

Caulmert Limited

Engineering, Environmental & Planning
Consultancy Services

Aberthaw Quarry

RWE Generation UK Plc

Hydrogeological Risk Assessment Review 2018

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ABERTHAW ASH DISPOSAL SITE – HYDROGEOLOGICAL RISK ASSESSMENT REVIEW 2017
TABLE OF CONTENTS

1	INTRODUCTION	1
1.1	Background.....	1
2	REVIEW OF THE CONCEPTUAL HYDROGEOLOGICAL MODEL.....	3
2.1	Introduction	3
2.2	Site setting and development	3
2.3	Source.....	4
2.4	Pathway.....	6
2.5	Aquifer Characteristics	7
2.6	Groundwater Levels and Flow Direction-Limestone.....	7
2.7	Groundwater Quality	9
2.8	Summary and Discussion.....	22
3	HYDROGEOLOGICAL RISK ASSESSMENT	24
3.1	The nature of the hydrogeological risk assessment.....	24
3.2	Proposed assessment scenarios.....	24
3.3	Priority contaminants to be modelled	26
3.4	Sensitivity analysis.....	27
3.5	Review of technical precautions	27
4	REQUISITE SURVEILLANCE.....	29
4.1	Leachate monitoring	29
4.2	Groundwater monitoring	29
4.3	Surface Water monitoring.....	30
5	CONCLUSIONS	33

FIGURES

Figure 1	Average Groundwater levels 2012 to 2017
Figure 2	Groundwater levels Feb 2017.
Figure 3	Average (2012 to 2017) Molybdenum concentrations in groundwater
Figure 4	Average (2012 to 2017) Molybdenum concentrations in Groundwater and Surface Water (ug/l)
Figure 5	Distribution of Average Molybdenum (ug/l) Ash Mound
Figure 6	Average (2012-2017) boron concentrations (ug/l) in groundwater
Figure 7	Spatial Distribution of Average Ammoniacal Nitrogen (mg/l) (2012 -2017)
Figure 8	Average (2012-2017) Sulphate concentrations in groundwater
Figure 9	Average (2012-2017) chloride concentrations

DRAWINGS

3220. HRA.01	Site Plan Monitoring Locations
3220.HRA.01 P1	Conceptual Model: Schematic Cross section

APPENDICES

Appendix 1:	Hydrographs
Appendix 2:	Environmental water quality
Appendix 3:	Groundwater calculations
Appendix 4:	Compliance and Control charts

1 INTRODUCTION

1.1 Background

- 1.1.1 Caulmert Limited has been commissioned by RWE Generation plc (the operator) to undertake a review of the existing hydrogeological risk assessment for the Ash Mound, Aberthaw in accordance with the Permit DP3432SW.
- 1.1.2 The original HRA was produced in April 2006 in support of the application for a Permit under the Pollution Prevention and Control Regulations 2000 (PPC). The application was submitted in April 2006. A Schedule 4 Notice was issued in October 2006 with a response by RWE in January 2007. The PPC Permit was issued by the Environment Agency in May 2007.
- 1.1.3 MMI Engineering Ltd, a subsidiary of Geosyntec Consultants Inc produced the most recent HRA Review in July 2012. Therefore, the objective of this review is to assess whether there has been any significant change in conditions at the site, and whether the site remains in compliance with the Environmental Permitting Regulations 2010. The review will also reflect changes in the regulatory environment since the previous review. This primarily relates to the classification of hazardous substances.
- 1.1.4 An initial meeting was held between NRW, RWE and Caulmert prior to the commencement of the project. The scope of the HRA review was discuss and specific items relating to change in legislation were raised by NRW.
- 1.1.5 In lieu of specific NRW guidance, this report utilises the Environment Agency's template for Hydrogeological Risk Assessment Reviews (2009) and adopts the terminology within the Groundwater Daughter Directive and Environmental Permitting Regulations 2014.
- 1.1.6 The following reports have been used for reference purposes:
- NRW, 26/11/2013, EPR Compliance Assessment Report, BP3339BH/0193845
 - NRW, 06/07/2015, EPR Compliance Assessment Report, BP3339BH/0243251
 - NRW, 01/09/2016, EPR Compliance Assessment Report, CAR_NRW0026321
 - RWE Generation, April 2018, 2017 Aberthaw Ash Quarry EP Annual Performance Report;
 - RWE Generation, March 2017, 2016 Aberthaw Ash Quarry EP Annual Performance Report;
 - RWE Generation, March 2016, 2015 EP Aberthaw Ash Quarry Annual Performance Report;
 - RWE Generation, March 2015, 2014 Aberthaw Ash Quarry EP Annual Performance Report;

- RWE Generation, March 2014, 2013 Aberthaw Ash Quarry EP Annual Performance Report;
- MMI, 2012, Aberthaw Quarry Ash Disposal Site, Four Yearly Review of Hydrogeological Risk Assessment (HRA), MMUK11-143
- Groundwater and surface water monitoring data 2012-2018;
- Public domain data sources including:
 - Geological and hydrogeological maps
 - Historic maps online viewing
 - Historic borehole records
 - Aerial imagery online.

2 REVIEW OF THE CONCEPTUAL HYDROGEOLOGICAL MODEL

2.1 Introduction

2.1.1 The conceptual site model (CSM) has been developed and updated during the development history of the site. The most recent hydrogeological risk assessment review undertaken by MMI in 2012.

2.1.2 Summary of the 2012 hydrogeological risk assessment review:

- The review contained a detailed assessment of the quality of the source term, compared and contrasted the different test methods and a revised source term was proposed
- The results of the leach tests were compared and contrasted to the concentrations observed in boreholes screened within the PFA fill.

2.1.3 In agreement with the guidance, only changes and a summary of the conceptual model are presented in the section below.

2.2 Site setting and development

2.2.1 Aberthaw Quarry Ash Disposal Site (AQAD) is located north east of Aberthaw Power Station, Aberthaw, Barry. The site comprising a quarry infill scheme within the Tarmac (formerly Lafarge) limestone quarry. This quarry is approximately 27Ha and 24m deep.

2.2.2 The site has been developed on a phased basis with first disposal of ash occurring in 2008. The construction details are:

Table 1: Construction Phases

Phase	Construction Dates	Filling Period	Capping	Hydro seeding
1	Mar-Oct 2008	Nov 2008-Nov 2010	Dec 2010	Apr 2011
2A West	Jul 2009-Jan2010	Nov 2010-Jul 2014	Aug 2014	Sept 2014
2B East		Oct 2012-July 2013	Aug 2013	Sept 2013
3AEast	Nov 2012- Apr2013	Aug 2013		
3B	Mar –Jul 2014	Apr 2015		

2.2.3 The quarry has been engineered to meet the requirements of the Landfill Directive.

2.2.4 The specified groundwater drainage layer thickness was 500mm thick to the base and 300mm to the batters, comprising the 125mm-20mm stone with a 75mm thick blinding layer of the 50mm-20mm stone. This stone comprises site won limestone, crushed to the appropriate size on site. A geotextile layer separates the groundwater drainage layer from the overlying lining/attenuation layer. The groundwater underdrainage layer discharges into

the perimeter surface water ditch along the south western boundary prior to discharge into the settlement lagoons.

2.2.5 The specification of the lining system for all phases comprised:

Table 2: Lining/ attenuation layer specification

Parameter	Test Method BS 1377:1990	Acceptance Criteria
Permeability	Part 6: Test 6	1.0×10^{-8} m/s to 2.0×10^{-10} m/s
Moisture Content	Part 2: Method 3.2	7% to 11%
Dry Density*	Part 9: Method 2.4	1.90 Mg/m ³ to 2.10 Mg/m ³
Thickness		750 mm

2.2.6 The fall on the base of the phases is designed to direct any infiltrated water towards a central spine drain which also discharges to the surface water ditch along the south western boundary.

2.3 Source

2.3.1 A detailed assessment of the leachate source term was undertaken by MMI in 2012. This suggested that some of the leach tests historically undertaken may have underestimated the source term and a review of results from column tests was undertaken.

2.3.2 The HRA review was consistent with regards to indicator species associated with PFA namely molybdenum and boron. No further detailed assessment of the leachability of the source term has been undertaken as part of this review. It is considered that the PFA constitutes as a monofill waste type that has been subject to a detailed characterisation to date. Compliance testing is undertaken by RWE with a summary of the results collected between 2012 and 2017 presented below. These leachate test (BSEN 10:1) results have been compared to the relevant water standard to demonstrate the relative risk ratio. It is noted that results between the leach tests (mg/kg) are not directly comparable to the assessment criteria.

2.3.3 The order of hierarchy for the criteria is based on hazardous substance reporting criteria in groundwater (UKTAG Jan 2017), followed by the surface water EQS. Where no EQS is available the water supply regulations 2000 or other relevant standard has been adopted for comparison purposes.

Table 3: Summary of Leachate Compliance Test Results v Environmental Water Quality standards

Parameter	WAC Test Results					GW standard	Freshwater EQS		DWS ug/l	WHO ug/l	Risk ratio.
	Units	Min	Mean	Max	No.	ug/l	AA ug/l	MAC ug/l			
Aluminium as Al (Dissolved)	mg/kg	2.4	21.9	75.4	15				200		377
Ammoniacal Nitrogen as N	mg/kg	4.2	83.5	158.1	15				0.5		316200

Antimony as Sb (Dissolved)	mg/kg	0.02	0.163	0.256	15				5		51
Arsenic as As (Dissolved)	mg/kg	0.077	1.907	3.313	15	5	50				663
Barium as Ba (Dissolved)	mg/kg	0.1	2.5	5.9	15						
Boron as B (Dissolved)	mg/kg	0.7	12.8	17.7	15		2000				9
Bromide as Br	mg/kg	0.6	71.5	293.5	15						
Cadmium as Cd (Dissolved)	mg/kg	0.0004	0.002	0.0056	15		0.25	1.5			4
Chromium as Cr (Dissolved)	mg/kg	0.01	0.3	1.03	15	5 (as Cr(VI))	4.7 as Cr III	32 (as Cr III)			206
Copper as Cu (Dissolved)	mg/kg	0.004	0.015	0.028	15		1 (bio)				28
Cyanide (Total) as CN	mg/kg	0.2	0.3	0.5	15		1	5			100
Dissolved Organic Carbon	mg/kg	2.2	22.6	43.3	15		5000	15000			3
Fluoride as F	mg/kg	2.3	23.5	45.1	15				1500		30
Iron as Fe (Dissolved)	mg/kg	0.52	1.03	1.52	15		1000				2
Lead as Pb (Dissolved)	mg/kg	0.013	0.034	0.083	15	5	1.2 (bio)	14			17
Manganese as Mn (Dissolved)	mg/kg	0.006	0.066	0.174	15		123 (bio)				1
Mercury as Hg (Dissolved)	mg/kg	0.0004	0.0057	0.0132	15	0.5		0.07			26
Molybdenum as Mo (Dissolved)	mg/kg	0.7	9.4	17.8	15					70	254
Nickel as Ni (Dissolved)	mg/kg	0.003	0.028	0.062	15		4(bio)	34			2
Nitrate as N	mg/kg	2.3	3.1	4.6	15				50000		0
Selenium as Se (Dissolved)	mg/kg	0.2	2.1	3.5	15				10		350
Sodium as Na (Dissolved)	mg/kg	9	821	2696	15						
Total Dissolved Solids	mg/kg	350	8888	21800	15						
Total Nitrogen as N	mg/kg	5	92.1	166	15						
Total Sulphur as SO4 (Dissolved)	mg/kg	170	3422	4271	15		400000				11
Vanadium as V (Dissolved)	mg/kg	0.4	2.39	3.59	15		60				60
Zinc as Zn (Dissolved)	mg/kg	0.01	0.14	0.57	15		10.9 (bio)				52

Note: (bio) standard for bioavailable concentration, Highlighted where risk ratio >100

2.3.4 The above table shows that the highest risk rating is for ammoniacal nitrogen followed by arsenic, aluminium, selenium, molybdenum and chromium respectively. However, this contradicts the environmental observations where boron and molybdenum concentrations are observed to be above background concentrations in affected locations.

