Report 11514290005.501/B.1

Table 1 Engineering Summary

Phase	Area	Cells	Lining System	Capping System
1	-	1 to 9	Unlined	Composite: 0.001m LLDPE 1m Engineered Clay
		10	Unlined	0.001m LLDPE
		11	1m Engineered Clay	Composite: 0.001m LLDPE 1m Engineered Clay
		12	Unlined	0.001m LLDPE
		13	1m Engineered Clay	0.001m LLDPE
		14	1m Engineered Clay	0.001m LLDPE
		15	Composite Liner: 0.002m HDPE, 1m Engineered Clay	0.001m LLDPE
2	A	1/2 North	Composite Liner: 0.002m HDPE, 1m Engineered Clay	0.001m LLDPE
		1/2 South	Composite Liner: 0.002m HDPE, Geo-synthetic clay liner 0.5m Engineered Clay	0.001m LLDPE
		3	Composite Liner: 0.002m HDPE, Geo-synthetic clay liner 0.5m Engineered Clay	0.001m LLDPE
	B	4 North	Composite Liner: 0.002m HDPE, Geo-synthetic clay liner 0.5m Engineered Clay	tbc
	C, D, E	Pre Operational	-	-
Valley		Cell N1, N2,N3 Cell S1	Composite Liner: 0.002m HDPE, Geo-synthetic clay liner 0.5m Engineered Clay	0.001m LLDPE

Information reported in[13] and various annual monitoring reviews, Phase 2, area B – Cell 4 (north) data from 2018 CQA[7]

Phase 1 (Cell 13)

Cell 13 is a crescent shape located in the southwestern corner of Phase 1. "It has a basal area of approximately 11,500 m^2. The basal lining system comprises 1 m thick engineered clay with a maximum permeability of 1×10^{-9} m/s (AIG Consultants Ltd., 2001[8] - reference in Golders 2007). The base of Cell 13 is 46.5 m AOD, increasing to 50 m AOD at the outer edges" [6].

Phase 1 (Cell 14)

"Cell 14 is a broad rectangular shape located in the north-western area of Phase 1. It has a basal area of approximately 6000 m2. The basal liner comprises 1 m thick engineered clay with a permeability of not more than 1×10^{-9} m/s (AIG Consultants Ltd., 2002[9]- referenced in

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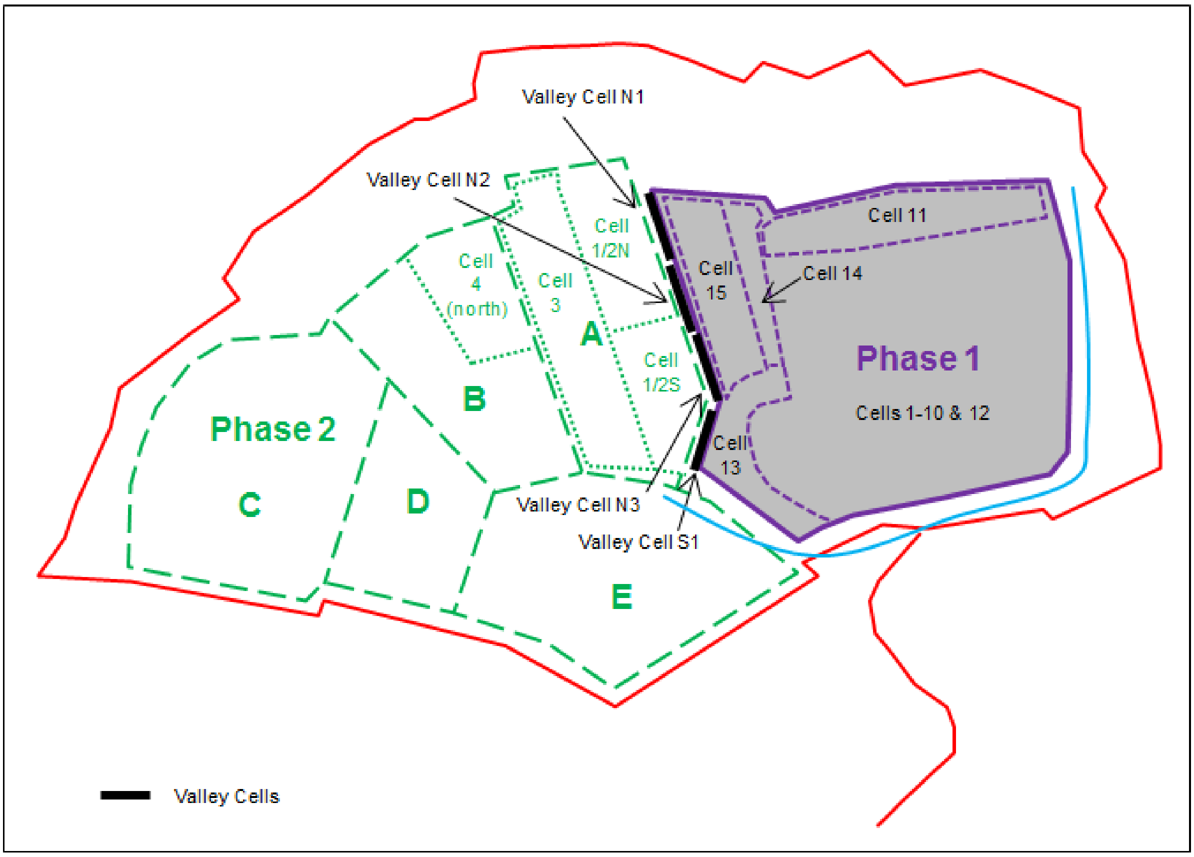
[7] CQA International Ltd (July 2018) Ref 30323-02

[8] AIG Consultants Limited (December 2001). Withyhedge Landfill Site Cell 13 CQA Certification Report, UK01/2139/6

[9] AIG Consultants Limited (October 2002). Withyhedge Landfill Site Cell 14 CQA Certification Report, UK02/2139/4

Golders 2007). Cell 14 basal elevations range from 48.7 mAOD to 45 mAOD at the collection sump".

Figure 2 Site Cell Layout



Red line = Permit Boundary.
Purple line; (Phase 1), green line; (Phase 2) blue line, groundwater cut-off barrier (taken from ESID 4, 2003) - All boundaries are indicative.

Phase 1 (Cell 15)

"Cell 15 is approximately rectangular and has an area of approximately 20,000 m^2. It is located in the north-western corner of Phase 1. The basal liner comprises 1 m thick engineered clay with a maximum permeability of 1 x 10^{-9} m/s. The engineered clay is overlain by a 2 mm thick smooth HDPE geomembrane, which is overlain by a protective geotextile (AIG Consultants Ltd., 2004[10] - referenced in Golders 2007). Based on the as built drawings for Cell 15, basal elevations range from 45.45 to 48.3 m AOD"[6].

Phase 2 – Area A (Cell 1/2N)

According to the 2008 Annual Monitoring Review[11], landfilling commenced in December 2006, the Cell1/2N area was constructed with a 1m clay liner overlain with a 2mm HDPE and protective geotextile. Further details are contained in the Golder Associates 2006b CQA

[10] AIG Consultants Limited (October 2004). Withyhedge Landfill Site Cell 15 Construction Quality Assurance Certification Report, UK04/2139/3
[11] Golder Associates UK Limited (July 2008). Withyhedge Landfill Site Phase 2 Environmental Monitoring Review

validation report[12] (not reviewed in this document). "*Basal elevations range from approximately 46.8 to 44.7 m AOD at the collection sump"* [6].

Phase 2 – Area A (Cell 1/2S)

According to previous summary tables[13] the base liner system is comprised of 0.5m engineered clay, 0.002m HDPE and geosynthetic clay liner. A CQA report[14] details that *"the lining system comprises a composite liner over the base and internal faces of the perimeter bunds. The lining system comprises a 0.5 m thick layer of engineered clay with a maximum permeability of 1.0 x 10^{-8} m/s overlain by a Geosynthetic Clay Liner (GCL) with a maximum permeability of 1.0 x 10^{-11} m/s and a 2 mm thick textured high density polyethylene (HDPE) geomembrane."*

"The engineered clay was overlain by a low permeability Geosynthetic Clay Liner (GCL) placed on the base and internal perimeter side slopes and anchored at the top of the side slopes." All testing criteria and results are included within the Report 07514290178.503" [14].
Clay liner formation levels according to drawing 503/3 fall from 47.6 mAOD in the south of the cell to circa 46 mAOD in the north.

Phase 2 – Area A (Cell 3)

Golders 2011[6] report that "*cell 3 was divided in to a north and south area, both comprise of a 0.5 m thick layer of engineered clay (maximum permeability of 1.0x10^{-8} m/s) overlain by GCL with a maximum permeability of 1.0x10^{-11} m/s and 2 mm HDPE geomembrane and protective geotextile. Base elevations for the south range from 46 to 43 mAOD and 44.5 to 42 mAOD for the north".*

Valley Cell N1 & N2

Since the submission of the 2012 HRAR by SUEZ, the Valley area has been designed; permitted and infilled, details are contained in Report 2185-R3-1 (2015)[15].

After formation preparation, the *in-situ* clay was reworked and placed in 250 mm layers with a shear strength of greater than 50 kN/m^2. Surveying demonstrated a thickness equal to or greater than 500 mm, a Geosynthetic Liner (GCL) was placed over the engineered clay liner. The GCL was placed in rolls simultaneously with the overlying FML to ensure that the GCL was not prematurely hydrated by rainfall. Top of formation according to CQA drawing 2185/7/001 ranges between 46.3 mAOD (southern end) and 43.9 mAOD, (northern end) clay thickness is typically 600 – 660 mm. Top of clay liner is typically 46.9 mAOD in the south and 45.1 mAOD in the north (drawing 2185/7/004).

The FML comprised of a 2 mm High Density Polyethylene, air pressure seam testing was carried out on all welds prior to the placement of the protective geotextile. All testing criteria and results are included within the TerraConsult Report 2185-R3-1[15].

[12] Golder Associates UK Limited (2006b). Withyhedge Landfill Site Phase 2, Construction of Cell 1 and 2 North CQA Report, 06529233.505
[13] SUEZ (Sept 2010-Aug 2011). Withyhedge Landfill Site Environmental Monitoring Review and Risk Assessment
[14] Golder Associates UK Limited (Jan 2008). Withyhedge Landfill Phase 2, Construction of Cells 1 and 2 South. CQA Report 07514290178.503
[15] TerraConsult (November 2008). Withyhedge Landfill Site Valley Cells N1 & N2 Construction Works – Validation Report Ref 2185-R3-1

Valley Cell N3 & S1
Top of formation according to CQA drawing 2185/8/001 for N3 ranges between 47.6 mAOD (southern end) and 46.2mAOD, (northern end) clay thickness is typically 600 – 800 mm. Essentially, N3 forms part of the N2 and N1 cells, draining leachate northwards. Top of clay liner is typically 48.2mAOD in the south and 47.1mAOD in the north (drawing 2185/8/004).

Cell S1 ranges from 48.3 mAOD in the north and 47.3 at the southern end (drawing 2185/8/001 with a clay thickness of typically 700 mm. Top of clay liner is typically 49.1 mAOD in the north and 48.5 mAOD in the south (drawing 2185/8/004).

The FML comprised of a 2mm High Density Polyethylene, air pressure seam testing was carried out on all welds prior to the placement of the protective geotextile. All testing criteria and results are included within the Report 2185-R4-1 (2016)[16].

Phase 2 – Area B (Cell 4 North)
The cell is the latest at site, the eastern edge ties into Cells 3N and 3S. Average Clay permeability ranged is stated at $2.2x10^{-10}$m/s, top of formation ranges between 41mAOD in the south eastern-corner reducing to 39mAOD in the north-western corner. Clay thickness is typically 600-700mm[7].

2.3 Leachate Management

Phase 1 (Cells 1 to 10 and 12)

"Leachate is managed within Cells 1 to 10 and 12 by a 300 mm diameter perforated perimeter collection pipe which extends around the southern and eastern perimeter of the Site. The pipework is set within a 20 mm gravel trench. The pipe falls from the southeast corner of Phase 1 from an invert elevation of 54.96 m AOD westwards to an invert elevation of 51.87 m AOD at its closest point to Cell 13 (SW SUMP).

The pipe also falls northwards to the north-eastern corner (LD3). The collection sumps comprise 1200 mm diameter concrete rings set on to a concrete base and tanked using bitumen and bentonite slurry. The perimeter pipe is actively dewatered locally reducing the leachate head to the invert levels. The main objective of this pipe is to prevent leachate breakout along these boundaries of the Site".

Phase 1 (Cell 11)

"Spinal leachate collection system falling from the mid-point of the cell towards two leachate collection chambers, Sump B to the west and Sump C to the east, at a gradient of 1 in 50. The collection pipes comprise perforated 150 mm diameter HDPE pipe set within 40 mm gravel. The leachate collection chambers comprise perforated 900 mm diameter HDPE tower and concrete base".

[16] TerraConsult (March 2016). Withyhedge Landfill Site Valley Cells N3 & S1 Construction Works – Validation Report Ref 2185-R4-1

Phase 1 (Cell 13)

"900 mm diameter central sump at an elevation of 46.5 m AOD, connected to two 150 mm diameter spine drains falling from the cell perimeter towards the sump at a gradient of 1:50. The spine drains are set within 40 mm gravel."

Phase 1 (Cell 14)

"900 mm diameter sump with concrete base at an elevation of 45 m AOD connected to 150 mm diameter drains in a herringbone pattern falling towards the sump at a gradient of 1:100. The drains are set within 40 mm gravel."

Phase 1 (Cell 15)

"500 mm thick basal stone drainage blanket into which a herringbone pattern of leachate pipework and extraction sump has been constructed".

Phase 2 – Area A (Cell 1/2N)

According to the 2008 monitoring review[11], a 500mm drainage blanket was installed with feeder drains and spine drain. The base of the blanket (lower 150 mm) comprises a 5 to 20 mm gravel overlain by 350 mm of 2 to 125mm gravel[6]. Perforated HDPE pipes feed collection chambers (x2) in the north of the cell.

Phase 2 – Area A (Cell 1/2S)

"The leachate drainage blanket has a total thickness of 300 mm on the base of the cells and comprises natural crushed rock gravel with a typical particle size range of between 10 and 20 mm. The leachate collection and removal system also comprises a network of 150 mm diameter HDPE main spine drain with 100 mm diameter HDPE feeder pipes at a maximum of 50 m centres. In addition, the main spine drain has been connected to the existing pipework of Cells 1 and 2 (North), which are extended through the northern inter-cell bund of Cells 1 and 2 (South). There are also two leachate extraction and two leachate monitoring wells (one of each in each cell)" [6,14].

"A non-woven needle-punched geotextile was placed directly above the geomembrane to protect the liner from damage by the gravel drainage layer. A single vertical monitoring and two extraction points (one vertical and one upslope) were installed in each cell. Leachate collection chambers (x2) are located in the north of the cell" [6].

Phase 2 – Area A (Cell 3)

"The drainage blanket has a total thickness of 300 mm with crushed rock with a nominal particle size between 10 and 20 mm. The leachate system comprises of a 160 mm hDPE main spine drain with 120 mm HDPE feeder pipes at 30 m centres. A leachate collection chamber is located in the north of the cell" [6].

Valley Cell N1, N2, N3 & S1

The leachate drainage stone installed was a 500mm thick layer with 20 mm - 40 mm screened aggregate. Spine roads of 1000 mm thickness were placed using an excavator, over HDPE pipe with a 184 mm ID. Three leachate extraction points and one monitoring point (VL1, VL2, VL3 and VLM1) were installed (drawing 2185/2/003).

Phase 2 – Area B (Cell 4 North)
The drainage blanket has a thickness of 300mm (20-40mm gravel), leachate collection pipework feeds a collection sump, 2 monitoring points have been installed.

2.4 Groundwater Management

It was previously stated that *"A groundwater cut off wall was constructed in 1995 with the intention of diverting the north westerly flow of groundwater around the periphery of the Site. A trench was constructed 500 mm into the shale below and sealed using bentonite cement slurry. Bentonite matting was used to form a low permeability barrier within the trench prior to backfilling with nominally compacted clay.*
The trench extends along the southern, eastern and southern most part of the western boundaries (to the west of Cell 13). At its western end the trench is over 4.5 m deep and therefore extends to approximately 44.5 m AOD[17]."

The site operator has not indicated that any additional groundwater management occurs at the site. Leachate monitoring points LD3 and SW Sump are concrete chambers that collect leachate in an external drain to the east and south of Phase 1. Leachate captured is diluted by groundwater which is also intercepted by the drain. Levels are maintained by pneumatic pumps[1].

2.5 Surface Water Management

Monitoring location points are detailed on drawing 3933/1/001 (2018). It is understood that during 2011 the previously proposed surface water lagoon A was constructed to collect surface water from the Phase 2 area of site. Although some monitoring data has been collected historically (monitoring point D2) there is no discharge from this storage pond and water is diverted via the Lake outfall (D1). Proposed surface water lagoon B (far eastern margin of Phase 2) has not been constructed; this is where outfall D3 has previously been proposed.

2.6 Capping and Restoration

As reported in the 2017 annual review[18], a surface emissions walkover survey was undertaken at the site by Enitial during October/November 2017 and the results assessed against operational assessment limits as specified within LFTGN07. Five zones were surveyed.

Zone 1 comprises of the western half of Phase 1, Zone 3 comprises the majority of Cell 3 and Zone 4 comprises Cell 1/2 N, Cell 1/2 S and Cell 15 all three zones have a permanent welded geomembrane cap. Zone 2 is permanently capped with lapped geomembrane and comprises the eastern half of Phase 1.

Zone 5 is temporarily capped and comprises the south western portion of Cell 3. The new permanent capping between zones 1 and 4 was not accessible due to vehicle movements and as such is to be surveyed in 2018. It was previously reported that the majority of Phase 1 is permanently capped with an overlapped geomembrane and composite on to which restoration materials have been placed[6].

[17] CL Associates (1996). Withyhedge Landfill. Geosynthetic Clay Liner Groundwater Cut Off Barrier. 6770/10. February 1996 – Referenced in Golders 2007.

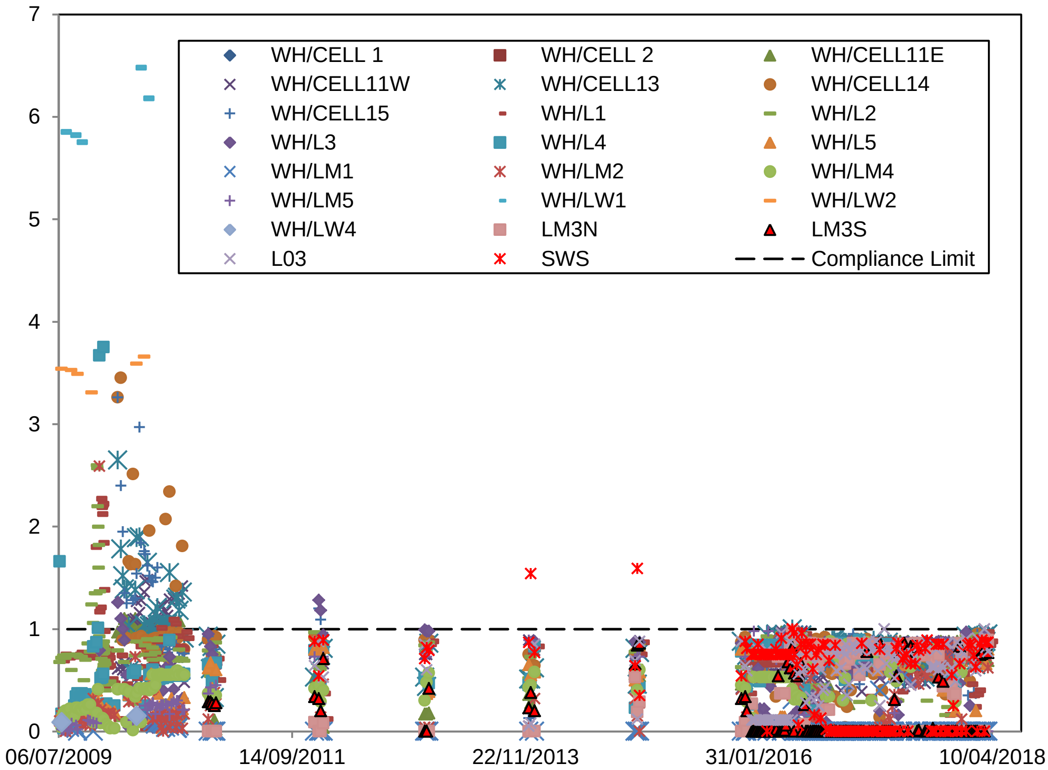
2.7 Leachate Height

Leachate is monitored at the site in the dilute and disperse area, (Phase 1) engineered cells (Phase 2) and Valley Cells. With the exception of late 2009, early 2010 the leachate levels reported by the operator (Figure 3) illustrate compliance with the 1m head limit (for all areas of the site). Many of the leachate wells are often reported as "dry"[18].

Table 2 Leachate Infrastructure

Phase	Area	Cells	Installed	Currently Monitored (data Reported)
1	-	1-10 & 12	LE1, LE2, LE3, LE4, LE5, LE6 LD3 LW1, LW2, LW4, SW (SUMP)	LE1, LE2, LE3, LE4, LE5, LE6 LD3 LW1, LW2, LW4, SW (SUMP)
		11	Cell 11W, Cell 11E	Cell 11W, Cell 11E
		13	Cell 13	Cell 13
		14	Cell 14	Cell 14
		15	Cell 15	Cell 15
Valley	-	N1	VL1 (+ monitoring well VLM1)	VL1, VLM1
	-	N2	Monitoring Well (not named)	-
	-	N3	VL3 (+ monitoring well not named)	-
	-	S1	VL2 (+ monitoring well)	-
2	A	1/2N	L1, LM1, L2, LM2	L1, LM1, L2, LM2
		1/2S	L4, LM4, L5, LM5	L4, LM4, L5, LM5
		3	L3, LM3(N), LM3(S)	L3
	B	4N	tbc	tbc

Figure 3 Leachate Height (m) - All data / Cells 2008 - 2018



Phase 1 - Cell 1, Cell 2 (data from 2008/2009)
No leachate levels recorded in the Valley Cells, they are recorded as "dry"

[18] TerraConsult (January 2018) (Ref 2932/R/005/01). Withyhedge Landfill Site 2017 Annual Review Condition 4.2.2 Section a) of Environmental Permit EPR/MP3330WP (with reference to EPR/GP3630HT/V002)

2.8 Leachate Chemistry

Leachate data is included in Appendix A (A1-A5). The leachate is consistent with expectations for a non-hazardous municipal solid waste landfill. It is a sodium bicarbonate solution, with significant ammoniacal-N (Figure 4), and chloride (Figure 5), COD (Figure 6), potassium (Figure 7) and recalcitrant organic matter. Calcium, magnesium and sulphate are low compared to the other ions in solution (Table 3).

The leachate concentration range is consistent with that of many non-hazardous landfills across the UK.

Table 3 Leachate Quality Summary Average Concentration 2010 - 2018

Phase & (Cell)		NH_4-N	Alk	Ca	COD	TOC	EC	Cl	SO_4	Mg	K	Na
		mg/l	mg/l	mg/l	mg/l	mg/l	µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l
1 (1-10 & 12)	LW1	239	2027	152	536	100	5494	712	134	31	321	736
	LW2	81	690	220	724	77	2096	174	26	23	89	207
	SW (S)	3	220	126	66	85	665	51	143	12	5	23
	LD3	7	290	125	92	37	830	26	177	12	11	25
	Cell 1#	520	5147	399	4018	1236	1240	1240	63	178	453	1095
	Cell 2#	418	4655	1237	10290	3831	1099	1099	105	167	530	849
1 (11)	Cell11E	331	2484	141	898	469	228	228	86	47	162	308
	Cell11W	419	3553	143	626	373	394	394	44	56	257	471
1 (13)	Cell13	458	3494	151	484	269	388	388	62	41	259	463
1 (14)	Cell14	1020	10185	108	2135	713	12557	949	125	63	515	1019
1 (15)	Cell15	524	4699	153	974	370	7048	446	37	38	287	509
2 (1/2N)	L1	583	4791	191	1175	380	7849	562	123	57	353	730
	L2	567	6080	180	1207	356	7909	719	144	60	425	857
	LM1*	-	66	24	89	12	230	19	-	7	4	19
	LM2*	-	57	26	109	12	231	28	-	7	4	19
2 (1/2S)	L4*	1080	9150	107	1647	1287	11110	25	50	41	412	819
	L5*	1000	2440	111	1605	2087	11140	29	44	44	435	872
	LM4*	-	37	24	117	13	218	20	-	6	3	19
	LM5*	-	67	24	80	13	221	20	-	6	4	17
2 (3)	L3	735	6062	191	2201	662	10498	748	80	61	465	985
	LM3 (N)	-	-	-	-	-	-	-	-	-	-	-
	LM3 (S)	-	-	-	-	-	-	-	-	-	-	-
	LM3	-	78	24	140	12	223	24	-	6	3	18

*** Only 1 result recorded**
 # Cell 1 and cell 2 data recorded from 2008 only.
Cell 4N (Phase 2, area B) is a new cell, at the time of writing of the HRAR there is no data for review.

The variation in leachate concentrations between Phase 1 and Phase 2 cells is apparent particularly with regard to lower concentrations of ammoniacal-N, alkalinity, TOC, chloride and potassium in Phase 1.

This reflects the age of the waste deposited and degradation, the lower concentrations are evident on the time-series graphs Figure 4, Figure 5 and Figure 6. It is noted that a minimal dataset for Phase 2 is available currently.

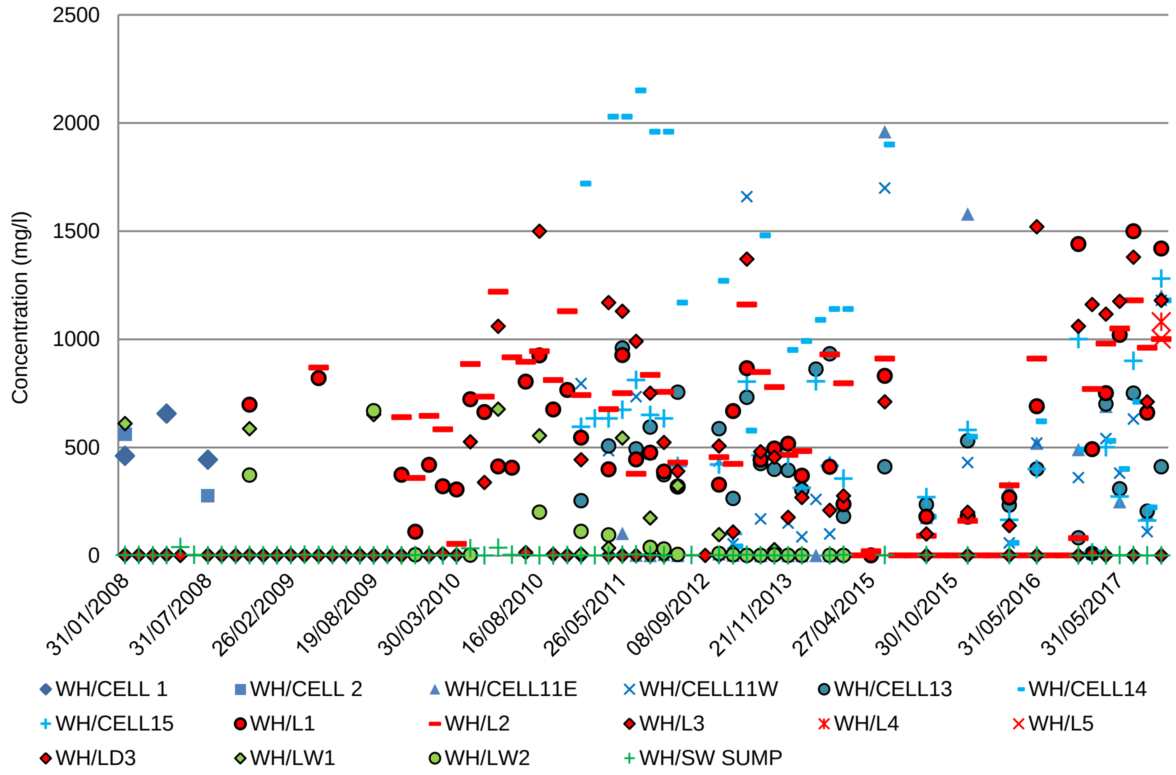
A hazardous organic screen is also required on an annual basis for the uncapped cells. Screens are undertaken annually for a combination of hazardous and non-hazardous substances.

The 2008 to 2018 data demonstrates that there are two potentially significant types of organic substance present within the leachate (Table 4), namely the hydrolysis products formed when organic matter is exposed to moisture. These soluble organic products have no long term significance and contribute to the short term BOD pulse which forms during the acetogenic stage of a landfill cell.

The most significant group of chemicals are the BTEX and associated substituted aromatics at <1 - 84µg/l. These are natural and expected breakdown products which are primarily removed by the landfill gas collection system.

Since these are secondary products formed during the methanogenic stage of a site, they are only present whilst there is sufficient degradable organic matter present within the site to sustain landfill gas generation, as such the BTEX generation rate will decrease in parallel with landfill gas depletion.

Figure 4 Leachate Ammoniacal-N 2008 - March 2018



Chlorinated solvents are at negligible concentrations within the leachate, however, there is one chlorinated herbicide, namely mecoprop within the leachate at ~1 – 168 µg/l where present between 2008 and 2018.

It should be noted that although mecoprop appears to be the most significant substance present, since the original permit application, mecoprop has been reclassified as a non-hazardous substance. Notwithstanding this concentrations from the recent screens demonstrate that mecoprop is present a marginally higher concentration than observed previous although average concentrations are lower. The dataset indicates an increase in naphthalene and nickel concentrations over those previously modelled (Table 5).

Figure 5 **Leachate Chloride 2008 - March 2018**

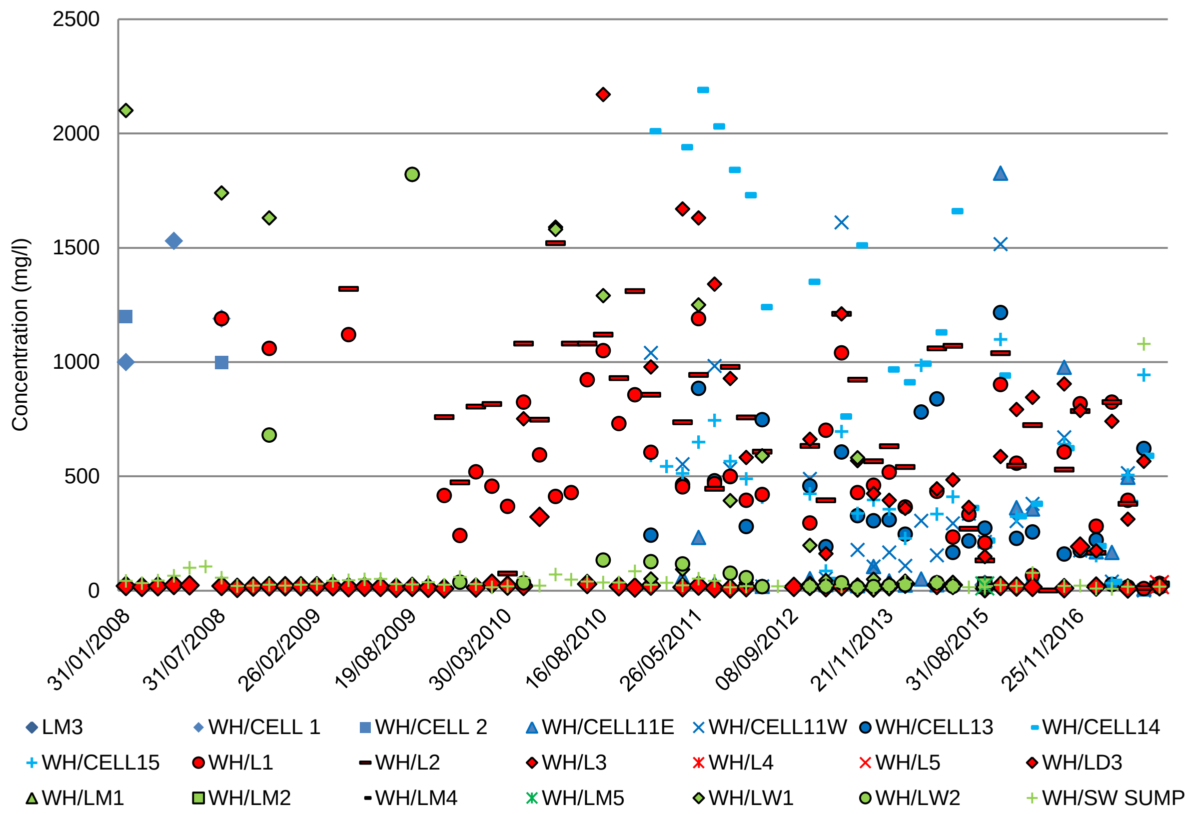


Figure 6 **Leachate COD 2008 - March 2018**

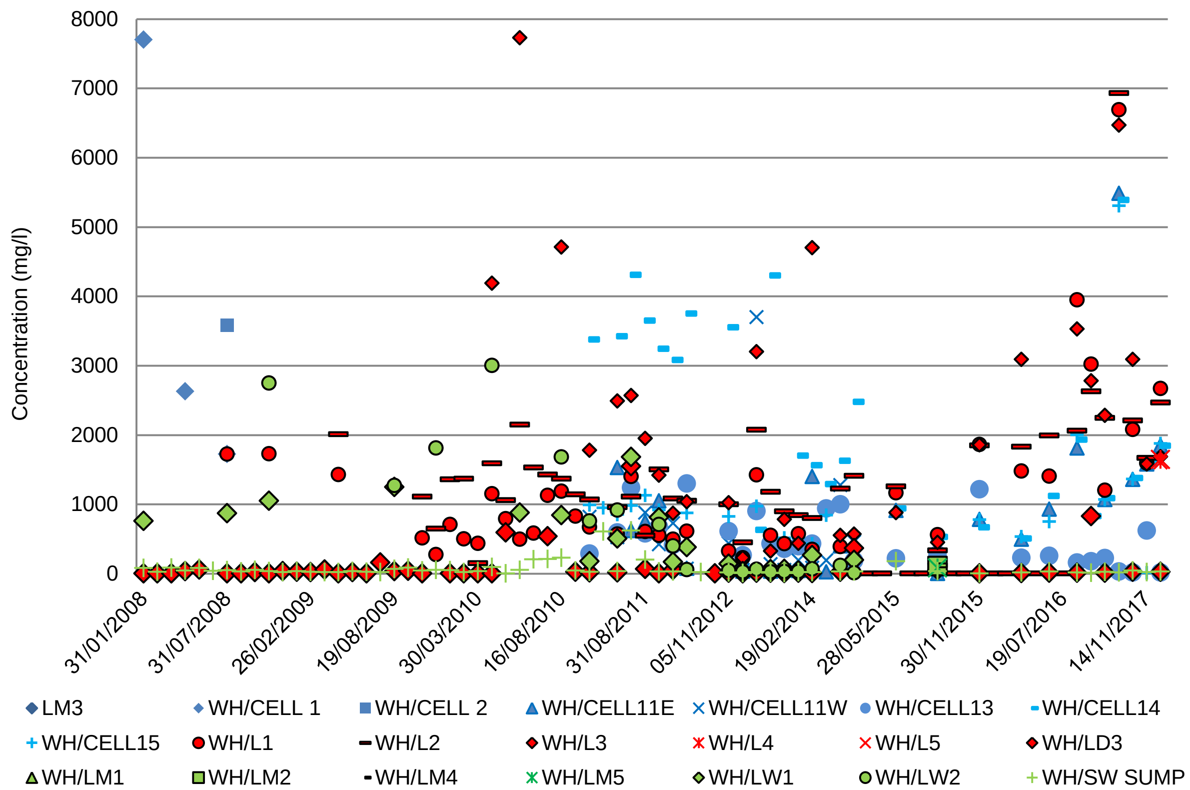


Figure 7 Leachate Potassium 2008 - March 2018

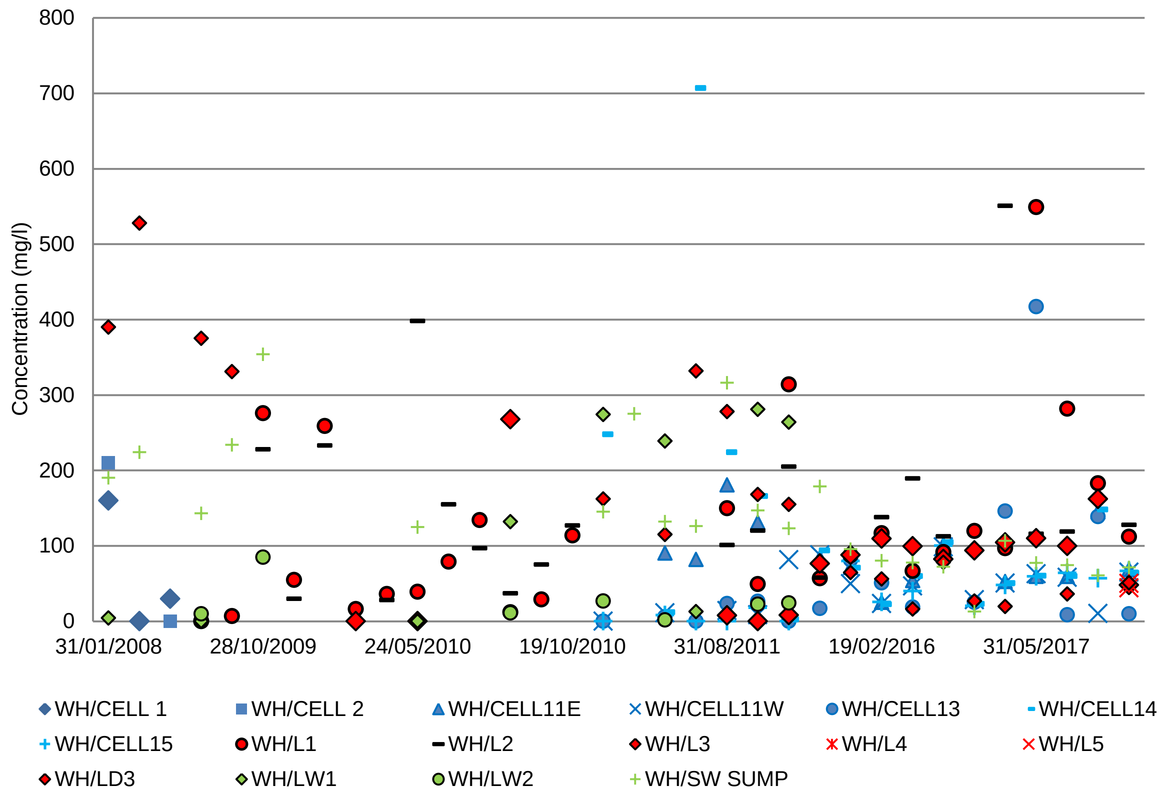


Table 4 Leachate Hazardous and Non-Hazardous Organic Screen Substances Identified as Present

Leachate	Units	All Cells	Date Range
Primary Volatile Organic Degradation Products			
Ethyl Benzene	µg/l	2 - 84	2010 - 2013
Toluene	µg/l	3 - 55	2010 - 2013
m,p-Xylene	µg/l	1 - 67	2010 - 2013
o-Xylene	µg/l	5 - 53	2010 - 2013
1,2,4-trimethylbenzene	µg/l	5 - 27	2008 - 2013
p-Isopropyltoluene	µg/l	1 - 43	2008 - 2013
Naphthalene	µg/l	<1 - 14	2008 - 2018
Organochloride Substances			
Mecoprop	µg/l	1 - 168	2008 - 2018
Hydrolysed Organic Degradation Products			
2,4-Dimethylphenol	µg/l	3 - 20	2008 – 2018
2-Methylphenol	µg/l	24	2008 – 2018
3 & 4-Methylphenol	µg/l	1 - 60	2008 – 2018
3,5-Dimethylphenol	µg/l	4 - 36	2008 – 2018
4-Chloro-3-methylphenol	µg/l	60	2008 – 2018
Phenols (monohydric)	mg/l	<1 - 7	2008 – 2018
Dimethylphenols	mg/l	<1 - 5	2008 – 2018

Naphthalene outlier of 136 (Nov 2015) not included in data range; no mecoprop > 56µg/l post 2015.

Table 5 Comparison Targeted Substances During Previous HRA and Recent Concentrations (2008-2018)

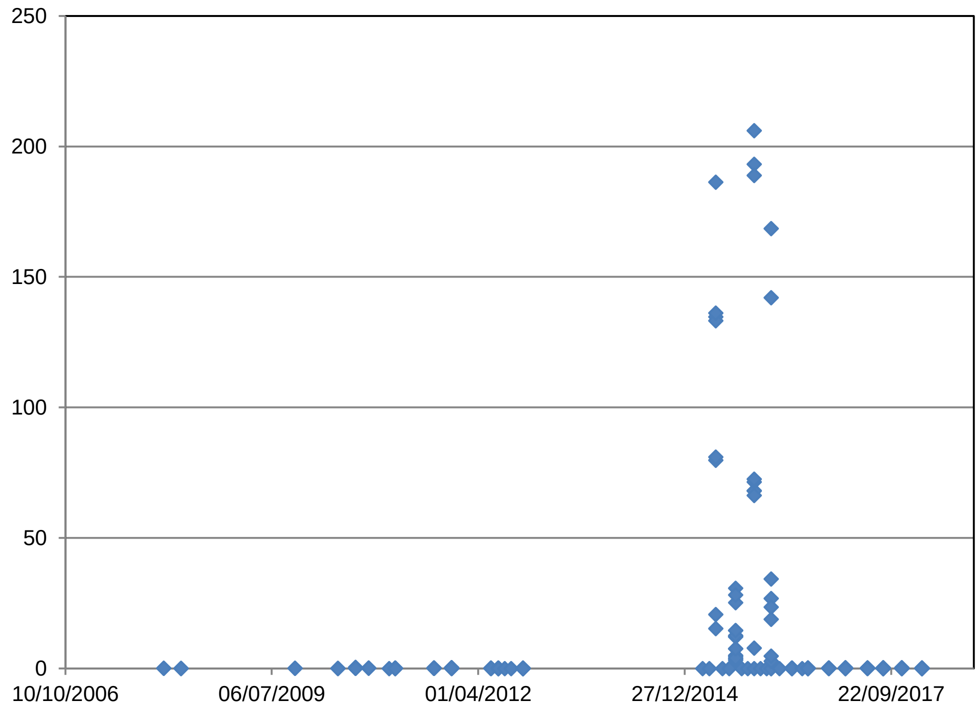
	Minimum		Average		Maximum	
	2012	2018	2012	2018	2012	2018
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Mecoprop	4e-5	<0.00001	0.0035	**0.019**	0.122	**0.168**
Naphthalene	5e-5	<0.00001	0.00046	**0.0025**	0.011	**0.014**
Phenols	5e-5	<0.0005	-	-	12	0.06
Cadmium	0.0019	<0.0001	0.0101	0.002	0.105	0.09
Nickel	0.0088	0.003	0.12	**0.13**	2.21	**4.95**

2012 data for Phase 2 included for comparison as Phase 1 data is less concentrated and reflected in the 2012 LandSim model. No average for Phenol in 2012 as modelled using log uniform distribution. Bold annotation indicates average and maximum exceedance of previous modelled concentrations.

Where cadmium is observed, concentrations are below the 5µg/l Drinking water Standard (DWS), with average concentrations at 0.03µg/l, 3 significant outliers are noted in the dataset of 2.1 mg/l, 1 mg/l and 2.5 mg/l (all in November 2015).

Regarding the priority metal nickel, the dataset indicates a dramatic increase in concentration during 2015 (May) to 2016 (February) as indicated in Figure 8 below.

Figure 8 Leachate Nickel (2008-2018) mg/l



A closer inspection of the data indicates that all monitoring locations are affected by the increases on the same dates, the most plausible explanation is transcription error where the results have been inputted to monitoring record tables as µg/l as opposed to mg/l, e.g. Cell 14, 28/05/15 should be 0.136mg/l not 136mgl. In May 2016 the result for Cell 14 was 0.16mg/l.

This error is potentially reflected in all data during the same data period (evident in the zinc dataset) hence statistical summaries are potentially skewed. Where obvious anomalies have been identified and statistical summaries are required, erroneous data has been ignored.

Average concentrations of the hazardous metals As, Pb and Hg in addition to the Non-hazardous pollutants Cd, Cu and Zn are present in the site leachate at approximate to or lower concentrations than their respective drinking water standard concentrations.

2.9 Source Term Summary

The leachate is typical of that expected from a MSW landfill site.

Hazardous substance concentrations are low to negligible within the leachate; however, non-hazardous substance concentrations are environmentally significant. Ammoniacal-N and chloride are in excess of most terrestrial waters, unless artificially or naturally salinated. Potassium concentrations are also significant compared to terrestrial waters. Nickel and chromium are the most significant priority metals within the leachate relative to their drinking water standards of 20μg/l and 50μg/l respectively.

The leachate chemistry is reducing in concentration for Phase 1 (blue and green symbols in Figure 4 to Figure 7) based on a comparison of data with more recent cells, albeit historic data for cells 1-10 & 12 is limited.

Phase 2 (Area A, and B) and the Valley cells are in an early part of the landfill's leachate generation capability and hence are expected to increase in concentration to some degree before stabilising.

3. PATHWAYS

3.1 Geological Succession

The superficial geology comprises:

- None on Site according to the BGS, previous reports confirm presence of deposits[19,3,1]
- Head – clay, silt, sand and gravel deposits (Quaternary age) – to north of Site;
- Glacial Sand and Gravel deposits (Mid Pleistocene age) – to the west of Site and further north;
- Alluvium – Further west, in the channel of the Western Cleddau.

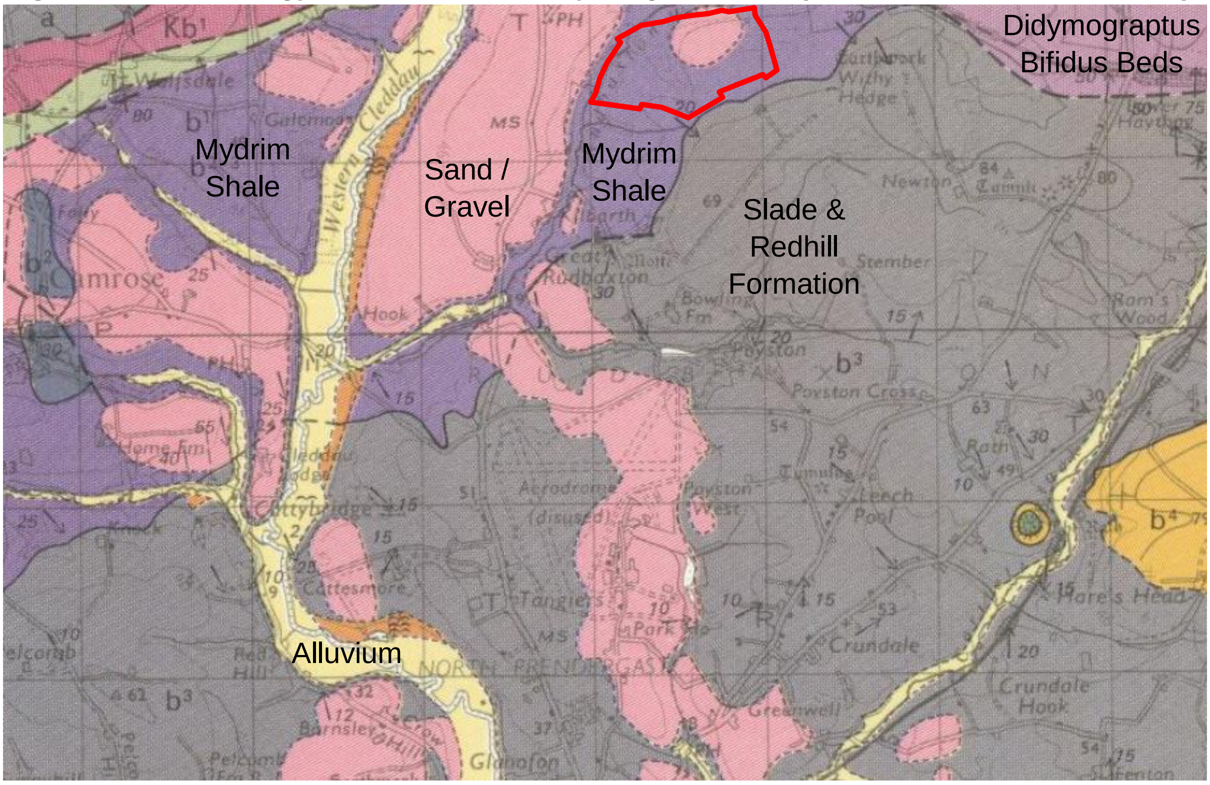
The local bedrock geological sequence comprises:

- Slade and Redhill Formation (formerly the Hendre mudstone of Ordovician age) – to the south and southeast;
- Drefach Group (mudstone of Ordovician age) – to the north and includes the Mydrim Shales Formation on Site, to the west, to the southwest and to the northwest;
- Didymograptus Bifidus Beds (mudstone of Ordovician age) – strata to the east.

3.2 Superficial Geology

The British Geological Survey (BGS) website[20] and historic BGS Map Sheet 228, 1976 (Haverfordwest) both indicate that there are little or no superficial deposits on Site, with only localised deposits in the wider surrounding area (Figure 9).

Figure 9 Geology in the area of Withyhedge Landfill (from BGS Sheet 228 - 1976)



Red boundary indicates approximate site location – indicative only

[19] AIG Consulting Ltd (October 2003). Withyhedge Landfill Site, Part B, ESID Report
[20] Geology of Britain Viewer, BGS, 2018: http://mapapps.bgs.ac.uk/geologyofbritain/home.html

Superficial deposits on site are referred to in previous investigations, more recently (within the valley area between Phase 1 and Phase 2, orange / brown clay material has been identified overlying the Mydrim Shales, it was previously stated previously that on site clays will be stockpiled to be used as engineered lining systems[3]. A number of boreholes and trial pits have been progressed beneath the foot print of the development. These prove the Drift deposits to be between 1.4 and 5.8 m thick and underlain by Shale constituting either the Slade and Redhill Beds or the Hendre and Mydrim Shales[3].

3.3 Bedrock Geology

The Drefach Group is an Ordovician lithostratigraphic group (a sequence of rock strata) in west Wales. The Group comprises the Mydrim Shales Formation, the Mydrim Limestone Formation, the Hendre Shales Formation, Asaphus Ash Formation and at its base, the underlying Felin-wen Formation[21]. The Group in some areas is more than a 400m thickness of mudstones (Mydrim Shales Formation), turbidite mudstones (Hendre Shales Formation), limestone (Mydrim Limestone Formation), tuffs and tuffites laid down in the marine Welsh Basin during the Llanvirnian and Caradocian epochs of the Ordovician period.

The Mydrim (or Dicranograptus) Shales in the area marked a resumption of black, pyritic and graptolitic mudstone deposition[22].

3.4 Pathway Properties

The potential pathways were discussed in the Golder Associates 2005 ESID[3].

It was stated:
'Withyhedge Phase 2 Landfill Site will be engineered to ensure that a 1m unsaturated zone will remain beneath the site. Leachate levels will be above groundwater levels and contaminants have the potential to migrate downward from the various phases of the site via the containment systems. Basal leakage from the landfill can ultimately recharge the water table beneath. The unsaturated zone will comprise unsaturated fluvio-glacial drift deposits or weathered bedrock (Hendre and Mydrim Shale). The Hendre and Mydrim Shale has been classified as a Non-Aquifer and the fluvio-glacial deposits as a Minor Aquifer. The saturated Hendre and Mydrim Shale will nonetheless act as a pathway to transport leakage from beneath the site towards Rudbaxton Water'.

The pathway was discussed in Golders 2007[2], an *unsaturated zone is present beneath most of the Site. The unsaturated zone varies spatially due to the water surface and the differences in basal elevations for each cell. An unsaturated zone is present beneath engineered Cells 11, 13, 14 and 15, however at maximum water levels; the unsaturated zone could be as thin as 0.1 m. The base of Cells 1 to 10 and 12 is unknown exactly, however it is believed that the bases of these cells lie at between 47 and 48 m AOD (AIG 2003). It is reported that an area to the east was excavated further due to demand for road building materials and therefore this area is likely to have been excavated deeper. Based upon this and water level contours, it is likely that beneath some parts of Cells 1 to 10 and 12 there is no unsaturated zone, particularly during times of higher groundwater levels.*

[21] http://www.bgs.ac.uk/Lexicon/lexicon.cfm?pub=DRE (BGS on-line lexicon of rock units)
[22] Norton, G E, Cooper, D C, Davies, J R and Cornwell, J D. (2000). Evidence for gold mineralisation in the Lower Palaeozoic and Precambrian rocks of south-west Wales. BGS Research Report RR/00/10. DTI Minerals Programme Publication No. 5.

The leachate level in this area is also above the level of groundwater, therefore there is a net outward hydraulic gradient for leachate and potential for leakage. Leakage will therefore be considered through the unsaturated zone (and landfill liner where present). The saturated shale will act as a pathway to transport leakage from beneath the Site towards Rudbaxton Water.

Since the production of the 2012 HRAR, the Valley Cells (in-between Phase 1 and Phase 2) have been designed; permitted and infilling has been taking place. Orange / Brown clay material in this area was reworked as part of the basal lining system, remoulded vertical permeability's are reported for the clay source under the Valley Cells N1 and N2[15] of $3.4x10^{-10}$m/s, $1.4x10^{-10}$m/s, $3.5x10^{-10}$m/s, $1.6x10^{-10}$m/s, $4x10^{-10}$m/s and $3.8x10^{-10}$m/s.

Remoulded vertical permeability's for material under the Valley Cells N3 and S1[16] are reported at $1.5x10^{-10}$m/s, $2x10^{-10}$m/s, $1.7x10^{-10}$m/s, $1.4x10^{-10}$m/s, $1.5x10^{-10}$m/s, at $1.6x10^{-10}$m/s and $2.2x10^{-10}$m/s.

The underlying natural strata were investigated through a detailed SI programme prior to 2003, as detailed in the AIG (2003) ESID[19]. The ground conditions were summarised as comprising *Topsoil up to 0.75 m in thickness overlying generally cohesive Glaciofluvial Deposits with a maximum penetrated thickness of 5.4 m. Where penetrated, Glaciofluvial Deposits were found to be underlain by variably weathered dark grey and black carbonaceous shales representing the Mydrim and Hendre Shales. Groundwater was found to be present at relatively shallow depth beneath much of the installation with monitored groundwater levels of between 37.44 mOD at the monitoring standpipe installed within AIGBH101 and 42.24 mOD at the monitoring standpipe installed within AIGBH104. In-situ permeability of the variably weathered shale strata was found to be between $1.47x10^{-8}$ and $2.0x10^{-5}$ m/s.*

Further engineering and analytical details for pathway properties are provided in AIG 2003.

4. RECEPTORS

4.1 Groundwater

The most recent HRAR (2012)[1] detailed that the receptors at site as:

- For Hazardous Substances – the base of the unsaturated zone at the point of entry into groundwater present within the fluvio-glacial deposits and Hendre and Mydrim Shale bedrock, subject to dilution that occurs within the mixing zone.
- For Non Hazardous Substances – the groundwater at the downstream (permit) boundary of the site. Although much of the fluvio-glacial deposits have been removed. The Hendre and Mydrim Shales are classified as “Secondary B” Aquifers.
- Rudbaxton Water - surface water feature to which groundwater discharges

It is noted that hazardous substances are now assessed at the edge of site, (site boundary) thus allowing dilution and attenuation along the groundwater flow-path. This review has not identified any other changes to the receptors previously identified.

We note however that Rudbaxton Water should be considered as the primary receptor, as groundwater flow within the underlying strata is a pathway to the receptor. Groundwater in the bedrock, (and any remaining superficial strata) do not fulfil a role as a useable water resource (i.e. there is no available land in-between the site and Rudbaxton Water where the groundwater would potentially be used). It is apparent from site plans that the site boundary is coincident with the course of Rudbaxton Water.

It has been stated previously that the site does not fall within a Source Protection Zone[3] (SPZ) and all previously identified abstraction zones (within 5km) are all up gradient or cross gradient[3]. This HRAR has not identified any new abstraction points.

Reviewing current aquifer designation at http://magic.defra.gov.uk/magicmap.aspx indicates that the underlying bedrock is classified as “Secondary B”, there are no superficial strata in the area with an aquifer designation.

4.2 Groundwater Levels and Hydraulic Direction

Groundwater level monitoring data is obtained currently from 22 boreholes located around the periphery of the installation (see drawing 3933/1/001, August 2018). Since the writing of the 2012 HRAR, in July 2015 monitoring points BH21, BH22 (GA02) and BH23 located in the Valley area were decommissioned as development commenced[23].

Groundwater level monitoring (Figure 10) confirms the north-westerly hydraulic gradient consistent with previous HRA’s and associated reports (e.g. Golder 2005[3]). There is an indication that the flow direction reverts to a north north-westerly direction towards the western area of the site (i.e. through Phase) which is coincident with topography and the change in direction of the course of Rudbaxton Water. The position of the groundwater boreholes and inferred groundwater surface (June – Sept 2017 average levels) is presented on Figure 11. The long term trends show groundwater levels to have remained relatively stable between 2006 and 2018 (anomalous spikes are clearly evident in the dataset). Only levels BH4 appears to have declined recently, assumptions regarding unsaturated zone thickness remains as previously assessed and modelled.

[23] ExCal Ltd. (June 2016). KE 240-01-08/Rev 1/Annual Report (1st January 2015 – 31st December 2015)

Figure 10 Groundwater Levels (2006 – March 2018)

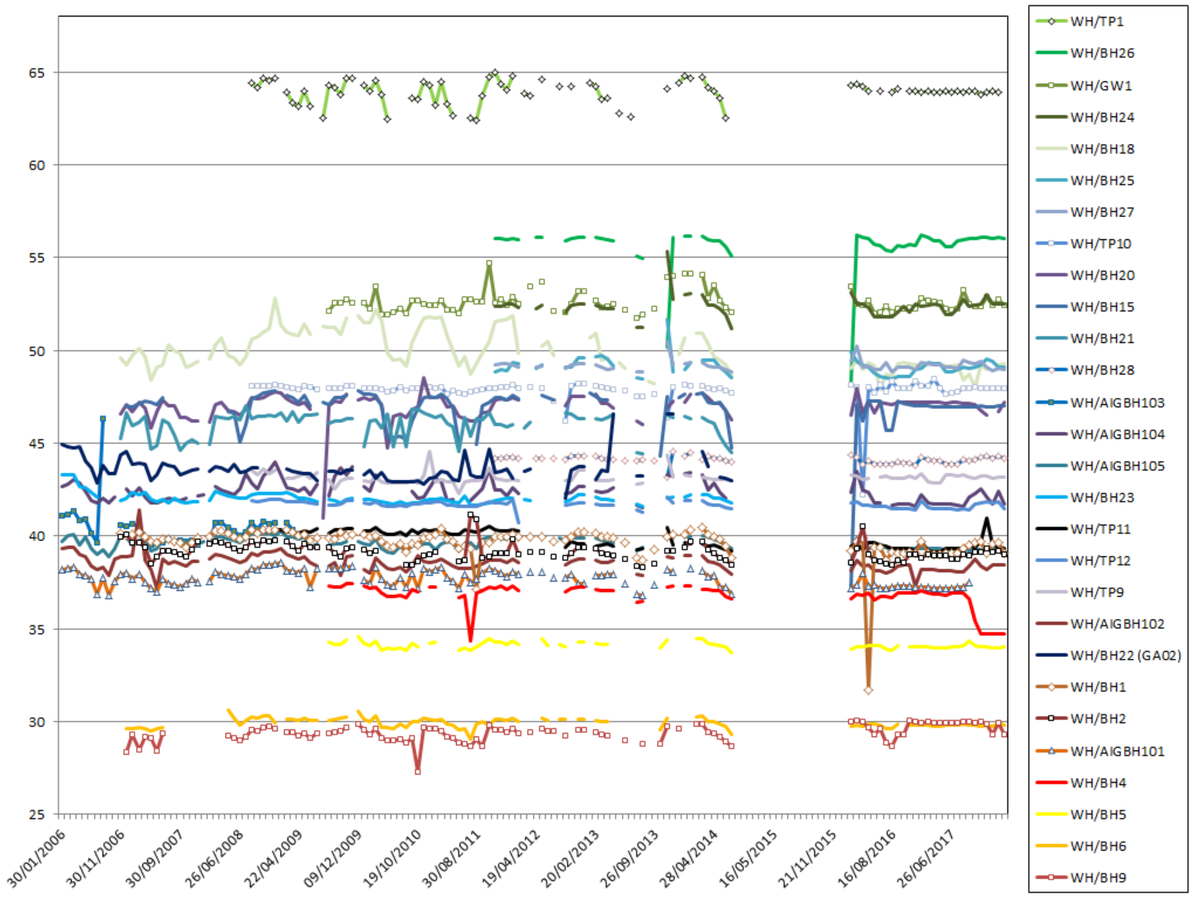
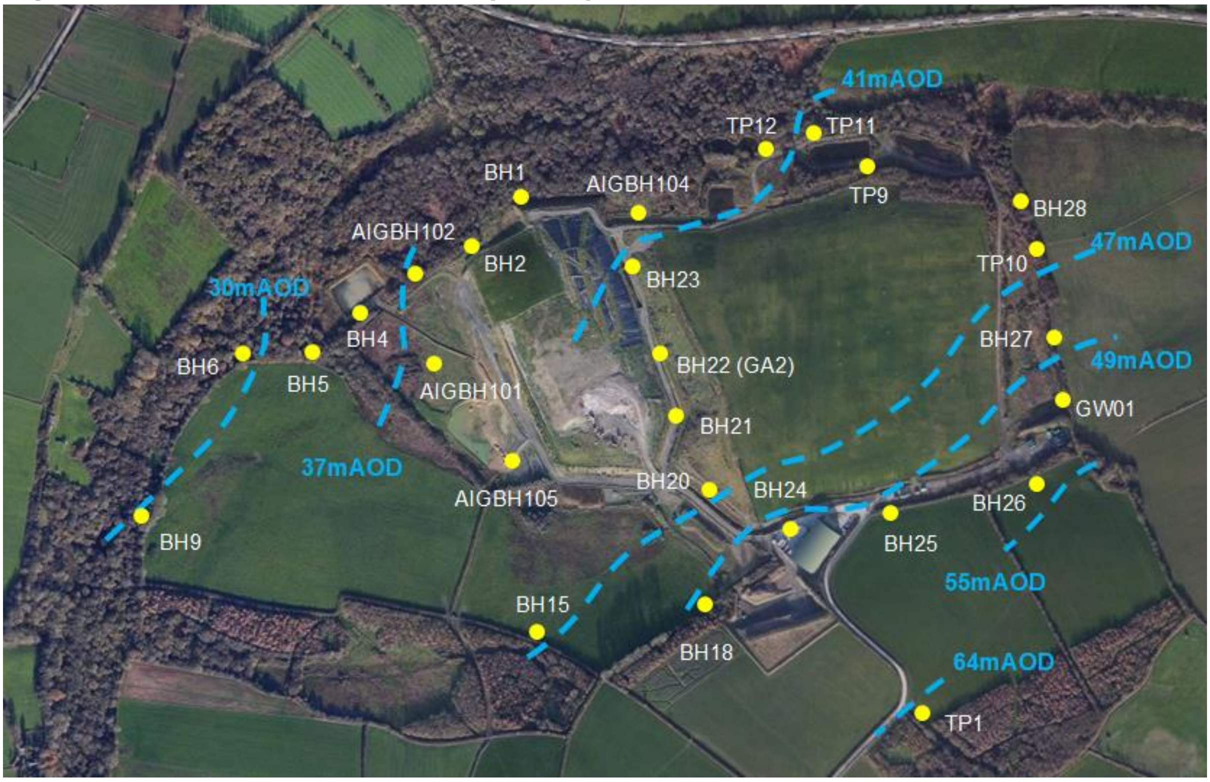
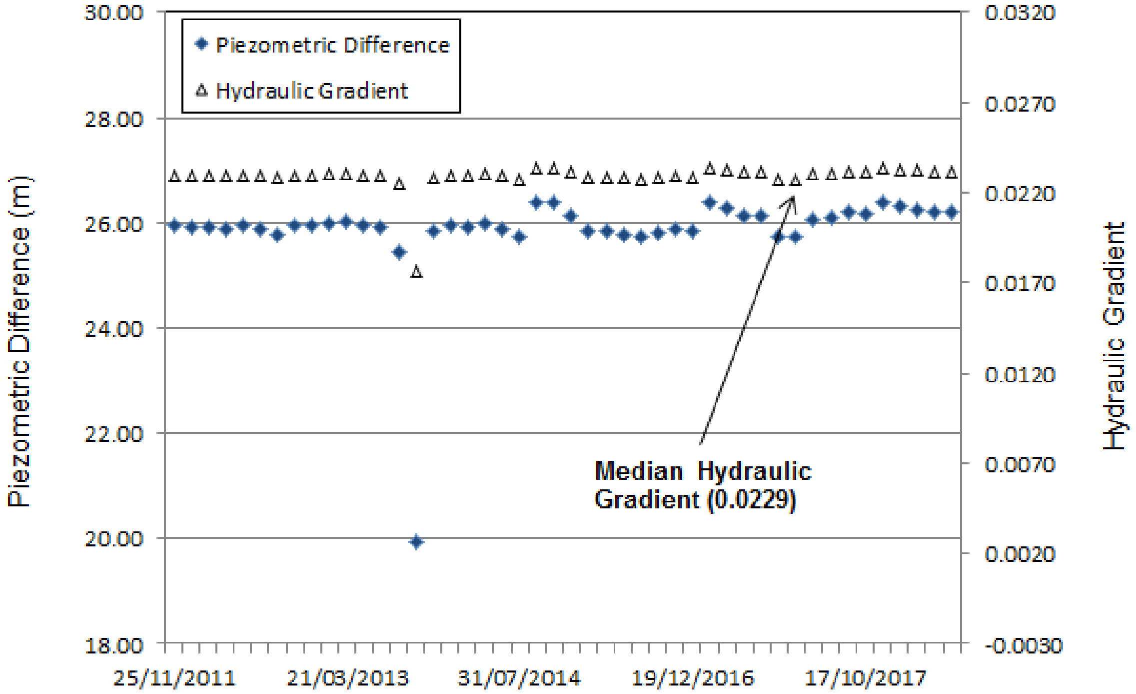


Figure 11 Groundwater Levels (mAOD)



Groundwater level difference between BH26 and BH6 over a distance of 1130m gives a hydraulic gradient of between 0.0177 and 0.0234, average of 0.0229 (Figure 12). Groundwater levels to the north of the site and west fall between 40 and 30mAOD which are coincident with elevation of Rudbaxton Water and further confirm base-flow contribution as previously inferred.

Figure 12 Hydraulic Gradient



4.3 Groundwater Quality

Groundwater level monitoring data is obtained currently from 17 boreholes located around the periphery of the installation (see drawing 3933/1/001, August 2018).

Groundwater quality assessments at landfill sites are usually initially undertaken by comparing the concentration of the principle leachate constituents, ammoniacal-N and chloride between the upgradient and downgradient monitoring points.

Groundwater level monitoring confirms a north west to west gradient, statistical analysis has been undertaken on all boreholes, (where data is available) the data is presented in Table 6 (average concentration) and Table 7 (maximum concentrations).

Groundwater quality data is summarised in Appendix B as time series plots of each monitoring point and specific determinants (Figures B1 – B32).

The tables have been subdivided based on borehole position in relation to the groundwater flow path. It is evident that concentrations are similar for both up-gradient and downgradient locations with the exception of ammoniacal-N which is more concentrated on the northern site boundary however WH/GW1 (up-gradient) also exhibits higher concentrations, higher than the DWS concentration.

Table 6 Groundwater Matrix Constituents Average Concentration (2012 - 2018)

	EC	NH_4-N	COD	TOC	Ca	Mg	Na	K	Cl	SO_4	Alk
	µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Eastern Locations – Up-gradient of Phase 1 & South of Phase 2											
WH/BH28	-	-	-	-	-	-	-	-	-	-	-
WH/TP10	272	0.12	128	4	21	4	15	0.4	19	24	67
WH/BH27	-	-	-	-	-	-	-	-	-	-	-
WH/GW1	846	2.02	1161	15	94	42	27	13	29	94	162
WH/BH26	270	0.33	165	8	2	11	13	0.6	18	28	18
WHBH25	-	-	-	-	-	-	-	-	-	-	-
WH/TP1	346	0.13	240	10	53	5	19	4	29	19	128
WH/BH24	-	-	-	-	-	-	-	-	-	-	-
WH/BH18	300	0.70	44	5	27	8	18	1	30	33	97
WH/BH15	227	0.07	84	9	33	5	16	2	24	23	101
Cross-gradient or locations south or west of Phase 2											
WH/BH20	255	0.14	80	8	39	5	21	0.3	31	44	105
WH/AIGBH105	393	0.27	84	25	62	7	15	0.7	22	21	204
WH/AIGBH101	258	0.45	326	6	50	3	8	5	20	120	103
WH/BH4	271	0.10	103	6	41	8	17	0.5	22	17	125
WH/BH5	324	0.15	230	14	39	9	15	1	21	29	109
WH/BH6	189	0.09	66	7	25	2	12	0.1	18	23	61
WH/BH9	183	0.06	60	11	25	2	13	0.5	19	21	60
Downgradient or locations on the northern boundary											
WH/TP9	558	0.76	127	8	48	15	30	3	56	44	131
WH/TP11	214	0.13	53	13	27	5	35	0.4	37	31	203
WH/TP12	489	0.12	1073	11	56	9	18	0.4	31	94	207
WH/AIGBH104	2691	0.34	280	12	71	5	17	5	25	55	198
WH/BH1	304	0.43	137	11	49	2	31	0.6	2	62	99
WH/BH2	458	0.25	482	8	67	19	23	2	55	207	44
WH/AIGBH102 (BH3)	241	0.43	234	5	61	2	7	6	21	20	106
Valley Area, Formerly Cross-gradient / Downgradient of Phase 1 (Now beneath the Valley Cells)											
WH/BH21	434	3.77	168	9	48	8	26	5	37	89	117
WH/BH22 (GA2)	407	2.53	225	4	48	8	18	8	30	27	140
WH/BH23	466	0.18	113	4	127	12	35	1	156	39	113
(2008-2009)											
WH/AIGBH103	428	1.39	137	3	145	-	-	4	29	48	221

- no data

Shaded cells denote exceedance of DWS (0.39mg/l NH4-N) (250mg/l Chloride / Sulphate). Spurious data excluded (19/01/17, 06/04/17, 11/07/17, 07/09/17). WH/AIG103, BH21, BH22, BH23 not monitored currently as lost under cell development. BH27 & BH28 only report groundwater level.

The recent monitoring data indicates spurious data for both chloride (Figure 13) and ammoniacal-N (Figure 15) within the 2017 data. To explore this anomaly further, species targeted time-series plots have been assessed. Figure 17 clearly demonstrates that all boreholes on 4 specific monitoring dates have increased in ammoniacal-N concentrations coincidently on the same date prior to a return to baseline concentrations.

The chloride and sulphate data (Appendix B) also confirm this anomalous data and hence monitoring data for the 19/01/17, 06/04/17, 11/07/17 and 07/09/17 are discounted from this review.

Typical concentrations for chloride are <150 mg/l, (Figure 13) with many boreholes typically <60 mg/l (Figure 14). BH23 is anomalous, with concentrations varying between 150 and 375 mg/l prior to decommissioning in 2015 and building of the Valley Cells.

Table 7 Groundwater Matrix Constituents Maximum Concentration (2012 - 2018)

	EC	NH_4-N	COD	TOC	Ca	Mg	Na	K	Cl	SO_4	Alk
	μS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Eastern Locations – Up-gradient of Phase 1 & South of Phase 2											
WH/BH28	-	-	-	-	-	-	-	-	-	-	-
WH/TP10	1298	8.6	411	35	95	5.	21.4	0.7	71	74	202
WH/BH27	-	-	-	-	-	-	-	-	-	-	-
WH/GW1	1710	15.5	2800	55	168	42	125	21	139	456	427
WH/BH26	368	1.6	165	22	92	12	24	1	90	52	242
WHBH25	-	-	-	-	-	-	-	-	-	-	-
WH/TP1	562	4.3	240	50	131	6	45	5	128	322	317
WH/BH24	-	-	-	-	-	-	-	-	-	-	-
WH/BH18	860	17.4	185	34	47	16	24	2	147	70	287
WH/BH15	621	1.8	299	39	75	9	26	4	1339	90	634
Cross-gradient or locations south or west of Phase 2											
WH/BH20	1020	3.6	294	38	171	6	44	8	148	116	570
WH/AIGBH105	875	8.8	321	422	82	9	19	1	59	97	647
WH/AIGBH101	1520	13.6	1750	37	217	3	9	28	96	1200	714
WH/BH4	430	3.4	450	35	133	8	45	0.8	124	209	445
WH/BH5	626	2.4	980	166	87	20	26	2	72	105	281
WH/BH6	914	3.2	317	45	51	3	20	0.3	128	61	250
WH/BH9	621	1.3	216	95	64	3	20	0.7	119	61	234
Downgradient or locations on the northern boundary											
WH/TP9	927	5.9	373	37	131	28	76	5	192	82	316
WH/TP11	387	3.6	140	262	160	6	408	1	256	72	4026
WH/TP12	935	7.9	5220	97	149	12	23	0.7	112	150	2170
WH/AIGBH104	95600	5.8	818	49	170	7	46	19	132	191	578
WH/BH1	1840	10.5	1020	74	188	4	116	0.9	169	212	525
WH/BH2	458	0.3	482	66	277	82	59	7	205	1230	281
WH/AIGBH102 (BH3)	920	15.5	583	23	274	3	8	28	60	29	788
Valley Area, Formerly Cross-gradient / Downgradient of Phase 1 (Now beneath the Valley Cells)											
WH/BH21	1300	19.8	857	32	59.6	10	35	8	191	144	284
WH/BH22 (GA2)	1930	19.6	1300	13	85	12	28	10	138	55	328
WH/BH23	1210	6.5	372	48	655	18	50	2.2	418	122	820
(2008-2009)											
WH/AIGBH103	766	11.6	354	15	783	-	354	20	57	94	827

- no data

Shaded cells denote exceedance of DWS (0.39mg/l NH4-N) (250mg/l Chloride / Sulphate) – clear outliers are evident in the dataset (compare to average concentrations in table 8 and time-series charts at Appendix A). Spurious data excluded (19/01/17, 06/04/17, 11/07/17, 07/09/17). BH27 & BH28 only report groundwater level.

There are no clear rising trends for chloride within the detail time-series plot presented at Figure 14. There is slight indication that concentrations at TP9 and WH/BH2 exhibit a concentration relationship with seasonality, with higher concentrations in the summer / autumn.

A cross-plot of ammoniacal-N and chloride for WH/BH23 does not indicate any correlation (Appendix B-32) however there is an evident increase in chloride over the time-series data and a to a lesser degree at WH/BH2. The previous increase at WH/BH2 has reduced post 2012.

Ammoniacal-N concentrations overall have shown a declining trend over the previous 10 years (Figure 15). The borehole with most impact are those directly downgradient of the Phase 1 area of site (e.g. WH/BH22 (GA2), WH/BH21 and those on the northern boundary).

Figure 13 Groundwater Chloride

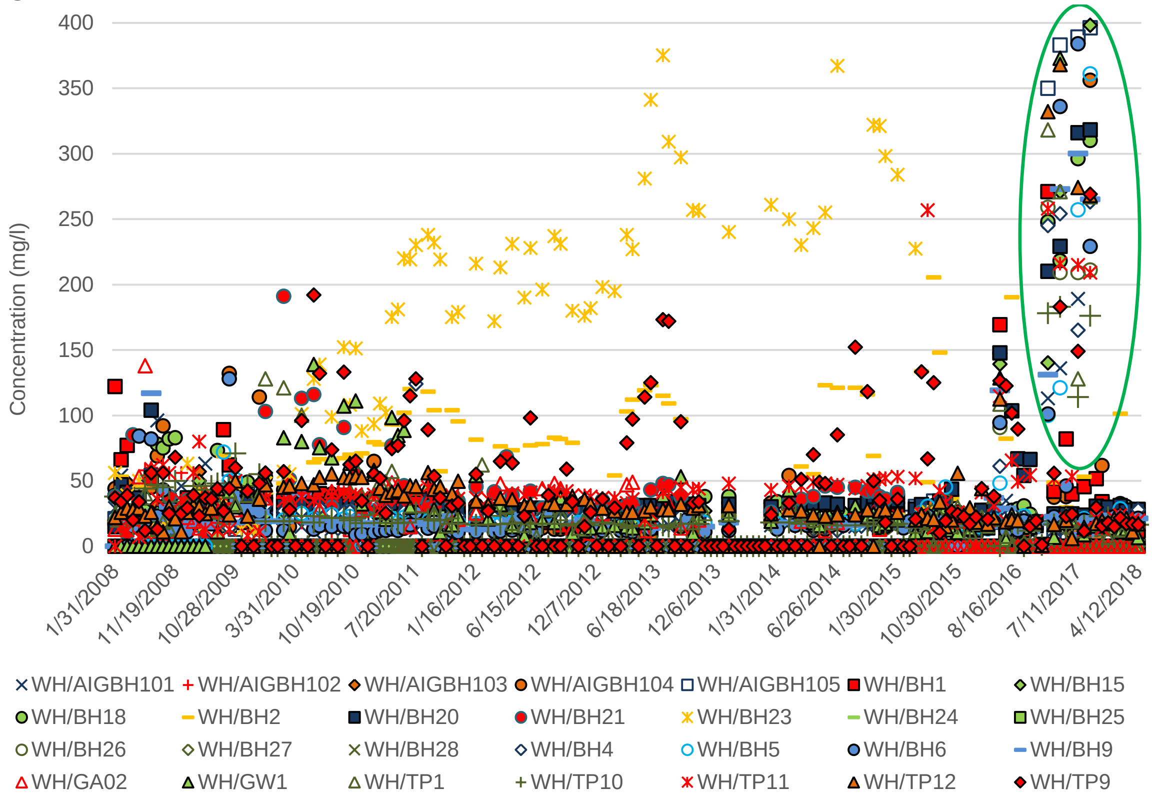


Figure 14 Groundwater Chloride – detail

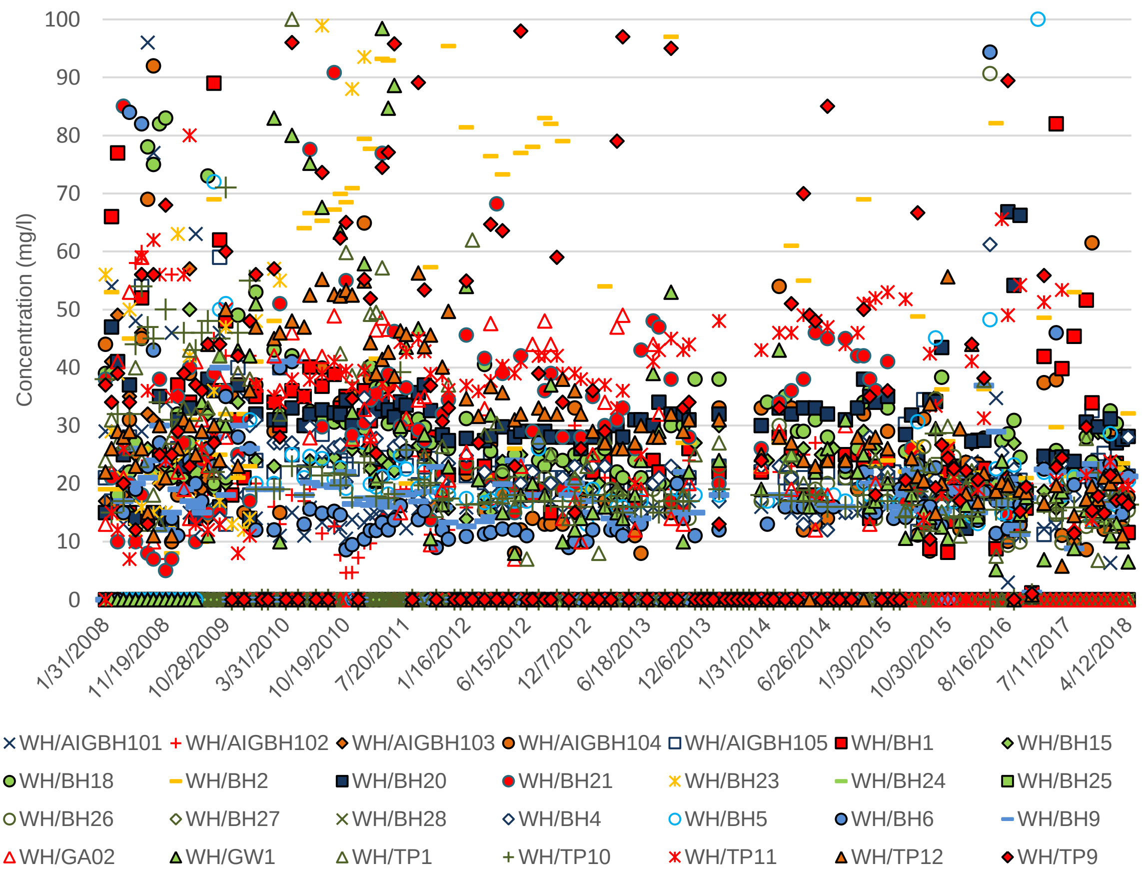


Figure 15 Groundwater Ammoniacal-N

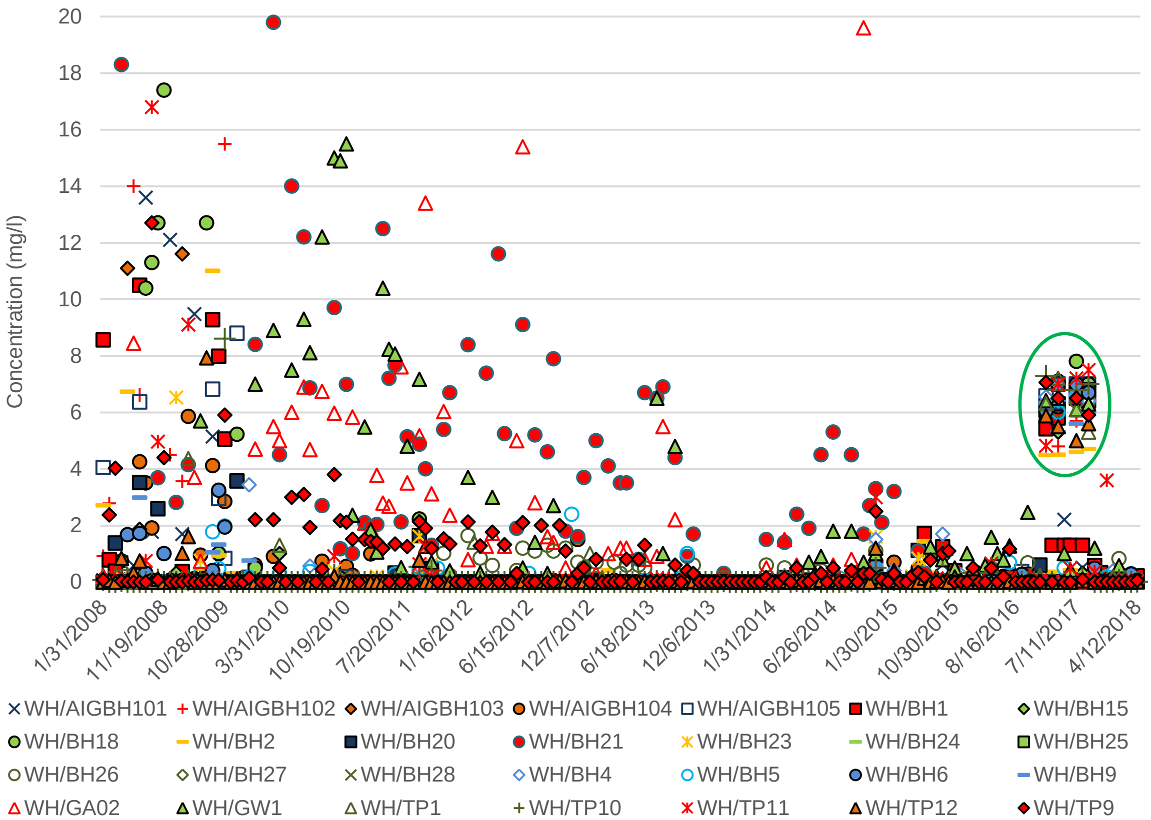


Figure 16 Groundwater Ammoniacal-N - detail

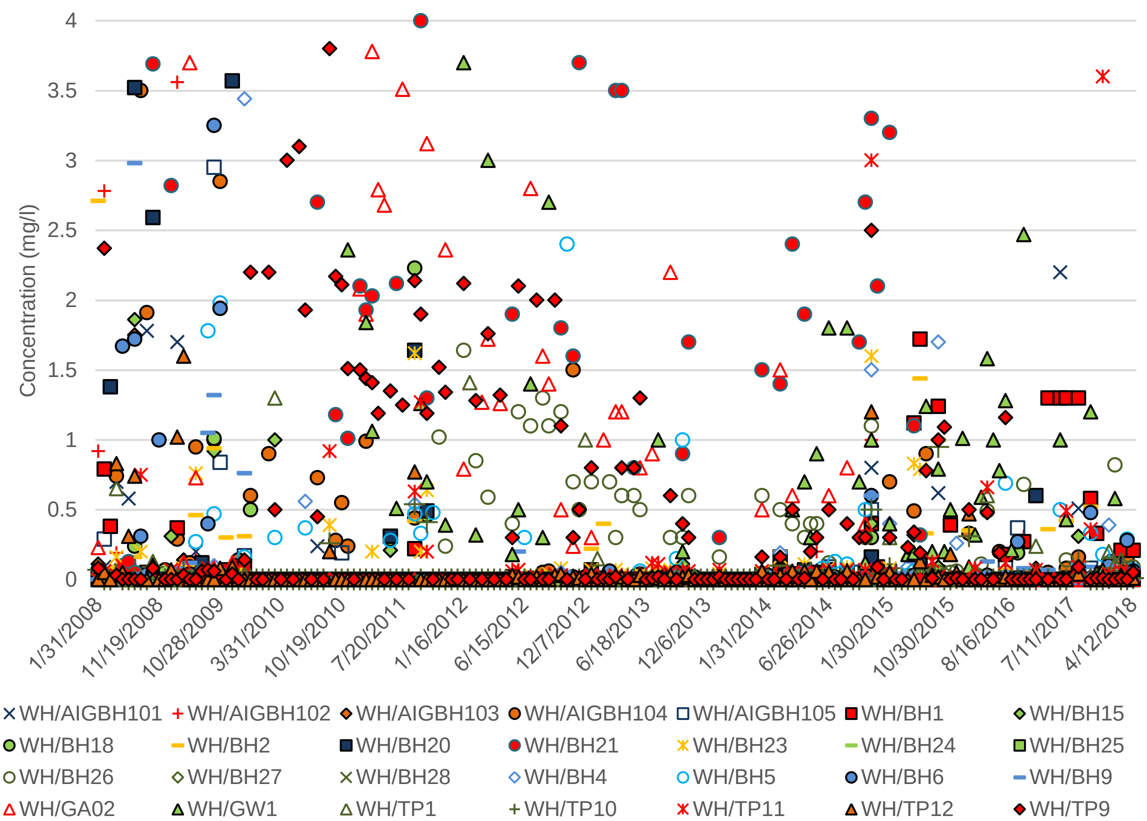
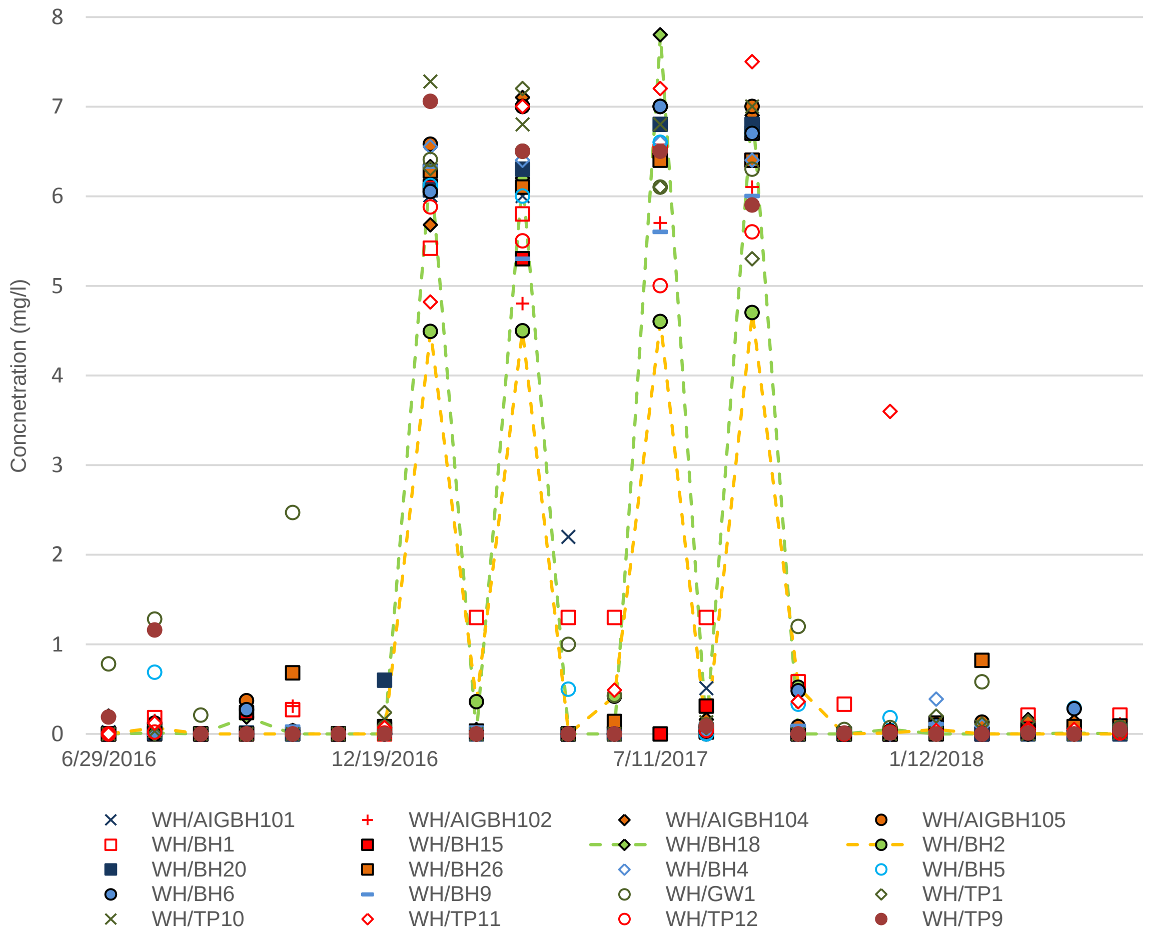


Figure 17 Groundwater Ammoniacal-N – (2016-2018)



Previous HRA's have detailed the advance of a leachate plume emanating from the unlined Phase 1 area of site.