2.3.5 The concentrations for the most recent (Jan 2017) compliance testing are consistent with previous years. The previous source term was determined by MMI as

Extract from HRA Review 2012 by MMI

	Revised Source Term Concentration							
	NH ₄ (mg/l, as N)	B (mg/l)	Mo (mg/l)	As (µg/l)	Cd (µg/l)	Hg (µg/l)	Se (µg/l)	Sulphate (mg/l)
Revised Source Term [Appendix B: Tables 1, 2, 3, 4, and 5)	10 to 20	4 to 10	2 to 4	50 to 100	0.3 to 2	0.3 to 2	100 to 300	600 to 1,600
Declining source	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Background ¹ [Table 7 Appendix F]	0.03	0.28	0.003	7	0.12	0.03	3.5	70
Revised source term exceeds background for: Ammonium; Boron; Mercury; Molybdenum and Arsenic. Background concentrations exceed the revised source terms for: Cadmium; Selenium; Sulphate								

2.3.6 In addition, observations from the environmental monitoring suggest that there is the potential for the quality of the water used to condition the ash to affect the groundwater quality, specifically chloride concentrations. Monitoring of the water source used for the conditioning of the ash does vary with time, however the concentrations of indicator species molybdenum are generally less than those observed in surface water samples.

2.3.7 RWE have confirmed that sea water is used to condition the ash following prolonged dry periods when insufficient runoff is available across the site. The implications are discussed below with respect to the indicator species.

2.4 Pathway

2.4.1 The geology and hydrogeology of the area have been established throughout the development of the site. Two new boreholes were installed during this review period: E15/1 and E15/2 (January 2015). Borehole E15/2 has been dry throughout and is not discussed further. These new boreholes support the understanding of the geological succession around the site summarised as:

Table 4: Summary of Lithology

Lithology	Description
Lower Lias Limestone	Thinly interbedded limestones and calcareous mudstones of Jurassic age, colloquially known as the 'Blue Lias'. The proportion of limestone to mudstone varies throughout the sequence, but limestone is generally more than 50% in that part of the succession (the Porthkerry Member) that immediately underlies the power station and ash disposal sites.

2.4.2 Therefore, in order to interpret the hydrogeological data, it is essential to consider the units that the boreholes are screen within and how this relates to the established pathways at the site. A summary of the boreholes is presented below.

Table 5: Summary of borehole infrastructure

	BH Drilled Depth (mbgl)	BH Plumbed Depth (mbgl Jun-14)	Response Zone Interval (mbgl)	Screened Geology
E09/01A	25.00	25.27	18-24	Limestone and shale bands
E09/01B	31.00	31.27	24-30	Limestone
E09/02A	28.00	28.55	21-27	Limestone and shale bands
E09/02B	34.00	34.70	27-33	Limestone and shale bands
E15/1	30.00	30.19	17-29	Limestone
E15/2	7.00	Dry	1-7	Made Ground
E05/03	15.00	15.24	3-15	Limestone and shale bands
E05/04	20.00	19.55	2.5-20	Limestone and shale bands
E06/01	15.00	15.14	3-15	Limestone and shale bands
E06/02	10.00	10.55	2-10	Limestone and shale bands
E06/03	10.00	9.49	2-10	Limestone and shale bands
E06/04	10.00	9.85	2-10	Limestone and shale bands
E06/05	8.00	8.14	2-8	Limestone and shale bands

2.5 Aquifer Characteristics

2.5.1 The aquifer comprises Lower Lias Porthkerry Formation limestones and mudstones. The Porthkerry Formation is a Secondary Aquifer of local importance. Groundwater flow is likely to be predominantly through fractures in the limestone and mudstones. Entec 2005 reported on-site measurements of hydraulic conductivity of the Porthkerry Formation in the range 2×10^{-8} to 7×10^{-6} m/s, with a logarithmic mean of 1.5×10^{-7} m/s. Therefore, the Porthkerry Formation has relatively low hydraulic conductivity.

2.6 Groundwater Levels and Flow Direction-Limestone

2.6.1 The groundwater levels in the boreholes screened in the limestone display relatively consistent patterns within the groundwater.

2.6.2 The groundwater contour plot below presents the average groundwater levels across all boreholes at the site. This plot clearly shows the effect of the quarry on the regional groundwater levels with groundwater flow being inwards to the quarry. The westerly component of flow correlates to the presence of the tidal creek beneath the ash mound to which groundwater historically would have been expected to discharge to.

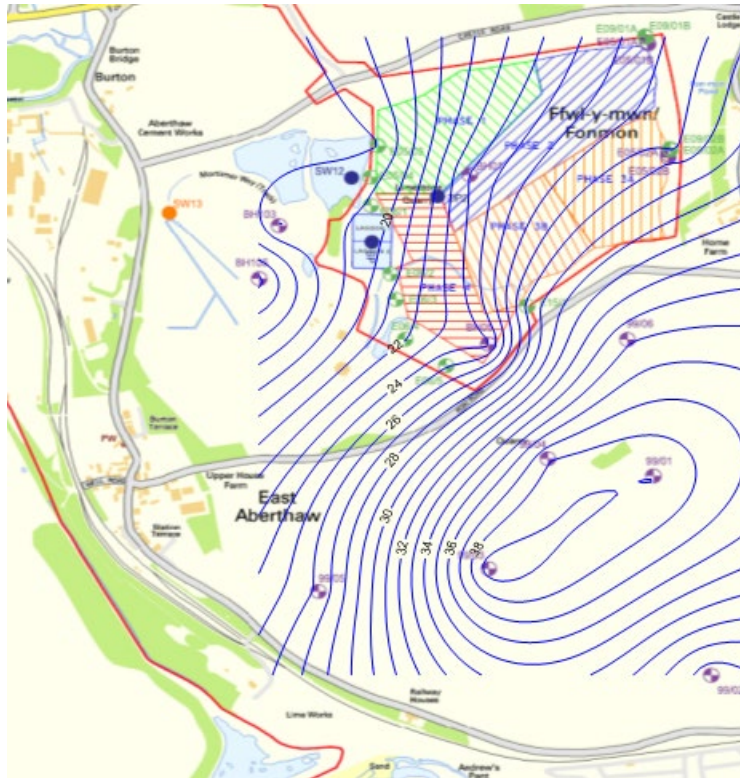


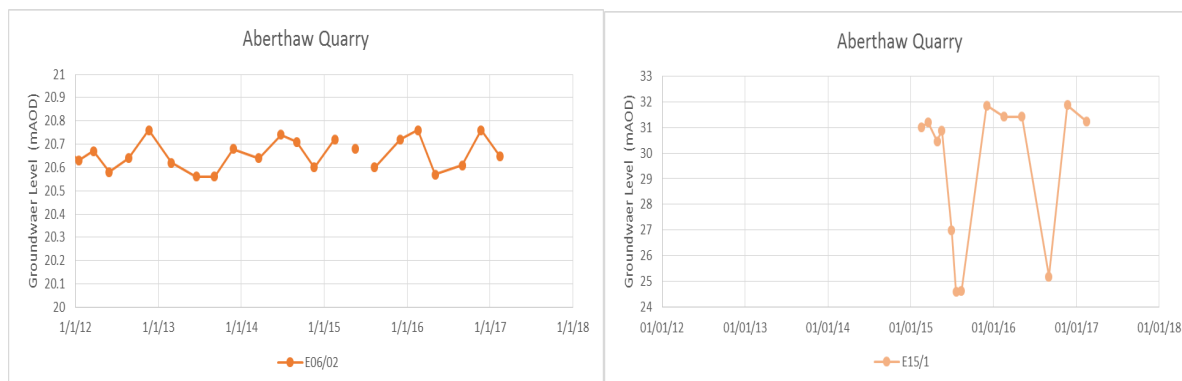
Figure 1: Average groundwater levels (2012 to 2017)

2.6.3 The current groundwater contour plot (Figure 2 below) presents groundwater levels for February 2017 and indicates that the groundwater flow remains towards the quarry and is consistent with the long term trend. This is in agreement with the HRA Review undertaken in 2012 and is considered to indicate long term stable groundwater flow.



Figure 2: Groundwater levels Feb 2017

- 2.6.4 The hydrographs are presented in Appendix 1 with selected graphs displayed below. The groundwater levels and season fluctuation vary across the site with the relatively stable levels being observed in E06/02 and significant variations observed in E15/1 (note the variation in scale).



- 2.6.5 The water levels in E06/02 are considered to reflect the effect of quarry dewatering on the groundwater resulting in more stable levels within the base of the site. Conversely the groundwater levels are more likely to reflect recharge events and potentially flow at different horizons within the limestone. It is noted that this borehole is close to a spring line within the quarry wall prior to engineering works. This is considered to confirm the potential for perching and flow at variable levels.

2.7 Groundwater Quality

- 2.7.1 During the review period, the legislation regarding the classification of hazardous substances in groundwater has changed. In January 2018 JAGDAG published a list of confirmed hazardous substances¹. Within this list Cadmium is defined as non-hazardous, nickel (as Nickel 2) has been revised down from an interim hazardous substance and remains classified non-hazardous. Chromium VI, arsenic, lead and mercury are all defined as hazardous substances.
- 2.7.2 It is noted that lead is not required to be monitored at the site and that chromium is monitored as total dissolved Cr which prevents its direct comparison against the relevant screening criteria. It is recommended that chromium is monitored as Cr (III) and Cr(VI) within future monitoring rounds.

Selection of Assessment Criteria

- 2.7.3 The 2012 hydrogeological review assessed the monitoring results against the UK Drinking water standards. It is more appropriate to assess the groundwater data against the EQS for groundwater and surface water respectively. A summary the existing compliance and control levels is presented in the table below together with the background water quality from the up-gradient monitoring boreholes.

¹ JAGDAG, January 2018, 2018 01 31 Confirmed hazardous substance list.pdf as published on <https://www.wfduk.org/resources/groundwater-hazardous-substances-standards>

Table 6: Environmental Acceptable Limits

Parameter	Units	Reference Values					Control Levels		Compliance Limits	
		EAL (Freshwater)			Site Baseline					
		GW								
		AA	MAC	Source	95%	MAX				
Hazardous Substances:								Applies to:		Applies to:
Mercury	µg/l	-	0.07	EQS	0.01	all	0.03	E05/03	0.03	E05/03
Arsenic*	µg/l	5	-	GW	2.75	E09/2A	10	E05/04 E06/01 E06/02 E06/03 E06/04	10	E05/04 E06/01 E06/02 E06/03 E06/04
Chromium (VI)	µg/l	4.7	32	EQS	2.2 (as Cr total)	E09/01A	TBC	E06/05	N/A	E06/05
Non-Hazardous Substances:								Applies to:		Applies to:
Aluminium	µg/l	200		DWS	13	E09/02B	33	E05/03	50	E05/03
Ammoniacal-Nitrogen	mg/l	(unionised EQS 21 µg/l)			2.5	E09/2A	1.4	E05/04 E06/01 E06/02	1.6	E05/04 E06/01 E06/02
Cadmium	µg/l	0.25	1.5	EQS	0.1	E09/2A	0.4	E06/03	1.5	E06/03
Boron	mg/l	2		EQS	205	E09/02B	2500	E06/04 E06/05	2800	E06/04 E06
Molybdenum	µg/l	70		WHO	3.5	E09/2A	35		50	
Sulphate	mg/l	-	-	DWS	122	E09/02B	330		400	
Vanadium	µg/l	100		EQS	2	E09/2A	12		20	
GW- UKTAG definition of hazardous substances in groundwater January 2018										
EQS - Freshwater water criteria										

Groundwater Quality – Trends and Spatial Analysis

2.7.4 Groundwater quality has been monitored at the site for a significant amount of time. Areas of the site have been seeded and vegetation has become established, however other areas of the site are actively managed with respect to the placement and movement of ash. The quarry activities are considered as part of the discussion on groundwater quality below.

2.7.5 The timeseries data is presented in Appendix 2. There are known increasing trends with respect to molybdenum in both groundwater and surface water. The source is PFA, however the mechanism by which it is affecting the groundwater is complex. Each of the PFA indicator species is discussed below.

Hazardous Substances:

2.7.6 **Mercury:** Mercury is almost entirely consistently recorded below the limit of detection in all boreholes through the review period. The uncertainty within the early data from 2012 has been documented and within this period (March 2012) a number of locations had recorded concentrations of mercury including up gradient boreholes. This data is not considered to be representative of true groundwater concentrations.

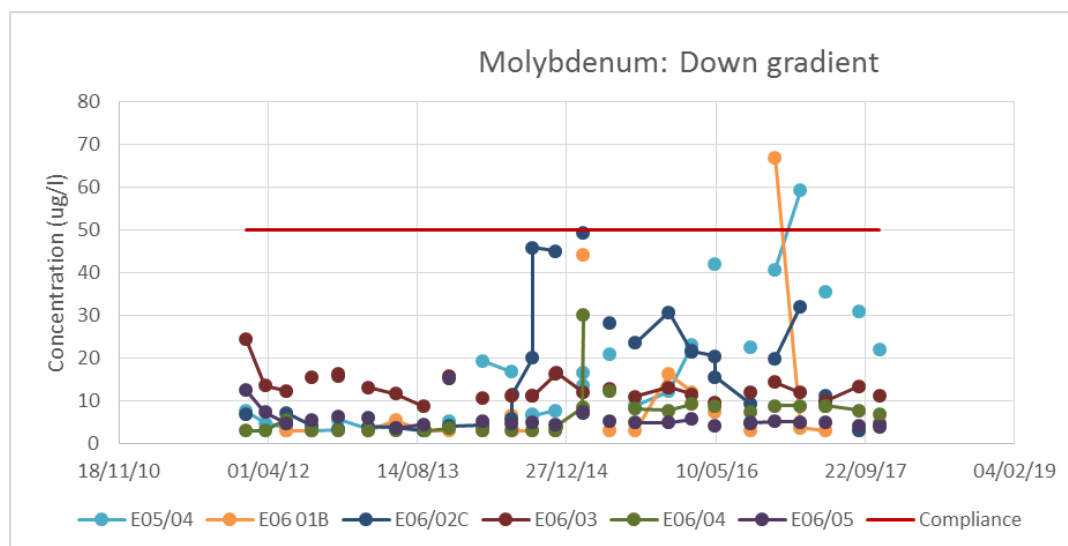
2.7.7 **Arsenic:** Concentrations within upgradient boreholes are predominantly below the detection limits, however where detected, the concentrations are close to the detection

limit, ie. 2 ug/l with a detection limit of 1ug/l. The concentrations in down gradient boreholes are more variable with borehole E05/04 recording concentrations above the detection limit on almost all occasions. These concentrations again were around the detection limit with a maximum value of 2.54 ug/l compared to the compliance limit of 10ug/l. These concentrations are also significantly below the groundwater hazardous substance value of 5 ug/l and are therefore not considered to be of concern.

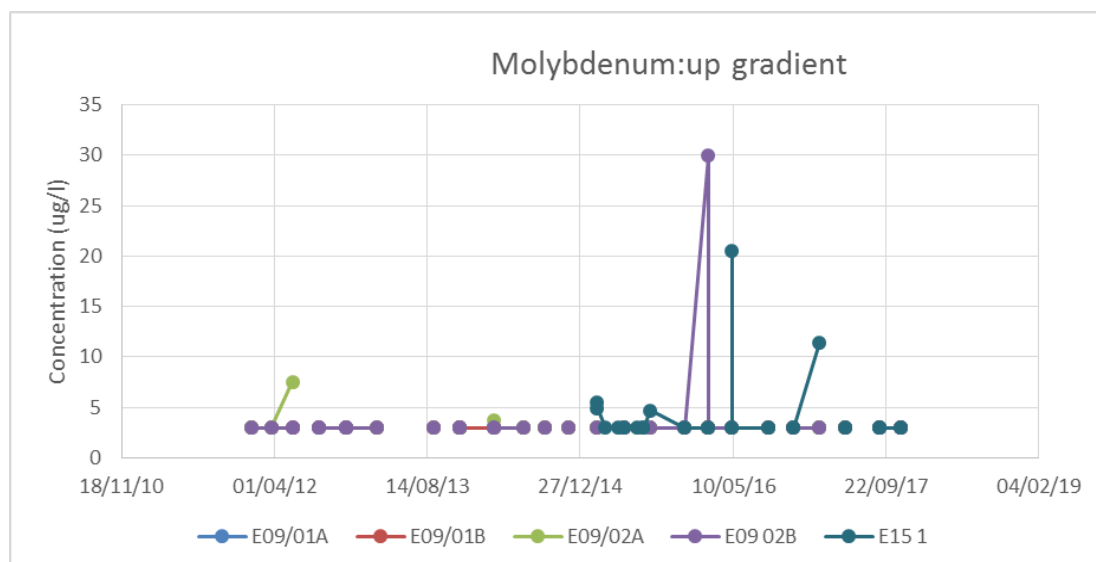
- 2.7.8 **Chromium VI:** As indicated above, only total chromium is currently monitored and therefore no assessment can be made at this stage.

Non hazardous substances

- 2.7.9 **Molybdenum** is widely regarded as the key indicator species for the leachate derived from PFA. There is no prescribed environmental water quality standard for groundwater or surface water as documented under the surface water pollution risk assessment guidance. There are no specific UK quality standards for this parameter and only a World Health Organisation (2004) value is available. This suggests a water quality standard of 70ug/l however the compliance limits have previously been set at 50ug/l for downgradient boreholes. This is assumed to reflect that the background molybdenum concentrations are below the 50 ug/l assessment criteria.
- 2.7.10 All boreholes have been compliant throughout the review period with the exception of a single results for both boreholes E06/01B and E05/04. The chart below indicates that there are no discernible trends other than a tentatively identified increase in E05/04.



- 2.7.11 The up gradient groundwater quality contains lower concentrations of molybdenum with typical values less than 5 ug/l. This is consistent with the 2012 HRA review and suggest no change in upgradient quality.



2.7.12 Notwithstanding the data being generally compliant with the environmental permit requirements, it is recognised that there is a difference between the up gradient and down gradient boreholes with respect to this parameter. The contour plot presented below indicates the spatial distribution of the average molybdenum concentrations in groundwater. This indicates that the highest average concentrations are observed in the downgradient monitoring wells suggesting a groundwater flow pathway.

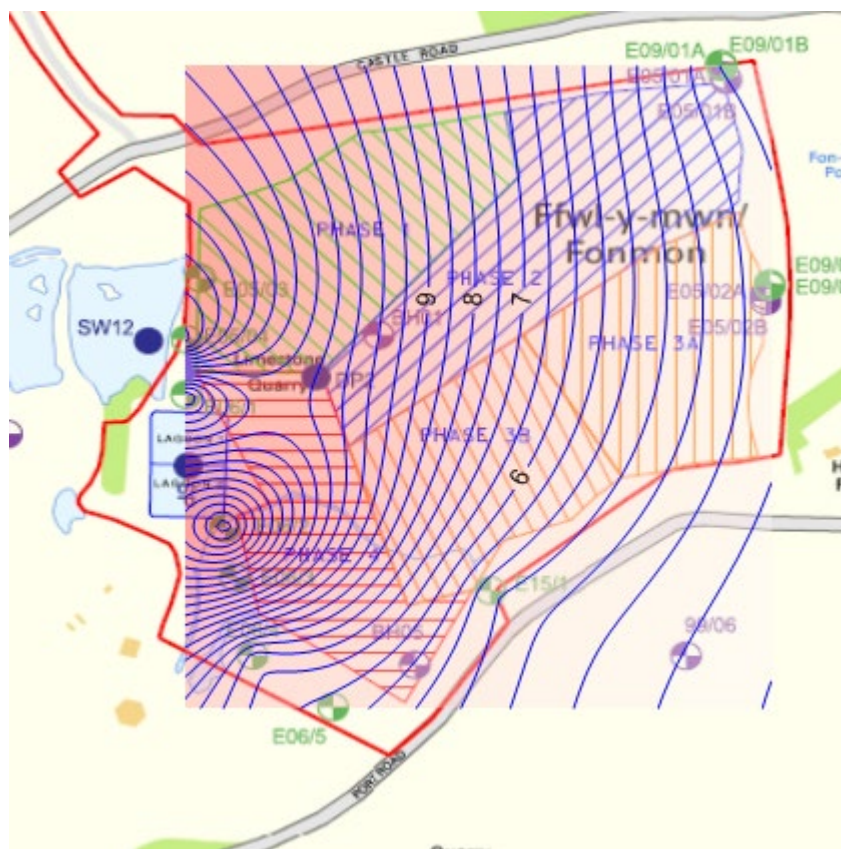


Figure 3: Average (2012 to 2017) Molybdenum concentrations in groundwater

2.7.13 However, when the surface water concentrations are considered in tandem, the mechanisms of this effect become more complex. The concentrations in the surface water

are significantly greater (by an order of magnitude), implying contaminant transport via a surface water mechanism as opposed to groundwater.