Average concentrations for 9 boreholes over the 2012 - 2018 period are greater than the DWS however it can be seen that many boreholes approximate to the DWS or are lower in concentration (Table 6). Average concentrations at TP9 are greater than DWS at 0.76 mg/l however concentrations downgradient at TP11 and TP12 are less than 0.2 mg/l over a distance less than 100 m which are closer to the site boundary and Rudbaxton Water.

There are sporadic exceedances of the chloride and sulphate DWS concentrations (see Table 7, maximum values) however these are clearly outliers when reviewed against borehole specific time-series charts in Appendix B and the average concentrations presented in Table 6.

In comparison to previously presented datasets (Table 8) it is evident that concentrations have reduced at almost all boreholes. This is particularly evident for WH/BH21 (now under Valley Cell S1) where average ammoniacal-N concentration of 25.7 mg/l (2005 – 2003 data) reduced to 4.2 mg/l (2012 – 2008) and subsequently to 3.8 mg/l (2015 – 2012) prior to borehole decommissioning.

Table 8 Comparison Groundwater Average & Maximum Concentrations

	2018 HRAR *(2018-2012)*				***Data (2012-2008)***				**2012 HRA *(2010-2008)***				**2007 HRA *(2007-2005)***			
	Average (mg/l)		***Max (mg/l)***		***Average (mg/l)***		***Max (mg/l)***		***Average (mg/l)***		***Max (mg/l)***		***Average (mg/l)***		***Max (mg/l)***	
	NH_4-N	**Chloride**	**NH_4-N**	**Chloride**	**NH_4-N**	**Chloride**	**NH_4-N**	**Chloride**	**NH_4-N**	**Chloride**	**NH_4-N**	**Chloride**	**NH_4-N**	**Chloride**	**NH_4-N**	**Chloride**
Eastern Locations – Up-gradient of Phase 1 & South of Phase 2																
WH/BH28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WH/TP10	0.12	19	8.6	71	0.17	27	8.6	71	-	-	0.11	23	0.18	24	1.60	150
WH/BH27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WH/GW1	2.02	29	15	139	3.92	44	15	139	-	-	13.60	139	-	-	-	-
WH/BH26	0.33	18	1.6	90	0.85	20	1.6	24	-	-	-	-	-	-	-	-
WHBH25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WH/TP1	0.13	29	4.3	128	0.19	36	4.3	128	-	-	3.44	128	0.25	25	3.12	50
WH/BH24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WH/BH18	0.70	30	17.4	147	1.27	33	17.4	83	-	-	0.50	53	-	-	-	-
WH/BH15	0.07	24	1.8	1339	0.09	25	1.8	56	-	-	1.00	50	-	-	-	-
Cross-gradient or locations south or west of Phase 2																
WH/BH20	0.14	31	3.6	148	0.23	30	3.6	104	-	-	0.07	34	0.19	21	0.80	29
WH/AIGBH105	0.27	22	8.8	59	0.58	25	8.8	59	-	-	0.37	40	-	-	-	-
WH/AIGBH101	0.45	20	13.6	96	0.75	24	13.6	96	-	-	0.07	26	-	-	-	-
WH/BH4	0.10	22	3.4	124	0.12	26	3.4	124	-	-	0.56	37	-	-	-	-
WH/BH5	0.15	21	2.4	72	0.23	24	2.4	72	-	-	0.76	40	-	-	-	-
WH/BH6	0.09	18	3.2	128	0.19	22	3.2	128	-	-	0.07	44	-	-	-	-
WH/BH9	0.06	19	1.3	119	0.12	22	2.9	117	-	-	0.07	47	-	-	-	-
Downgradient or locations on the northern boundary																
WH/TP9	0.76	56	5.9	192	1.45	54	12.7	192	-	-	3.52	192	1.96	105	4.60	700
WH/TP11	0.13	37	3.6	256	0.61	35	16.8	80	-	-	0.12	43	0.24	37	1.16	44
WH/TP12	0.12	31	7.9	112	0.24	37	7.9	56	-	-	0.14	59	0.08	36	0.50	60
WH/AIGBH104	0.34	25	5.8	132	1.28	30	36.8	132	-	-	16.8	77	0.08	16	0.65	28
WH/BH1	0.43	2	10.5	169	0.80	33	10.5	122	-	-	0.08	40	-	-	-	-
WH/BH2	0.25	55	0.2	205	0.43	51	11	120	-	-	0.30	67	-	-	-	-
WH/AIGBH102 (BH3)	0.43	21	15.5	60	0.80	24	15.5	118	-	-	0.46	34	-	-	-	-
Valley Area, Formerly Cross-gradient / Downgradient of Phase 1 (Now beneath the Valley Cells)																
WH/BH21	3.77	37	19.8	191	4.21	39	19.8	191	-	-	19.80	191	25.71	464	55.00	1400
WH/BH22 (GA2)	2.53	30	19.6	138	2.80	33	15.4	138	-	-	36.80	132	0.32	22	2.8	39
WH/BH23	0.18	156	6.5	418	0.18	108	6.5	238	-	-	0.83	139	0.32	25	0.75	33

- no data, 2012 HRA average data not reported.
Shaded cells denote exceedance of DWS (0.39mg/l NH4-N) (250mg/l Chloride)
2007 HRA (data for TP boreholes and selected BH's, Jan05-Jul07; other BH's, Oct06-Jul07).Spurious data excluded (19/01/17, 06/04/17, 11/07/17, 07/09/17)

4.4 Surface Water

Surface water run-off from restored phases at the site is channelled into a sequence of lagoons constructed as the individual cells within each phase are progressively capped. These lagoon systems then discharge into Rudbaxton Water, which is the closest watercourse to the site and which flows along the northern perimeter of Phase 1 in a westerly direction and Phase 2 in a south-westerly direction. Rudbaxton Water later joins the Western Cleddau River approximately 2 km southwest of the site. Rudbaxton Water is the primary receptor at site as groundwater is conceptualised to provide a base-flow contribution.

Surface water quality monitoring in accordance with the permit is required to be undertaken at monitoring points D1, D2 and D3, these are discharge points from the surface water settlement lagoons north of Phase 1 (D1) and Phase 2 (D2 and D3). There are no discharges from D2 or D3.

Rudbaxton Water is monitored monthly at points SP1, SP3, SP5, SP6 and SP7 in accordance with Table S4.10 of the current permit, these monitoring points do not have specified compliance limits. All surface water monitoring points are listed in Table 9 below. Surface water monitoring locations provided on drawing 3933/1/001.

Table 9 Surface Water Monitoring Points

Monitoring Point	Description
SP1	Rudbaxton Water, upstream of Site
SP3	Surface water lagoon, beneath TP10 and SP1
SP5	Rudbaxton Water, downstream of Phase 1 and WH/D1 but upstream of Phase 2
SP6	Surface water inlet to lagoon servicing WH/D2
SP7	Rudbaxton Water, downstream of Site
D1	Formerly referred to as WH/L out, located at the outfall of the Phase 1 surface water lagoon system to Rudbaxton Water
D2	*Yet to be constructed*
D3	*Yet to be constructed*

It has been previously argued that "*contaminants such as ammoniacal nitrogen and chloride are good indicators for landfill leachate, and their similar concentrations upstream and downstream suggest that landfilling activities have not impacted the quality of Rudbaxton Water*[2]*.*"

Time series graphs are included in Appendix C (Figures C1-3). There is no clear evidence of deterioration or impact from the landfill on the quality of Rudbaxton Water (SP1, SP3, SP5, SP7). Concentrations of chloride are typically <30 mg/l, 2016 onwards (Figure 18) and ammoniacal-N concentrations are <0.5 mg/l (Figure 19). Some increases above 0.5 mg/l are evident however some of these occasional increases are associated with SP1 (up-gradient of the site – see time-series plot C3 at Appendix C).

There are no clear increasing trends (long-term) observed in the data set. Most visually evident is an increase recently at WH/SP1 (upstream) and WH/SP6 (Surface water inlet to lagoon servicing WH/D2) in Figure 19 however there are no coincident increases in chloride concentrations.

Overall, the quality of Rudbaxton Water is similar both up-gradient and downgradient based on the average concentrations detailed in Table 10.

Figure 18 Surface Water Quality (Chloride mg/l) 2008 - 2018

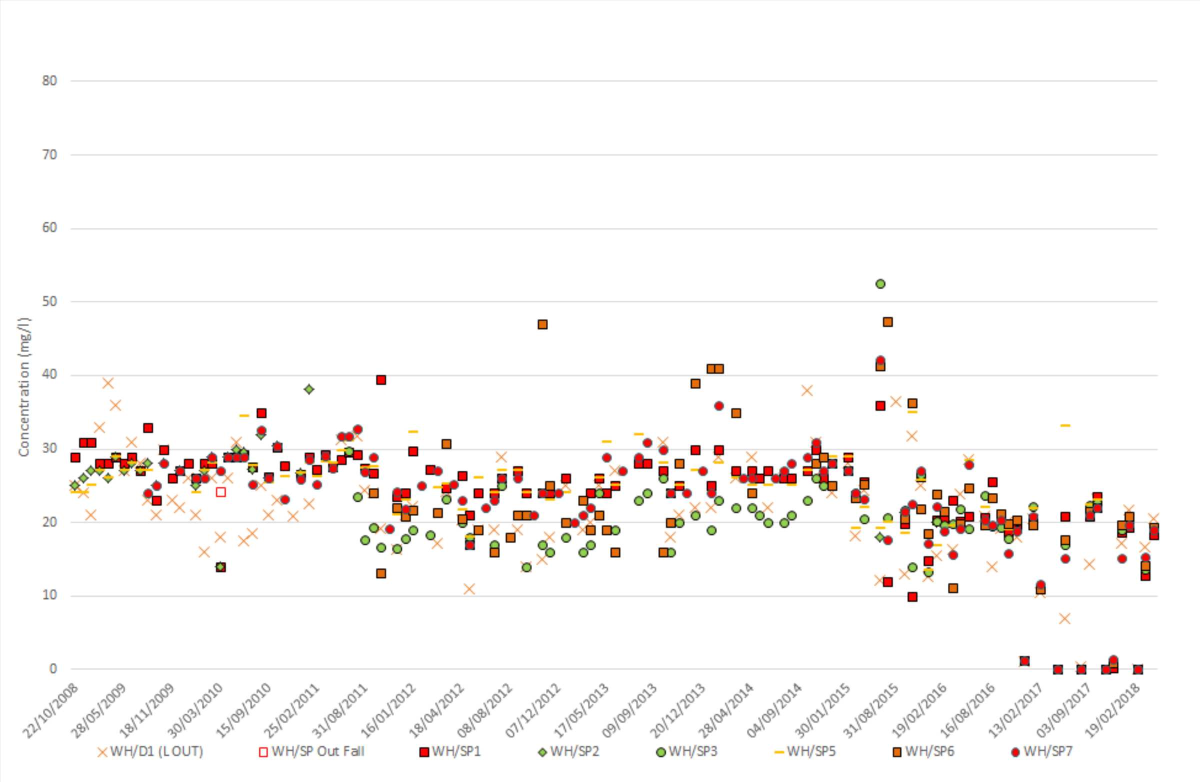


Figure 19 Surface Water Quality (Ammoniacal-N mg/l) 2008 - 2018

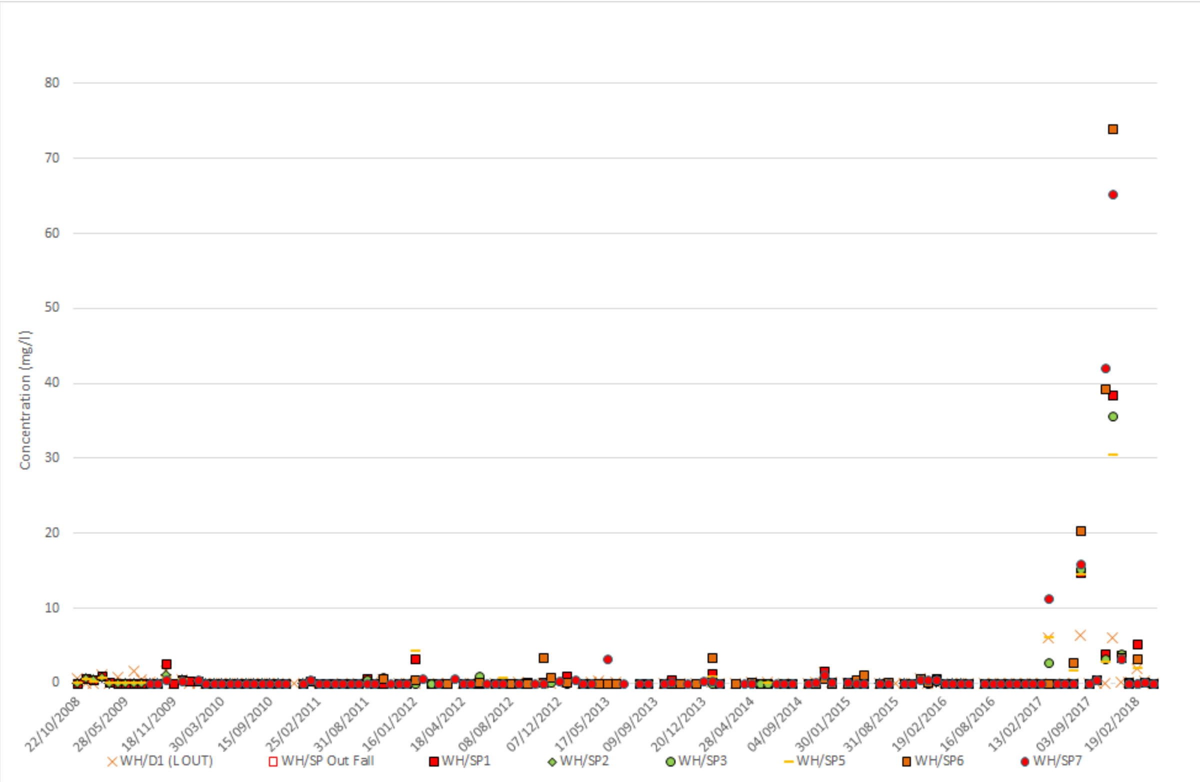


Table 10 Surface Water Matrix Constituents Average Concentration (2008- 2018)

	EC	NH_4-N	COD	TOC	Ca	Mg	Na	K	Cl	SO_4	Alk
	µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
SP1	212	0.8	19	1.9	-	-	-	-	24	-	36
SP3	234	0.8	15	<0	-	-	-	-	19	-	-
SP5	219	0.7	17	<0	-	-	-	-	23	-	-
SP6	257	2.0	23	<0	-	-	-	-	21	-	-
SP7	216	1.5	22	<0	-	-	-	-	23	-	-
D1	303	0.3	20	<0	-	-	-	-	22	54	-

SP6 - Surface water inlet to lagoon servicing WH/D2

Summary

The groundwater at Withyhedge landfill is primarily a calcium bicarbonate solution with secondary sulphate, chloride, magnesium and sodium. The groundwater is however relatively potassium and organic carbon deficient. Concentrations of key leachate substances in groundwater have shown an observed decline of a leachate influence on the groundwater system.

This is most evident in regard to the ammoniacal-N data (Figure 20). Key boreholes have been highlighted and best fit curves applied to WH/BH21 (black dashed line); WH/GW1 (green dashed line) and WH/BH22 (GA02) – black line.

Concentrations have declined between 2010 and 2016, this also evident in regard to other boreholes on Figure 20. The data for the 2016 to 2018 period has indicated that groundwater concentrations (all boreholes) for ammoniacal-N are typically below 2.5mg/l.

One outlier however at WH/TP11 is evident in the recent data at 3.6mg/l, (Dec 2017) the subsequent 5 data points up to April 2018 were all less than 0.06mg/l.

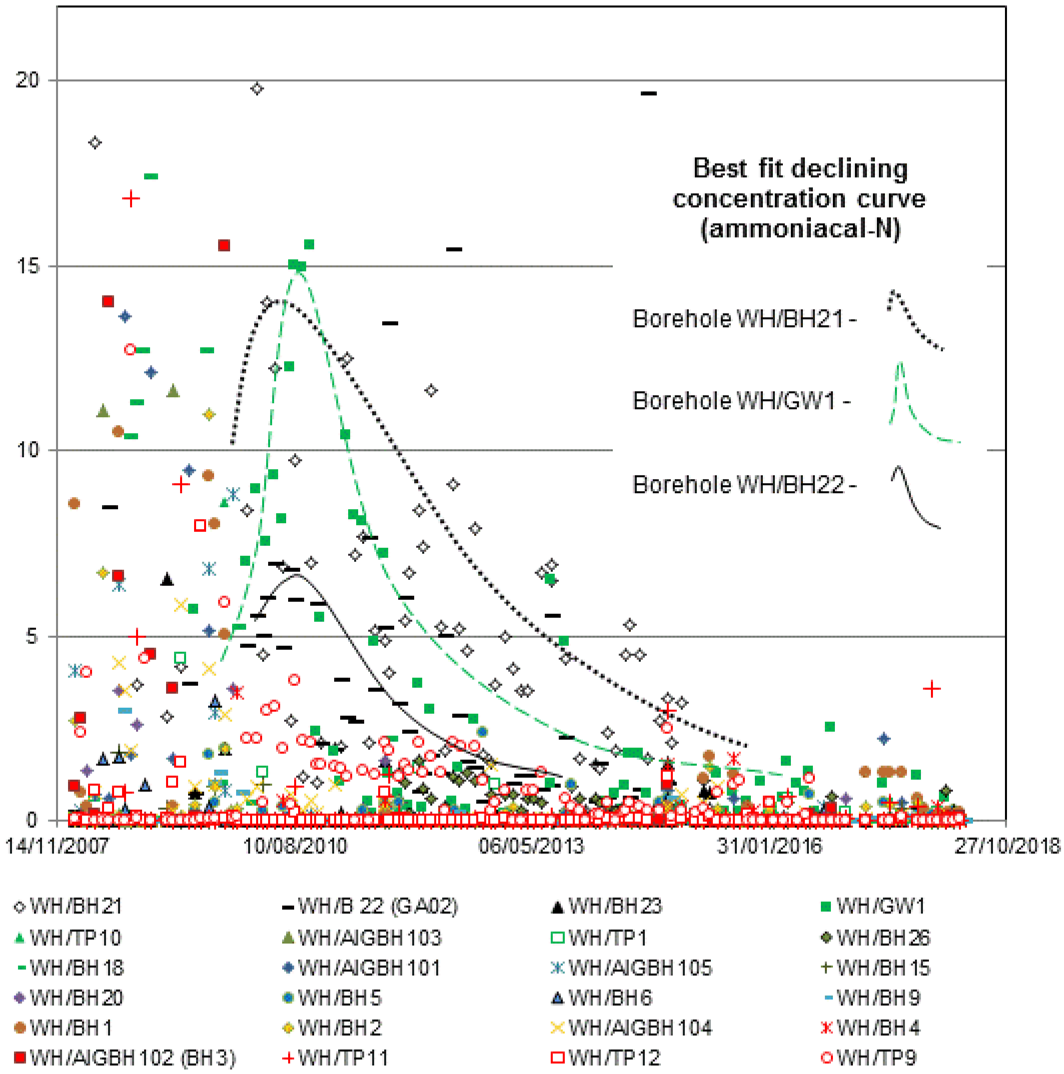
Previous concerns and commentary regarding leachate plume recognition (emanating from Phase 1) and future prediction / migration are not addressed here. What can be stated is that the greatest impact locally at site appears to have passed. This is potentially in response to leachate management and capping of the site.

All new Phases / cells are constructed on the premise of engineered containment where previous modelling has indicated no emissions.

Subsequent HRAR's should establish if the declining trends identified in this review continue however at this point, the previous high concentration of ammoniacal-N in the range of 6 – 20mg/l (2008 – 2014, Figure 15 and Figure 20) have declined and there is no consistent impact observed in the surface water monitoring data of Rudbaxton water.

Previous impact upgradient of the site at BH/GW1 (green square symbols on Figure 20) have been attributed to an unlined leachate lagoon that has been decommissioned[1], the dataset indicates concentrations upgradient of the site have also declined.

Figure 20 Groundwater Ammoniacal-N detail (mg/l)



5. CONCEPTUAL SITE MODEL

A simple conceptual model (CSM) can be constructed for the site, based on the relationship

Source → Pathway → Receptor

The previous HRA (2012)[1] summarised the CSM as:

Source -

- Leachate generated within lined cells of Phase 2
- Leachate generated within lined Cells 11, 13, 14 and 15 of Phase 1
- Leachate generated within the unlined Cells 1 to 10 and 12 of Phase 1.

Potential Primary (Unsaturated) Pathways -

- Unsaturated zone flow in a vertical direction through the engineered barrier systems of Phase 2 engineered to ensure the presence of a minimum 1m unsaturated of fluvio-glacial deposits or weathered Hendre and Mydrim Shale bedrock.
- Unsaturated zone flow vertically through the engineered barrier of lined cells within Phase 1 and through a varying thickness of unsaturated fluvio-glacial deposits or weathered Hendre and Mydrim Shale bedrock.
- Unsaturated zone flow from the unlined cells of Phase 1 through a varying thickness of the fluvio-glacial and shale pathway.

Potential Secondary (Saturated) Pathways -

- Groundwater flow in a north / north westerly direction through any of the fluvio-glacial deposits not removed and through the Hendre and Mydrim Shale bedrock.

Receptors

- For Hazardous Substances – the base of the unsaturated zone at the point of entry into groundwater present within the fluvio-glacial deposits and Hendre and Mydrim Shale bedrock, subject to dilution that occurs within the mixing zone.
- For Non Hazardous Substances – the groundwater at the downstream (permit) boundary of the site. Although much of the fluvio-glacial deposits have been removed (no aquifer designation). The Hendre and Mydrim Shales are classified as Secondary B aquifers
- Rudbaxton Water, surface water feature to which groundwater discharges.

In accordance with this 2018 HRAR, the CSM is updated and summarised as:

Source -

- Leachate generated within lined cells of Phase 2 *and Valley Cells*
- Leachate generated within lined Cells 11, 13, 14 and 15 of Phase 1
- Leachate generated within the unlined Cells 1 to 10 and 12 of Phase 1.

Potential Primary (Unsaturated) Pathways -

- Unsaturated zone flow in a vertical direction through the engineered barrier systems of Phase 2 *and Valley cells* engineered to ensure the presence of a minimum 1 m unsaturated of fluvio-glacial deposits or weathered Hendre and Mydrim Shale bedrock.

- Unsaturated zone flow vertically through the engineered barrier of lined cells within Phase 1 and through a varying thickness of unsaturated fluvio-glacial deposits or weathered Hendre and Mydrim Shale bedrock.
- Unsaturated zone flow from the unlined cells of Phase 1 through a varying thickness of the fluvio-glacial and shale pathway.

Potential Secondary (Saturated) Pathways -

- Groundwater flow in a north / north westerly direction through any of the fluvio-glacial deposits not removed and through the Hendre and Mydrim Shale bedrock.

Receptors

- For Hazardous Substances – *the downgradient site boundary* present within the fluvio-glacial deposits and Hendre and Mydrim Shale bedrock, subject to *dispersion and attenuation* within the mixing zone.
- For Non Hazardous Substances – *the downgradient site boundary*. Although much of the fluvio-glacial deposits have been removed. The Hendre and Mydrim Shales are classified as Secondary B Aquifers *and are hence not a primary receptor.* There is no available land in-between the site and the permit boundary where the groundwater would ever be used, or be required to be used as a groundwater resource.
- Rudbaxton Water, surface water feature to which groundwater discharges.

In simple terms, although assessment levels will be monitored in boreholes on the downgradient boundary site boundary, (most recently detailed in the CAR form ID: 5091, dated 13th March 2013) the groundwater is not a primary receptor and only provides a pathway to Rudbaxton Water.

The conceptual model is unchanged from previous understandings, based on an outwards hydraulic gradient caused by a leachate head acting on the base of the site and then vertical migration through the basal liner, (relevant Phases / cells) unsaturated materials, saturated materials before entering the Groundwater, the previously modelled receptor. A review of groundwater level data indicates no change to those previously considered, leachate levels are compliant based on information reviewed.

The leachate source term has not increased significantly and there are no upward rends in the downgradient groundwater data however the most recent agreed modelling undertaken in 2012[1] has been updated to reflect the changes to the source term component of the model for completeness.

6. RISK ASSESSMENT

6.1 Justification for Modelling Approach and Software

The site risk assessment was originally undertaken using the LandSim model. The LandSim model[24] was developed on behalf of the Environment Agency by Golder Associates is the preferred model for assessing risks to groundwater from landfill sites by each of the UK's Environment Agency bodies.

A model based on the principles of a landfill has been produced because of the similarities between the conceptual design of a landfill and the proposed development of the site. The LandSim model is a Monte Carlo simulator, which is a probabilistic simulator to assess contaminant migration from a source through a barrier system which underlies the potential polluting source, vertically through an unsaturated zone beneath the barrier, and a saturated pathway before entering an aquifer.

The Monte Carlo Simulator allows for a stochastic approach to be taken for the model. Stochastic models allow a range of values to be input for each parameter. The model then selects a value for each parameter when running a simulation. Thus the model overcomes difficulties associated with deterministic models which take a single value for each parameter when a series of end member scenarios are run without understanding how each parameter interacts or their relative importance.

The model also performs multiple simulation runs and the simulation programme compiles the results as a statistical probability of a particular result occurring. When the results are statistically combined, the likelihood of each of the 'worst-case' parameters occurring simultaneously can be compared with the general case which is actually expected to happen. The impact of each of these cases and that of intervening probabilities can then be compared with relevant EQS to determine if the risk is acceptable.

The model also predicts timescales that any potential impact is likely to occur over. This includes factoring in whole lifecycle factors such as active or passive engineered controls and the polluting lifespan of the contaminant source.

The model is therefore designed to assess adjacent phases / cells with varying engineering characteristics, such as at Withyhedge.

It is therefore considered appropriate to continue using LandSim as a primary assessment tool.

6.2 Model Parameterisation

The majority of the site model had been developed into its current form when assessed in 2012 with respect to the engineering and all associated parameters. As per this review, the leachate inventory is the most significant change which has been updated accordingly (Table 11). Changes are only made when leachate source term parameters have increased over previous concentrations. Since the production of the 2012 HRAR, the valley cells have been designed and built, this has been reflected in the updated modelling.

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[24] Golder Associates (UK) Ltd (2003). LandSim. Landfill Performance Simulation by Monte Carlo Method. *Environment Agency R&D Publication 120*

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Table 11 Model Parameterisation – changes for the 2018 HRAR are shaded cells

Infiltration		**Valley**	**Phase 2A**	**Phase 2B- 2E**	**Cell 1 - 10, 12**	**Cell 11, 13, 14 & 15**
Cap design infiltration	mm	30	30	30	20	30
Infiltration to waste	mm	338	338	338	338	338
Infiltration to grassland	mm	268	268	268	268	268
End of filling	years	*Specific to each element of the model – see HRAR 2012 (Appendix G) for detail – no changes in this HRAR*				
Start of cap degradation	years	250	250	250	250	250
End of cap degradation	years	1000	1000	1000	1000	1000
Cell dimensions						
Cell length and width	m	*Specific to each element of the model – see HRAR 2012 (Appendix G) for detail – no changes in this HRAR*				
Cell top and base area	ha	*Specific to each element of the model – see HRAR 2012 (Appendix G) for detail – no changes in this HRAR*				
Number of cells	no.	1	4	6	1	1
Total base & top area	ha	*Specific to each element of the model – see HRAR 2012 (Appendix G) for detail – no changes in this HRAR*				
Surface water breakout	m	2	4	8	8	3.5
Waste porosity	fraction	0.1, 0.25	0.1, 0.25	0.1, 0.25	0.49, 0.52	0.49, 0.52
Final waste thickness	m	6, 22	6, 24	6, 24	8, 18	3.5, 10.5
Field capacity	fraction	0.08, 0.15	0.08, 0.15	0.08, 0.15	0.4, 0.43	0.4, 0.43
Waste density	kg/l	0.8, 1.07	0.8, 1.07	0.8, 1.07	0.39, 0.49	0.39, 0.49
Source concentration						
Ammoniacal nitrogen	mg/l	4.37, **735, 1520**	4.37, **735, 1520**	4.37, **735, 1520**	7.5, 298, 700	4.37, **1020**, **2150**
Cadmium	mg/l	0.0019, 0.0101, 0.105	**0.0001, 0.0004, 0.0034**	0.0019, 0.0101, 0.105	0.001, 0.002	0.0019, 0.0101, 0.105
Chloride	mg/l	36.6, 2270, 2385	36.6, 2270, 2385	36.6, 2270, 2385	100, 1808, 2100	36.6, 2270, 2385
Mecoprop	mg/l	4e-5, **0.019, 0.168**	4e-5, **0.019, 0.168**	4e-5, **0.019, 0.168**	4e-5, **0.019, 0.168**	4e-5, **0.019, 0.168**
Naphthalene	mg/l	**5e-5, 0.0025, 0.014**	**5e-5, 0.0025, 0.014**	**5e-5, 0.0025, 0.014**	0.0001, 0.00046, 0.011	0.0001, 0.00046, 0.011
Nickel	mg/l	0.00883, 0.12, 2.21	**0.005, 0.57, 4.95**	0.00883, 0.12, 2.21	**0.003, 0.42, 2.81**	0.00883, 0.12, 2.21
Phenols	mg/l	5e-5, 12	5e-5, 12	5e-5, 12	0.00025, 0.012	0.00025, 0.012, 0.07
Barrier information						
Design thickness of clay	m	**0.7**	1	1	1	1
Density of clay	kg/l	**2.00, 2.05**	1.53, 1.96	1.53, 1.95	1.7	1.548, 1.71, 1.971
Moisture content	fraction	**0.19, 0.22**	0.16, 0.18	0.16, 0.18	0.3	0.275, 0.338, 0.409
FML degradation	years	150	150	150		
Longitudinal dispersivity	m	**0.07**	0.1	0.1	0.1	0.1

Time for defects to double	years	100	100	100		
Conductivity	m/s	**4e-10, 2.4e-10. 1.4e-10**	1e-11, 4.35e-10, 1e-9	3e-10, 4.35e-10, 1e-9	1.00E-10	4.1e-12, 5.9e-10, 5.9e-10
Organic carbon	fraction	0.001, 0.004	0.001, 0.004	0.001, 0.004	0.001, 0.004	0.001, 0.004
Membrane defects						
Pin holes	no. per ha	13	5	5		
Holes	no. per ha	3	2	2		
Tears	no. per ha	0.1, 1.0	0	0		
Retardation						
Kd (NH4N)	l/kg	0.125, 0.883, 2.4	0.125, 0.883, 2.4	0.125, 0.883, 2.4	0.125, 0.883, 2.4	0.125, 0.883, 2.4
Kd (Cadmium)	l/kg	127, 11147, 16657	127, 11147, 16657	127, 11147, 16657	127, 11147, 16657	127, 11147, 16657
Kd (Chloride)	l/kg	0	0	0	0	0
Kd (Nickel)	l/kg	85.7	85.7	85.7	85.7	85.7
Koc (Mecoprop)	ml/g	11, 25	11, 25	11, 25	11, 25	11, 25
Koc (Naphthalene)	ml/g	1288	1288	1288	1288	1288
Koc (Phenols)	ml/g	22, 27	22, 27	22, 27	22, 27	22, 27
Unsaturated Pathway						
Pathway length	m	1, 1.5	1	1	0.01, 3	0.1, 2.5
Mositure content	fraction	0.16, 0.18	0.16, 0.18	0.16, 0.18	0.213, 0.236, 0.292	0.213, 0.236, 0.292
Density	kg/l	1.53, 1.95	1.53, 1.95	1.53, 1.95	1.785, 1.9402, 1.979	1.785, 1.9402, 1.979
Conductivity	m/s	2.2e-8, 1e-5	2.2e-8, 1e-5	2.2e-8, 1e-5	2.2e-8, 1e-5	2.2e-8, 1e-5
Longitudinal dispersivity	m	0.1, 0.15	0.1	0.1	0.001, 0.3	0.01, 0.25
Organic carbon	fraction	0.002, 0.005, 0.019	0.002, 0.005, 0.019	0.002, 0.005, 0.019	0.002, 0.005, 0.019	0.002, 0.005, 0.019
UZ Retardation						
Kd (NH4-N)	l/kg	0.119, 0.535, 2.4	0.119, 0.535, 2.4	0.119, 0.535, 2.4	0.02647, 0.6929	0.119, 0.535, 2.4
Kd (Cadmium)	l/kg	127, 11147, 16657	127, 11147, 16657	127, 11147, 16657	694, 3927, 3927	694, 3927, 3927
Kd (Chloride)	l/kg	0	0	0	0	0
Kd (Nickel)	l/kg	85.7	85.7	85.7	85.7	85.7
Koc (Mecoprop)	ml/g	11, 25	11, 25	11, 25	11, 25	11, 25
Koc (Naphthalene)	ml/g	1288	1288	1288	1288	1288
Koc (Phenols)	ml/g	22, 27	22, 27	22, 27	22, 27	22, 27

6.3 Source Term

Leachate quality screening to the time of the first HRA identified even substances as appropriate for modelling. There are no additional priority pollutants present within the leachate than considered previously based on the data supplied. Consequently it is considered that additional substances need not be modelled.

A revised source term has therefore been developed based on the historic and recent monitoring data. Some parameter concentrations have increased but those that have increased have not changed substantially from those previously detailed or assumed.

6.4 Emissions to Groundwater

Groundwater risk assessments are undertaken to one of two compliance points, namely:

- for hazardous substances after mixing with groundwater at the edge of the site; and
- for non-hazardous substances at a downgradient monitoring point (Compliance Point).

According to the previous HRA, it was stated that "*in order to determine the discharge to Rudbaxton Water and to determine compliance with the Groundwater Regulations (1998) and Environmental Permitting Regulations (2008) assessment of the predicted discharge have also been made using the compliance point in LandSim. This has been set at a point in the model which represents the Site Permit boundary and thus is very close to the point at which groundwater will discharge into Rudbaxton Water. This approach has been adopted within this revised report as the original method of using dilution calculations was flawed and overly complex given the facility within LandSim to set a point at an identified receptor as well as the edge of each individual phase.*

Considering the nature of the underlying groundwater within a shale bedrock (Secondary B aquifer) and direct flow towards Rudbaxton Water (the primary receptor) the rationale adopted previously appears reasonable in assessment of discharge from the site. LandSim results are presented in Table 12.

Table 12 LandSim Predicted Concentrations at the Cumulatively Impacted Edge of Site Compliance Point

Substance	Compliance Point		
	Most Likely	Max	Peak
	mg/l	mg/l	yrs
Ammoniacal-N	0.02	0.30	388
Cadmium	$<10^{-9}$	$<10^{-9}$	-
Chloride	2.1	7.7	335
Mecoprop	$<10^{-9}$	$<10^{-9}$	-
Naphthalene	$<10^{-9}$	$<10^{-9}$	-
Nickel	$3.6x10^{-5}$	0.0003	550
Phenol	$1.5x10^{-10}$	$3.3x10^{-9}$	75

The model predicts that ammoniacal-N (Figure 21), chloride (Figure 22), nickel (Figure 23) and phenol (Figure 24) would not adversely affect groundwater quality the edge of the site

(Table 12). All maximum concentrations are less than DWS concentrations or typical assessment levels, 0.39mg/l for ammoniacal-N, 250mg/l for chloride and 0.02mg/l for nickel.

Mecoprop, naphthalene and phenol are predicted at extremely low concentrations at the compliance point. The results are consistent with the monitoring data at Rudbaxton Water.