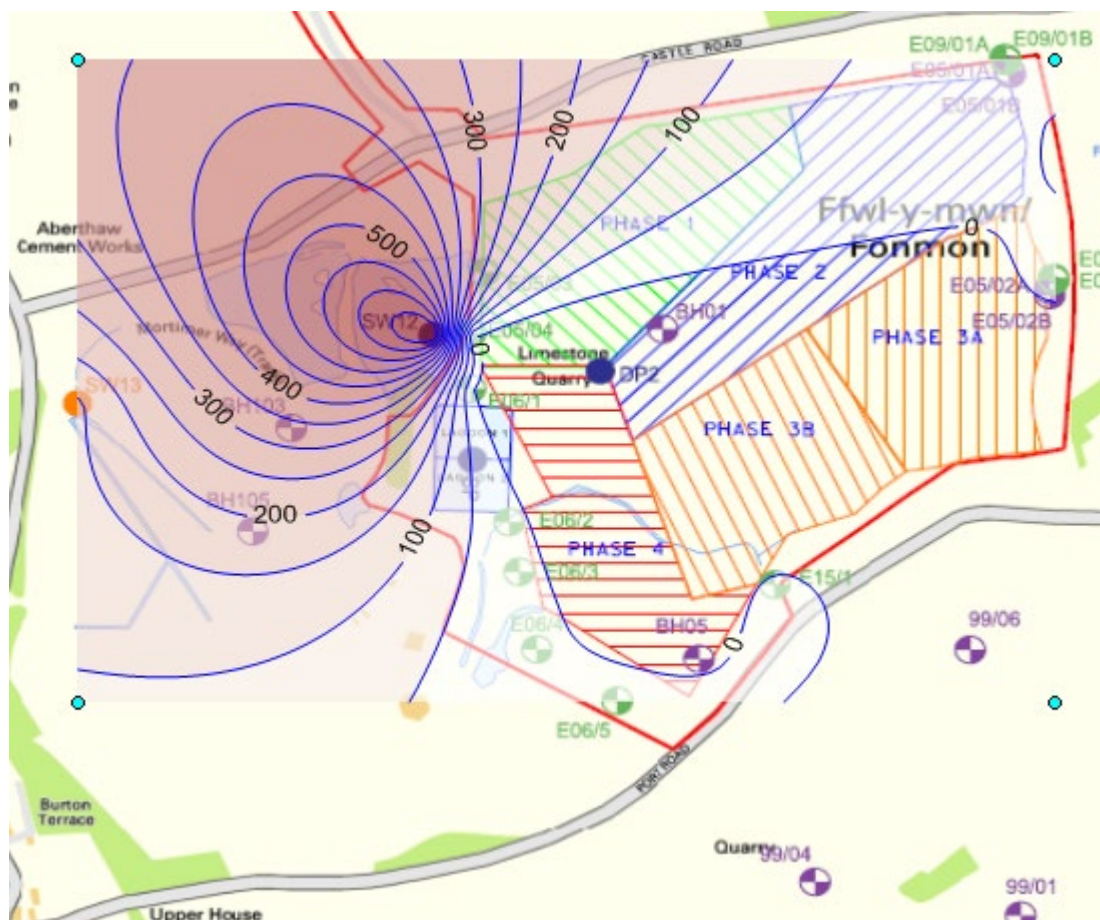
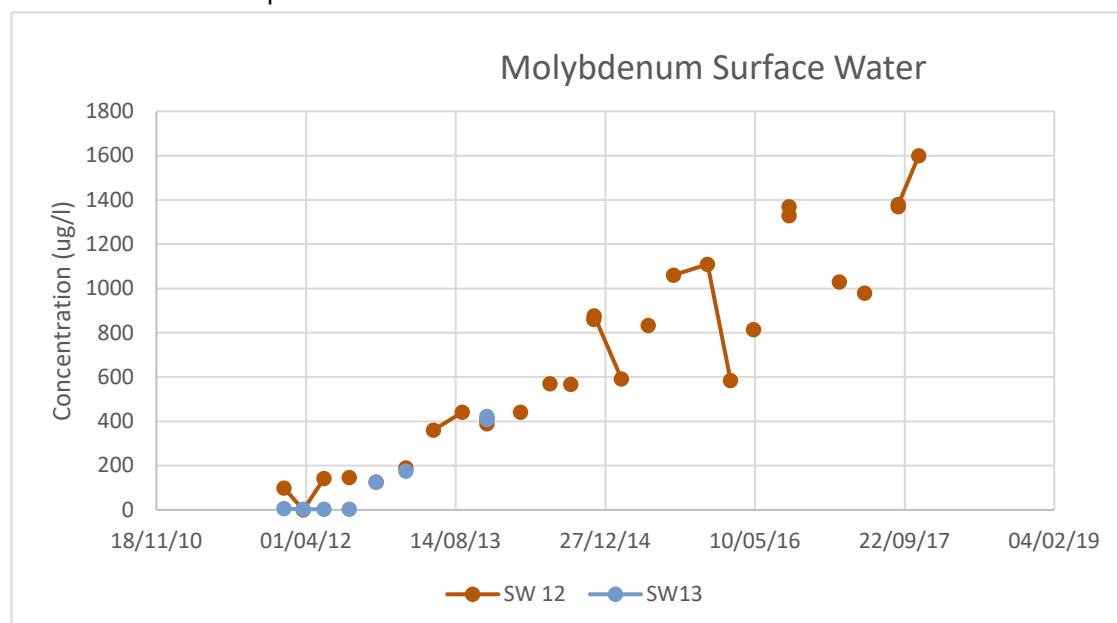


Figure 4: Average (2012 to 2017) Molybdenum concentrations in Groundwater and Surface Water

2.7.14 The concentration of Molybdenum continues to rise within the surface environment. The rate of increase implies that concentrations will continue to increase in this area.



- 2.7.15 It is noted that the concentrations observed in SW12 are not dissimilar to the concentrations observed in the surface water around the neighbouring PFA Ash mound where concentrations are greater than 2400 ug/l.

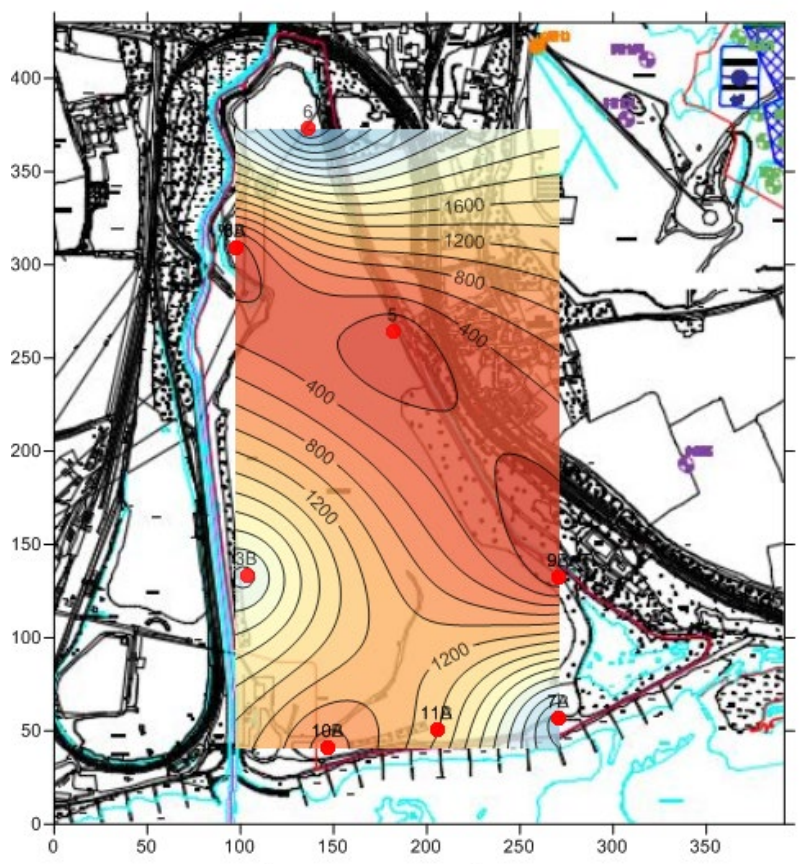
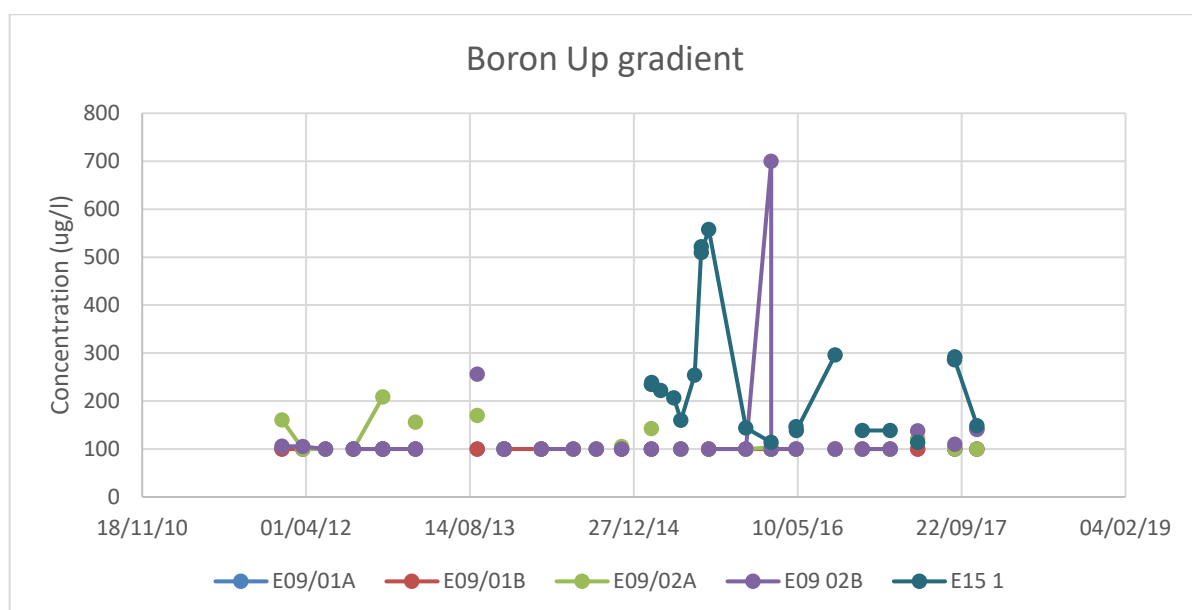
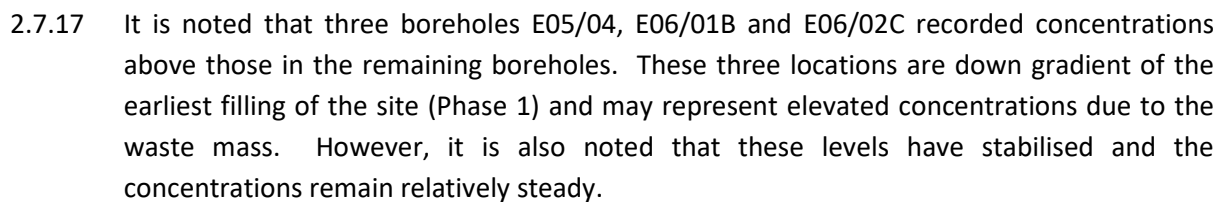


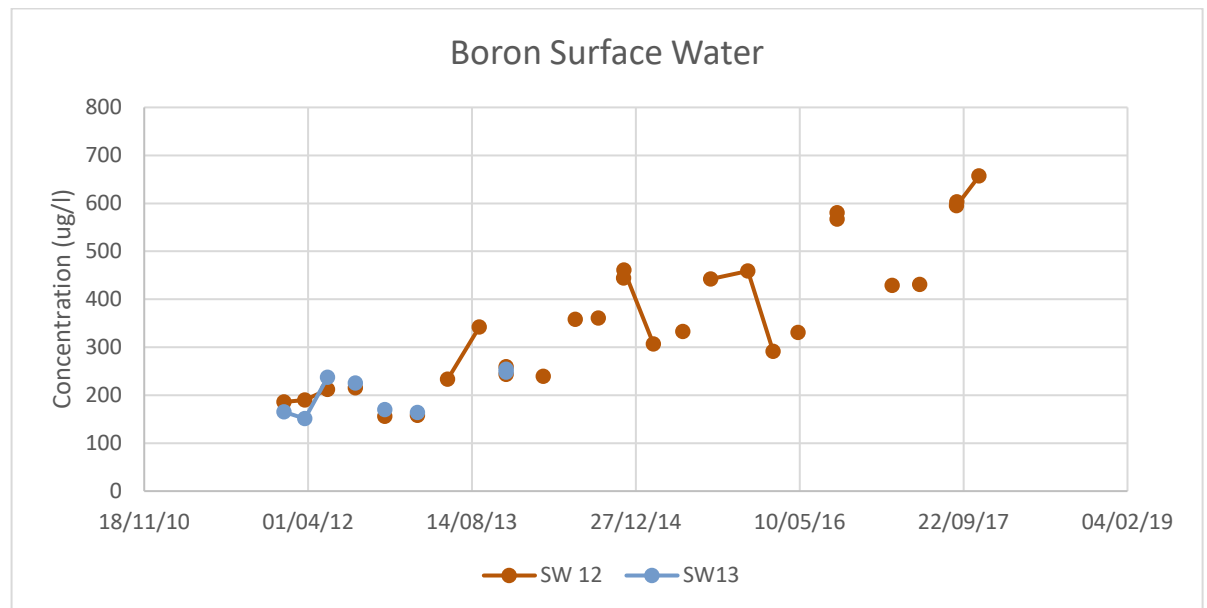
Figure 5: Distribution of Average Molybdenum (ug/l) Ash Mound.

- 2.7.16 **Boron:** Boron is another indicator species for PFA. The two charts below also indicate the significant difference between the up gradient boreholes and down gradient wells.





- 2.7.18 The spatial distribution of the boron concentrations is also very similar to Molybdenum, with low concentrations observed in up gradient. The main apparent difference is the concentrations in the down gradient boreholes are more consistent resulting in a smoother contour plot.
- 2.7.19 The surface water quality displays a lower effect from boron compared to molybdenum although the concentrations of boron are increasing. The surface water concentrations remain significantly below the compliance limit of 2000 ug/l.



- 2.7.20 **Ammoniacal nitrogen** is theoretically one of the most significant contaminants of concern with respect to the potential source concentrations relative to the environmentally acceptable limits. This potential effect is not observed within the down gradient boreholes. These concentrations are below the compliance target on all occasions. To date, there are no deteriorating trends in the groundwater with respect to this parameter.
- 2.7.21 The surface water indicates elevated ammoniacal nitrogen concentration at DP which is the located at the edge of the waste mass within the surface water ditch. These concentrations have decreased to below the compliance limit by the settlement pond (SP) monitoring point. Therefore, although there is evidence of a deterioration in water quality adjacent to the ash mound, the water quality is within the acceptable range prior to release to the wider environment and the concentrations in DP are not considered to be significant. RWE have confirmed that there has been no change in the technology /usage of ammonia at the power station in the last 5 years.

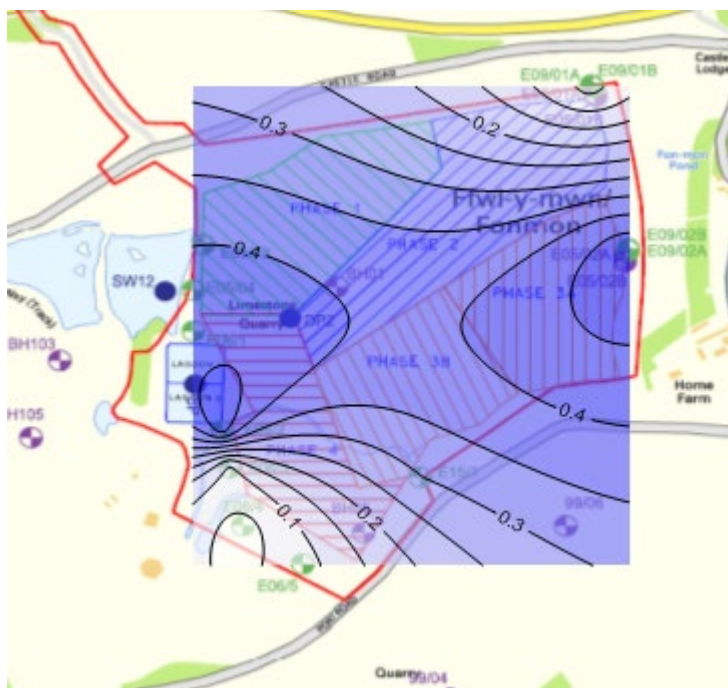
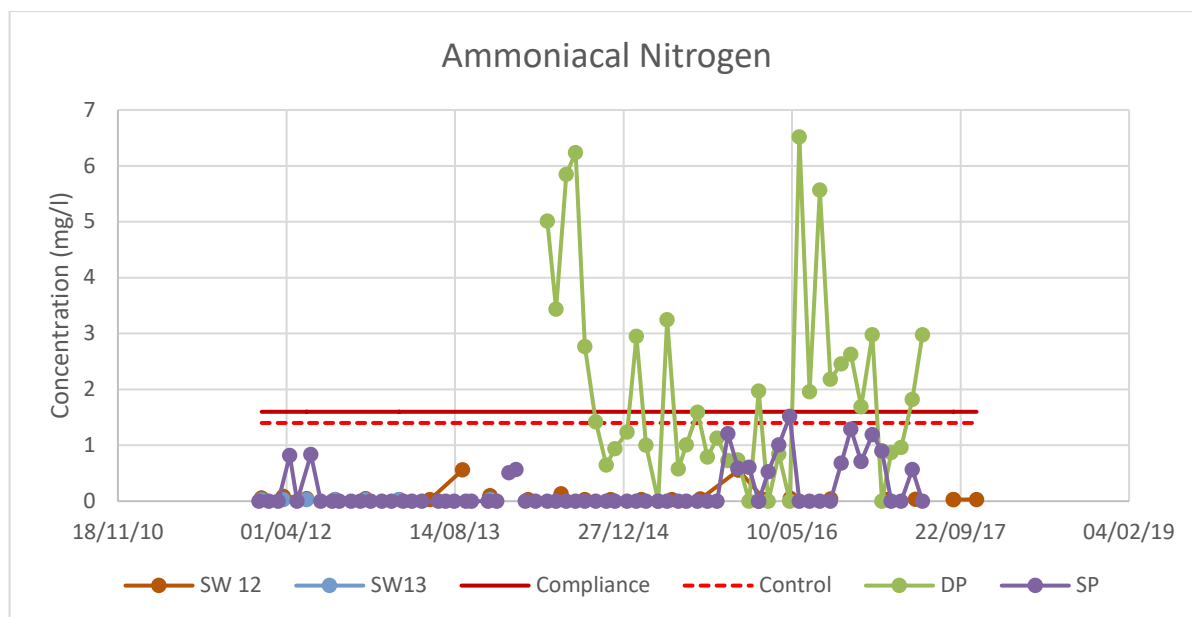
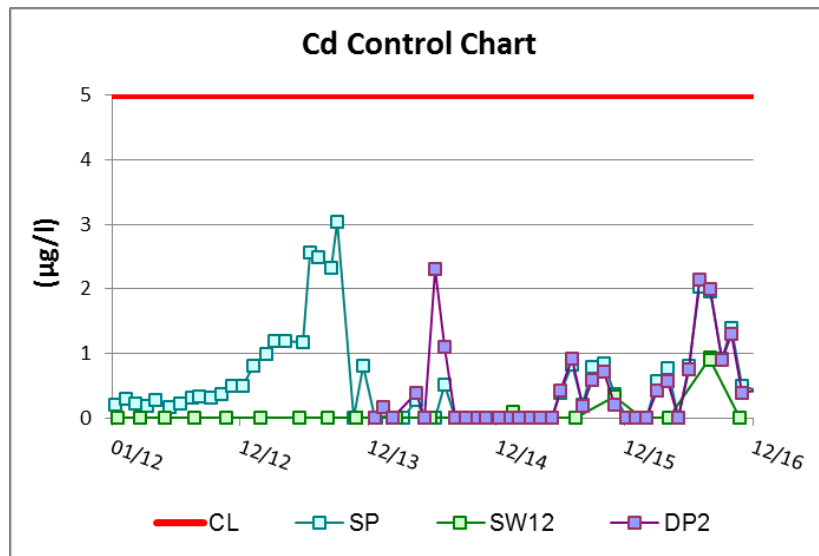


Figure 7: Spatial Distribution of Average Ammoniacal Nitrogen (mg/l) (2012 -2017)

2.7.22 **Cadmium** is now defined as a non-hazardous substance and consequently discernible concentrations are permitted in groundwater provided that they do not constitute pollution. The EQS for freshwater is defined as an annual average value of 0.25 ug/l and a MAC of 1.5 ug/l. The concentrations of cadmium are predominantly less than detection limit (0.1ug/l) in all borehole. There is uncertainty within the data base with sporadic concentrations recorded above detection. It is noted that the majority of recorded concentrations fall within SW12 however the concentrations remained below the compliance limit of 5 ug/l. It is noted that the additional monitoring points SP and DP confirm the elevated cadmium concentrations. The response in both additional monitoring locations is identical suggesting that the source is arising upstream of DP2.



- 2.7.23 **Aluminium and vanadium:** The concentrations of these determinands remain variable as identified in the 2012 review despite improvements in the sampling technique. The concentrations remain below the control level and are therefore not of concern. There are no patterns or correlations with regards to the spikes and therefore are not considered to be indicative of any event within the groundwater quality.
- 2.7.24 It is also noted that the compliance criteria for vanadium in surface water and groundwater are different at 60 ug/l and 20 ug/l respectively. It is proposed that since groundwater is discharging to the surface water environment (dewatering of the quarry) within the site boundary, that these two compliance limits should be consistent and reflective of the receiving water body that is surface water. There is no potential for groundwater to be used between the boreholes and the surface water body with such a limited distance of circa 10-20m.
- 2.7.25 **Sulphate:** The sulphate concentrations mirror the pattern identified in the chloride concentrations with the highest concentrations being observed in E06/5, however there is more of a general presence of sulphate across the area as expected from the lithology. The concentrations are consistently below the compliance criteria for both groundwater and surface water.

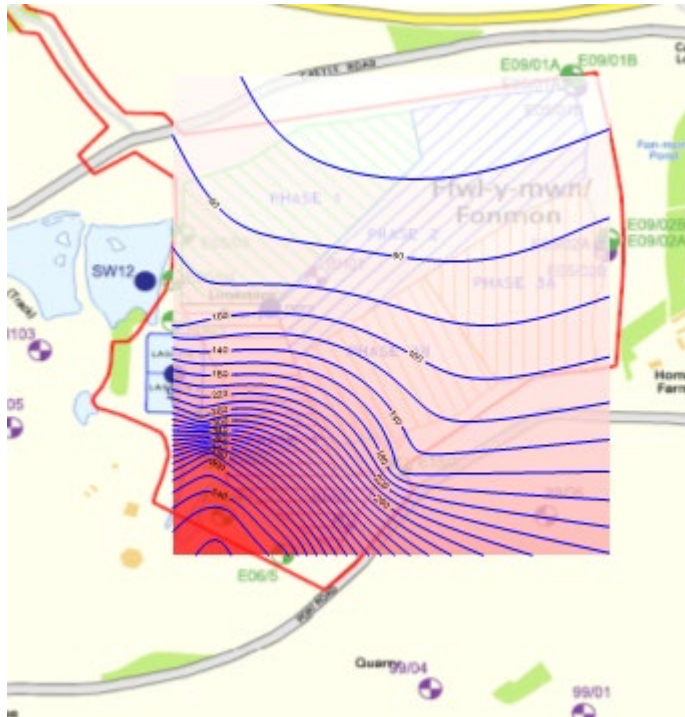


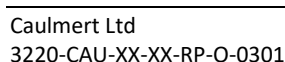
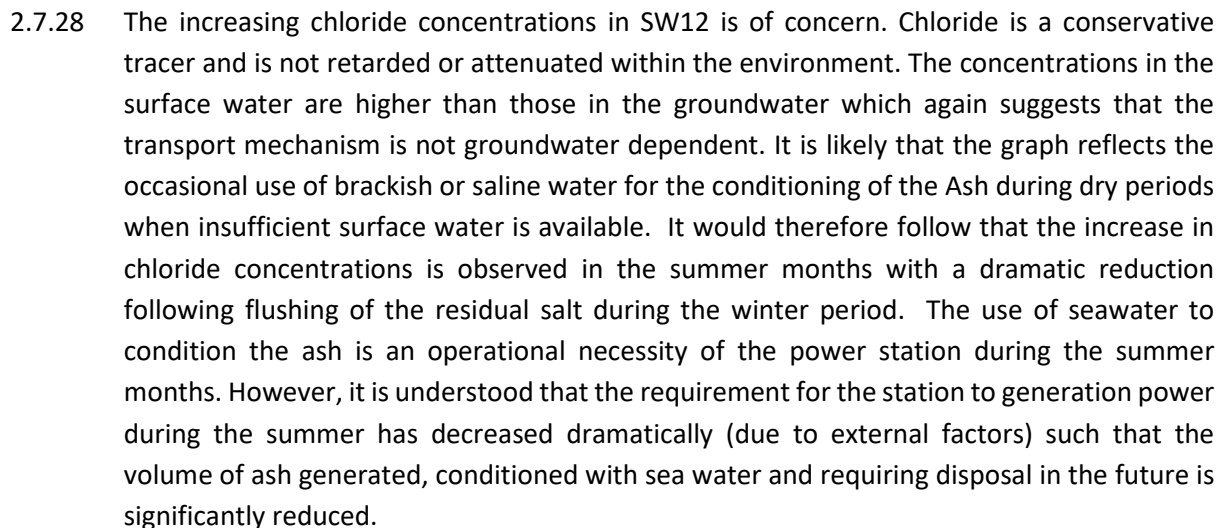
Figure 8: Average (2012-2017) Sulphate concentrations in groundwater