Figure 21 Predicted Ammoniacal-N Concentration at the Compliance Point

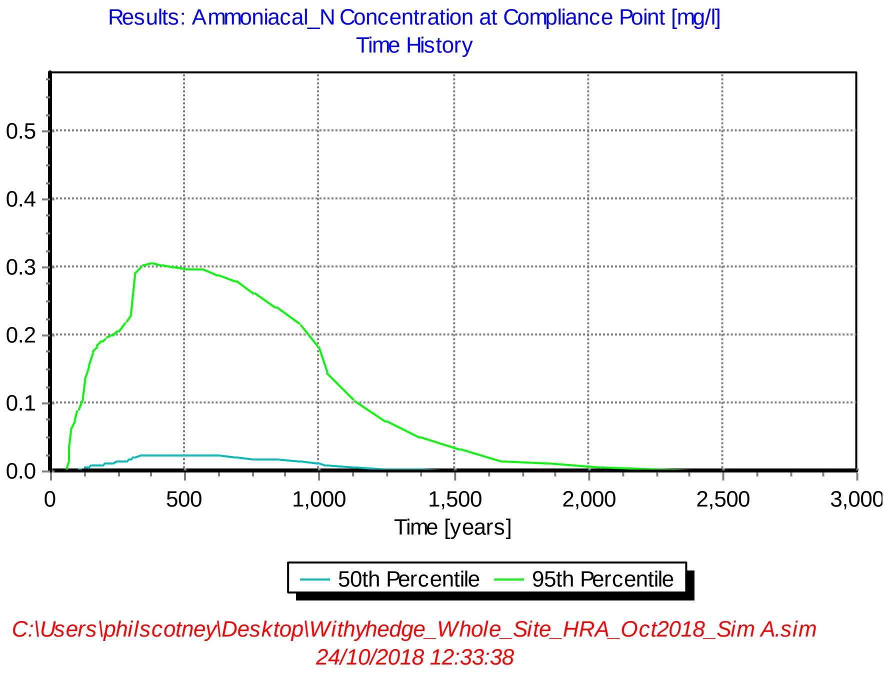


Figure 22 Predicted Chloride Concentration at the Compliance Point

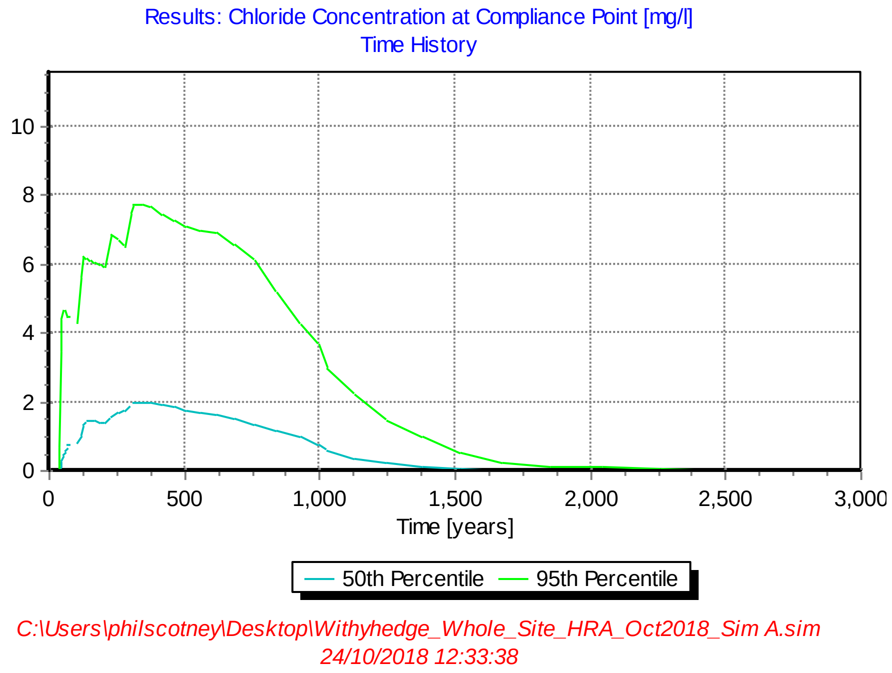


Figure 23 Predicted Nickel Concentration at the Compliance Point

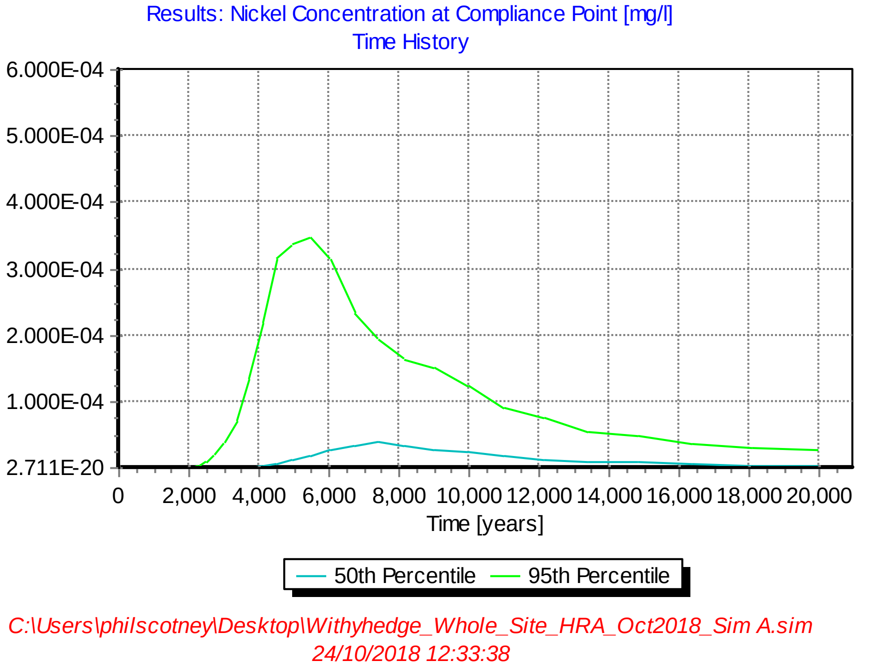
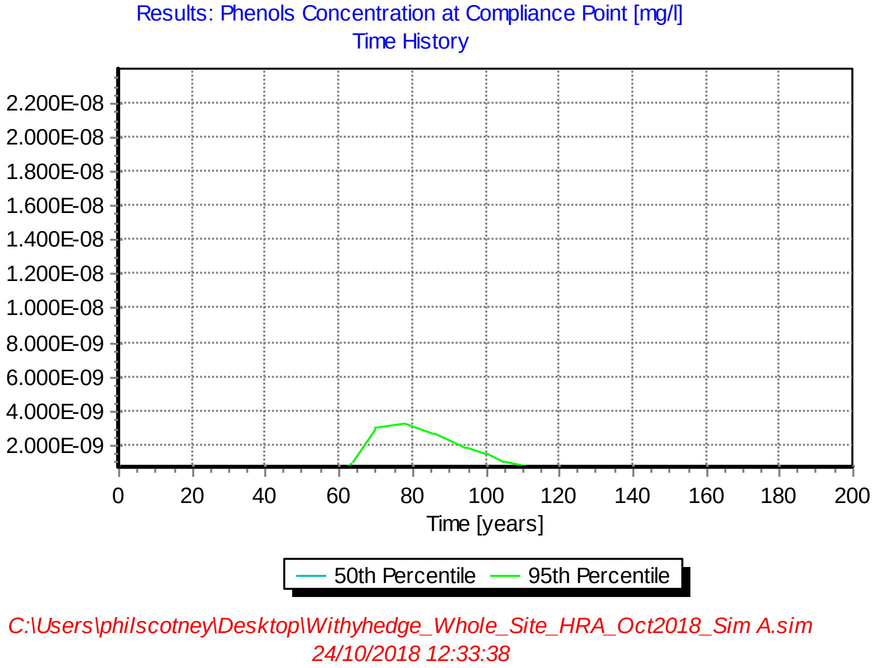


Figure 24 Predicted Phenol Concentration at the Compliance Point



The previously assumed parameterisation for Valley cells have been updated in the model based on CQA information (Table 11). LandSim predicts the following concentrations at the monitor well adjacent to these cells (Table 13). No additional sensitivity analysis is provided here as the 2012 HRAR established the modelling was insensitive to leachate head increases.

Table 13 LandSim Predicted Concentrations at the Monitor Well (Valley Cells)

Substance	Compliance Point		
	Most Likely	Max	Peak
	mg/l	mg/l	yrs
Ammoniacal-N	0.003	0.08	476
Cadmium	$<10^{-9}$	$<10^{-9}$	-
Chloride	2.1	6.1	416
Mecoprop	$<10^{-9}$	$<10^{-9}$	-
Naphthalene	$<10^{-9}$	$<10^{-9}$	-
Nickel	2.8×10^{-5}	9.9×10^{-5}	14700
Phenol	$<10^{-9}$	2.7×10^{-7}	75

7. REVIEW OF TECHNICAL PRECAUTIONS

7.1 Engineering Measures

Withyhedge Landfill is a two part site, one half that has no formal engineered liner (Phase 1, except Cells 11, 13, 14 and 15) and an above water table engineered containment landfill site (Phase 2).

The passive controls in place for Phase 2 (and Cells 11, 13, 14 and 15 of Phase 1) include:

- restoration soils
- a low permeability artificial cap
- a leachate drainage layer (including slotted collection pipes)
- an artificial sealing liner
- an artificial mineral liner for all cells, (either 0.5m or 1m) engineered to a hydraulic conductivity in the order of 10^{-10}m/s (CQA information not reviewed)
- basal profile sloped to aid leachate collection.

These engineering precautions were designed to ensure that the requirements of the groundwater and landfill directives were met.

7.2 Active Management

There is only one active management control which can affect leachate seepage, namely control of the leachate head acting on the base of the site.

This previous risk assessment demonstrated that managed leachate heads during the operational period will not cause harm with respect to basal seepage.

Where there is a potential environmental risk, it is with regard to leachate height associated with leachate overtopping from the most westerly cells into the open space to the west and south, i.e. the undeveloped areas of site Phase 2, areas C-E.

It is therefore proposed that the leachate height limit for the cells at 1m is appropriate at this time and no changes to leachate height are proposed in this review. A previously installed cut-off barrier potentially modifies groundwater flow locally and limits water influx / mixing with leachate under the Phase 1 area of site.

8. REQUISITE SURVELLIANCE

Historically there has been communication between the site operator and regulator regarding both control and trigger levels.

The current permit trigger limits are contained in the CAR report 5093 (dated 13th March 2013) along with control levels. Both are outdated and are essentially irrelevant with regard to recent monitoring results and are hence not reproduced here, discussion in section 4 has documented the recent improvement (particularly post 2016) of the groundwater quality at site.

There are various ways in establishing trigger levels for downgradient boreholes, they are discussed in the following text.

Firstly, the recent up-gradient maximum concentrations could be applied as a benchmark for downgradient groundwater quality. Applying this methodology would provide the following limits for WH/TP9, WH/TP11, WH/TP12, WH/AIGBH104, WH/BH20, WH/B1, WH/BH2, WH/AIGBH101, WH/AIG/BH102 (BH3), WH/BH4 and WH/BH5:

- Ammoniacal-N 2.47mg/l
- Chloride 30mg/l
- Nickel 0.08mg/l
- Phenol Not present – no limit required
- Cadmium 0.001mg/l
- Mecoprop 0.0005mg/l
- Naphthalene 0.000025mg/l

Trigger limits are not required for WH/BH21, WH/BH22 and WH/BH23 (decommissioned and under the valley cells) and WH/AIGBH105 is cross-gradient to groundwater flow.

Concentrations have been selected from the May 2015 to April 2018 data set in accordance with the observed decline recognised in Figure 20. The chloride outlier of 129mg/l has been omitted.

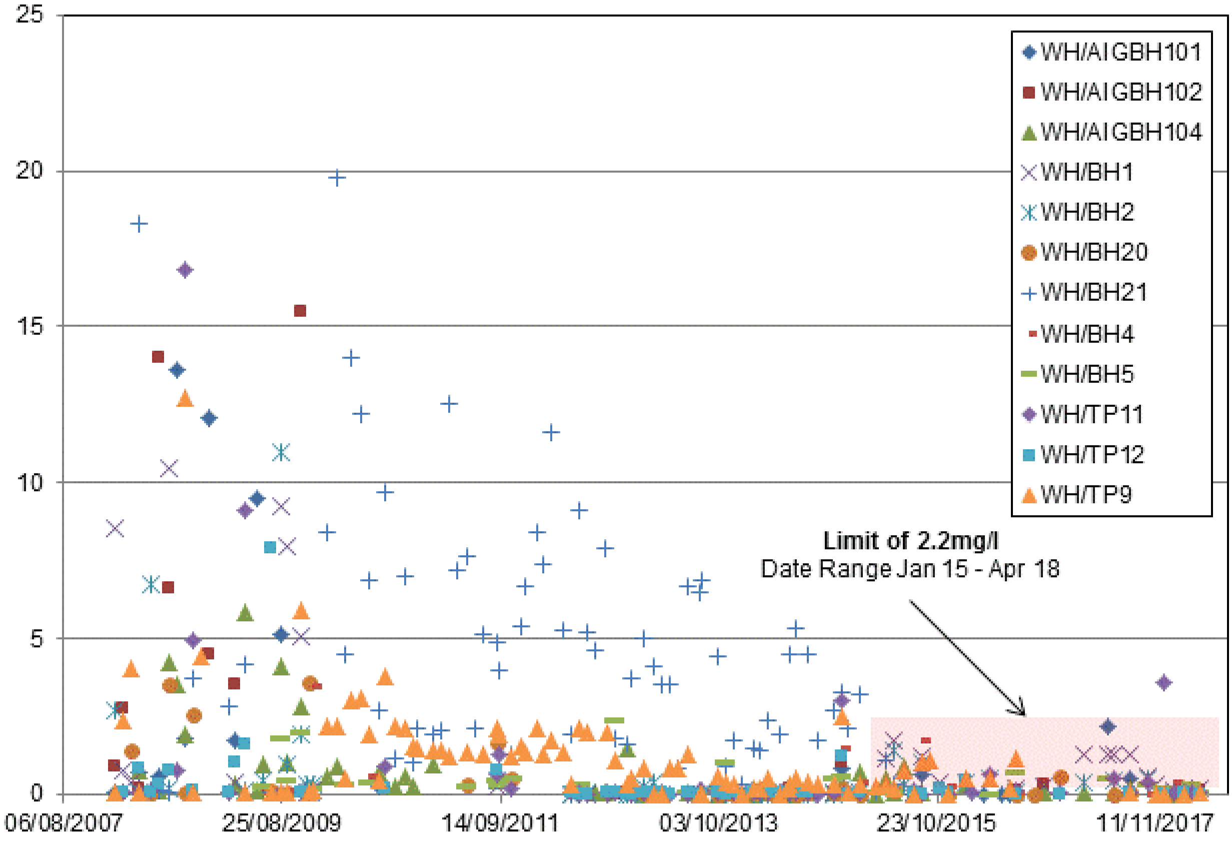
Only limited recent data is available for nickel, cadmium, mecoprop and naphthalene hence the entire dataset has been used in assigning the trigger limits above.

When these limits are viewed in light of time-series data, it is evident that a limit of 2.47mg/l (ammoniacal-N) is not greatly different to an upper limit of data for all downgradient boreholes excluding outliers values (see Figure 25).

In regard to chloride, a proposed limit of 30mg/l would be exceeded for a number of boreholes as chloride concentrations are fluctuating to a larger degree than ammoniacal-N (Figure 26). It is noted however that the boreholes with the greatest concentration fluctuation in chloride (WH/BH2 and WH/TP9) do not have a corresponding ammoniacal-N fluctuation. A cross-plot of chloride and ammoniacal-N (Figure 27) for WH/TP9 indicates there is no correlation between these parameters.

Downgradient groundwater nickel time-series data is presented in Figure 28, the up-gradient proposed limit of 0.08 appears appropriate based on the recent data.

Figure 25 Downgradient Ammoniacal-N Time series (mg/l) - setting of Trigger Limits



Mecoprop was last detected in the up-gradient WH/GW1 in November 2015, the down-gradient time-series data (Figure 29) indicates no positive detections of mecoprop since July 2015 hence it is proposed to continue with the current trigger limit of 0.0001mg/l.

Cadmium has been identified as positive detections on 5 occasions since November 2016, the maximum concentrations has been applied in this instance.

Naphthalene has not been detected post May 2015, previous positive results have been isolated and rarely repeated on subsequent monitoring visits hence it is proposed to continue with the current limit (but lowest trigger limit in CAR form 5093) of 0.00001mg/l.

Proposed limits here are based on a pragmatic approach as there is no rationale justification for having a trigger limit currently of 1.328mg/l at WH/BH1 and 5.2mg/l at the adjacent WH/BH2. The same can be said for all boreholes and all parameters, again by way of comparison WH/BH4 has a current trigger limit of 1.45mg/l for ammoniacal-N and adjacent WH/BH5 has a limit of 1.18mg/l.

Figure 26 Downgradient Chloride Time series (mg/l) - setting of Trigger Limits

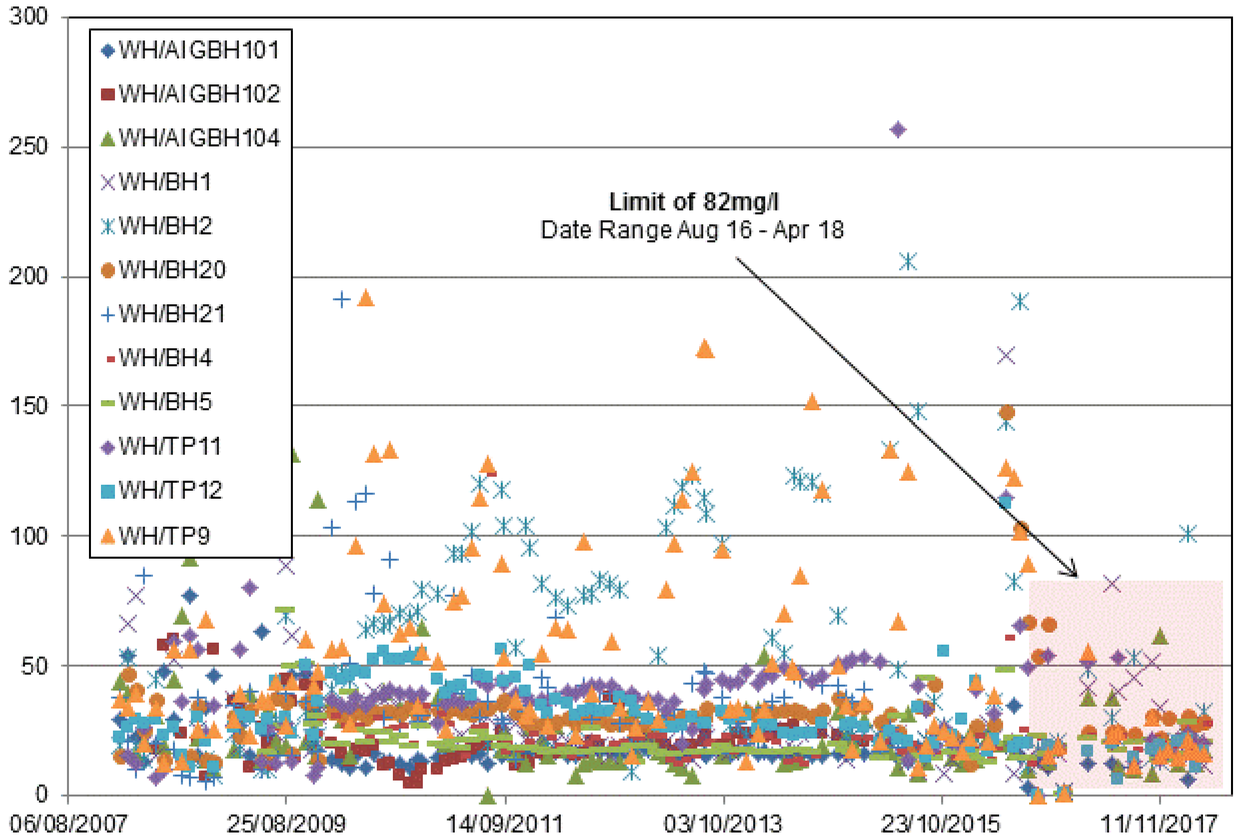


Figure 27 WH/TP9 Ammoniacal-N / Chloride cross-plot (mg/l)

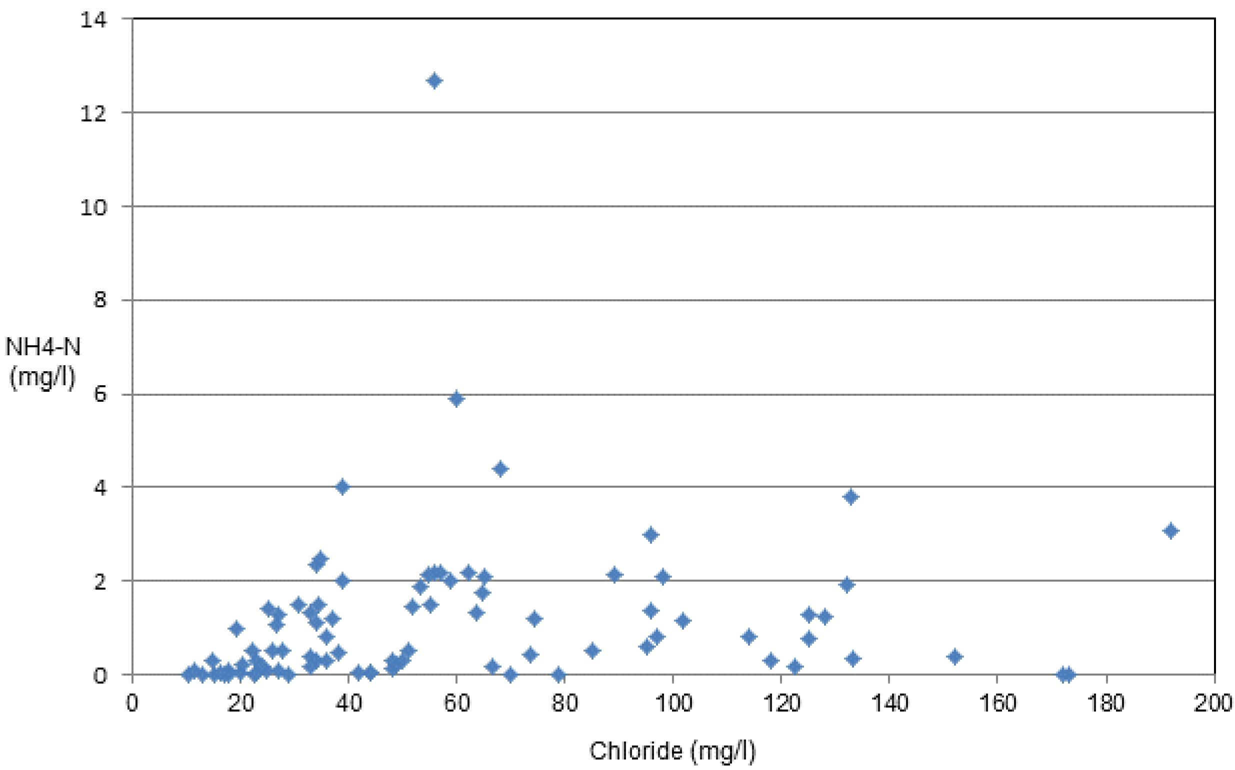


Figure 28 Downgradient Nickel Time series (mg/l) - setting of Trigger Limits

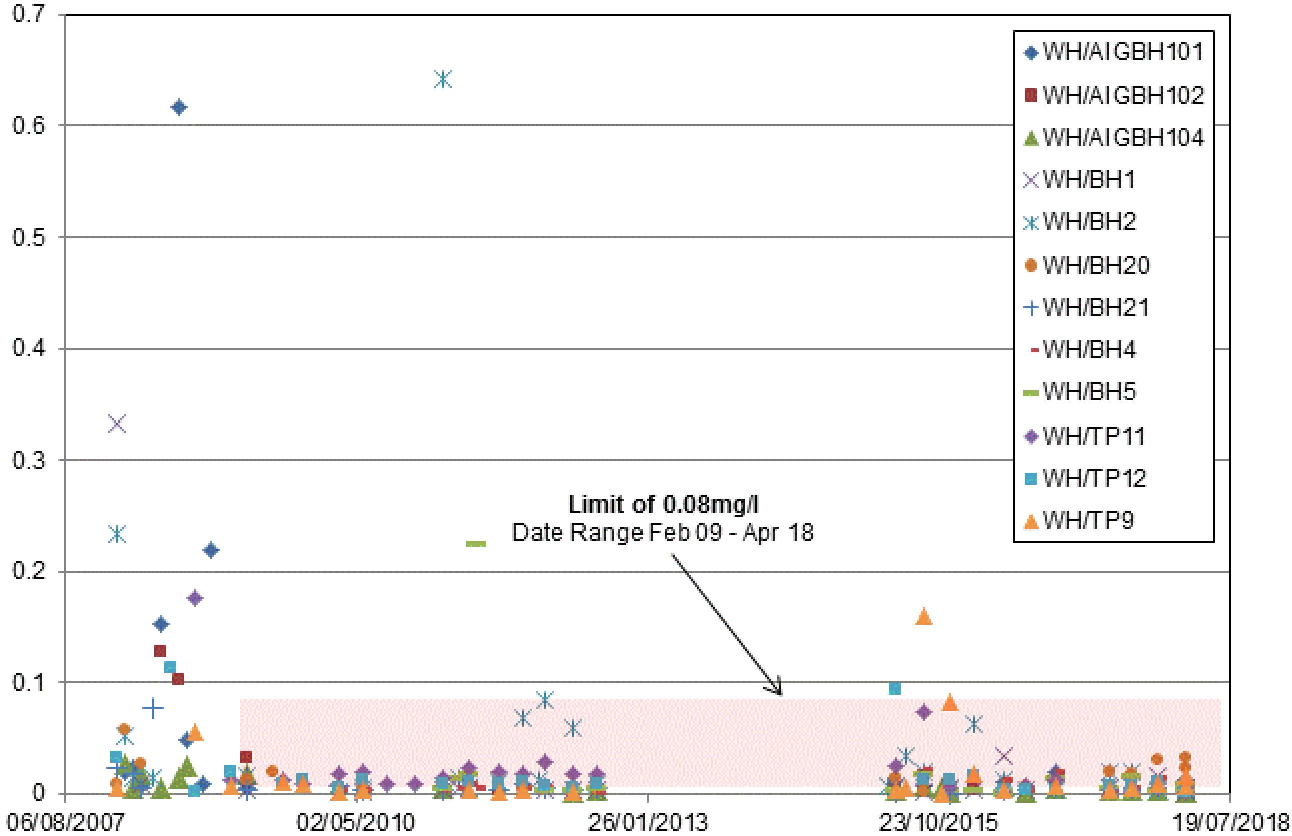
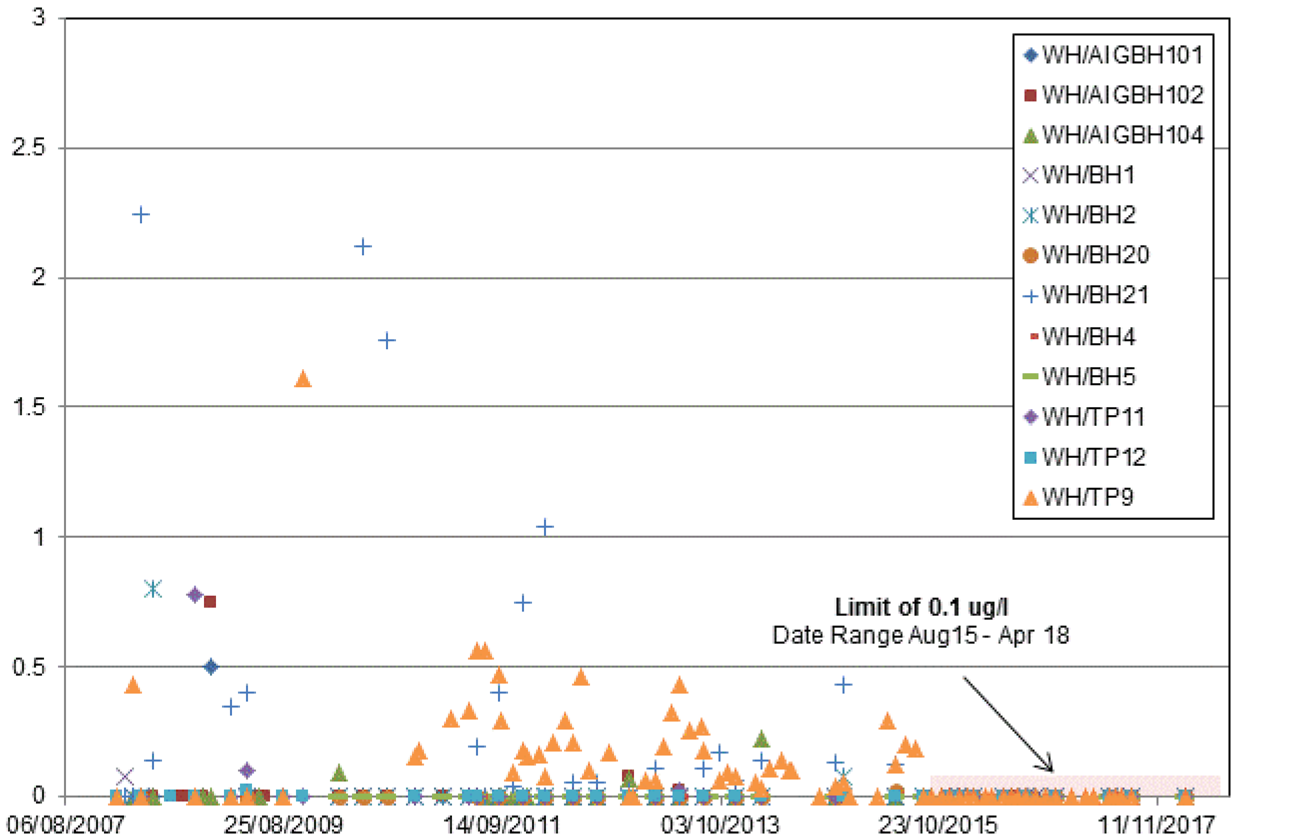


Figure 29 Downgradient Mecoprop Time series (ug/l) - setting of Trigger Limits



As the contaminant plume migration emanating from Phase 1 may continue for some time (albeit the data shows considerable recent improvement) further fluctuations in leachate parameters cannot be ruled out.

Assigning borehole specific trigger values does not improve environmental protection at the site and only increases regulatory burden on both the operator and regulator. The proposed limits presented here again are considered pragmatic and will allow some minor fluctuation without a limit breech. Again, any exceedance of a limit has no environmental significance when leachate is being removed and compliance levels for leachate are kept to a minimum. The impact from Phase 1 is a function of landfill design which was approved at the time of design.

Control limits should be removed from the permit, for the same reasons as outlined above. The CAR report 5093 details boreholes with individual concentrations on a borehole specific basis. These numbers are meaningless and do not provide any merit in site regulation. Very quickly, assigned numbers become outdated as identified by the time-series data presented in this report.

The current proposal for downgradient trigger limits is:

- Ammoniacal-N 2.47mg/l
- Chloride 30mg/l (not applicable to WH/BH2 and WH/TP9)
- Nickel 0.08mg/l
- Cadmium 0.001mg/l
- Mecoprop 0.0001mg/l
- Naphthalene 0.00001mg/l

Any future variation to incorporate these limits within the sites permit (at Table S4.5) should be revisited at the time of submission of any associated variation application. In simple terms, the limits proposed here are based on the data supplied and reviewed and may not be appropriate in in 12 months' time. Applying statistical analysis to individual boreholes to derive borehole specific limits is not deemed necessary or appropriate.

Leachate and groundwater monitoring is undertaken in accordance with the schedules contained within the site's Environmental Permit, these are not reproduced here. However it is recommended that the schedule is varied in line with the recent Regulatory Position Statement: Landfill monitoring and reporting standards, which was produced in parallel with the ongoing review and update of Environmental Permits into the updated template format.

There are no additional changes proposed to the monitoring schedules by virtue of this HRAR.

9. CONCLUSIONS

A hydrogeological risk assessment review has been undertaken for the Withyhedge landfill site. Landfilling operations more recently have been undertaken in Landfill Directive compliant engineered containment cells, the unlined Phase 1 (dilute and disperse area) has caused some historical impact however this review indicates an improvement in local downgradient groundwater quality particularly post 2010.

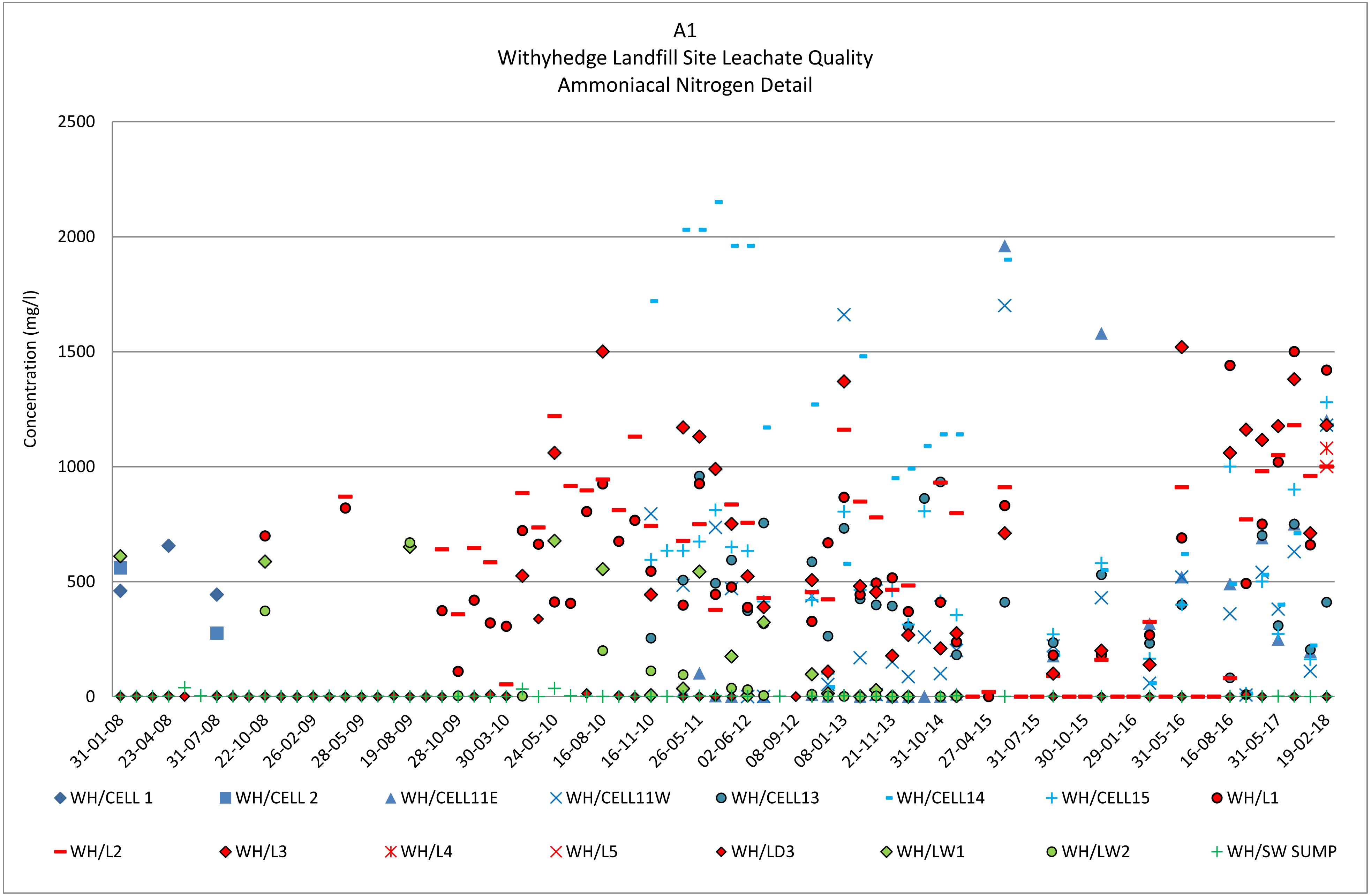
Albeit, local historic impact has occurred in the local groundwater this is not considered a useable resource or viable receptor. Notwithstanding this however, future discharges should be limited / prevented.

The groundwater provides a base-flow component to Rudbaxton water which is the primary receptor. Rudbaxton Water quality does not appear to have been impacted historically and current quality is apparently of good based on the received data.

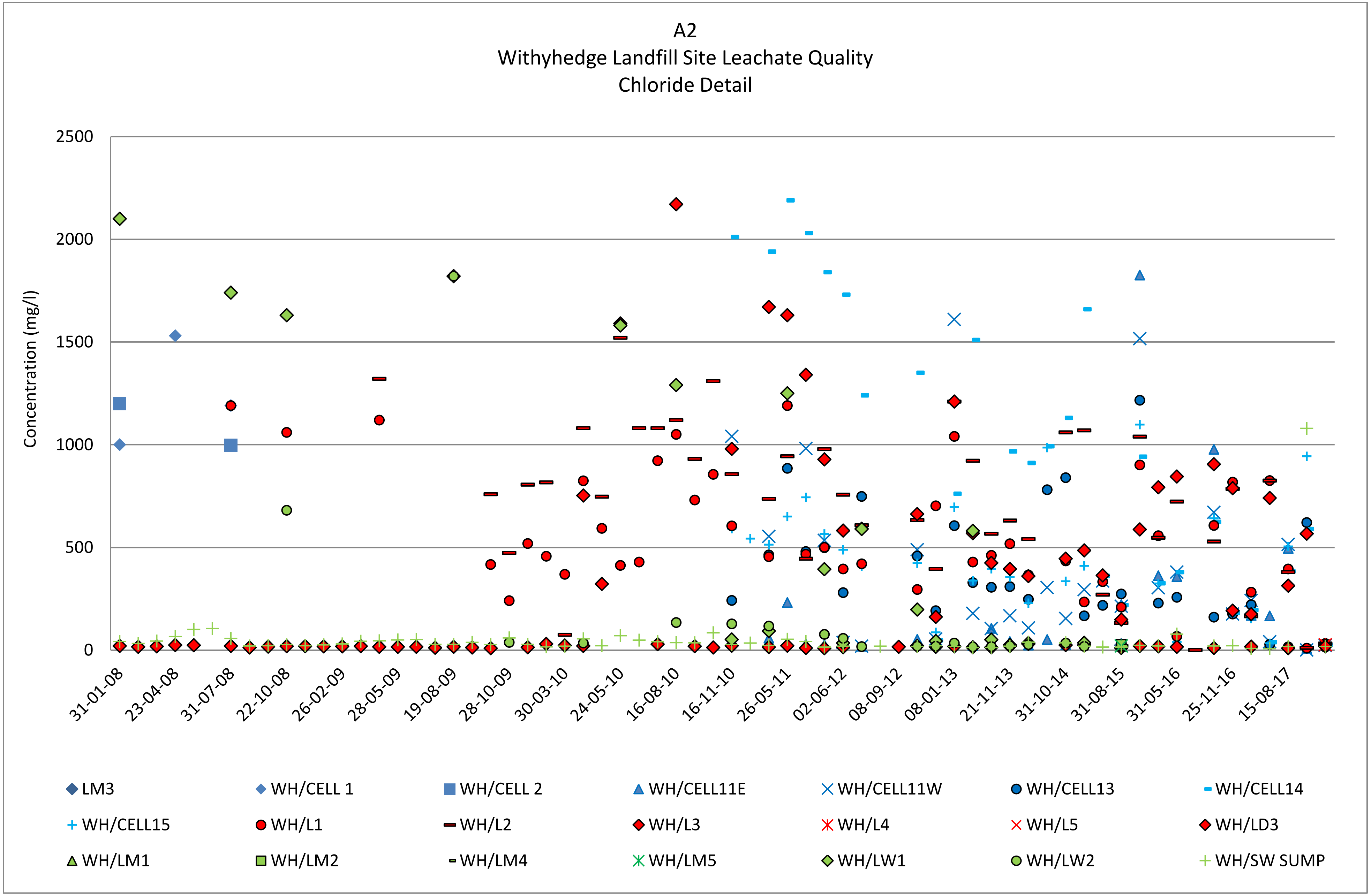
The site’s risk assessment has been updated and this assessment demonstrates that the controls in place will prevent pollution from non-hazardous substances.