- 2.7.26 **Chloride:** In general chloride concentrations are low across the site with similar concentrations observed in the upstream and downstream locations. There are two notable exceptions to this, borehole E06/04 which displays a significant increase in chloride concentration towards the end of 2014 and also the general increase in chloride within SW12.



Figure 9: Average (2012-2017) chloride concentrations

- 2.7.27 The increase in chloride concentration in E06/04 is contemporaneous with the importation of colliery spoil for the construction of phase 3B. It is understood that this material was stockpiled in an area close to this borehole. Following the initial impact there appears to be a steady decrease in concentrations throughout the review period. This would be consistent with a transient impact from minerals within the colliery spoil affecting the localised groundwater.

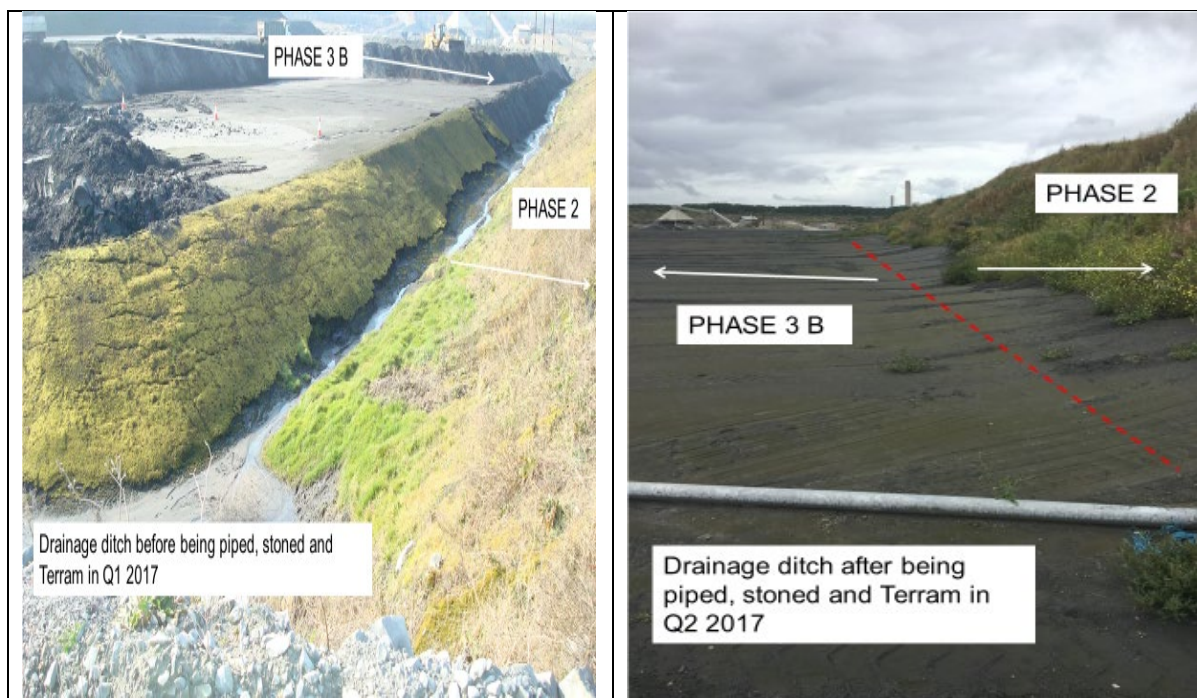


2.8 Summary and Discussion

- 2.8.1 The above assessment of the surface water and groundwater quality has indicated that the concentrations of PFA identifier species are significantly higher within the surface water environment in comparison to the groundwater environment. The concentrations in the surface water are over an order of magnitude higher in surface which suggests that the deterioration observed is more related to the flushing of the PFA by surface water or the mobilisation of fine particles within the waste mass.
- 2.8.2 Specifically, boron, molybdenum and chloride are all significantly higher in surface water.
- 2.8.3 There are two main groundwater observations one relating to the groundwater quality in E06/40 and the other relating to the series of boreholes along the western boundary.
- 2.8.4 The groundwater quality in E06/04 displays a marked change in some parameters prior to the engineering works in Phase 3B. In particular, chloride and sulphate concentrations have a large increase and are accompanied by sporadic elevated concentrations of the metal ions. It is known that the engineering material was brought on to site and stockpiled prior to commencement of the works. This engineering material comprised colliery spoil. The change in parameters would be consistent with runoff (or impact) from colliery spoil. This hypothesis is further strengthened by the prolonged and consistent reduction in these parameters following the completion of the engineering works. Therefore, groundwater quality within this borehole would be expected to continue to improve following this transient event. The concentrations of these parameters are below the requisite EALs and therefore no further works is required other than to continue to monitor the water quality within this borehole.
- 2.8.5 The boreholes along the western boundary comprising E06/01, E05/03 and E05/04 contain elevated concentrations of PFA indicator species albeit significantly below those in surface water quality. The mechanism by which these boreholes have been affected is complex. The contaminated surface water may potentially discharge and affect the groundwater environment via the unlined sections of ditch and similarly the groundwater drain is located directly on the limestone bed rock and any contaminated seepage could potentially migrate into the underlying limestone. The groundwater drain also discharges to the surface water perimeter ditches.
- 2.8.6 It is considered that the mechanism of the elevated concentrations in groundwater could arise from either pathway however is most likely to be a combination of these two mechanisms.
- 2.8.7 The long-term design of the site assumed that following seeding of the capping layer that the PFA dust was stabilised and that the runoff from the site would be 'clean'. This theory still holds true for once the vegetation is established and therefore in the long term the volume of contaminated surface water should reduce. However, under the current operational situation, the surface water runoff from the site appears to be contaminated with dissolved contaminants and fine PFA particles which collected within low points along

the surface water system resulting in the high concentrations observed in the surface water monitoring locations.

- 2.8.8 In recognition of the above statement, RWE have implemented additional measures to reduce the potential for sediment to enter the surface water systems. This included the engineering of the drainage ditch between Phases 2 and 3B (see images provided by RWE below) and the construction of an artificial channel at DP2.



Improvements to drainage ditch to reduce mobilisation of sediment



Improvements to DP2

3 HYDROGEOLOGICAL RISK ASSESSMENT

3.1 The nature of the hydrogeological risk assessment

- 3.1.1 The above review of the environmental data is in agreement with the existing conceptual model for the site (2012 HRA review). The conceptual model theoretically meets the conceptual model for LandSim however, the modelling undertaken to date utilises the site specific parameters obtained through testing and CQA and predicts no unacceptable effect. This is contradictory to the observations made on site from the environmental monitoring data which indicate that the site is not performing as designed. Therefore, it is considered that on the basis of the observed data that little will be gained by remodelling the site using LandSim without any additional data.
- 3.1.2 Instead the environmental monitoring data is considered to indicate that preferential pathways and contaminant migration mechanisms are present which are not included within the LandSim model. Such mechanisms may include mobilisation of fine particles via surface flow, preferential groundwater flow paths, influence of surface water runoff. A more holistic approach is required to assess the potential long term influence of the site on the wider environment.
- 3.1.3 It was discussed and agreed with NRW at the pre-commencement meeting that numerical modelling of the site would not further the understanding and assessment of the risks at the site and that the risk assessment review should focus upon the direct evidence collected from the environmental monitoring and the validation of this data. In addition, the assessment of the significance of the on-site monitoring data has been compared to the risks to the wider environment. This has been undertaken using a simplified approach using a water balance, surface water pollution risk assessment approach. The objective is to provide an indication of the most likely potential effect on the wider environment.

3.2 Proposed assessment scenarios

- 3.2.1 The review of the most likely potential effect of the site on the groundwater immediately prior to discharge to the River Thaw has been calculated using a water balance technique to generate the potential volume of leachate generated at the site which could potentially discharge into groundwater.
- 3.2.2 The volume of leachate generated is based on an assumed infiltration rate into the PFA. The average annual rainfall for the site is estimated to be 998mm/yr based on published rain data for St Athan weather station (1km north north-west of the ash mound). This is based on data from 1981 to 2010.

Extract from www.metoffice.gov.uk/public/weather/climate/gcjs3tzpf#averages table.

Month	Max. temp (°C)	Min. temp (°C)	Days of air frost (days)	Sunshine (hours)	Rainfall (mm)	Days of rainfall >= 1 mm (days)	Monthly mean wind speed at 10m (knot)
Jan	7.9	2.8	6.7	55.5	91.9	14.0	11.0
Feb	7.9	2.4	7.3	79.4	71.8	10.9	10.4
Mar	10.0	4.0	2.7	119.9	68.2	13.1	10.2
Apr	12.4	5.4	1.3	178.9	61.5	11.0	9.3
May	15.6	8.4	0.0	221.7	64.2	10.1	9.1
Jun	18.3	11.2	0.0	217.0	60.9	9.5	8.3
Jul	20.1	13.3	0.0	223.9	76.4	10.4	8.5
Aug	19.9	13.3	0.0	192.0	83.5	11.3	8.2
Sep	17.9	11.5	0.0	161.1	82.1	11.0	8.4
Oct	14.3	8.7	0.3	105.2	122.4	14.7	9.5
Nov	10.9	5.6	2.3	67.6	100.7	15.1	9.8
Dec	8.3	3.1	6.3	50.7	115.4	14.0	10.5
Annual	13.7	7.5	27.0	1673.0	998.9	145.1	9.4

3.2.3 The annual average potential evapotranspiration is reported to be 510 mm/yr², resulting in an equivalent effective rainfall of 488 mm/yr. A proportion of this rainfall will infiltrate the ground as recharge (leachate generation) with the remaining proportion as runoff. Based on the steepness of the slopes and the natural low permeability of the PFA itself, the proportion of runoff is anticipated to be high, however a range of values has been assessed to review the sensitivity of this parameter.

Table 6: Summary of estimate of recharge

Percentage of effective rainfall as recharge	Justification
30%	The NCB reported infiltration rates of 50% through temporary cover systems. This site has established vegetation and therefore this is considered to be a service estimate
10%	Considered to be a more realistic assessment of recharge base on the slope angles and low permeability of the PFA

3.2.4 The total area of the site is approximately 23 Ha.

² Ministry of agriculture fisheries and food, technical bulletin 35. The agricultural climate of England and Wales – Area 52.

Table 7: Summary of leachate generation estimate

Percentage of effective rainfall as recharge	Leachate volume (m ³ /yr)	Leachate volume (m ³ /day)
5%	5612	15
30%	33672	92

Flow in the Aquifer

- 3.2.5 Flow within the aquifer is based on Darcy's law using the hydraulic gradient presented on Figure 2 above (0.04) and the flow width base on these contours. It is assumed that the groundwater flow will be primarily contained within the top 10m of the aquifer, partially constrained by the elevation of the water table relative to sea level.

Table 8: Calculation of Aquifer Flow

Parameter	Unit	Max K	Ave K	Min K	Justification
K	m/s	7.00E-06	1.50E-07	2.00E-08	Range of values
I	-	0.04	0.04	0.04	Site specific Feb 2017
flow depth	m	10	10	10	Estimate of flow depth
flow width	m	500	500	500	Site specific Feb 2017
Q	m ³ /day	1.21E+02	2.59E+00	3.46E-01	Darcy's Law

3.3 Priority contaminants to be modelled

- 3.3.1 Based on the assessment above the priority substances to be modelled are:

Table 9: Summary of priority substances

Parameter	Units	Source Term		Background
		Min	Max	
NH4	mg/l	10	20	0.3
B	mg/l	4	10	0.28
Mo	mg/l	2	4	0.003
As	ug/l	50	100	7
Cd	ug/l	0.3	2	0.12
Hg	ug/l	0.3	2	0.03
Se	ug/l	100	300	3.5
So4	mg/l	600	1600	70

- 3.3.2 Based on mass balance calculations where the volume of leachate generated at the 'maximum' average concentrations (released to the underlying aquifer) are predicted are as follows:

Table 10: Summary of predicted groundwater concentrations

Dilution calc	Min	Min	Average	Average (2)	max
NH4	mg/l	19.6	8.6	3.4	0.4
B	mg/l	9.8	3.5	1.5	0.3
Mo	mg/l	3.9	1.7	0.6	0.0
As	ug/l	98.0	43.8	20.6	7.4
Cd	ug/l	2.0	0.3	0.2	0.1
Hg	ug/l	2.0	0.3	0.1	0.0
Se	ug/l	293.5	86.1	34.0	4.4
SO4	mg/l	1566.3	523.5	237.4	75.2

Key	
Min	Min groundwater flow maximum recharge, max conc
Ave	Ave Gw flow, max recharge
Ave(2)	Ave Gw flow, min recharge
max	Max gw flow, min recharge min conc

3.3.3 The model inputs and outputs are presented in Appendix 3.

3.4 Sensitivity analysis

3.4.1 A sensitivity analysis has been carried out with regards to the assumed infiltration coefficient with two values being considered. The results presented above indicate that the calculations are not overly sensitive to this value.

3.4.2 In addition the sensitivity of the assessment to permeability of the aquifer have also been assessed. These provide the range of potential concentrations within the aquifer as indicated above.

3.5 Review of technical precautions

Lining system

3.5.1 The evidence collected during the CQA of the lining works indicates that this system was constructed in accordance with the design although it is recognised that the arithmetical average for phase 3B was above the design parameters.

Leachate drainage

3.5.2 There is no leachate drainage employed at the site. The natural low permeability of the PFA together with Podsolization process was envisaged to minimise the requirement of a leachate containment system during the initial design of the site.

Groundwater Drainage

- 3.5.3 The groundwater drainage blanket is constructed below the base of the lining/ attenuation layer. This drainage stone is laid directly on the surface of the quarry however the fall of the topography is such that the groundwater drains towards the perimeter surface water management ditches under gravity such that there is no long-term pumping requirement.

4 REQUISITE SURVEILLANCE

4.1 Leachate monitoring

- 4.1.1 There is no leachate infrastructure at the site. It is considered that there is little to be gained with respect to detailed knowledge of the source term by the construction of any new boreholes within the PFA and therefore no additional wells are recommended.
- 4.1.2 The above assessment indicates that the quality of the water used for the conditioning of the ash prior to disposal may influence the quality of the runoff water from the material. In addition to the permit requirements, RWE monitor the quality of Coal Stock runoff water (used for conditioning).
- 4.1.3 This report has also identified that the use of sea water in the conditioning of ash has been identified as a primary mechanism for the elevated chloride concentrations. RWE have confirmed an undertaking to minimise the use of seawater and the expected reduction in summer running will further reduce the need to use seawater in the condition of ash.

4.2 Groundwater monitoring

- 4.2.1 The groundwater quality is currently monitored on a quarterly basis for a range of PFA indicator species. The current database has demonstrated that the groundwater quality has stabilised and that changes in concentrations are limited.
- 4.2.2 It is recommended that the following amendments are made to the monitoring suites:
- Aluminium is removed from the monitoring schedule on the basis that since the improved monitoring techniques have been employed this parameter is below the laboratory detection limits on almost every occasion. This indicates that this is not a persistent/consistent PFA indicator species and that the continued requirement to monitoring this parameter does not further the understanding at the site.
 - Selenium and Antimony are removed. Again, following improvements in the monitoring technique such that sediment is prevented to enter the sample, the concentrations of these parameters are predominantly below their respective laboratory detection limits. In addition, these parameters do not have defined water EQS and are considered to be of limited benefit in the continued assessment of the site.
 - Nickel is removed on the basis that it was previously retained as an interim hazardous substance. This has now been reclassified as non-hazardous. The potential effect of non-hazardous substances is presented by a number of substances including molybdenum which have a higher ratio in leachate to EQS (assessment) levels.
 - The addition of Chromium (VI) to the monitoring suite. This has been defined as a hazardous substance with a very low transitional/saline EQS. The continued

monitoring of total chromium does not enable the site to demonstrate compliance with the WFD.

Compliance levels

- 4.2.3 Following the improvement in the groundwater monitoring techniques, a number of the existing compliance levels are significantly higher than the groundwater quality which historically reflected the uncertainty within the database. The object of compliance and control levels is to identify change in groundwater quality prior to pollution occurring. In light of the improved techniques and the more stringent environmental water quality standards, the following control and compliance levels are proposed. This also reflects the proposed changes to the analytical requirements as indicated above. The values of the control and compliance level have been determined from the time series charts with due consideration of the EQS and background water quality. These are presented in Appendix 4. Compliance limits are only proposed for selected down gradient wells

Table 10: Proposed Compliance Limits

Parameter	Units	Reference Values				Control Levels		Compliance Limits	
					Up gradient Groundwater Background (E09/01A E09/01B)				
		AA	MAC	Source					
Hazardous Substances:								25%	
Arsenic*	µg/l	50	-	EQS	1	N/A	N/A	10	E05/03 & E05/04
Chromium (VI)	µg/l		5	GW	0.7	N/A	N/A	5	
Non-Hazardous Substances:							Location		
Ammoniacal Nitrogen as N	mg/l	(un-ionised EQS 21 µg/l)		EQS	0.3	1.4	E06/01 E05/03 & E05/04	1.6	E05/03 & E05/04
Cadmium (dissolved)	µg/l	0.25	1.5	EQS	0.1	0.4		1.5	
Boron	mg/l	2		EQS	0.01	2.5		2.8	
Molybdenum	µg/l	70		WHO	3	1800		2000	
Sulphate as SO4	mg/l	400		DWS	20	400		600	

N/A not applicable. Control levels are not applied to hazardous substance.

* No background quality data is available for Cr(VI), compliance level should be reviewed after 12 monitoring rounds. Currently set at MAC for Cr(VI)

- 4.2.4 It is noted that the down gradient monitoring locations E05/04 and E05/03 contain elevated concentrations of PFA indicators. Compliance levels for these boreholes are designed to allow the identification of any further deterioration in groundwater quality. It is considered that it would be of little benefit to set the compliance limit at the EQS or EAL as these locations would be continuously in breach of the level.

4.3 Surface Water monitoring

- 4.3.1 The surface water monitoring is undertaken at 2 locations, SW12 and SW13. Additional monitoring is undertaken by the operator at points DP and SP however these are not identified within the Permit. DP is located in closest proximity to the PFA and SP is a sample

point within the settlement lagoons. SW12 is the regulated surface water discharge point for the site.

4.3.2 Surface water compliance values have been determined for SW12.

Table 11: Proposed Compliance Limits Surface water

Parameter	Units	Reference Values			Control Levels		Compliance Limits	
		AA	MAC	Source				
Hazardous Substances:								
Arsenic*	µg/l	50	-	EQS	N/A	N/A	50	SW12
Chromium (VI)	µg/l		5	GW	N/A	N/A	5	
Non-Hazardous Substances:					Location			
Ammoniacal-Nitrogen as N	mg/l	(un-ionised EQS 21 µg/l)		EQS	0.5	SW12	0.6	SW12
Cadmium (dissolved)	µg/l	0.25	1.5	EQS	0.5		5	
Boron	mg/l	2		EQS	40		2.0	
Molybdenum	µg/l	70		WHO	6000		2000*	
Sulphate as SO4	mg/l	400		DWS	400		600	

*consistent with groundwater

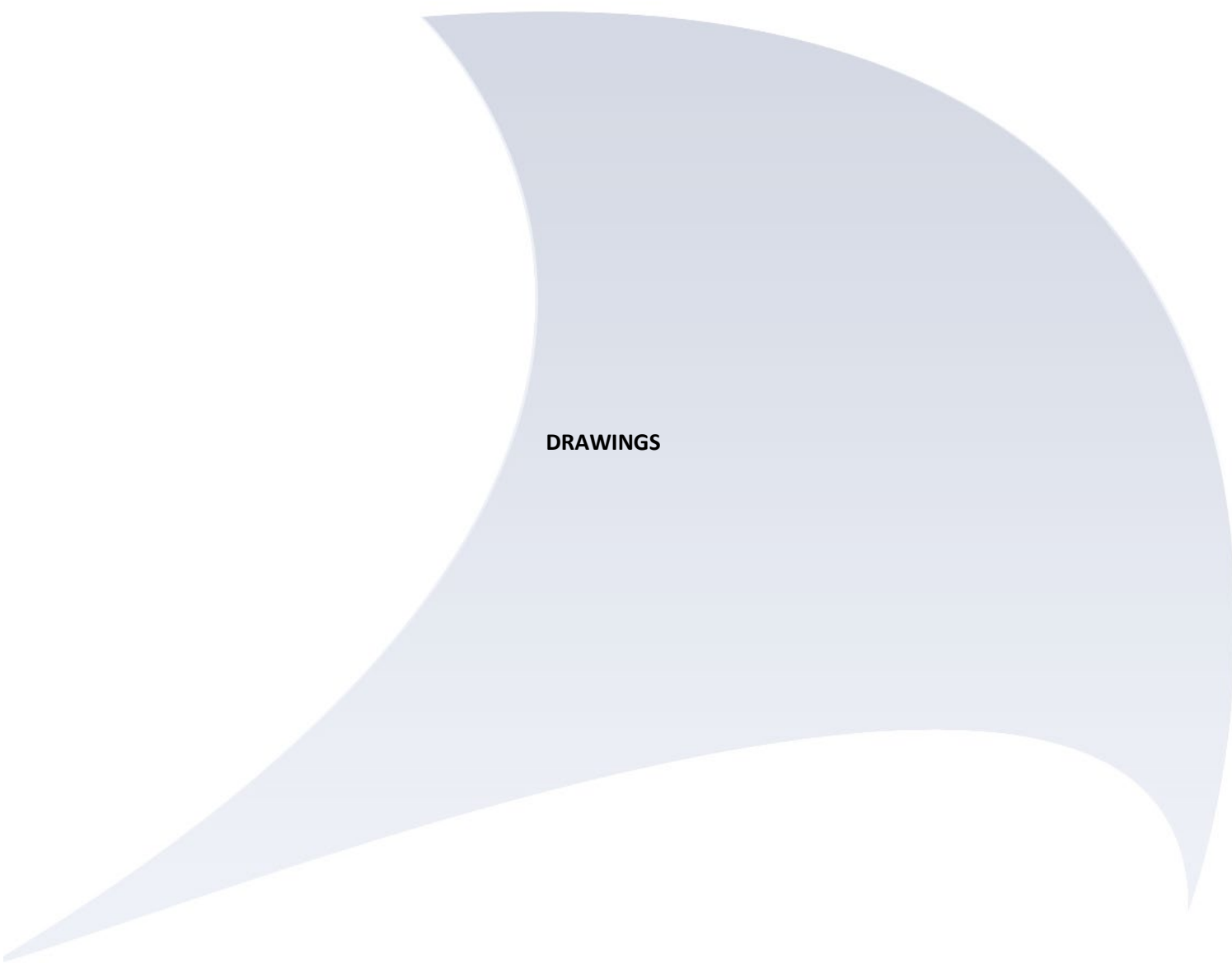
- 4.3.3 It is recommended that the monitoring of points SP and DP is continued in order to provide additional detail to the conceptual model where the current effect is more strongly observed in the surface water environment.