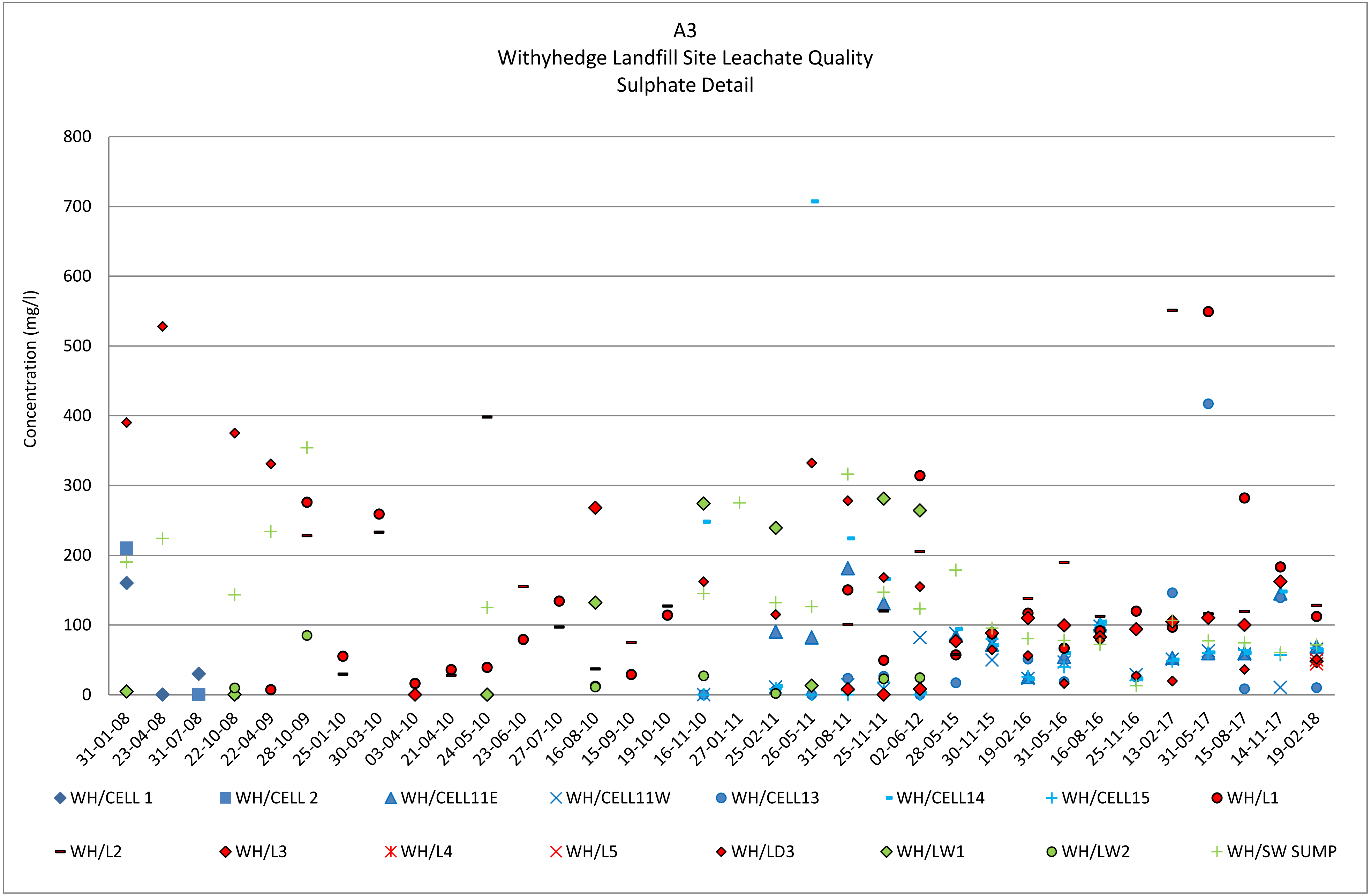
Appendix A

Leachate Quality Data



A1
Withyhedge Landfill Site Leachate Quality
Ammoniacal Nitrogen Detail
Concentration (mg/l)
2500
2000
1500
1000
500
0
31-01-08
23-04-08
31-07-08
22-10-08
26-02-09
28-05-09
19-08-09
28-10-09
30-03-10
24-05-10
16-08-10
16-11-10
26-05-11
02-06-12
08-09-12
08-01-13
21-11-13
31-10-14
27-04-15
31-07-15
30-10-15
29-01-16
31-05-16
16-08-16
31-05-17
19-02-18
WH/CELL 1
WH/CELL 2
WH/CELL11E
WH/CELL11W
WH/CELL13
WH/CELL14
WH/CELL15
WH/L1
WH/L2
WH/L3
WH/L4
WH/L5
WH/LD3
WH/LW1
WH/LW2
WH/SW SUMP


A2
Withyhedge Landfill Site Leachate Quality
Chloride Detail
Concentration (mg/l)
2500
2000
1500
1000
500
0
31-01-08
23-04-08
31-07-08
22-10-08
26-02-09
28-05-09
19-08-09
28-10-09
30-03-10
24-05-10
16-08-10
16-11-10
26-05-11
02-06-12
08-09-12
08-01-13
21-11-13
31-10-14
31-08-15
31-05-16
25-11-16
15-08-17
LM3
WH/CELL 1
WH/CELL 2
WH/CELL11E
WH/CELL11W
WH/CELL13
WH/CELL14
WH/CELL15
WH/L1
WH/L2
WH/L3
WH/L4
WH/L5
WH/LD3
WH/LM1
WH/LM2
WH/LM4
WH/LM5
WH/LW1
WH/LW2
WH/SW SUMP



A3
Withyhedge Landfill Site Leachate Quality
Sulphate Detail
Concentration (mg/l)
800
700
600
500
400
300
200
100
0
31-01-08
23-04-08
31-07-08
22-10-08
22-04-09
28-10-09
25-01-10
30-03-10
03-04-10
21-04-10
24-05-10
23-06-10
27-07-10
16-08-10
15-09-10
19-10-10
16-11-10
27-01-11
25-02-11
26-05-11
31-08-11
25-11-11
02-06-12
28-05-15
30-11-15
19-02-16
31-05-16
16-08-16
25-11-16
13-02-17
31-05-17
15-08-17
14-11-17
19-02-18
WH/CELL 1
WH/CELL 2
WH/CELL11E
WH/CELL11W
WH/CELL13
WH/CELL14
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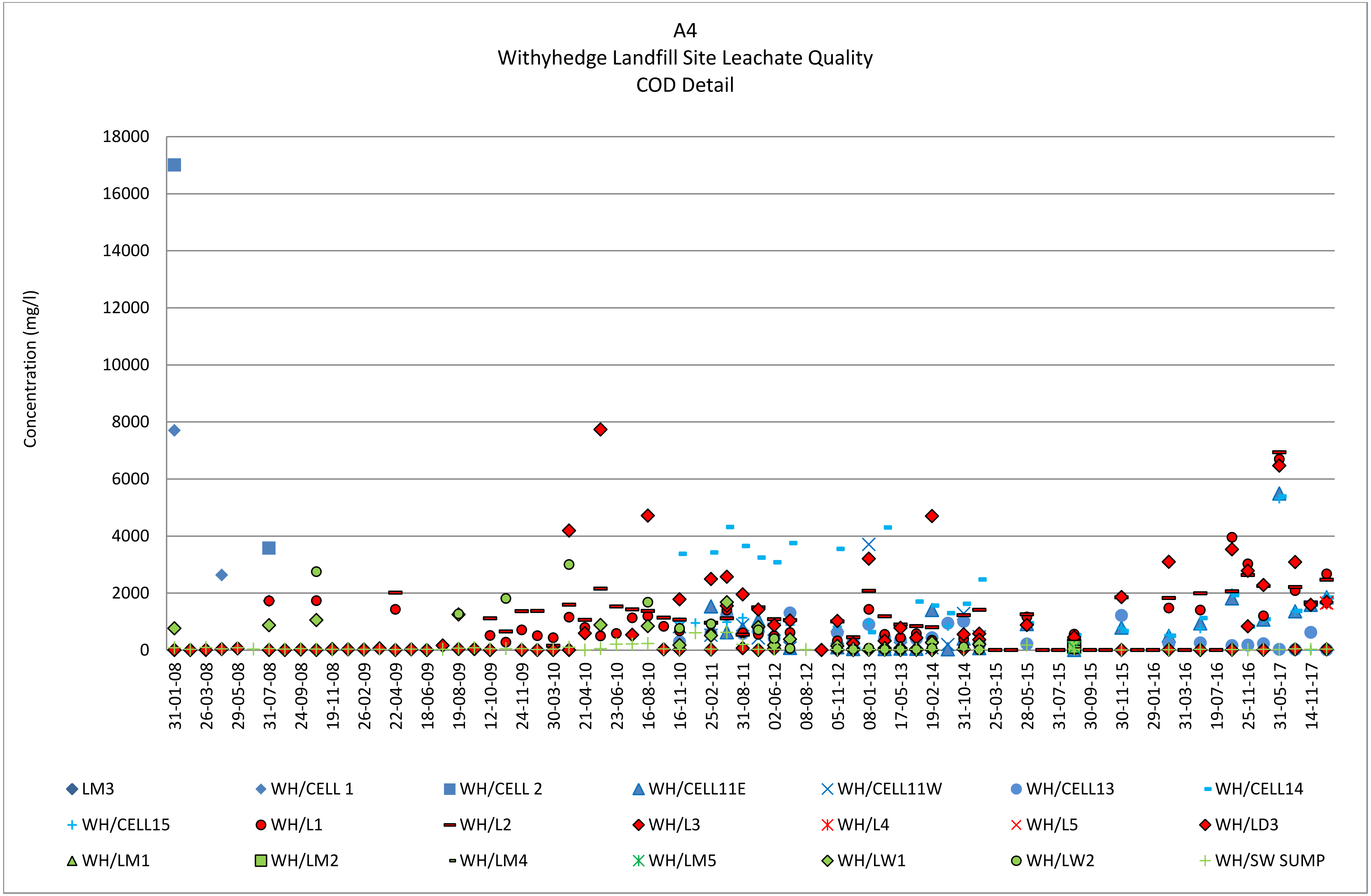
WH/LD3
WH/LW1
WH/LW2
WH/SW SUMP


A4
Withyhedge Landfill Site Leachate Quality
COD Detail
Concentration (mg/l)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
31-01-08
26-03-08
29-05-08
31-07-08
24-09-08
19-11-08
26-02-09
22-04-09
18-06-09
19-08-09
12-10-09
24-11-09
30-03-10
21-04-10
23-06-10
16-08-10
16-11-10
25-02-11
31-08-11
02-06-12
08-08-12
05-11-12
08-01-13
17-05-13
19-02-14
31-10-14
25-03-15
28-05-15
31-07-15
30-09-15
30-11-15
29-01-16
31-03-16
19-07-16
25-11-16
31-05-17
14-11-17
LM3
WH/CELL 1
WH/CELL 2
WH/CELL11E
WH/CELL11W
WH/CELL13
WH/CELL14
WH/CELL15
WH/L1
WH/L2
WH/L3
WH/L4
WH/L5
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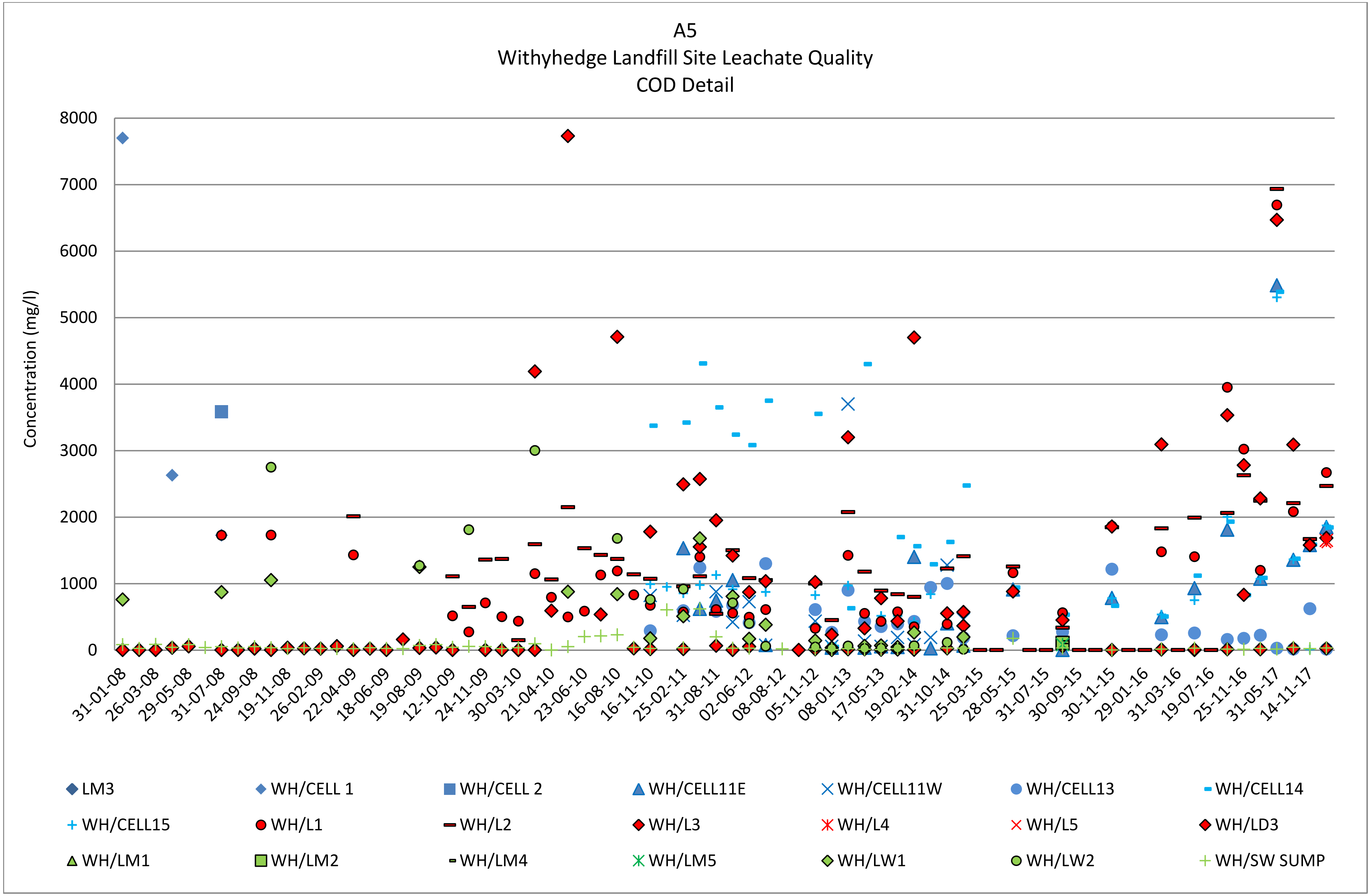
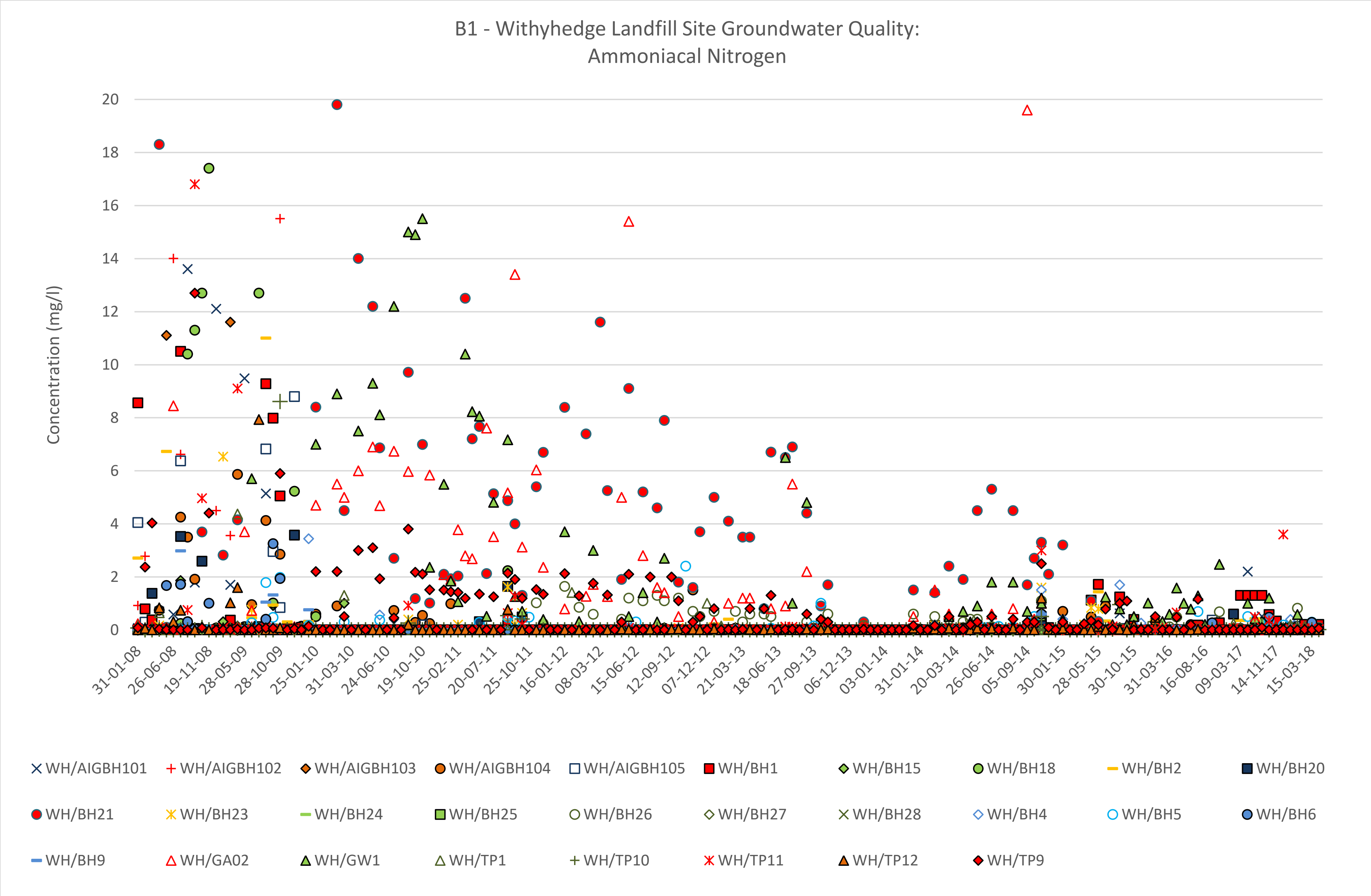
WH/LM2
WH/LM4
WH/LM5
WH/LW1
WH/LW2
WH/SW SUMP



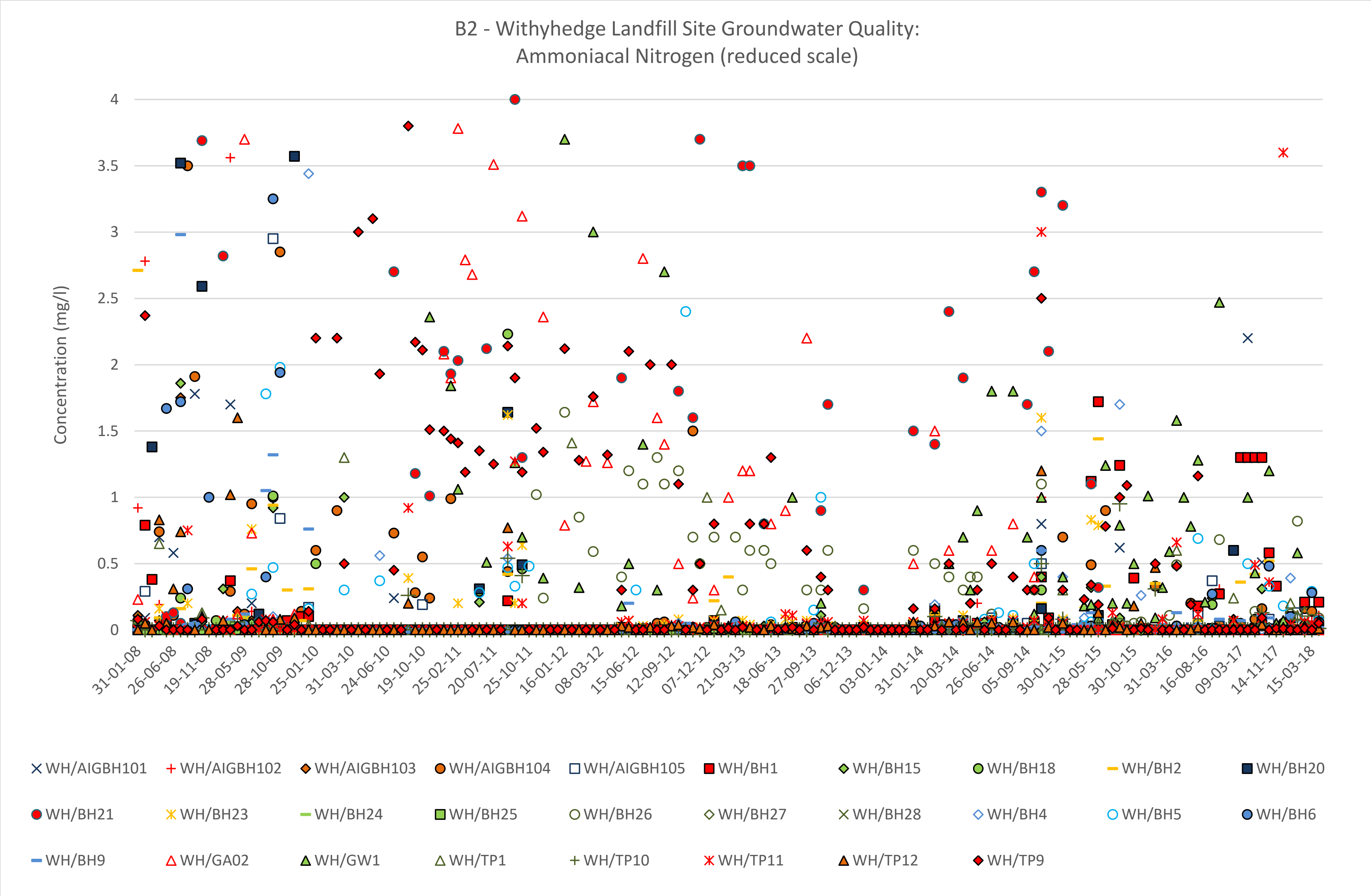
A5
Withyhedge Landfill Site Leachate Quality
COD Detail
Concentration (mg/l)
8000
7000
6000
5000
4000
3000
2000
1000
0
31-01-08
26-03-08
29-05-08
31-07-08
24-09-08
19-11-08
26-02-09
22-04-09
18-06-09
19-08-09
12-10-09
24-11-09
30-03-10
21-04-10
23-06-10
16-08-10
16-11-10
25-02-11
31-08-11
02-06-12
08-08-12
05-11-12
08-01-13
17-05-13
19-02-14
31-10-14
25-03-15
28-05-15
31-07-15
30-09-15
30-11-15
29-01-16
31-03-16
19-07-16
25-11-16
31-05-17
14-11-17
LM3
WH/CELL 1
WH/CELL 2
WH/CELL11E
WH/CELL11W
WH/CELL13
WH/CELL14
WH/CELL15
WH/L1
WH/L2
WH/L3
WH/L4
WH/L5
WH/LD3
WH/LM1
WH/LM2
WH/LM4
WH/LM5
WH/LW1
WH/LW2
WH/SW SUMP

Appendix B

Groundwater Quality Data



B1 - Withyhedge Landfill Site Groundwater Quality:
Ammoniacal Nitrogen
Concentration (mg/l)
0
2
4
6
8
10
12
14
16
18
20
31-01-08
26-06-08
19-11-08
28-05-09
28-10-09
25-01-10
31-03-10
24-06-10
19-10-10
25-02-11
20-07-11
25-10-11
16-01-12
08-03-12
15-06-12
12-09-12
07-12-12
21-03-13
18-06-13
27-09-13
06-12-13
03-01-14
31-01-14
20-03-14
26-06-14
05-09-14
30-01-15
28-05-15
30-10-15
31-03-16
16-08-16
09-03-17
14-11-17
15-03-18
WH/AIGBH101
WH/AIGBH102
WH/AIGBH103
WH/AIGBH104
WH/AIGBH105
WH/BH1
WH/BH15
WH/BH18
WH/BH2
WH/BH20
WH/BH21
WH/BH23
WH/BH24
WH/BH25
WH/BH26
WH/BH27
WH/BH28
WH/BH4
WH/BH5
WH/BH6
WH/BH9
WH/GA02
WH/GW1
WH/TP1
WH/TP10
WH/TP11
WH/TP12
WH/TP9



B2 - Withyhedge Landfill Site Groundwater Quality:
Ammoniacal Nitrogen (reduced scale)
Concentration (mg/l)
4
3.5
3
2.5
2
1.5
1
0.5
0
31-01-08
26-06-08
19-11-08
28-05-09
28-10-09
25-01-10
31-03-10
24-06-10
19-10-10
25-02-11
20-07-11
25-10-11
16-01-12
08-03-12
15-06-12
12-09-12
07-12-12
21-03-13
18-06-13
27-09-13
06-12-13
03-01-14
31-01-14
20-03-14
26-06-14
05-09-14
30-01-15
28-05-15
30-10-15
31-03-16
16-08-16
09-03-17
14-11-17
15-03-18
WH/AIGBH101
WH/AIGBH102
WH/AIGBH103
WH/AIGBH104
WH/AIGBH105
WH/BH1
WH/BH15
WH/BH18
WH/BH2
WH/BH20
WH/BH21
WH/BH23
WH/BH24
WH/BH25
WH/BH26
WH/BH27
WH/BH28
WH/BH4
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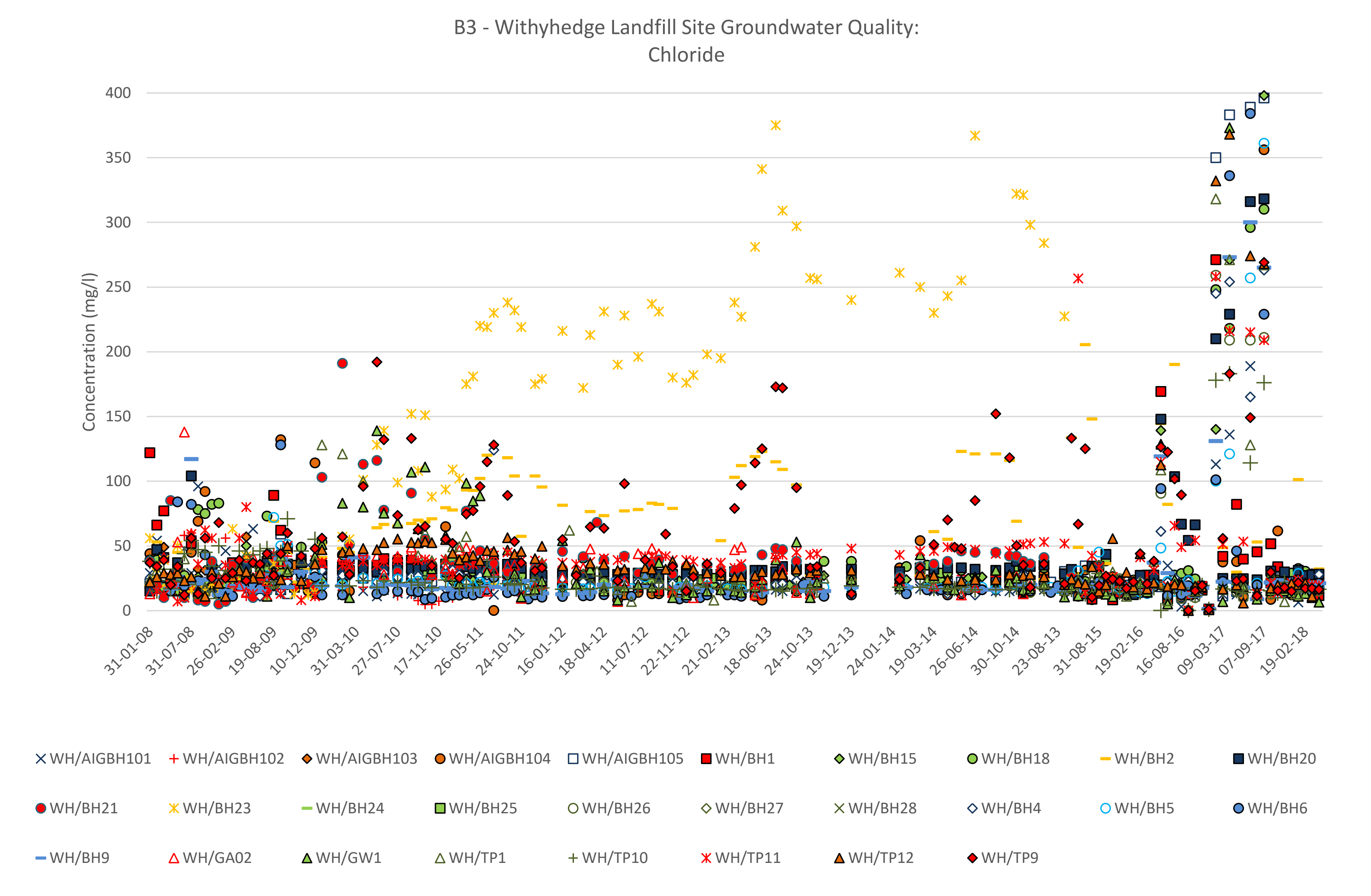
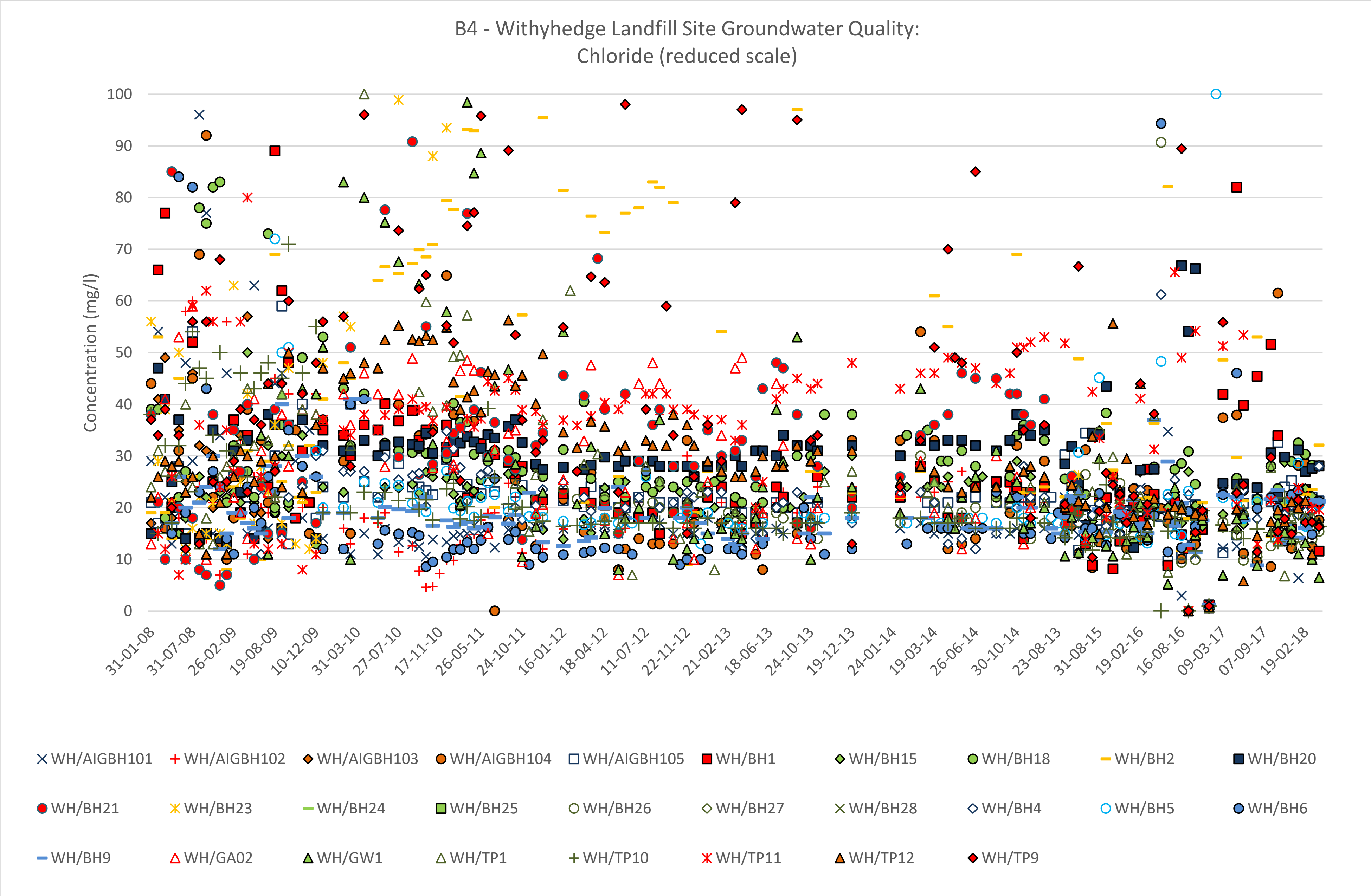
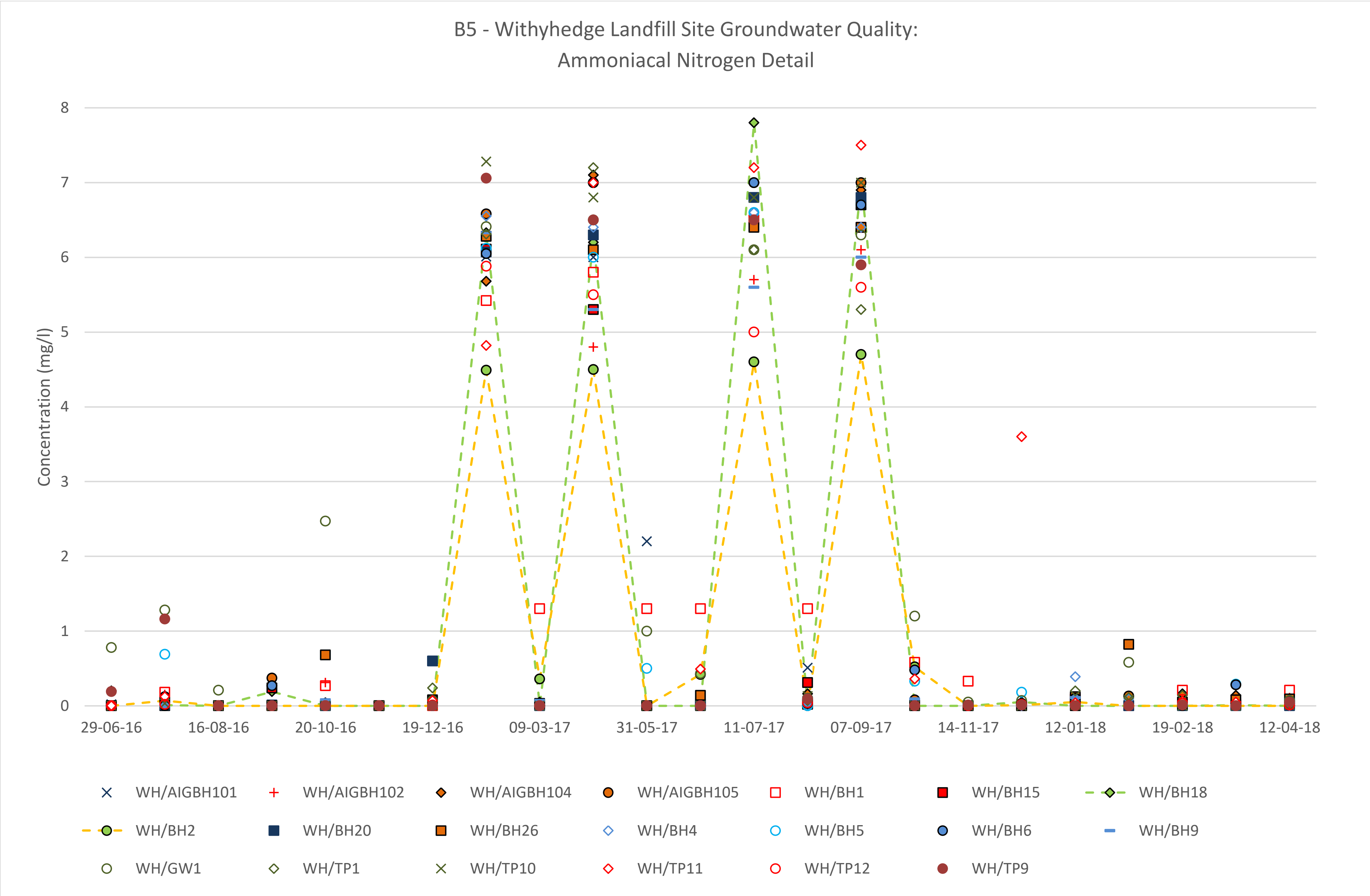
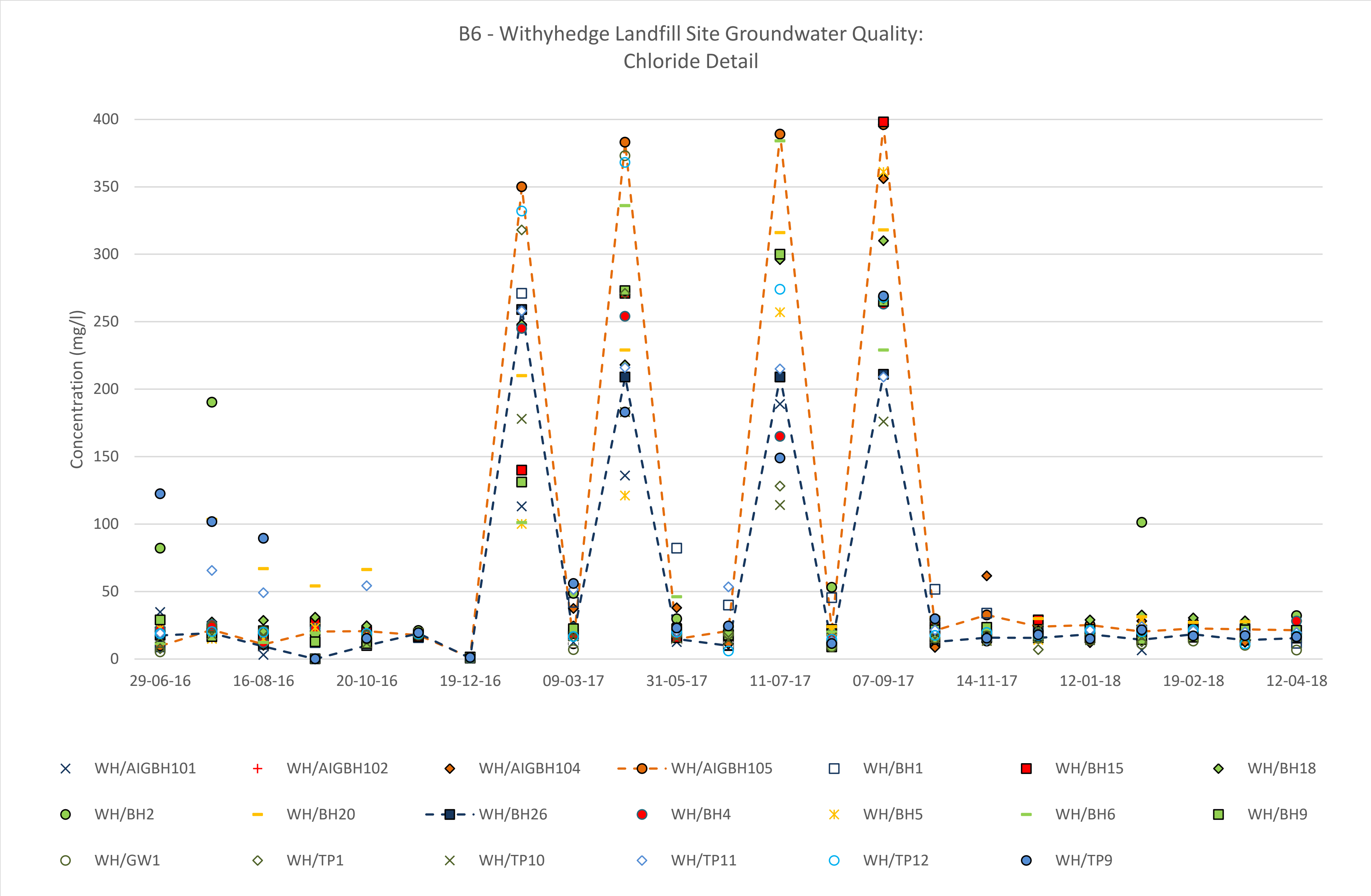
WH/BH6
WH/BH9
WH/GA02
WH/GW1
WH/TP1
WH/TP10
WH/TP11
WH/TP12
WH/TP9


B3 - Withyhedge Landfill Site Groundwater Quality:
Chloride
Concentration (mg/l)
400
350
300
250
200
150
100
50
0
31-01-08
31-07-08
26-02-09
19-08-09
10-12-09
31-03-10
27-07-10
17-11-10
26-05-11
24-10-11
16-01-12
18-04-12
11-07-12
22-11-12
21-02-13
18-06-13
24-10-13
19-12-13
24-01-14
19-03-14
26-06-14
30-10-14
23-08-13
31-08-15
19-02-16
16-08-16
09-03-17
07-09-17
19-02-18
WH/AIGBH101
WH/AIGBH102
WH/AIGBH103
WH/AIGBH104
WH/AIGBH105
WH/BH1
WH/BH15
WH/BH18
WH/BH2
WH/BH20
WH/BH21
WH/BH23
WH/BH24
WH/BH25
WH/BH26
WH/BH27
WH/BH28
WH/BH4
WH/BH5
WH/BH6
WH/BH9
WH/GA02
WH/GW1
WH/TP1
WH/TP10
WH/TP11
WH/TP12
WH/TP9

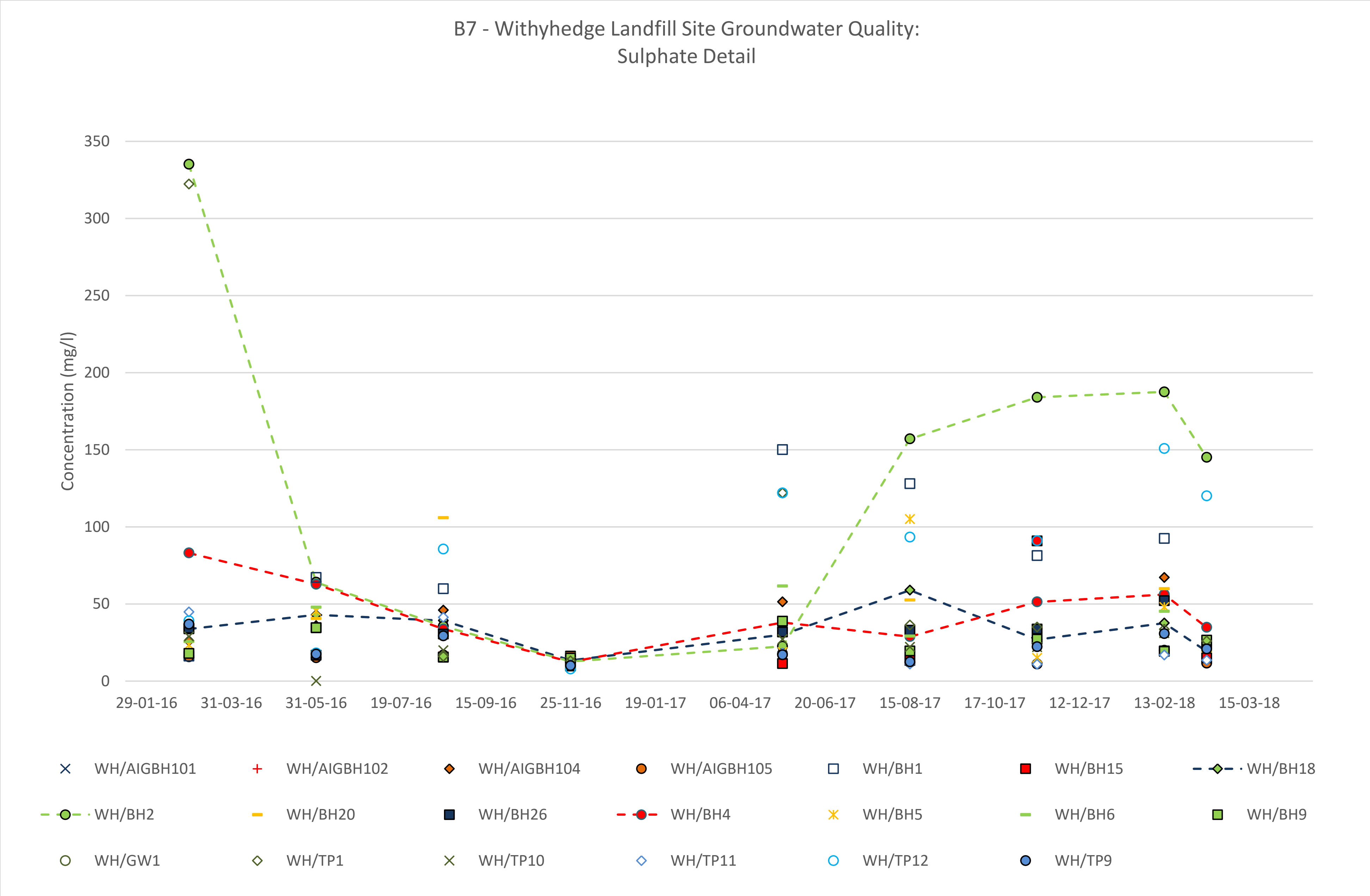


B4 - Withyhedge Landfill Site Groundwater Quality:
Chloride (reduced scale)
Concentration (mg/l)
100
90
80
70
60
50
40
30
20
10
0
31-01-08
31-07-08
26-02-09
19-08-09
10-12-09
31-03-10
27-07-10
17-11-10
26-05-11
24-10-11
16-01-12
18-04-12
11-07-12
22-11-12
21-02-13
18-06-13
24-10-13
19-12-13
24-01-14
19-03-14
26-06-14
30-10-14
23-08-13
31-08-15
19-02-16
16-08-16
09-03-17
07-09-17
19-02-18
WH/AIGBH101
WH/AIGBH102
WH/AIGBH103
WH/AIGBH104
WH/AIGBH105
WH/BH1
WH/BH15
WH/BH18
WH/BH2
WH/BH20
WH/BH21
WH/BH23
WH/BH24
WH/BH25
WH/BH26
WH/BH27
WH/BH28
WH/BH4
WH/BH5
WH/BH6
WH/BH9
WH/GA02
WH/GW1
WH/TP1
WH/TP10
WH/TP11
WH/TP12
WH/TP9

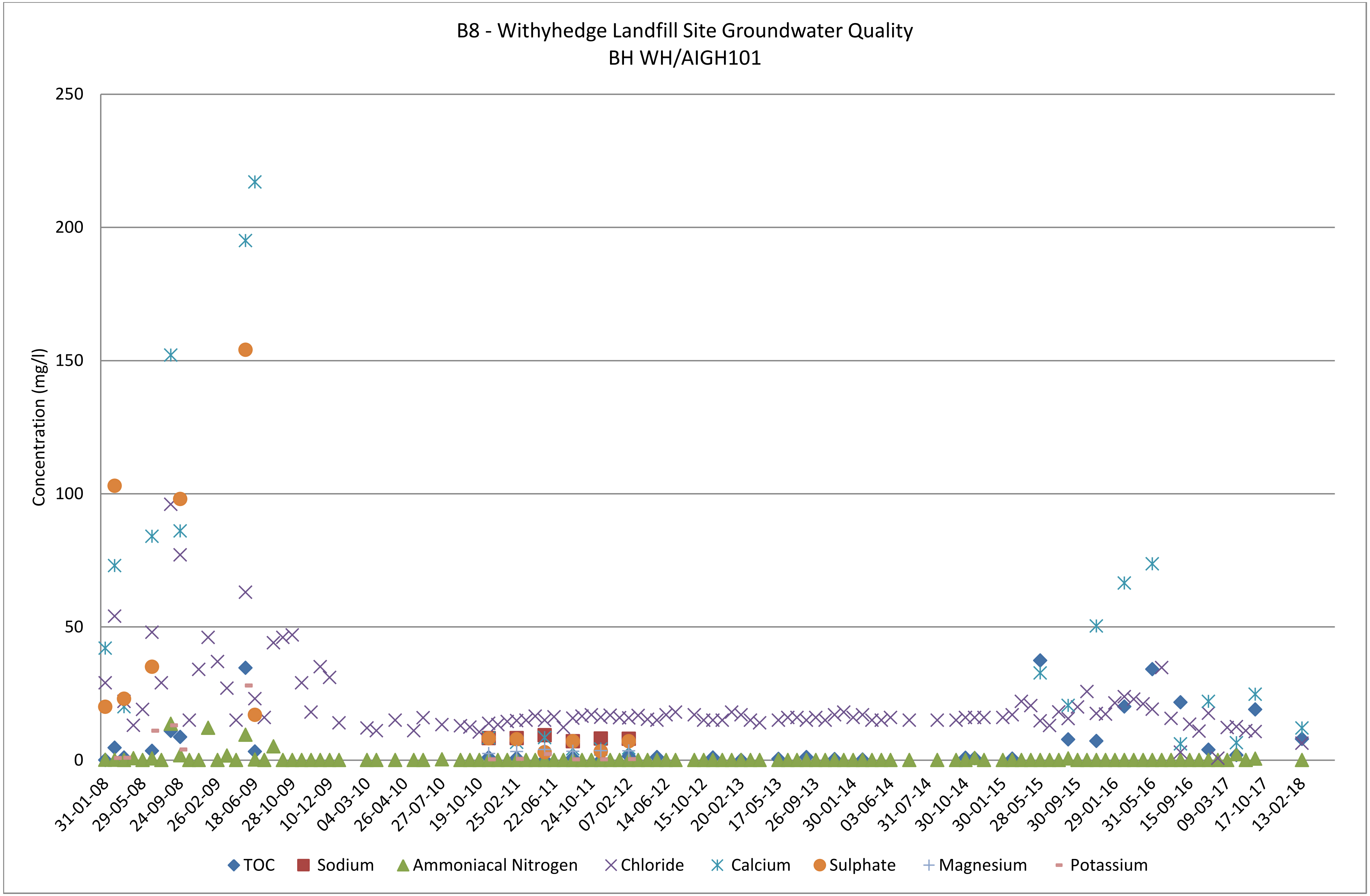

B5 - Withyhedge Landfill Site Groundwater Quality:
Ammoniacal Nitrogen Detail
Concentration (mg/l)
0
1
2
3
4
5
6
7
8
29-06-16
16-08-16
20-10-16
19-12-16
09-03-17
31-05-17
11-07-17
07-09-17
14-11-17
12-01-18
19-02-18
12-04-18
WH/AIGBH101
WH/AIGBH102
WH/AIGBH104
WH/AIGBH105
WH/BH1
WH/BH15
WH/BH18
WH/BH2
WH/BH20
WH/BH26
WH/BH4
WH/BH5
WH/BH6
WH/BH9
WH/GW1
WH/TP1
WH/TP10
WH/TP11
WH/TP12
WH/TP9



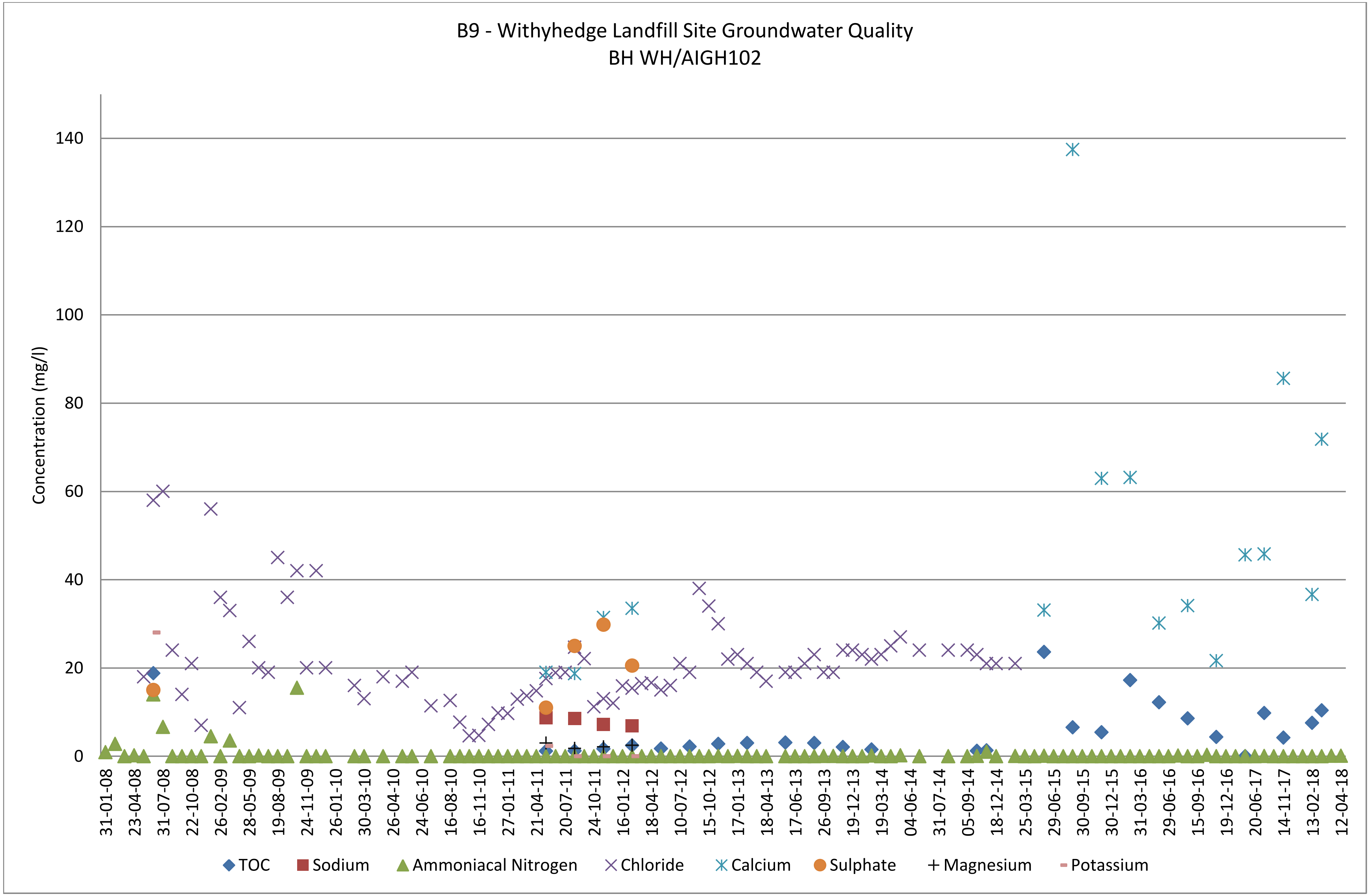
B6 - Withyhedge Landfill Site Groundwater Quality:
Chloride Detail
Concentration (mg/l)
0
50
100
150
200
250
300
350
400
29-06-16
16-08-16
20-10-16
19-12-16
09-03-17
31-05-17
11-07-17
07-09-17
14-11-17
12-01-18
19-02-18
12-04-18
WH/AIGBH101
WH/AIGBH102
WH/AIGBH104
WH/AIGBH105
WH/BH1
WH/BH15
WH/BH18
WH/BH2
WH/BH20
WH/BH26
WH/BH4
WH/BH5
WH/BH6
WH/BH9
WH/GW1
WH/TP1
WH/TP10
WH/TP11
WH/TP12
WH/TP9



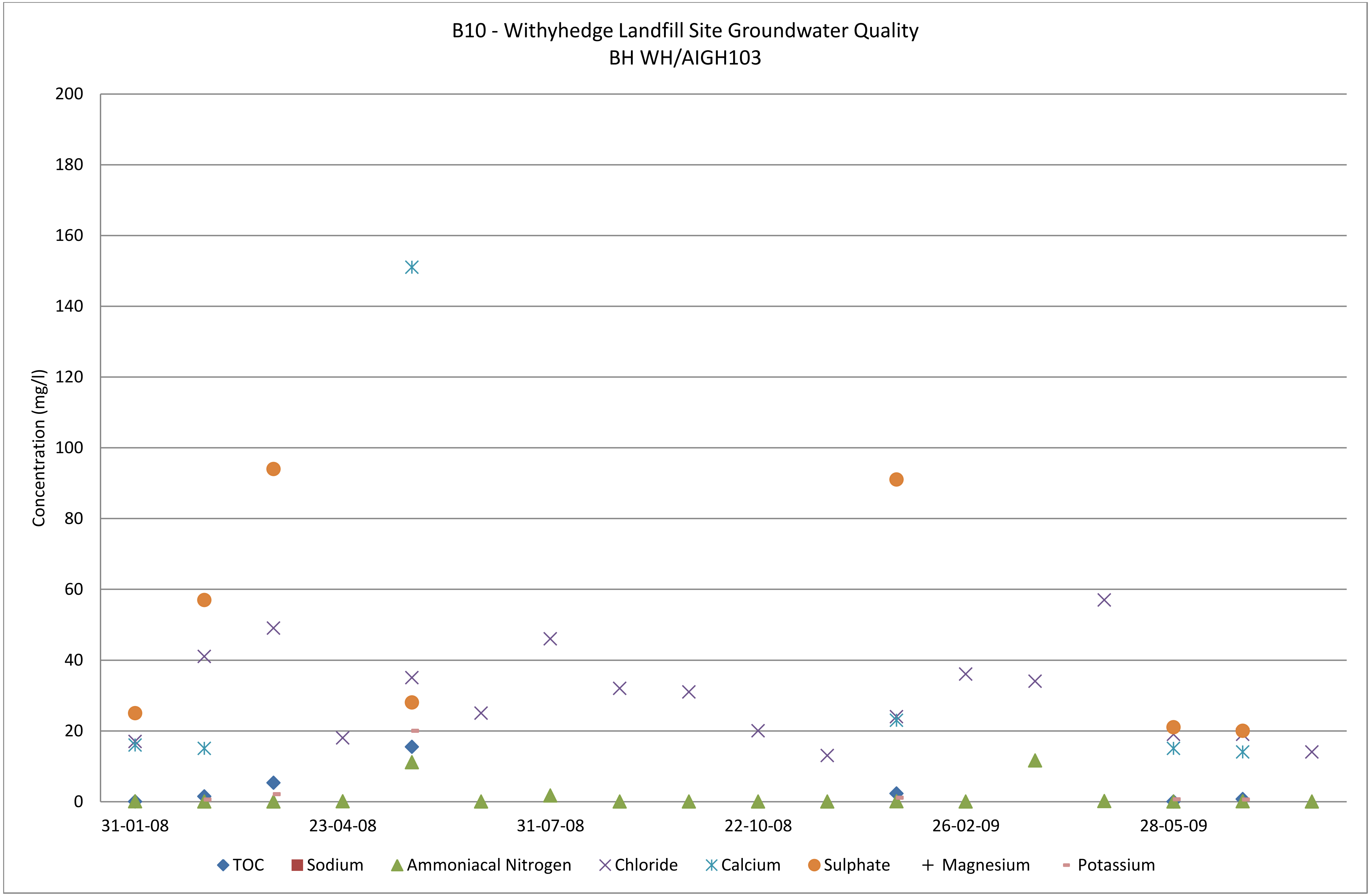
B7 - Withyhedge Landfill Site Groundwater Quality:
Sulphate Detail
Concentration (mg/l)
350
300
250
200
150
100
50
0
29-01-16
31-03-16
31-05-16
19-07-16
15-09-16
25-11-16
19-01-17
06-04-17
20-06-17
15-08-17
17-10-17
12-12-17
13-02-18
15-03-18
WH/AIGBH101
WH/AIGBH102
WH/AIGBH104
WH/AIGBH105
WH/BH1
WH/BH15
WH/BH18
WH/BH2
WH/BH20
WH/BH26
WH/BH4
WH/BH5
WH/BH6
WH/BH9
WH/GW1
WH/TP1
WH/TP10
WH/TP11
WH/TP12
WH/TP9



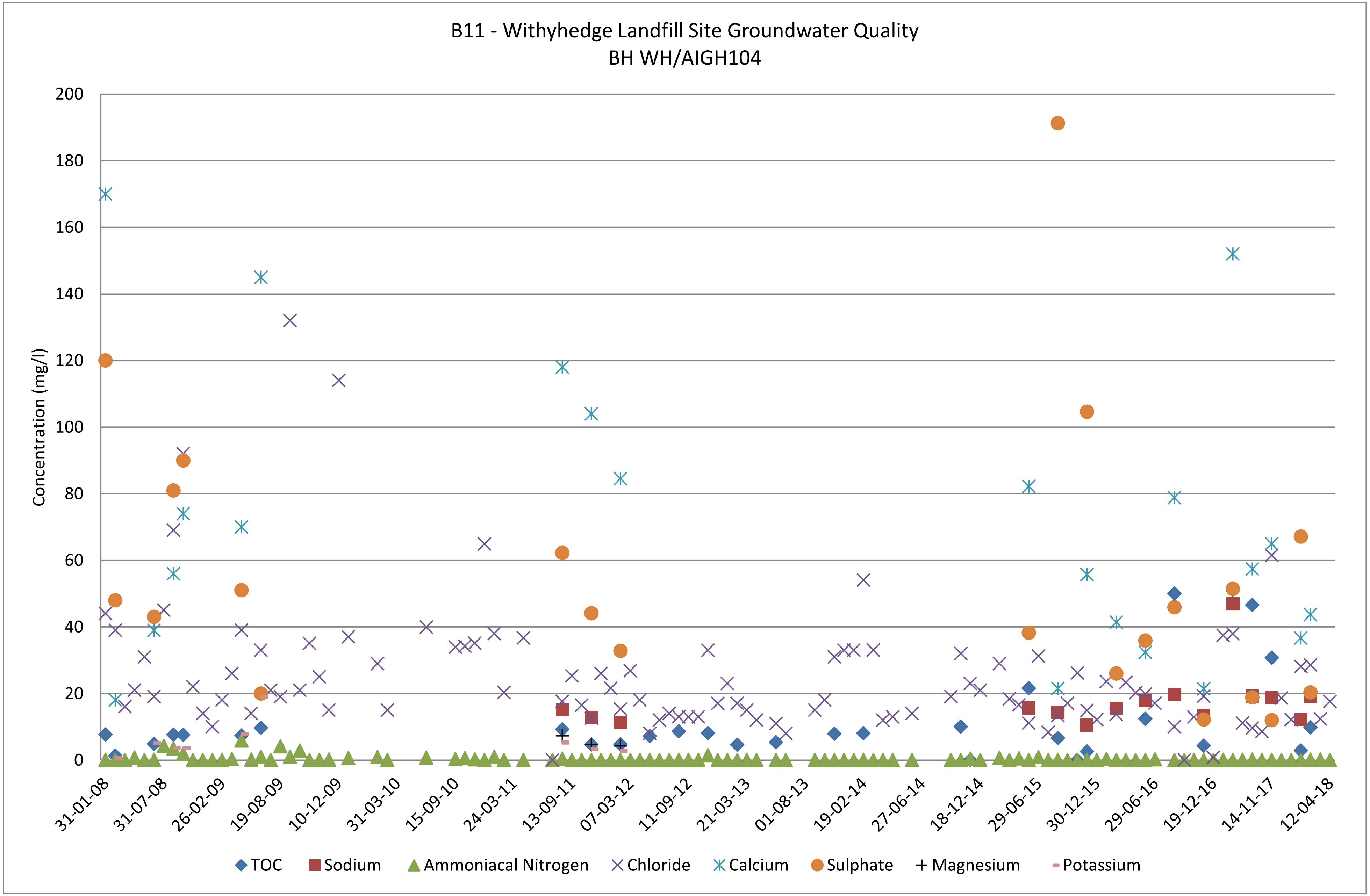
B8 - Withyhedge Landfill Site Groundwater Quality
BH WH/AIGH101
Concentration (mg/l)
250
200
150
100
50
0
31-01-08
29-05-08
24-09-08
26-02-09
18-06-09
28-10-09
10-12-09
04-03-10
26-04-10
27-07-10
19-10-10
25-02-11
22-06-11
24-10-11
07-02-12
14-06-12
15-10-12
20-02-13
17-05-13
26-09-13
30-01-14
03-06-14
31-07-14
30-10-14
30-01-15
28-05-15
30-09-15
29-01-16
31-05-16
15-09-16
09-03-17
17-10-17
13-02-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium



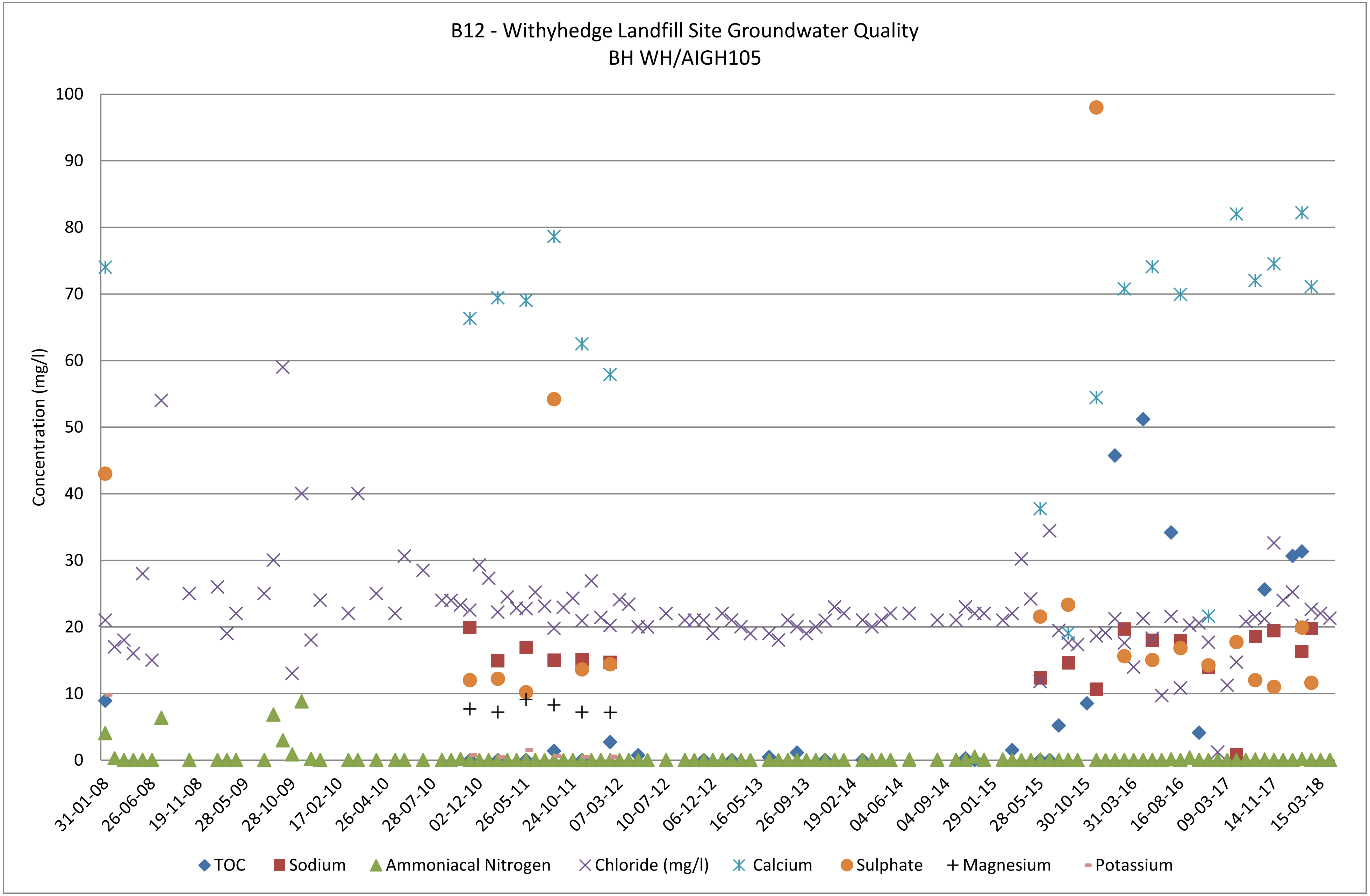
B9 - Withyhedge Landfill Site Groundwater Quality
BH WH/AIGH102
Concentration (mg/l)
0
20
40
60
80
100
120
140
31-01-08
23-04-08
31-07-08
22-10-08
26-02-09
28-05-09
19-08-09
24-11-09
26-01-10
30-03-10
26-04-10
24-06-10
16-08-10
16-11-10
27-01-11
21-04-11
20-07-11
24-10-11
16-01-12
18-04-12
10-07-12
15-10-12
17-01-13
18-04-13
17-06-13
26-09-13
19-12-13
19-03-14
04-06-14
31-07-14
05-09-14
18-12-14
25-03-15
29-06-15
30-09-15
30-12-15
31-03-16
29-06-16
15-09-16
19-12-16
20-06-17
14-11-17
13-02-18
12-04-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium



B10 - Withyhedge Landfill Site Groundwater Quality
BH WH/AIGH103
Concentration (mg/l)
200
180
160
140
120
100
80
60
40
20
0
31-01-08
23-04-08
31-07-08
22-10-08
26-02-09
28-05-09
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium



B11 - Withyhedge Landfill Site Groundwater Quality
BH WH/AIGH104
Concentration (mg/l)
200
180
160
140
120
100
80
60
40
20
0
31-01-08
31-07-08
26-02-09
19-08-09
10-12-09
31-03-10
15-09-10
24-03-11
13-09-11
07-03-12
11-09-12
21-03-13
01-08-13
19-02-14
27-06-14
18-12-14
29-06-15
30-12-15
29-06-16
19-12-16
14-11-17
12-04-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium



B12 - Withyhedge Landfill Site Groundwater Quality
BH WH/AIGH105
Concentration (mg/l)
100
90
80
70
60
50
40
30
20
10
0
31-01-08
26-06-08
19-11-08
28-05-09
28-10-09
17-02-10
26-04-10
28-07-10
02-12-10
26-05-11
24-10-11
07-03-12
10-07-12
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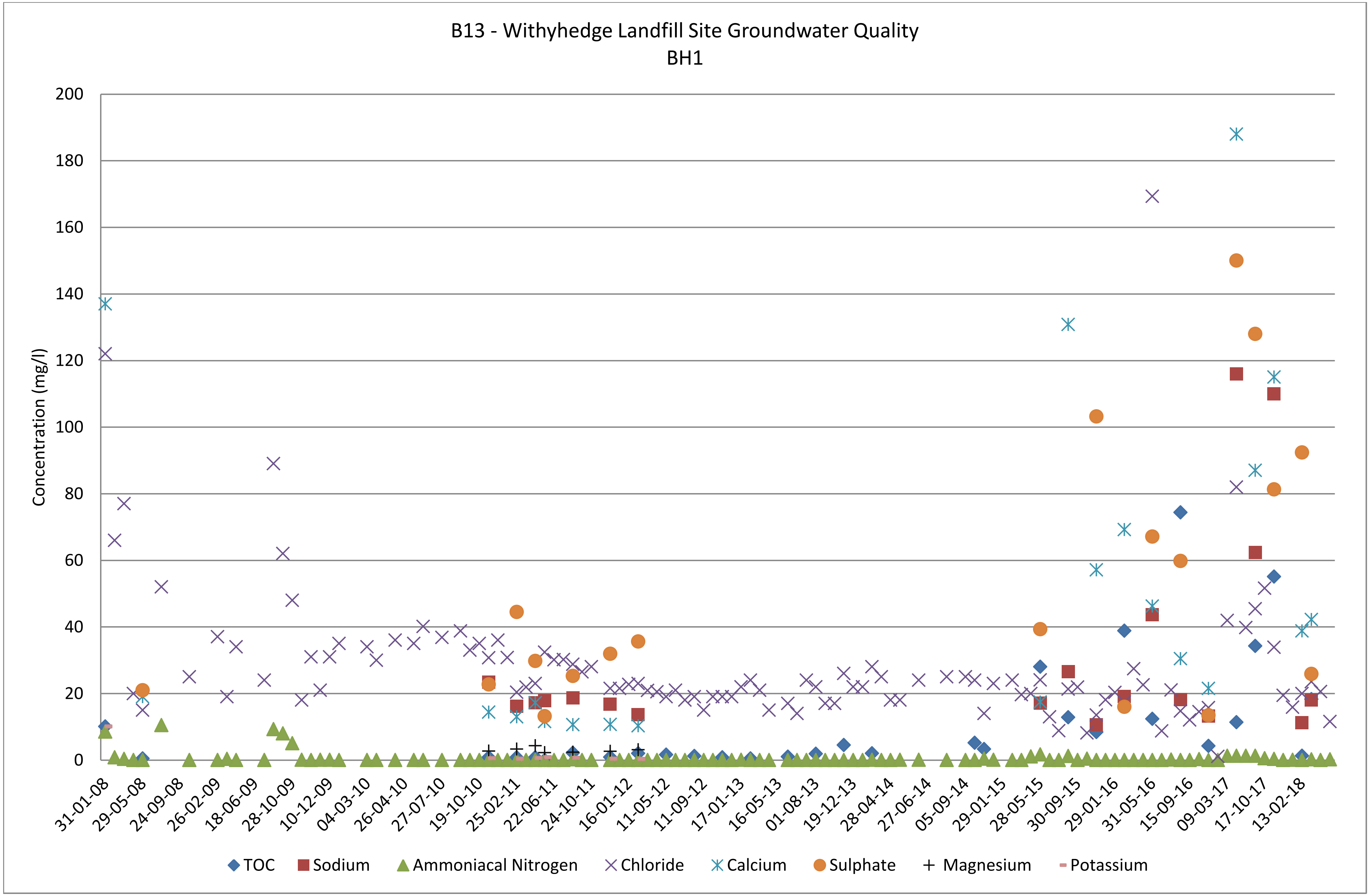
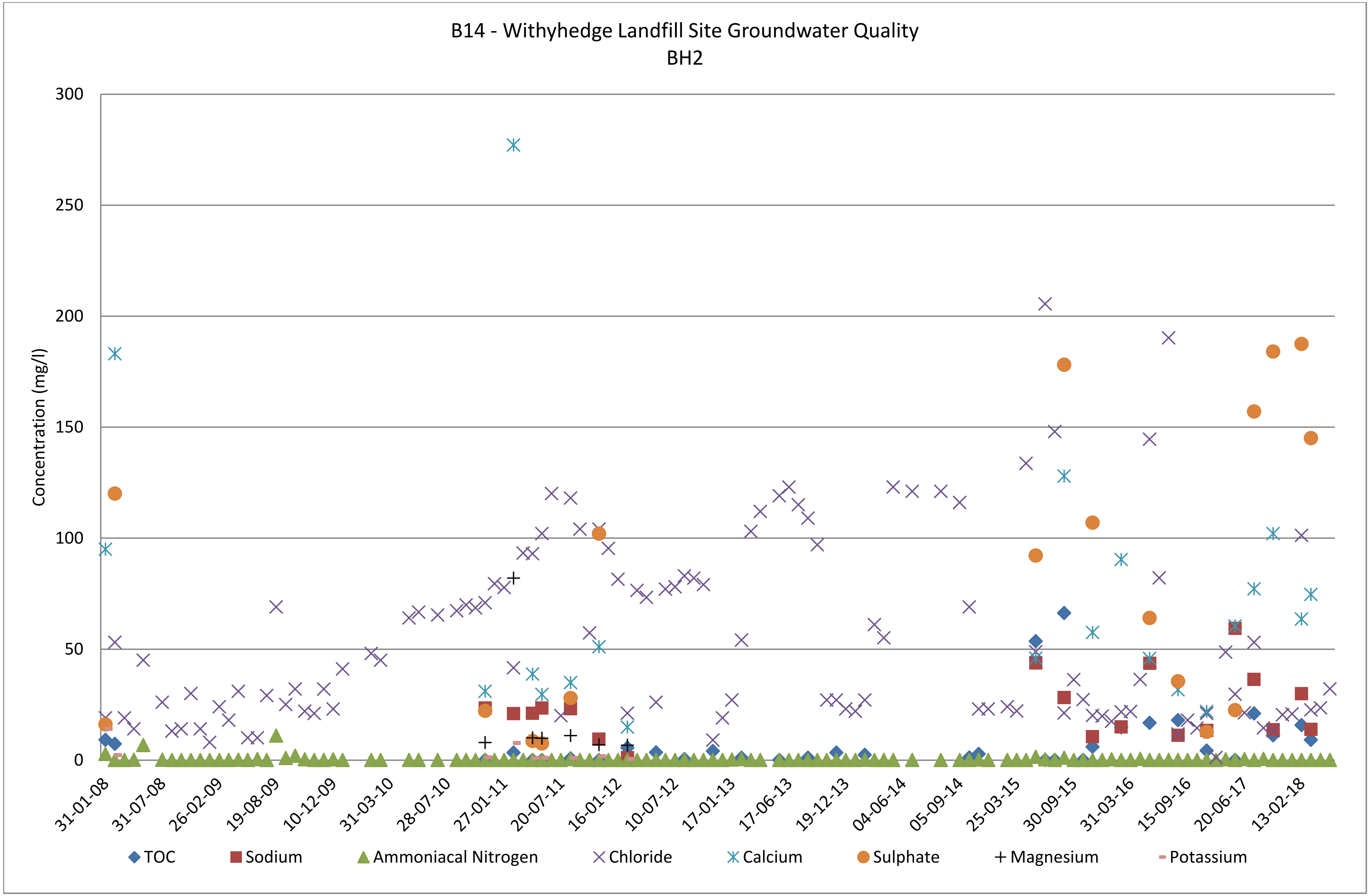
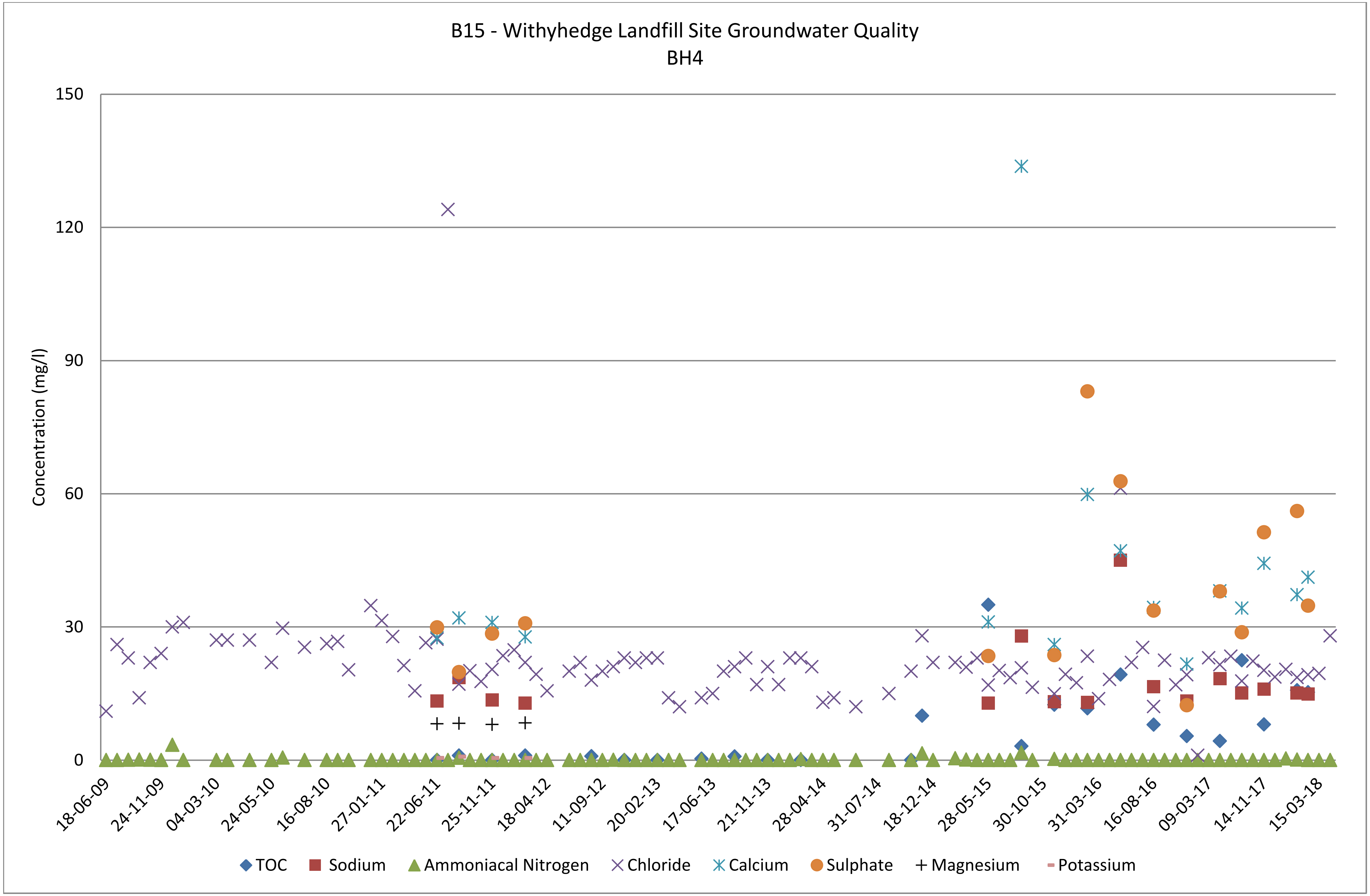
16-05-13
26-09-13
19-02-14
04-06-14
04-09-14
29-01-15
28-05-15
30-10-15
31-03-16
16-08-16
09-03-17
14-11-17
15-03-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride (mg/l)
Calcium
Sulphate
Magnesium
Potassium

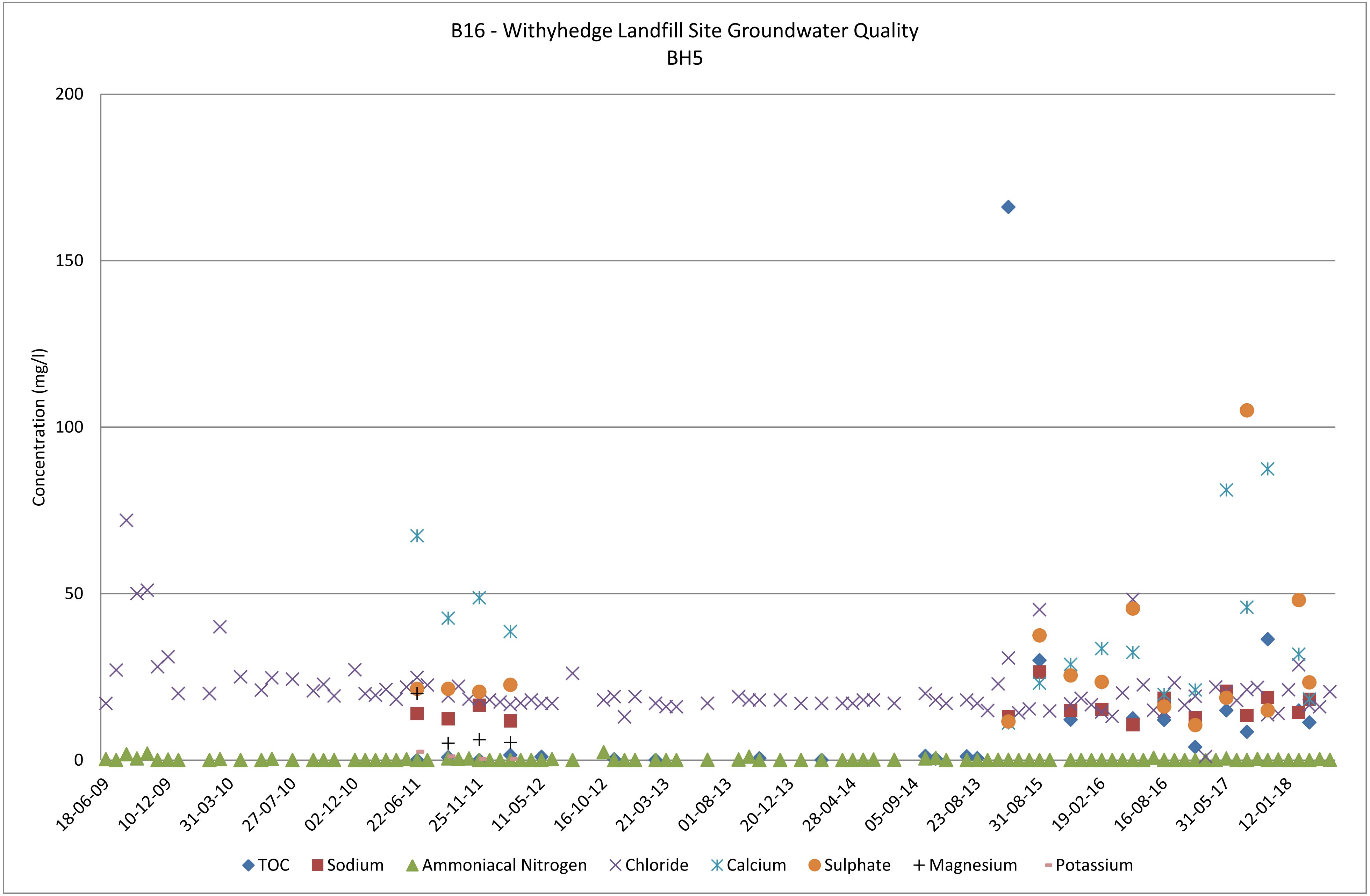


B13 - Withyhedge Landfill Site Groundwater Quality
BH1
Concentration (mg/l)
200
180
160
140
120
100
80
60
40
20
0
31-01-08
29-05-08
24-09-08
26-02-09
18-06-09
28-10-09
10-12-09
04-03-10
26-04-10
27-07-10
19-10-10
25-02-11
22-06-11
24-10-11
16-01-12
11-05-12
11-09-12
17-01-13
16-05-13
01-08-13
19-12-13
28-04-14
27-06-14
05-09-14
29-01-15
28-05-15
30-09-15
29-01-16
31-05-16
15-09-16
09-03-17
17-10-17
13-02-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

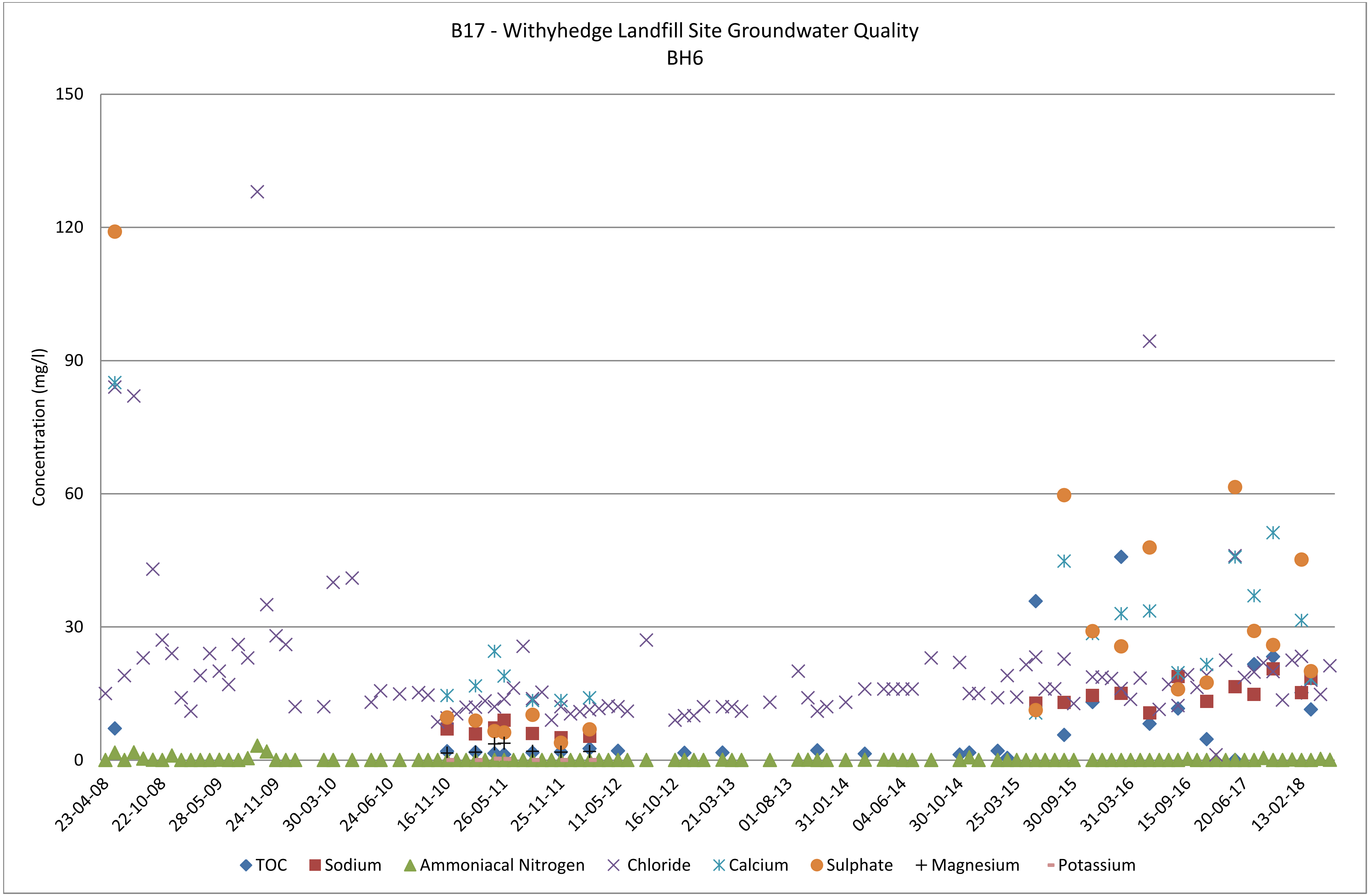

B14 - Withyhedge Landfill Site Groundwater Quality
BH2
Concentration (mg/l)
300
250
200
150
100
50
0
31-01-08
31-07-08
26-02-09
19-08-09
10-12-09
31-03-10
28-07-10
27-01-11
20-07-11
16-01-12
10-07-12
17-01-13
17-06-13
19-12-13
04-06-14
05-09-14
25-03-15
30-09-15
31-03-16
15-09-16
20-06-17
13-02-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

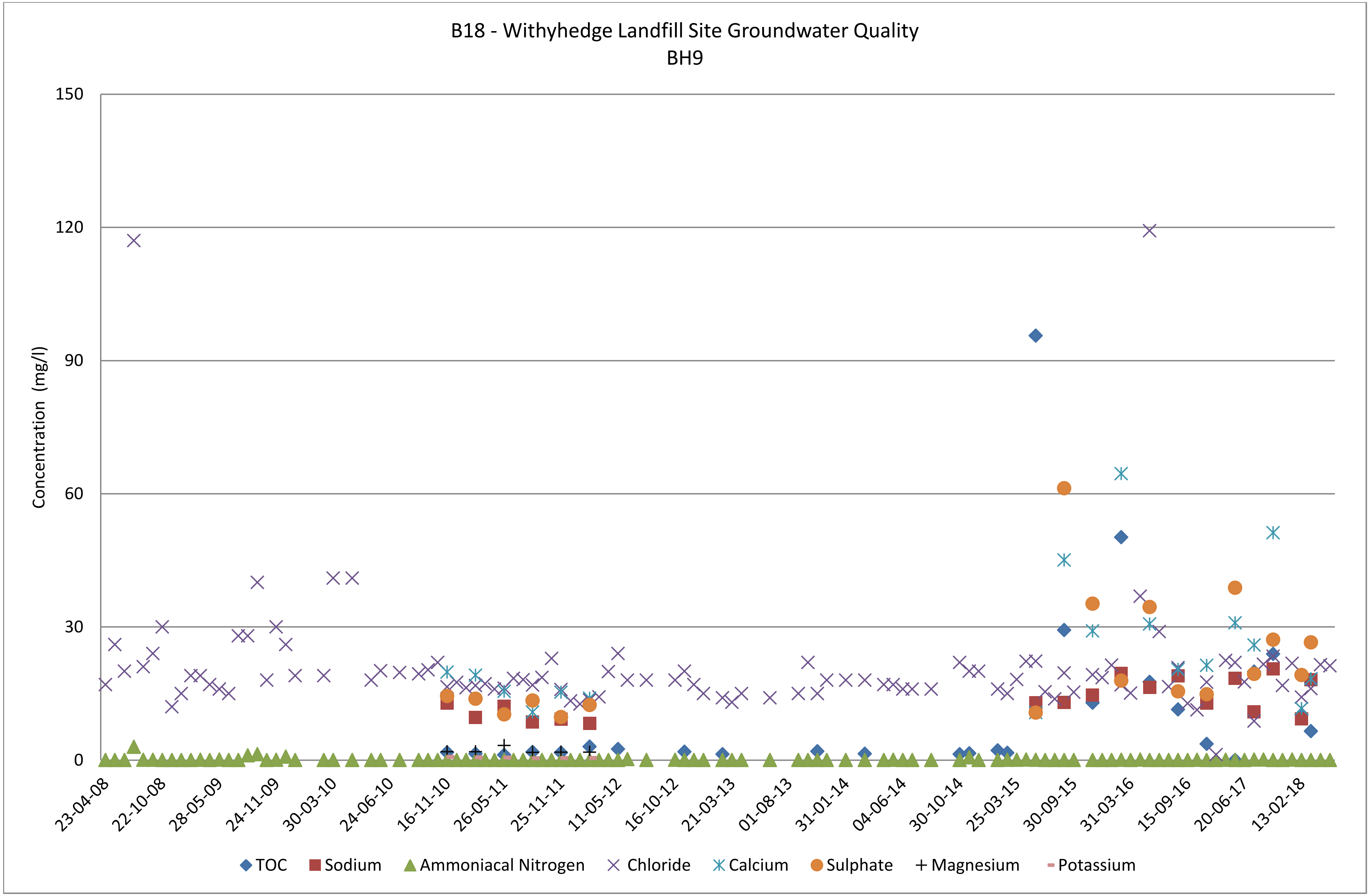


B15 - Withyhedge Landfill Site Groundwater Quality
BH4
Concentration (mg/l)
150
120
90
60
30
0
18-06-09
24-11-09
04-03-10
24-05-10
16-08-10
27-01-11
22-06-11
25-11-11
18-04-12
11-09-12
20-02-13
17-06-13
21-11-13
28-04-14
31-07-14
18-12-14
28-05-15
30-10-15
31-03-16
16-08-16
09-03-17
14-11-17
15-03-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

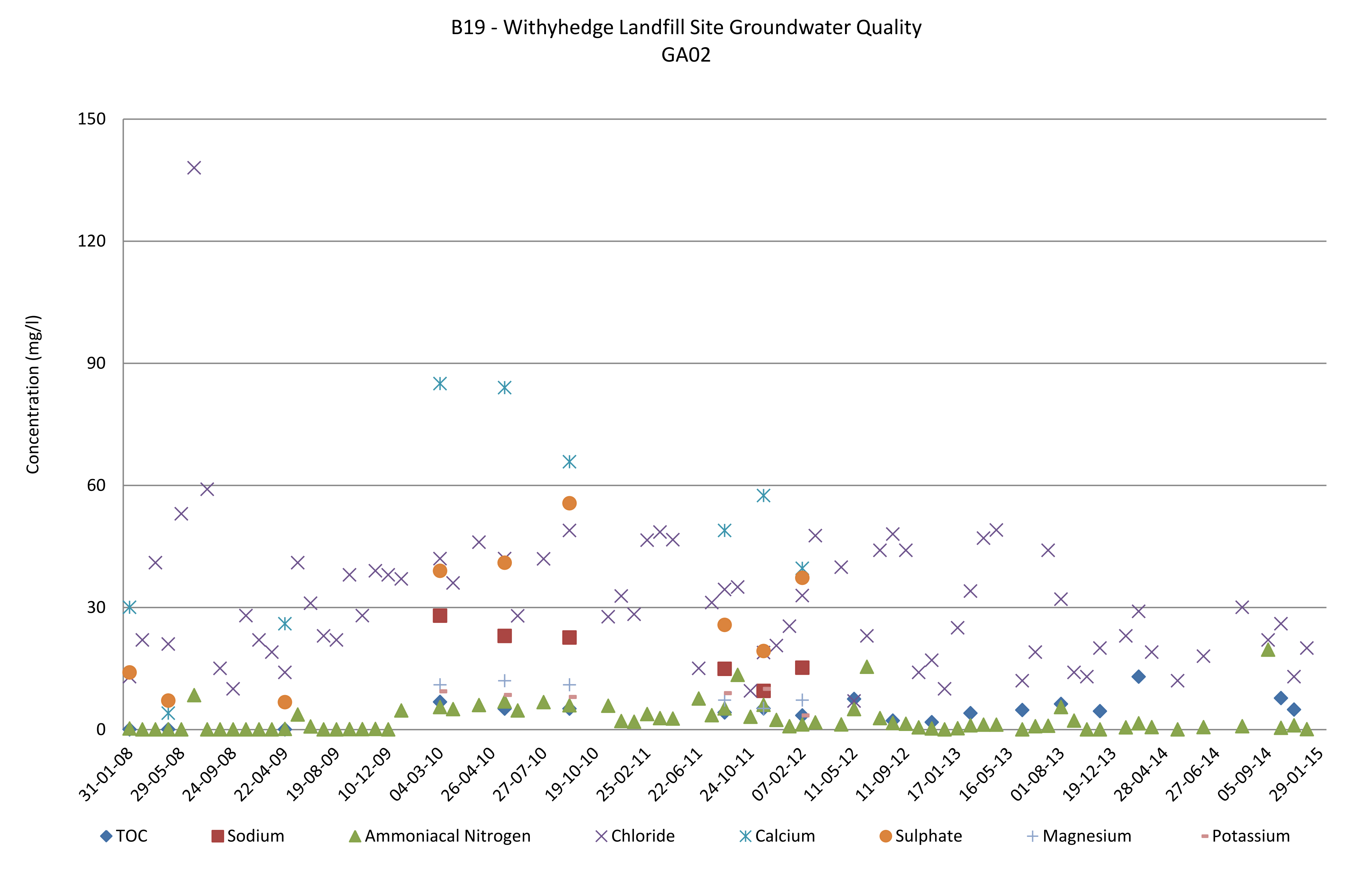


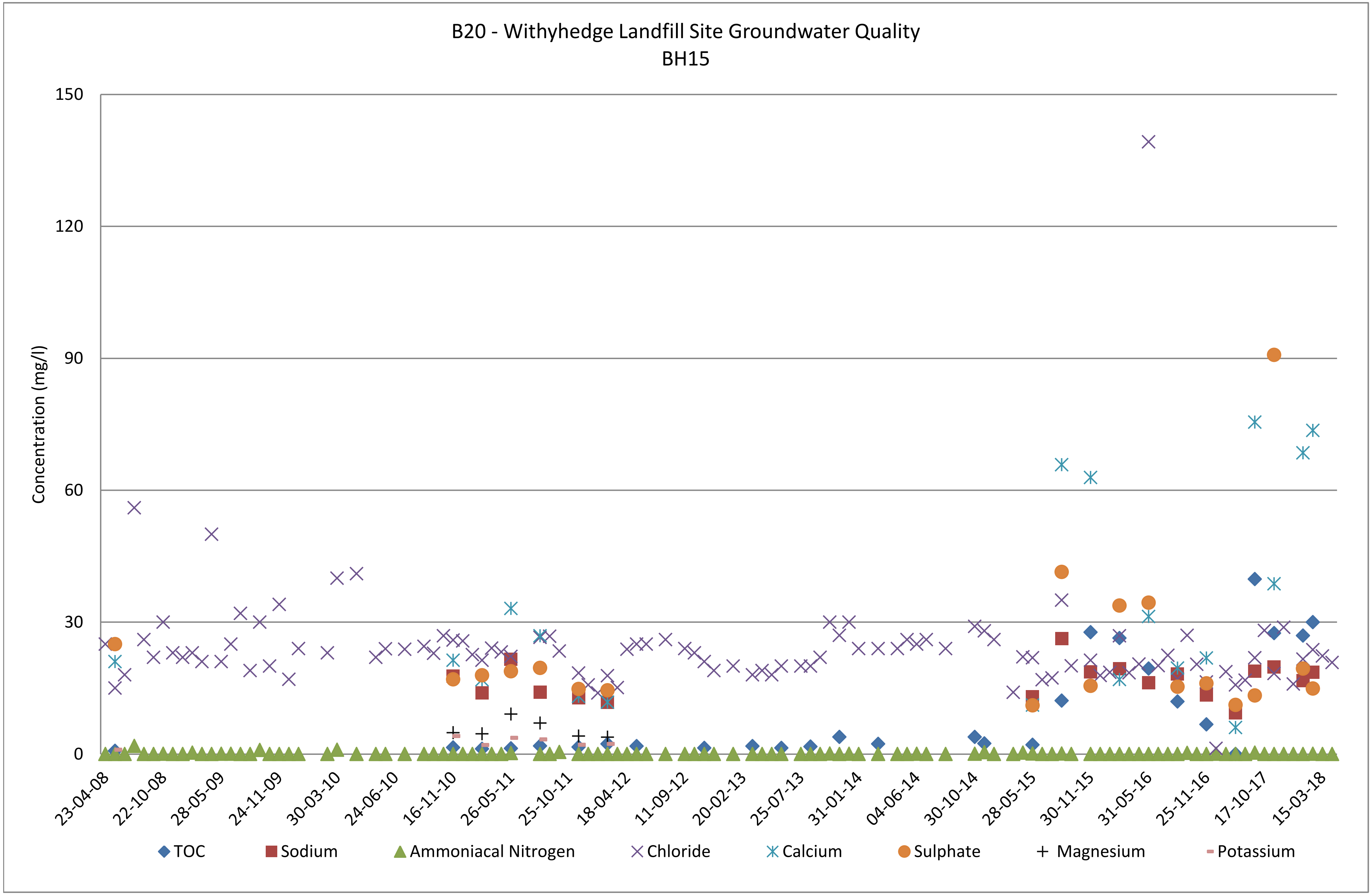
B16 - Withyhedge Landfill Site Groundwater Quality
BH5
Concentration (mg/l)
200
150
100
50
0
18-06-09
10-12-09
31-03-10
27-07-10
02-12-10
22-06-11
25-11-11
11-05-12
16-10-12
21-03-13
01-08-13
20-12-13
28-04-14
05-09-14
23-08-13
31-08-15
19-02-16
16-08-16
31-05-17
12-01-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium


B17 - Withyhedge Landfill Site Groundwater Quality
BH6
Concentration (mg/l)
150
120
90
60
30
0
23-04-08
22-10-08
28-05-09
24-11-09
30-03-10
24-06-10
16-11-10
26-05-11
25-11-11
11-05-12
16-10-12
21-03-13
01-08-13
31-01-14
04-06-14
30-10-14
25-03-15
30-09-15
31-03-16
15-09-16
20-06-17
13-02-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

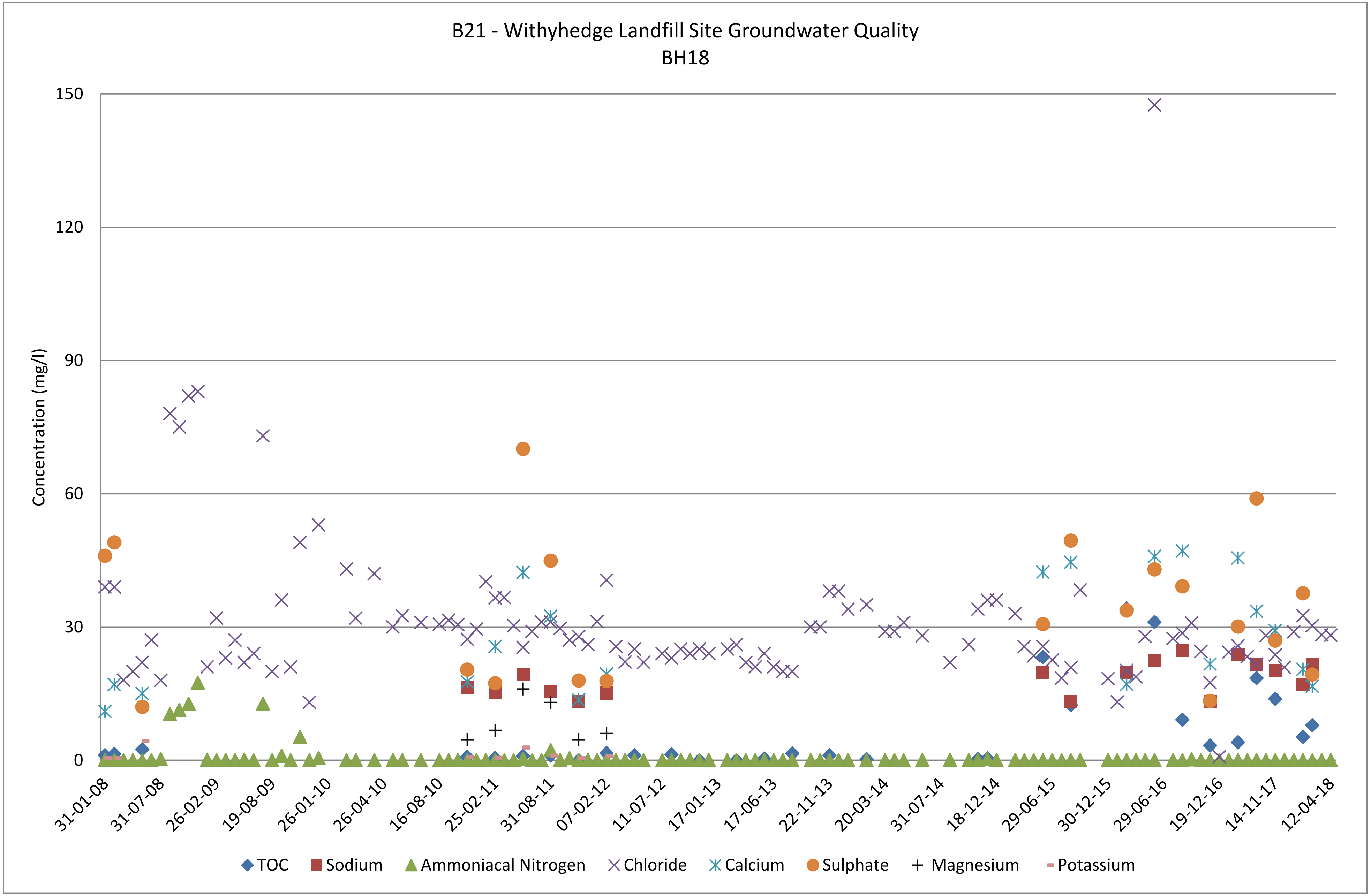


B18 - Withyhedge Landfill Site Groundwater Quality
BH9
Concentration (mg/l)
150
120
90
60
30
0
23-04-08
22-10-08
28-05-09
24-11-09
30-03-10
24-06-10
16-11-10
26-05-11
25-11-11
11-05-12
16-10-12
21-03-13
01-08-13
31-01-14
04-06-14
30-10-14
25-03-15
30-09-15
31-03-16
15-09-16
20-06-17
13-02-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

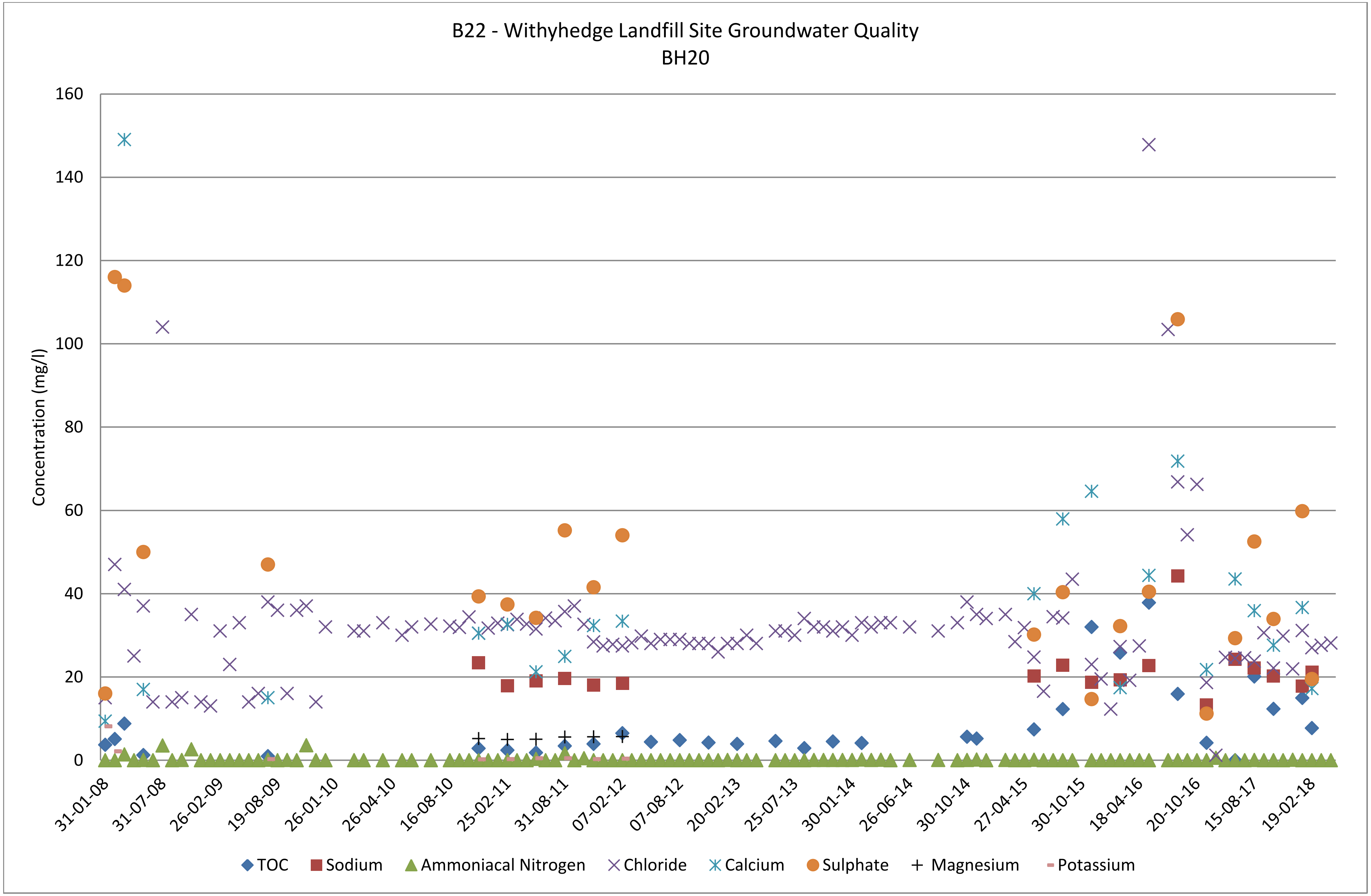

B19 - Withyhedge Landfill Site Groundwater Quality
GA02
Concentration (mg/l)
150
120
90
60
30
0
31-01-08
29-05-08
24-09-08
22-04-09
19-08-09
10-12-09
04-03-10
26-04-10
27-07-10
19-10-10
25-02-11
22-06-11
24-10-11
07-02-12
11-05-12
11-09-12
17-01-13
16-05-13
01-08-13
19-12-13
28-04-14
27-06-14
05-09-14
29-01-15
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

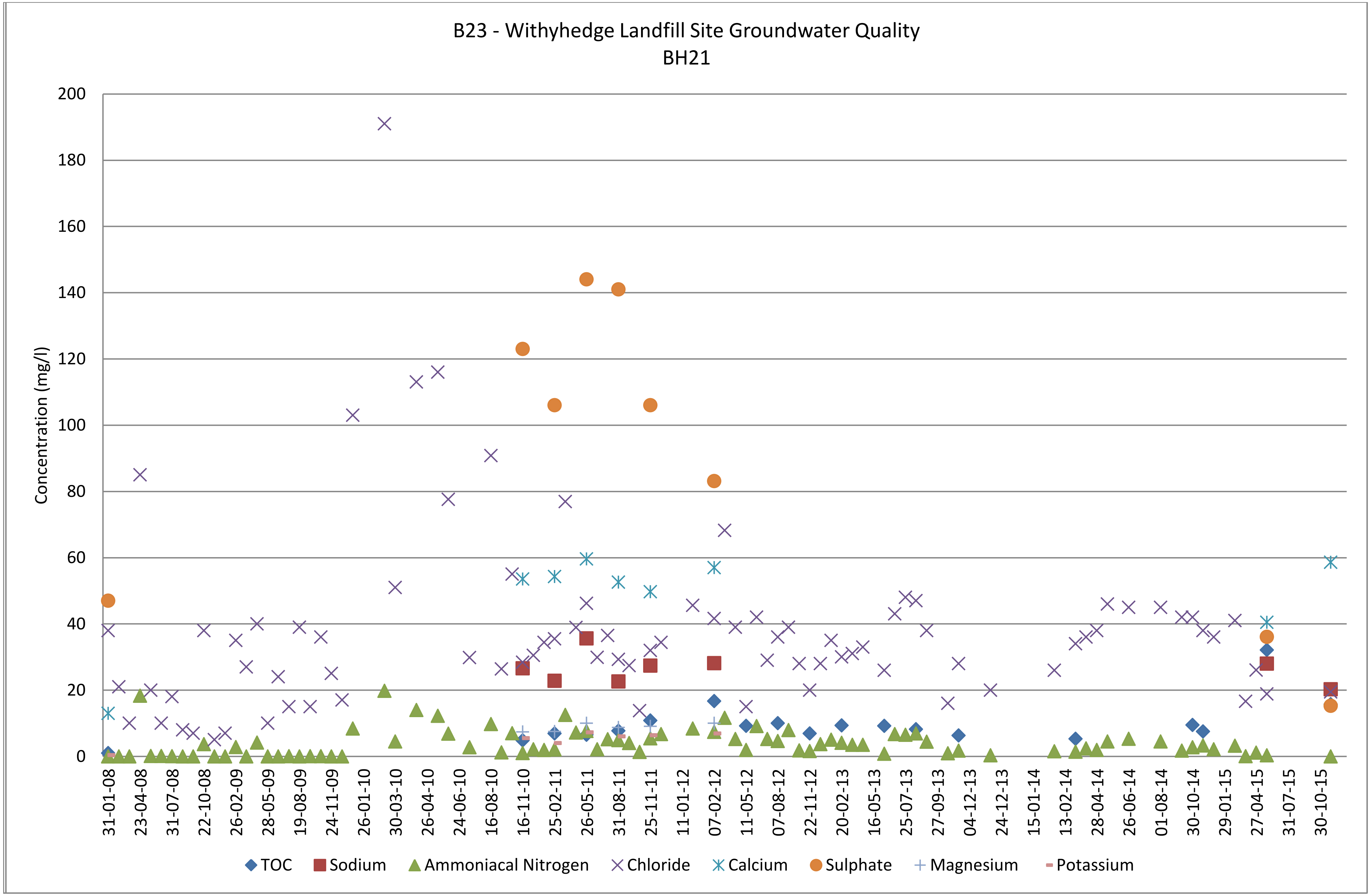


B20 - Withyhedge Landfill Site Groundwater Quality
BH15
Concentration (mg/l)
150
120
90
60
30
0
23-04-08
22-10-08
28-05-09
24-11-09
30-03-10
24-06-10
16-11-10
26-05-11
25-10-11
18-04-12
11-09-12
20-02-13
25-07-13
31-01-14
04-06-14
30-10-14
28-05-15
30-11-15
31-05-16
25-11-16
17-10-17
15-03-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

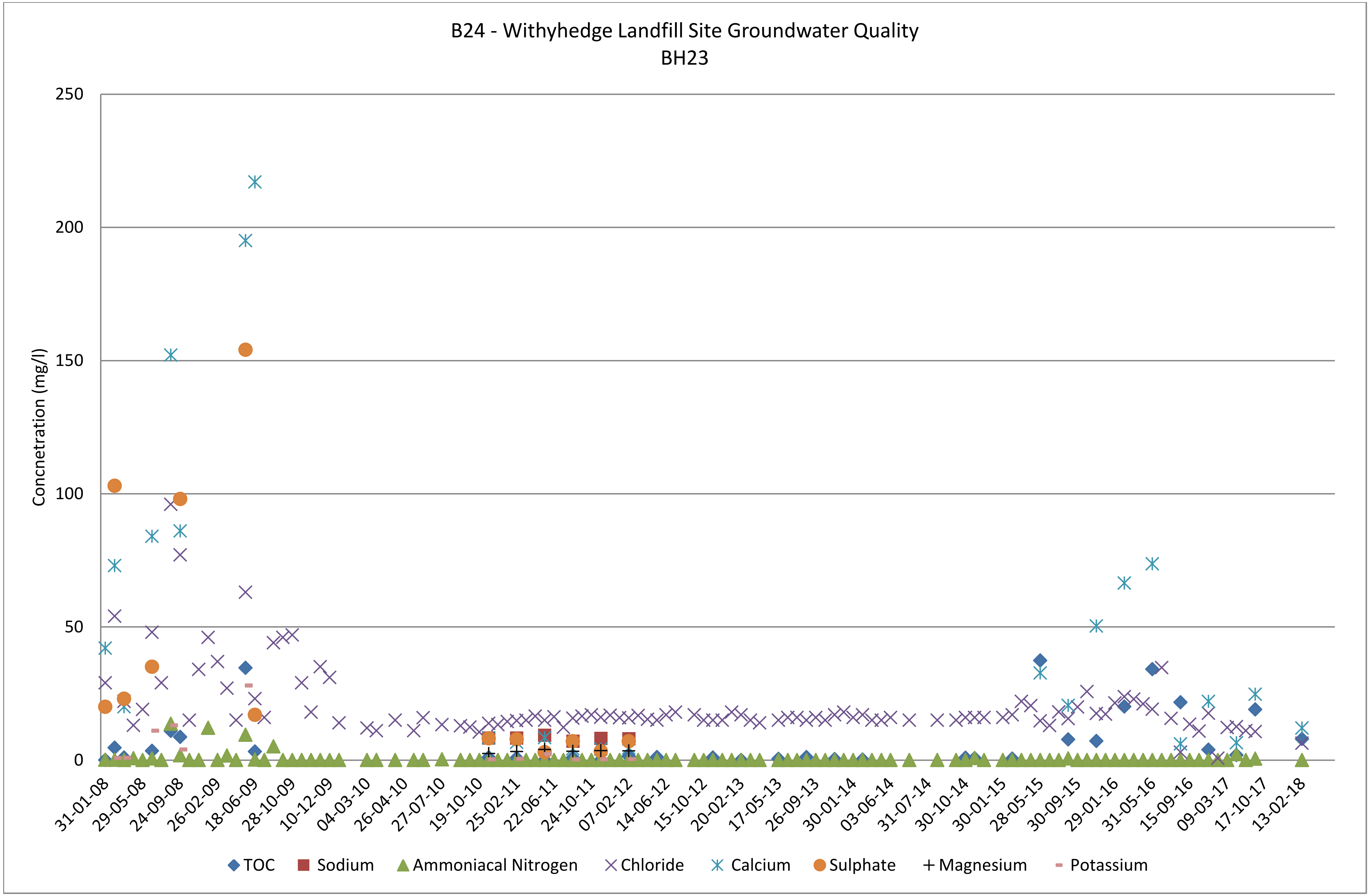


B21 - Withyhedge Landfill Site Groundwater Quality
BH18
Concentration (mg/l)
150
120
90
60
30
0
31-01-08
31-07-08
26-02-09
19-08-09
26-01-10
26-04-10
16-08-10
25-02-11
31-08-11
07-02-12
11-07-12
17-01-13
17-06-13
22-11-13
20-03-14
31-07-14
18-12-14
29-06-15
30-12-15
29-06-16
19-12-16
14-11-17
12-04-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

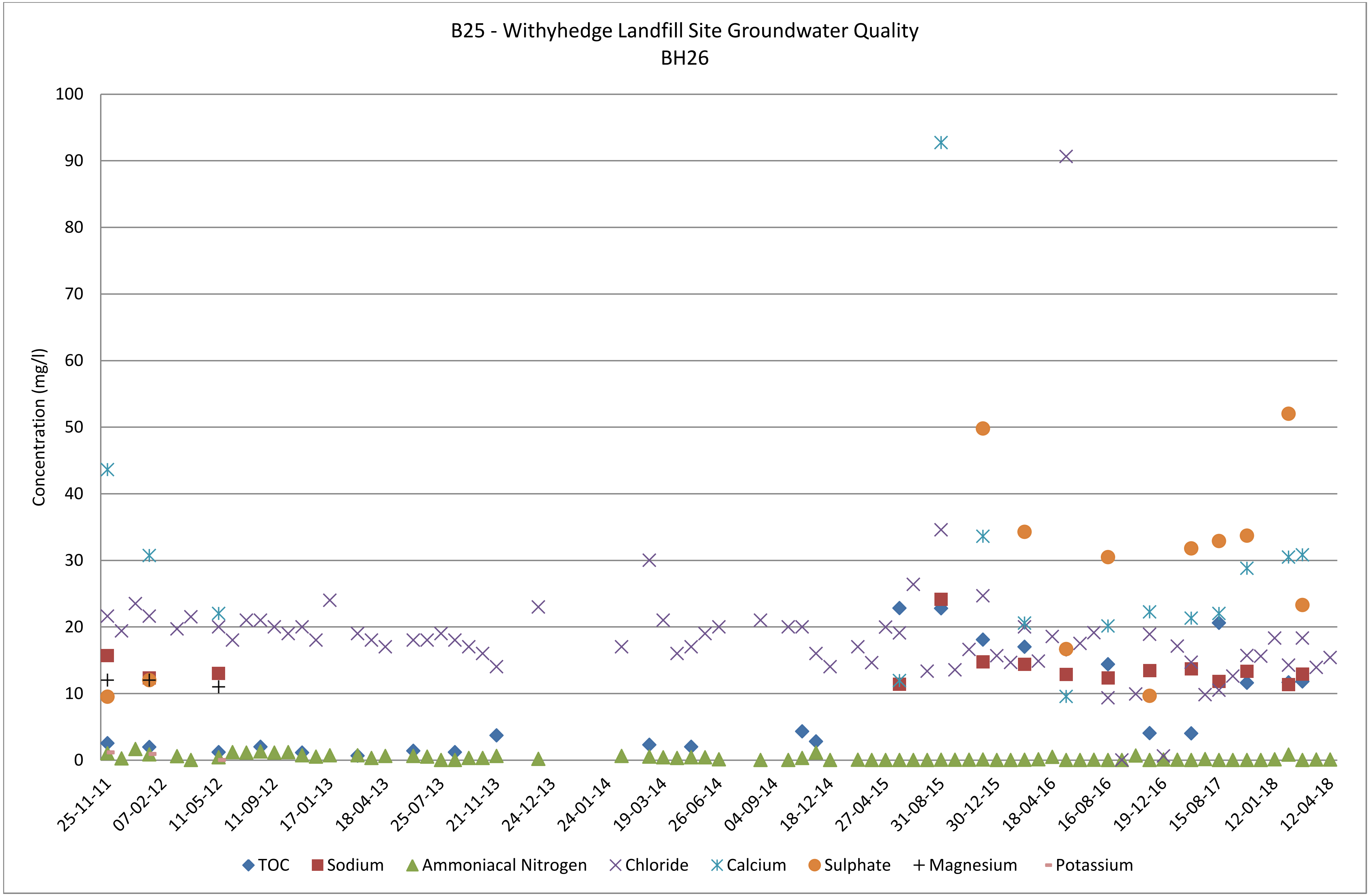

B22 - Withyhedge Landfill Site Groundwater Quality
BH20
Concentration (mg/l)
160
140
120
100
80
60
40
20
0
31-01-08
31-07-08
26-02-09
19-08-09
26-01-10
26-04-10
16-08-10
25-02-11
31-08-11
07-02-12
07-08-12
20-02-13
25-07-13
30-01-14
26-06-14
30-10-14
27-04-15
30-10-15
18-04-16
20-10-16
15-08-17
19-02-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium



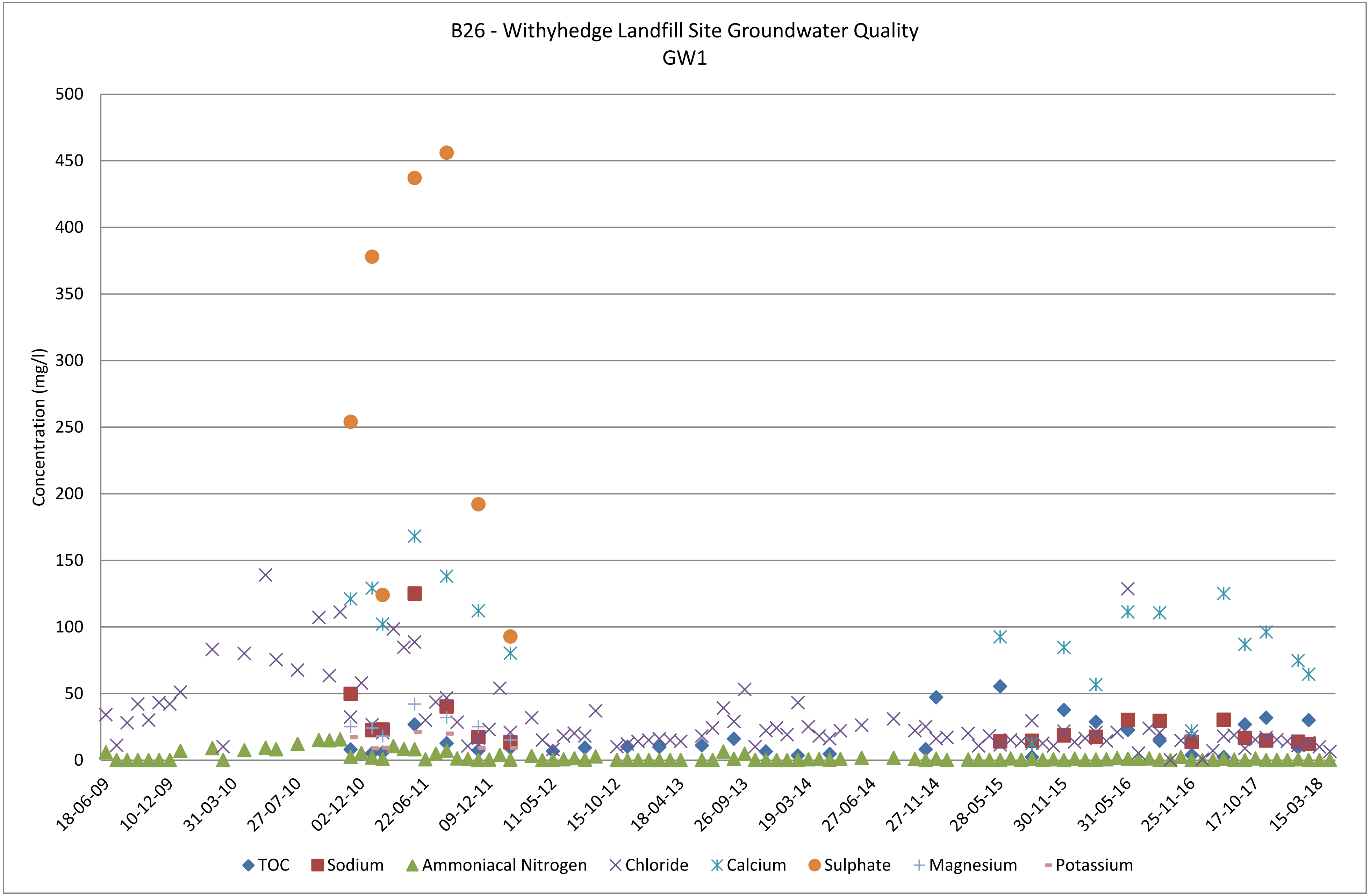
B23 - Withyhedge Landfill Site Groundwater Quality
BH21
Concentration (mg/l)
200
180
160
140
120
100
80
60
40
20
0
31-01-08
23-04-08
31-07-08
22-10-08
26-02-09
28-05-09
19-08-09
24-11-09
26-01-10
30-03-10
26-04-10
24-06-10
16-08-10
16-11-10
25-02-11
26-05-11
31-08-11
25-11-11
11-01-12
07-02-12
11-05-12
07-08-12
22-11-12
20-02-13
16-05-13
25-07-13
27-09-13
04-12-13
24-12-13
15-01-14
13-02-14
28-04-14
26-06-14
01-08-14
30-10-14
29-01-15
27-04-15
31-07-15
30-10-15
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

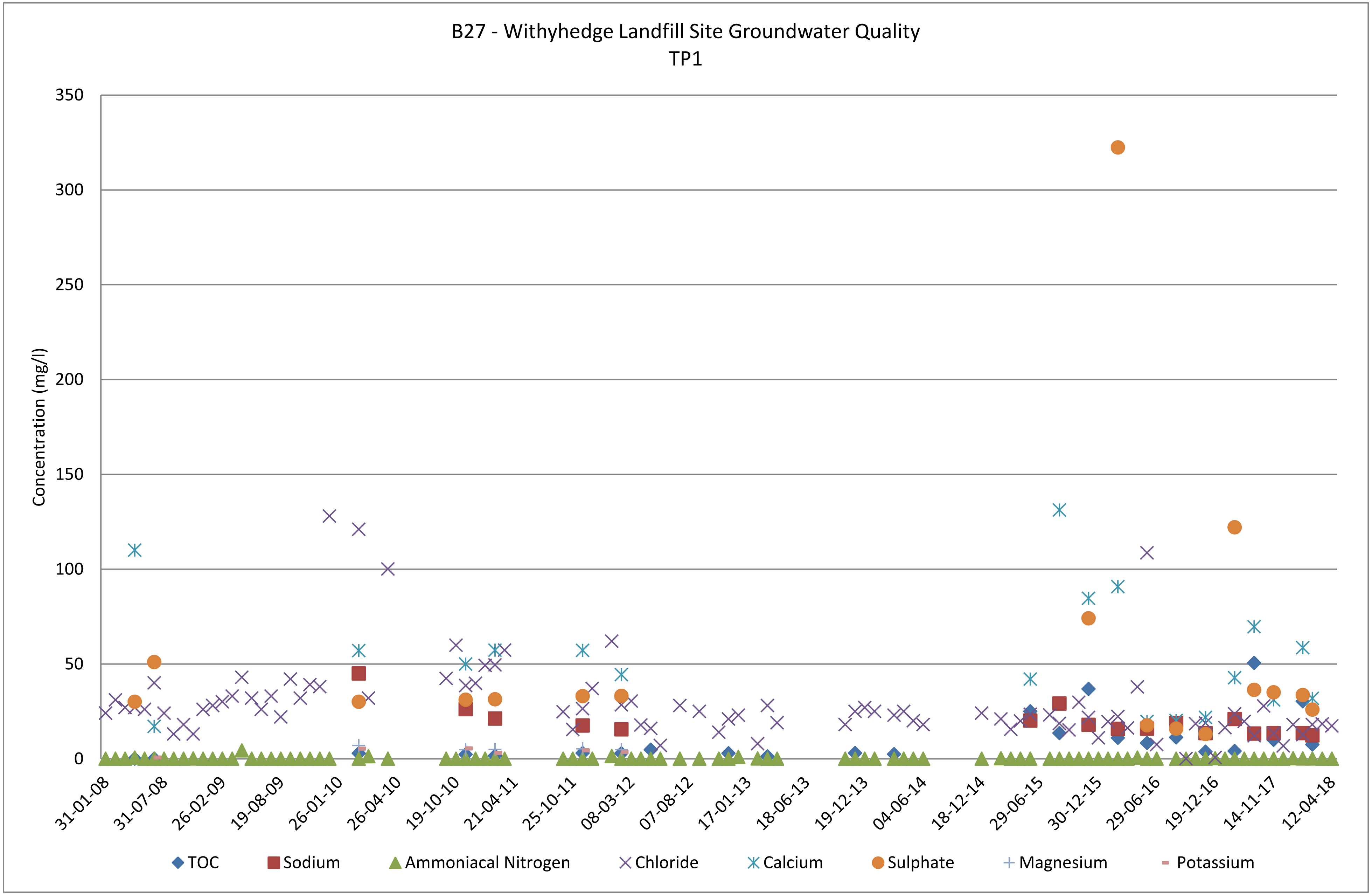


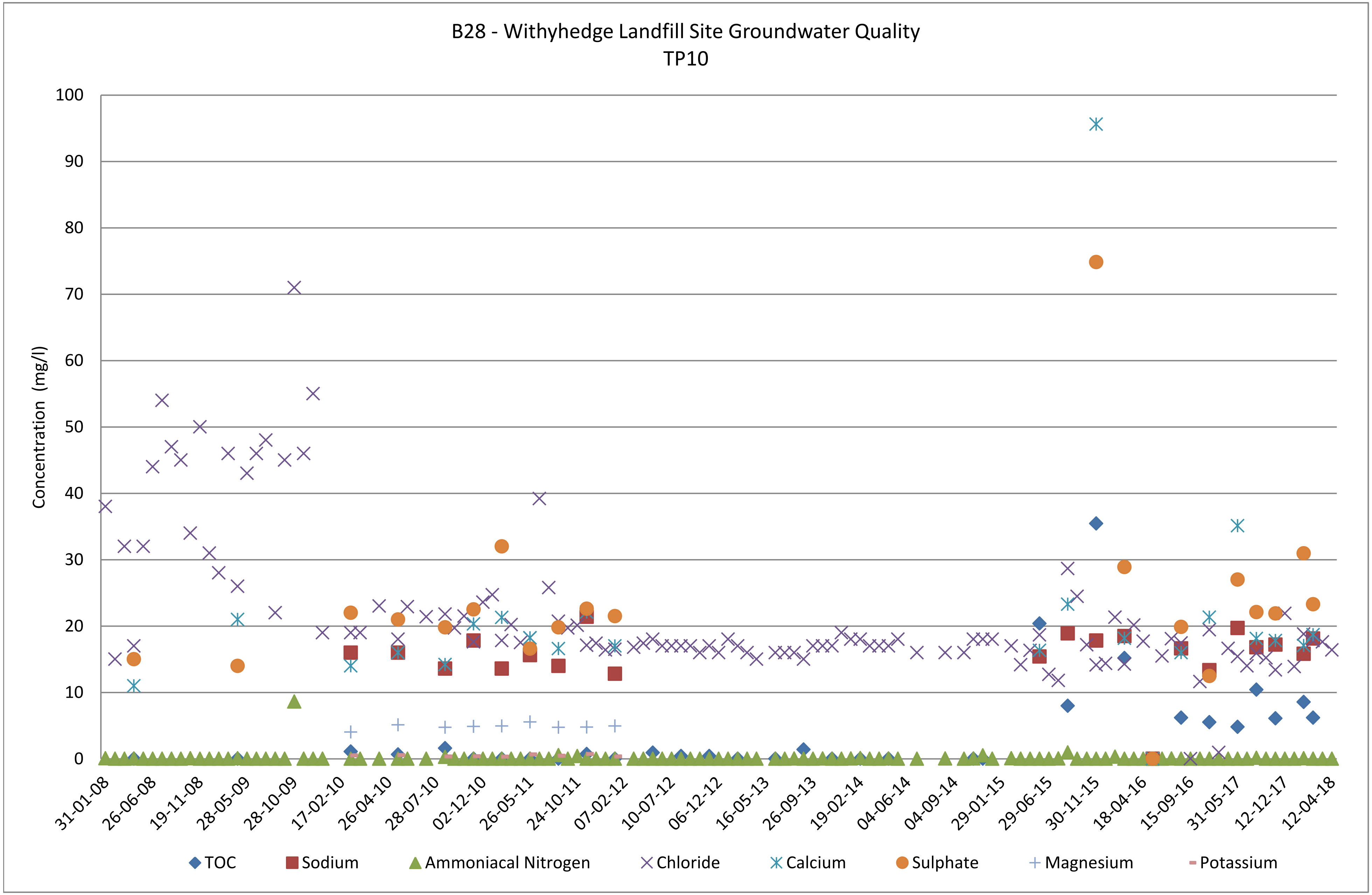
B24 - Withyhedge Landfill Site Groundwater Quality
BH23
Concnetration (mg/l)
250
200
150
100
50
0
31-01-08
29-05-08
24-09-08
26-02-09
18-06-09
28-10-09
10-12-09
04-03-10
26-04-10
27-07-10
19-10-10
25-02-11
22-06-11
24-10-11
07-02-12
14-06-12
15-10-12
20-02-13
17-05-13
26-09-13
30-01-14
03-06-14
31-07-14
30-10-14
30-01-15
28-05-15
30-09-15
29-01-16
31-05-16
15-09-16
09-03-17
17-10-17
13-02-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium



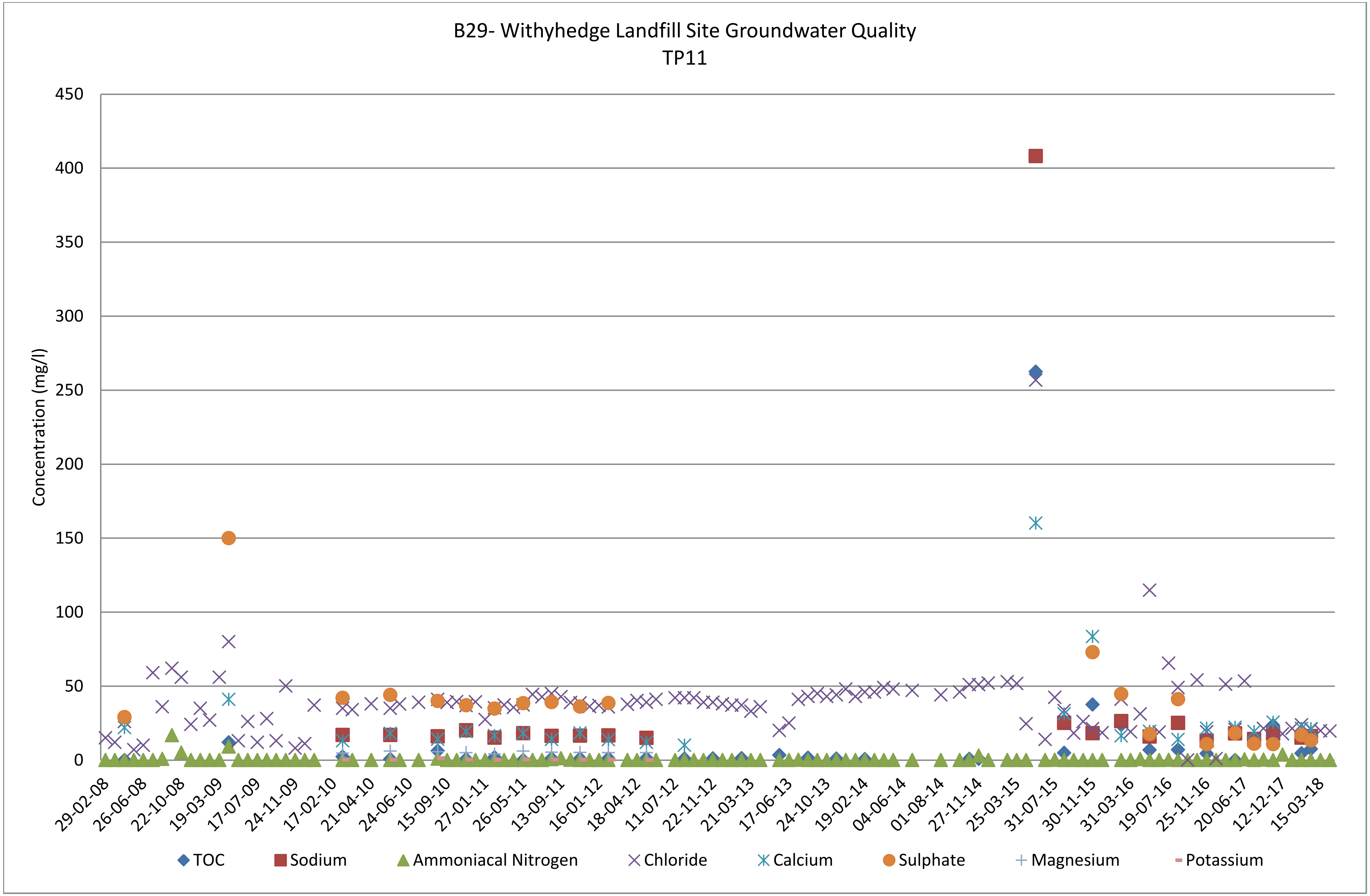
B25 - Withyhedge Landfill Site Groundwater Quality
BH26
Concentration (mg/l)
100
90
80
70
60
50
40
30
20
10
0
25-11-11
07-02-12
11-05-12
11-09-12
17-01-13
18-04-13
25-07-13
21-11-13
24-12-13
24-01-14
19-03-14
26-06-14
04-09-14
18-12-14
27-04-15
31-08-15
30-12-15
18-04-16
16-08-16
19-12-16
15-08-17
12-01-18
12-04-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

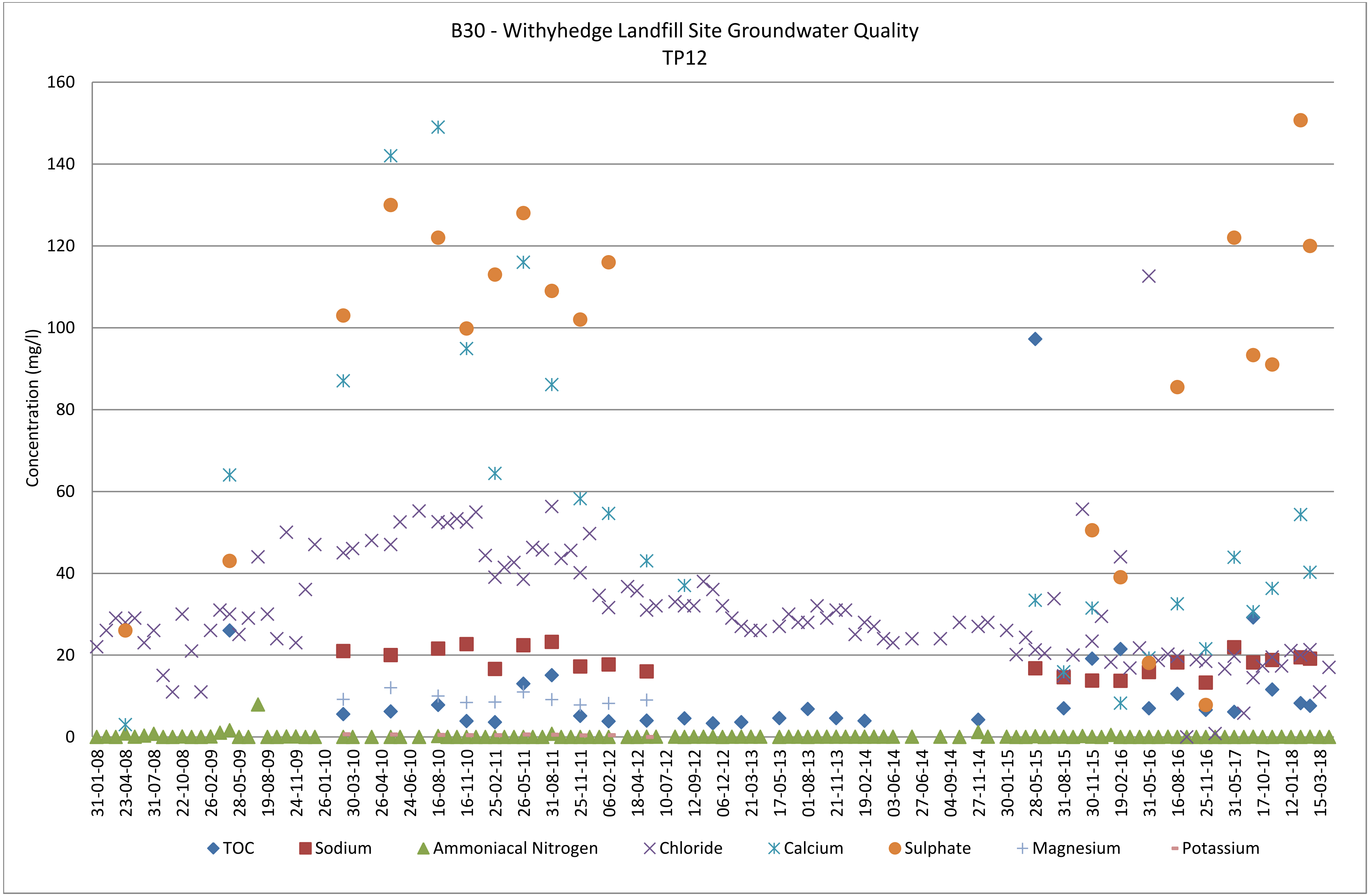

B26 - Withyhedge Landfill Site Groundwater Quality
GW1
Concentration (mg/l)
500
450
400
350
300
250
200
150
100
50
0
18-06-09
10-12-09
31-03-10
27-07-10
02-12-10
22-06-11
09-12-11
11-05-12
15-10-12
18-04-13
26-09-13
19-03-14
27-06-14
27-11-14
28-05-15
30-11-15
31-05-16
25-11-16
17-10-17
15-03-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

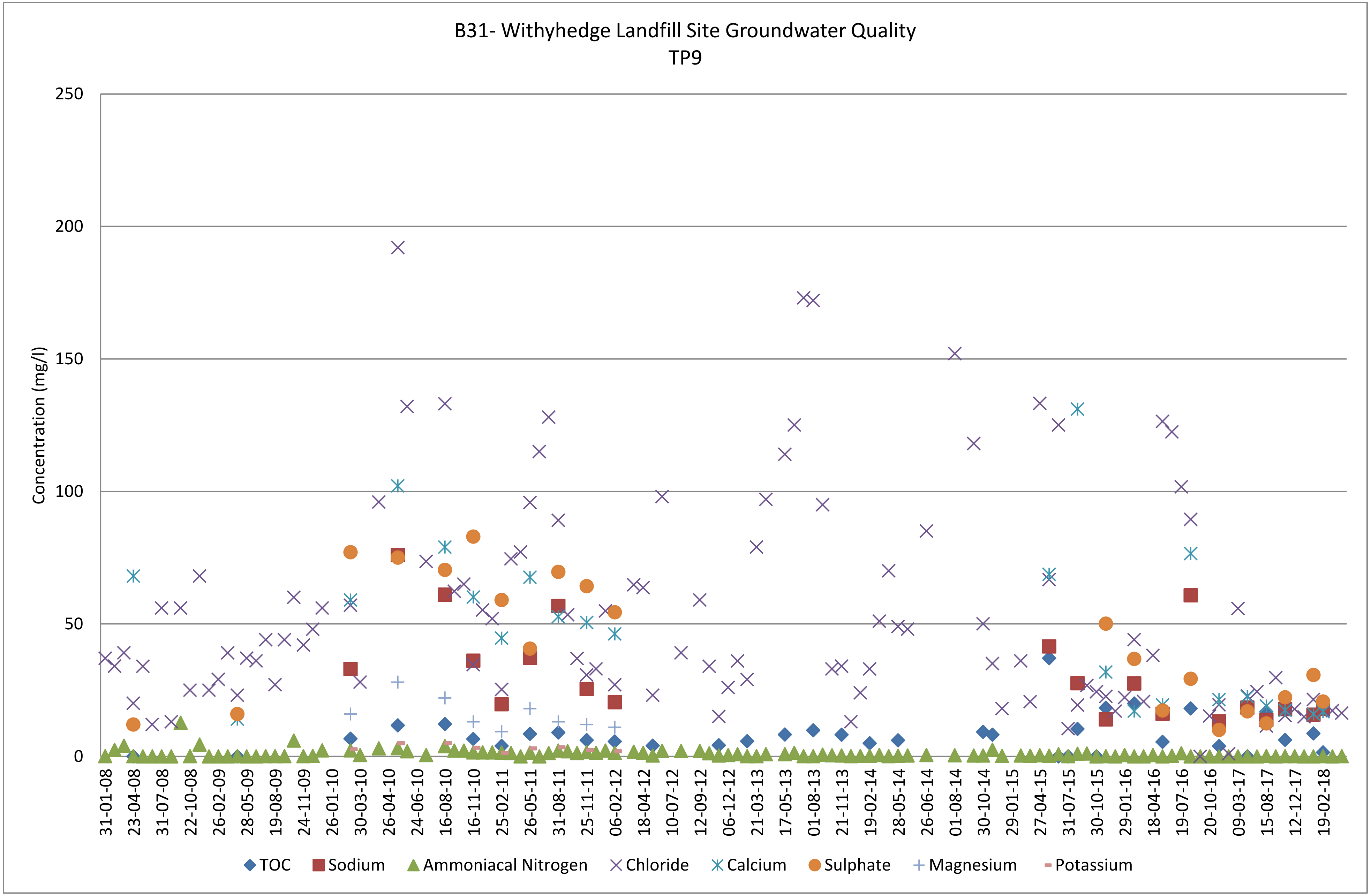

B27 - Withyhedge Landfill Site Groundwater Quality
TP1
Concentration (mg/l)
350
300
250
200
150
100
50
0
31-01-08
31-07-08
26-02-09
19-08-09
26-01-10
26-04-10
19-10-10
21-04-11
25-10-11
08-03-12
07-08-12
17-01-13
18-06-13
19-12-13
04-06-14
18-12-14
29-06-15
30-12-15
29-06-16
19-12-16
14-11-17
12-04-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium



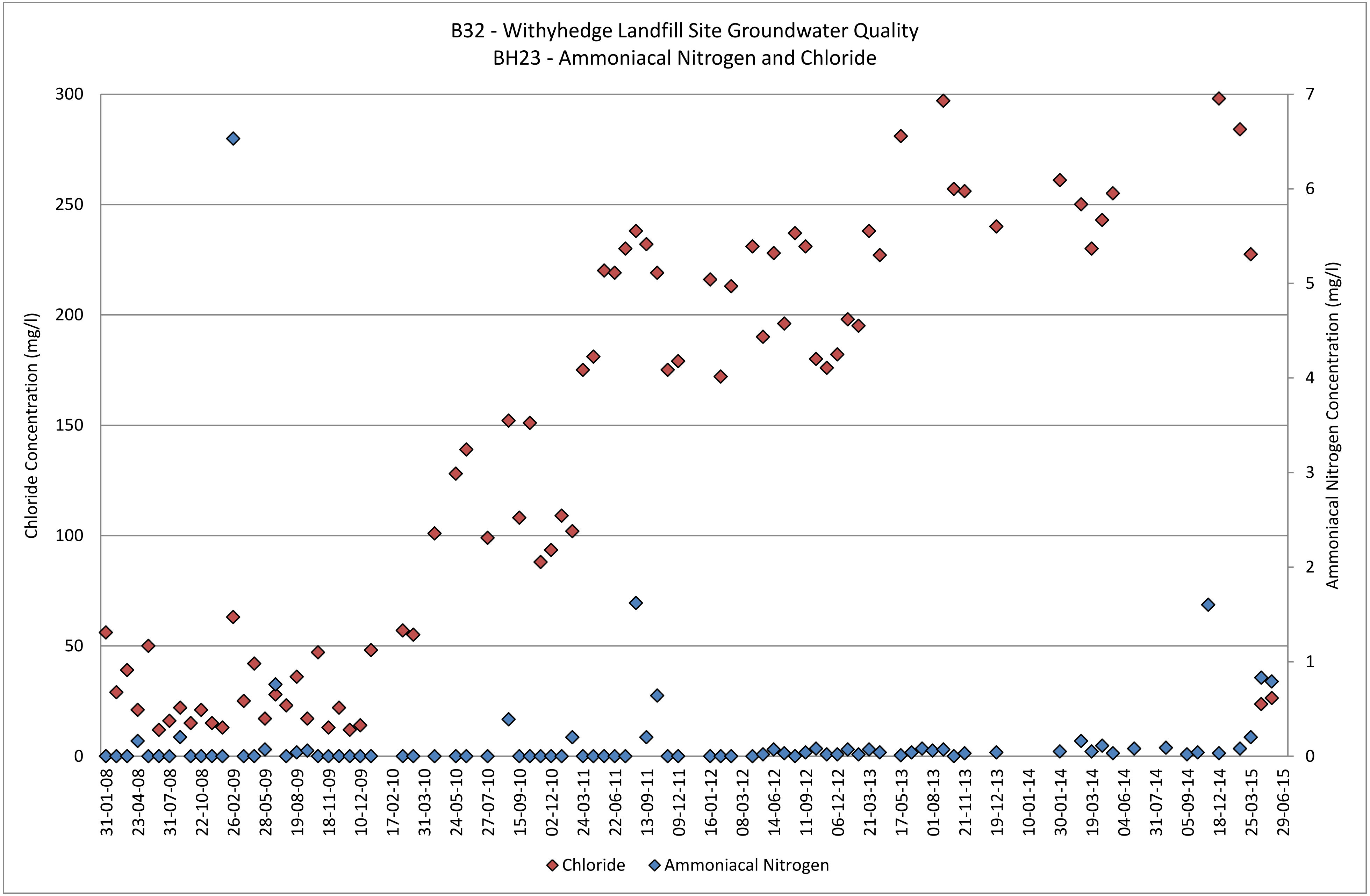
B28 - Withyhedge Landfill Site Groundwater Quality
TP10
Concentration (mg/l)
100
90
80
70
60
50
40
30
20
10
0
31-01-08
26-06-08
19-11-08
28-05-09
28-10-09
17-02-10
26-04-10
28-07-10
02-12-10
26-05-11
24-10-11
07-02-12
10-07-12
06-12-12
16-05-13
26-09-13
19-02-14
04-06-14
04-09-14
29-01-15
29-06-15
30-11-15
18-04-16
15-09-16
31-05-17
12-12-17
12-04-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium


B29- Withyhedge Landfill Site Groundwater Quality
TP11
Concentration (mg/l)
450
400
350
300
250
200
150
100
50
0
29-02-08
26-06-08
22-10-08
19-03-09
17-07-09
24-11-09
17-02-10
21-04-10
24-06-10
15-09-10
27-01-11
26-05-11
13-09-11
16-01-12
18-04-12
11-07-12
22-11-12
21-03-13
17-06-13
24-10-13
19-02-14
04-06-14
01-08-14
27-11-14
25-03-15
31-07-15
30-11-15
31-03-16
19-07-16
25-11-16
20-06-17
12-12-17
15-03-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium


B30 - Withyhedge Landfill Site Groundwater Quality
TP12
Concentration (mg/l)
160
140
120
100
80
60
40
20
0
31-01-08
23-04-08
31-07-08
22-10-08
26-02-09
28-05-09
19-08-09
24-11-09
26-01-10
30-03-10
26-04-10
24-06-10
16-08-10
16-11-10
25-02-11
26-05-11
31-08-11
25-11-11
06-02-12
18-04-12
10-07-12
12-09-12
06-12-12
21-03-13
17-05-13
01-08-13
21-11-13
19-02-14
03-06-14
27-06-14
04-09-14
27-11-14
30-01-15
28-05-15
31-08-15
30-11-15
19-02-16
31-05-16
16-08-16
25-11-16
31-05-17
17-10-17
12-01-18
15-03-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

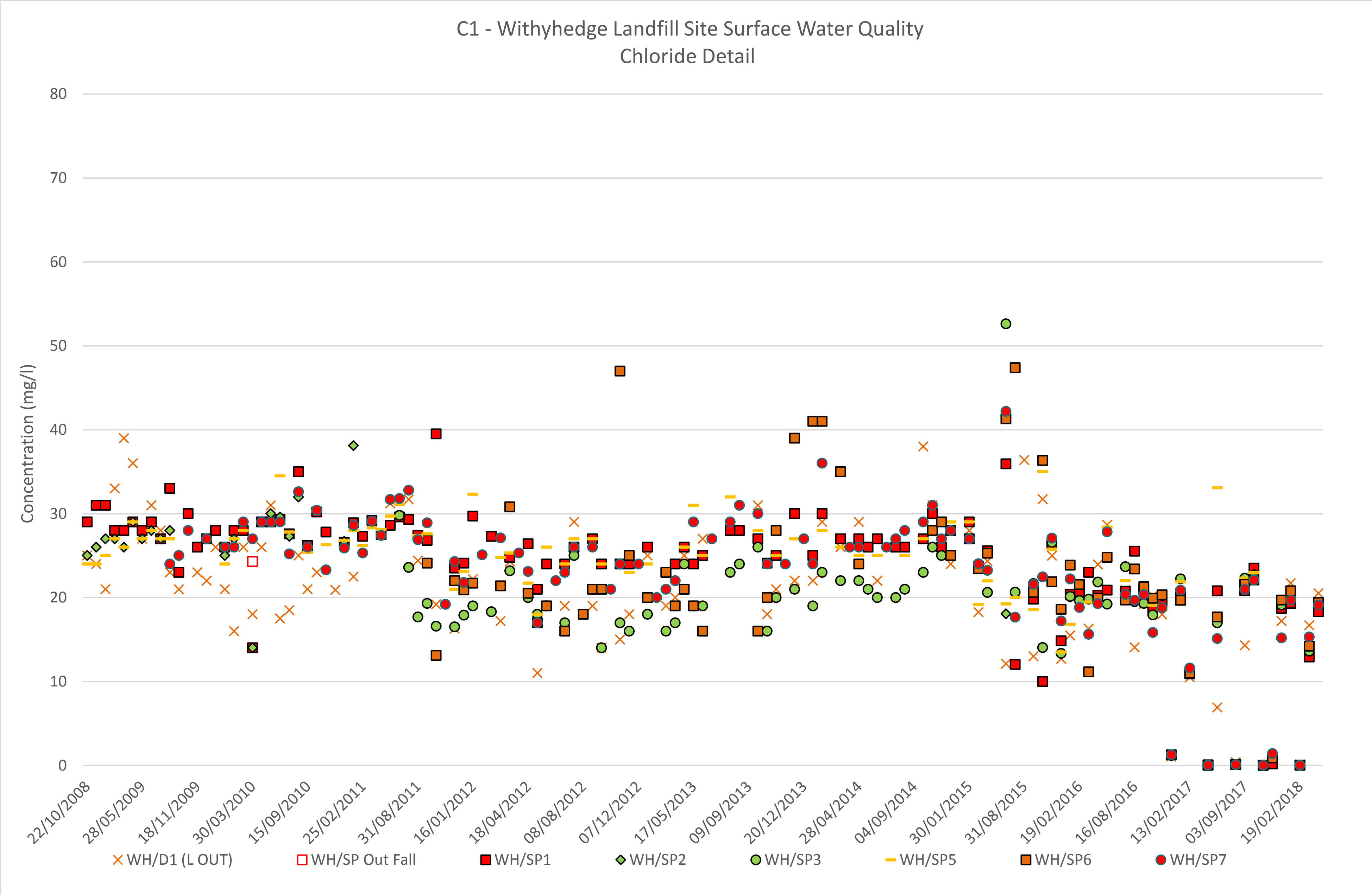


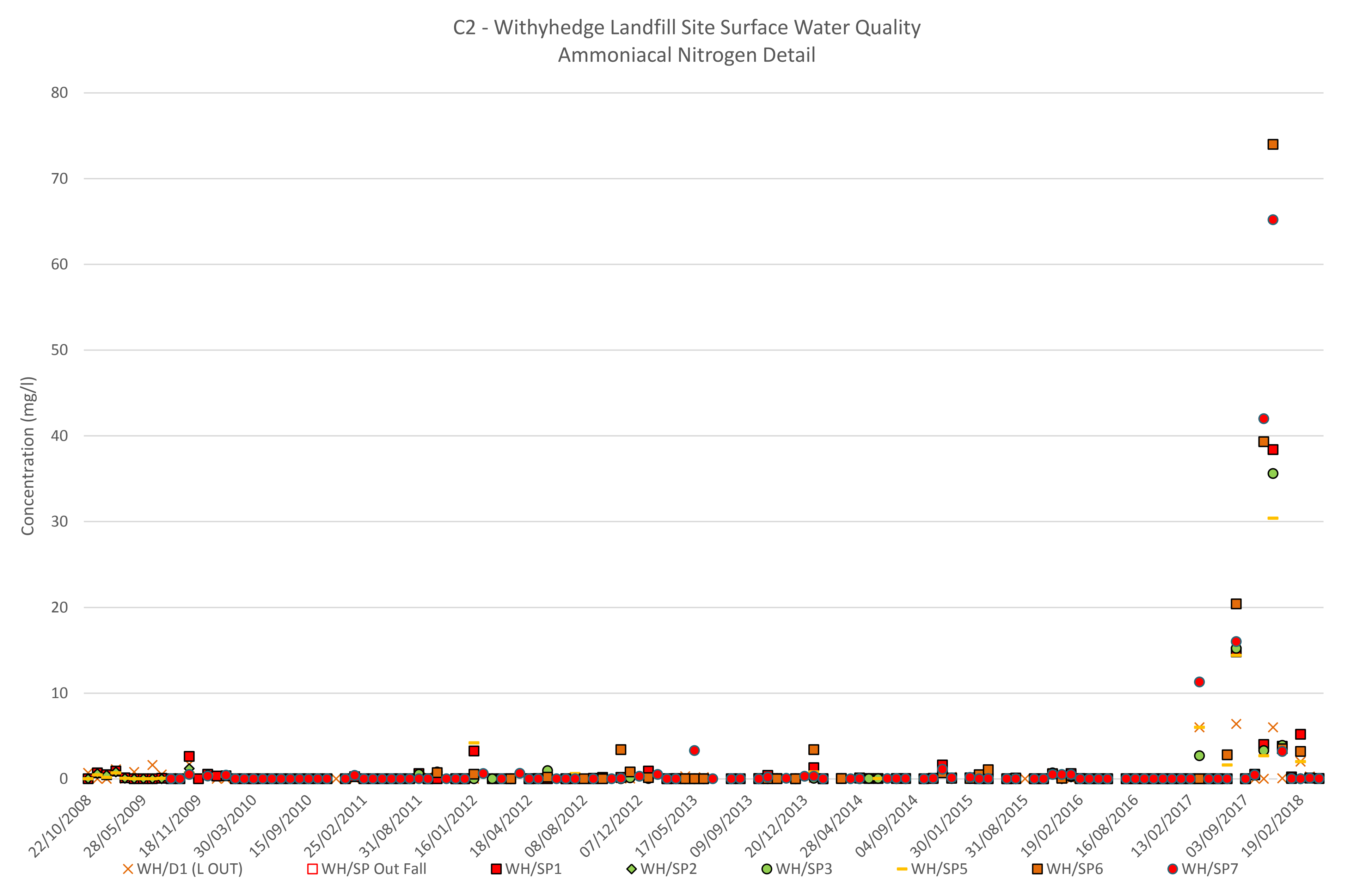
B31- Withyhedge Landfill Site Groundwater Quality
TP9
Concentration (mg/l)
250
200
150
100
50
0
31-01-08
23-04-08
31-07-08
22-10-08
26-02-09
28-05-09
19-08-09
24-11-09
26-01-10
30-03-10
26-04-10
24-06-10
16-08-10
16-11-10
25-02-11
26-05-11
31-08-11
25-11-11
06-02-12
18-04-12
10-07-12
12-09-12
06-12-12
21-03-13
17-05-13
01-08-13
21-11-13
19-02-14
28-05-14
26-06-14
01-08-14
30-10-14
29-01-15
27-04-15
31-07-15
30-10-15
29-01-16
18-04-16
19-07-16
20-10-16
09-03-17
15-08-17
12-12-17
19-02-18
TOC
Sodium
Ammoniacal Nitrogen
Chloride
Calcium
Sulphate
Magnesium
Potassium

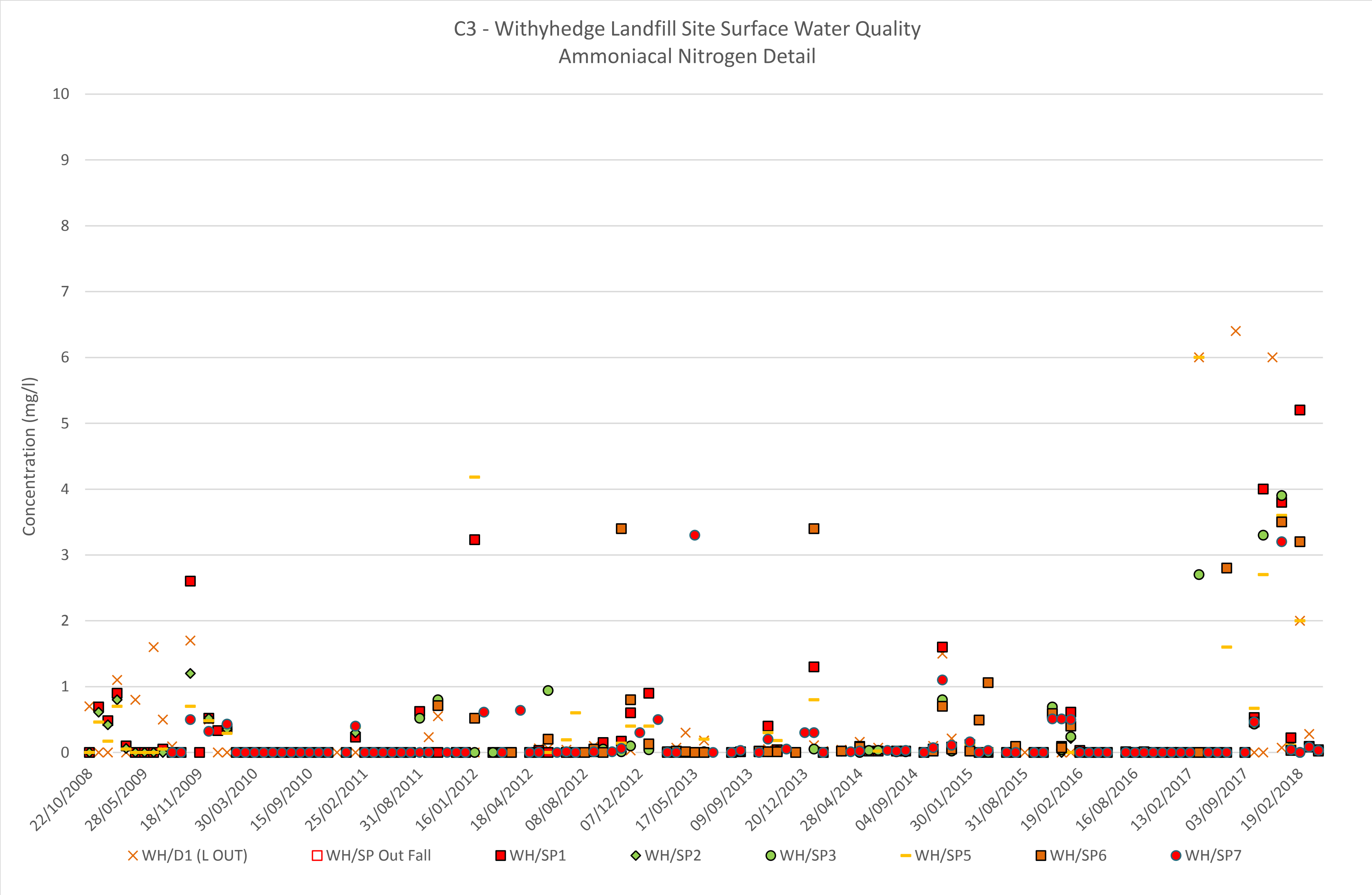

B32 - Withyhedge Landfill Site Groundwater Quality
BH23 - Ammoniacal Nitrogen and Chloride
Chloride Concentration (mg/l)
Ammoniacal Nitrogen Concentration (mg/l)
300
250
200
150
100
50
0
7
6
5
4
3
2
1
0
31-01-08
23-04-08
31-07-08
22-10-08
26-02-09
28-05-09
19-08-09
18-11-09
10-12-09
17-02-10
31-03-10
24-05-10
27-07-10
15-09-10
02-12-10
24-03-11
22-06-11
13-09-11
09-12-11
16-01-12
08-03-12
14-06-12
11-09-12
06-12-12
21-03-13
17-05-13
01-08-13
21-11-13
19-12-13
10-01-14
30-01-14
19-03-14
04-06-14
31-07-14
05-09-14
18-12-14
25-03-15
29-06-15
Chloride
Ammoniacal Nitrogen

Appendix C

Surface Water Quality Data


C1 - Withyhedge Landfill Site Surface Water Quality
Chloride Detail
Concentration (mg/l)
80
70
60
50
40
30
20
10
0
22/10/2008
28/05/2009
18/11/2009
30/03/2010
15/09/2010
25/02/2011
31/08/2011
16/01/2012
18/04/2012
08/08/2012
07/12/2012
17/05/2013
09/09/2013
20/12/2013
28/04/2014
04/09/2014
30/01/2015
31/08/2015
19/02/2016
16/08/2016
13/02/2017
03/09/2017
19/02/2018
WH/D1 (L OUT)
WH/SP Out Fall
WH/SP1
WH/SP2
WH/SP3
WH/SP5
WH/SP6
WH/SP7


C2 - Withyhedge Landfill Site Surface Water Quality
Ammoniacal Nitrogen Detail
Concentration (mg/l)
80
70
60
50
40
30
20
10
0
22/10/2008
28/05/2009
18/11/2009
30/03/2010
15/09/2010
25/02/2011
31/08/2011
16/01/2012
18/04/2012
08/08/2012
07/12/2012
17/05/2013
09/09/2013
20/12/2013
28/04/2014
04/09/2014
30/01/2015
31/08/2015
19/02/2016
16/08/2016
13/02/2017
03/09/2017
19/02/2018
WH/D1 (L OUT)
WH/SP Out Fall
WH/SP1
WH/SP2
WH/SP3
WH/SP5
WH/SP6
WH/SP7

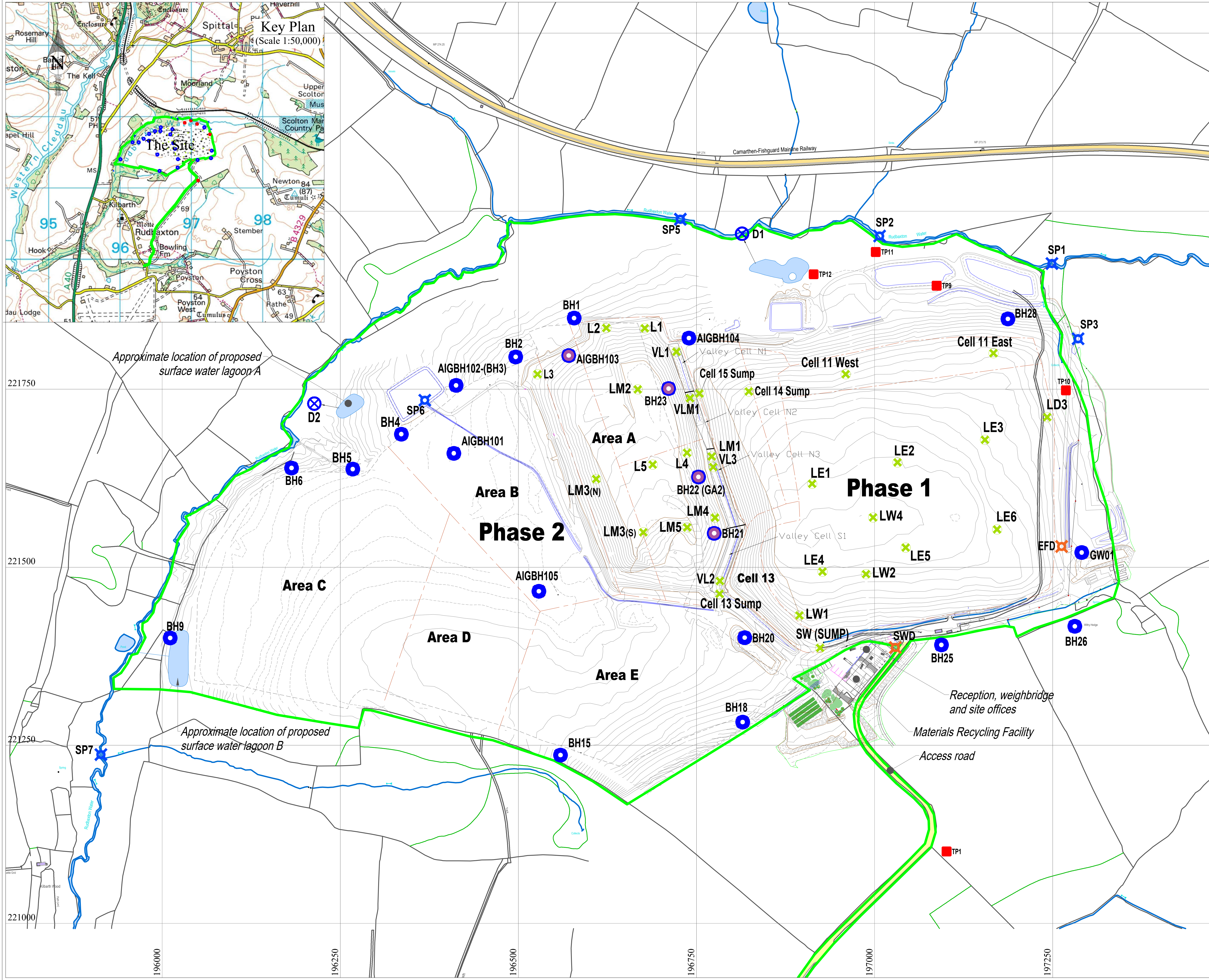


C3 - Withyhedge Landfill Site Surface Water Quality
Ammoniacal Nitrogen Detail
Concentration (mg/l)
10
9
8
7
6
5
4
3
2
1
0
22/10/2008
28/05/2009
18/11/2009
30/03/2010
15/09/2010
25/02/2011
31/08/2011
16/01/2012
18/04/2012
08/08/2012
07/12/2012
17/05/2013
09/09/2013
20/12/2013
28/04/2014
04/09/2014
30/01/2015
31/08/2015
19/02/2016
16/08/2016
13/02/2017
03/09/2017
19/02/2018
WH/D1 (L OUT)
WH/SP Out Fall
WH/SP1
WH/SP2
WH/SP3
WH/SP5
WH/SP6
WH/SP7

Appendix D

LandSim Model and Results File (On CD)

Drawings



Key

- Permit boundary (as original WML boundary)
- Break of slope
- BH Groundwater monitoring point
- BH Historic Groundwater monitoring point
- Leachate extraction/monitoring point
- TP9 Trial pit monitoring point
- D1 Water dischage monitoring point
- SP5 Surface water monitoring point
- SW Discharge from MRF

TerraConsult

Bold Business Centre, Bold Lane, Sutton, St Helens WA9 4TX

Client

RML
Resources Management (UK) Limited

Site

Withyhedge Landfill Site

Title

Site Monitoring Plan

Scale	1:5,000	@ A3
Drawing No.	3933/1/001	

Rev	Date	Description
1	20/08/2018	Addition of LW1, LW2 and SP6
2	11/09/2018	Addition of SWD, EFD, AIGBH103, SP2

File	3933/1/001/R2 Site Monitoring Plan		
Date	09/18	Engineer	PS
Drawn	KMB	Checked	JB