5 CONCLUSIONS

- 5.1.1 This Hydrogeological Risk Assessment review has been undertaken in line with the guidance on Hydrogeological Risk Assessment reviews and has comprised a detailed review of the environmental monitoring data from 2012 to 2017.
- 5.1.2 The environmental monitoring data has demonstrated that there is a discernible effect from the ash, on the groundwater and surface water quality. Concentration of PFA markers are present at higher concentrations in the surface water in comparison to the down gradient groundwater environment which implies the migration mechanism is being driven by the surface water flow mechanism.
- 5.1.3 The report has updated the conceptual model with respect to legislation changes in parameters defined as hazardous substances.
- 5.1.4 The improvements in monitoring techniques proposed in the 2012 HRA have had a significant effect on reducing the variability and uncertainty within the environmental data to the point that the current compliance limits are significantly above the observed water quality. Therefore, the compliance limits have been reviewed with alternative compliance values proposed where appropriate.
- 5.1.5 The observed environmental monitoring data indicates that the groundwater and surface water interactions are more complex than can be included within the existing LandSim model and therefore this tool is not considered to provide a further benefit in the assessment of the site. A more holistic approach has been undertaken on a water balance approach looking at the total concentrations potentially present within the groundwater environment.

Recommendations:

- 5.1.6 The following recommendations have been made throughout the report:
- Amend monitoring regime to add Chromium (VI) and remove aluminium, selenium, nickel and antimony.
 - Investigate the potential for ammonia to be present in current ash
 - Ongoing review of the effectiveness of the recent measures put in place within the quarry to minimise the disturbance and mobilisation of fine PFA dust to the surface water environment.



DRAWINGS

NOTE

1. DO NOT SCALE FROM THIS DRAWING. WORK FROM FIGURED DIMENSIONS ONLY. ALL DIMENSIONS ARE IN MILLIMETRES AND ALL LEVELS ARE IN METRES ABOVE ORDNANCE DATUM U.N.O.

2. NO DEVIATION FROM THE DETAILS SHOWN ON THIS DRAWING WILL BE ALLOWED WITHOUT THE PRIOR PERMISSION IN WRITING.

3. THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ALL RELEVANT ARCHITECTS, ENGINEERS AND SPECIALIST DRAWINGS AND SPECIFICATIONS.

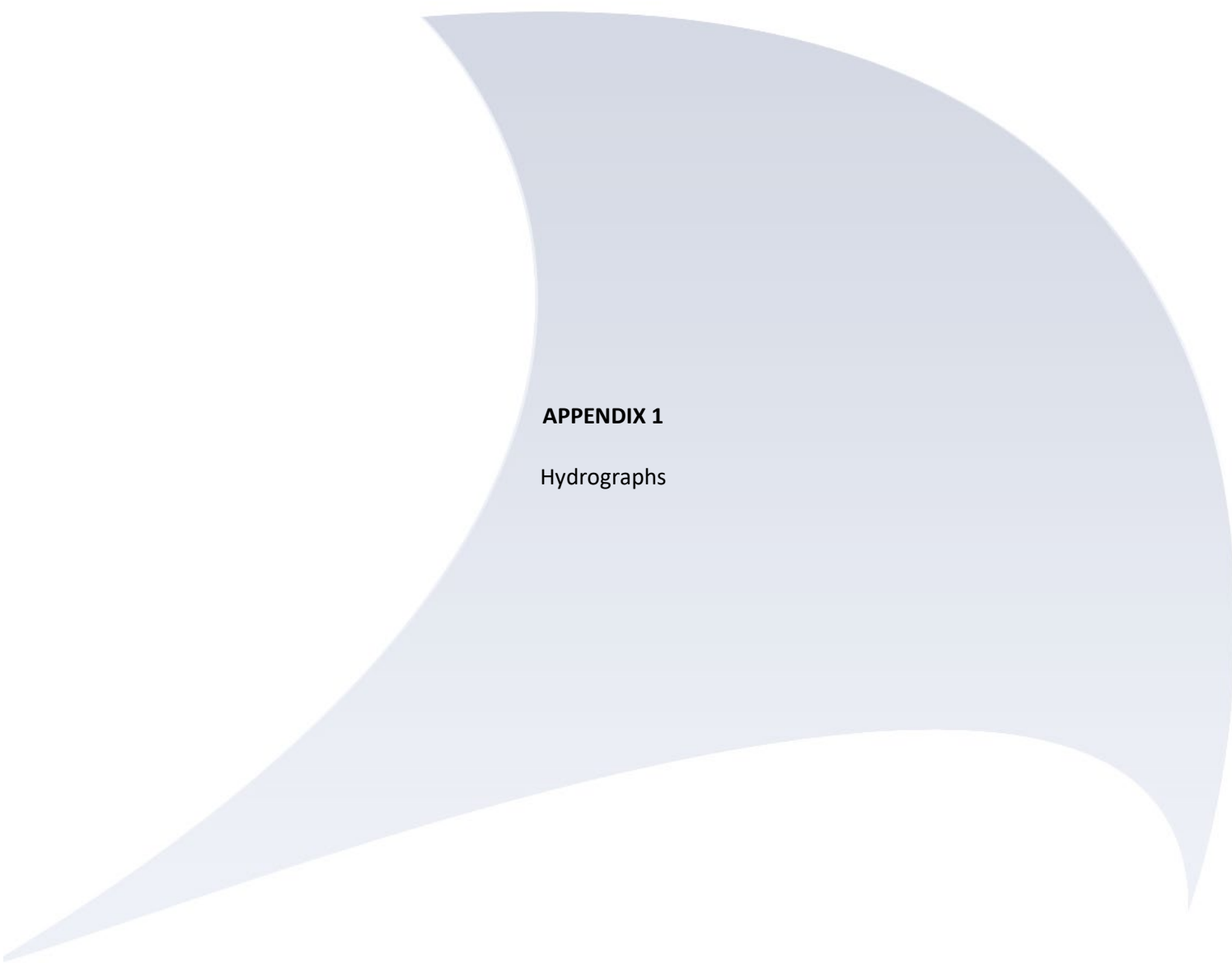
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REVIEWED BY	XX	SCALE @ A1	1:5000	JOB REF:	3220
AUTHORISED BY	XX	ISSUE	-	REVISION	-
DRAWING NUMBER 3220.HRA.01					
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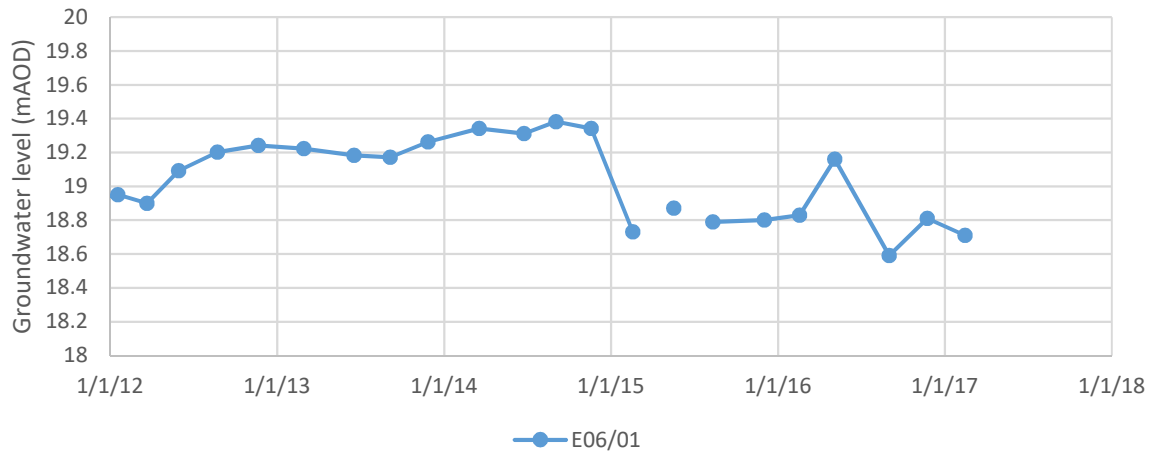
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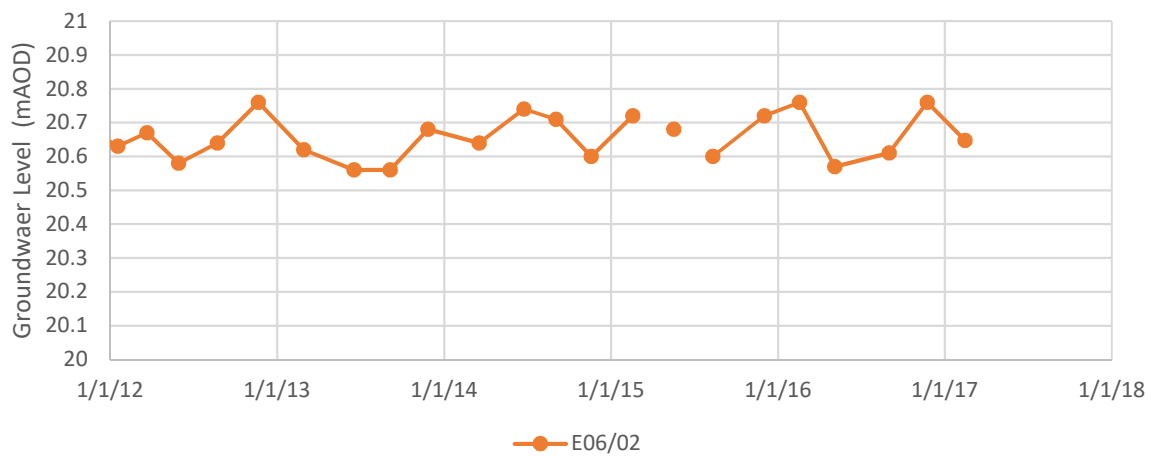
APPENDIX 1

Hydrographs

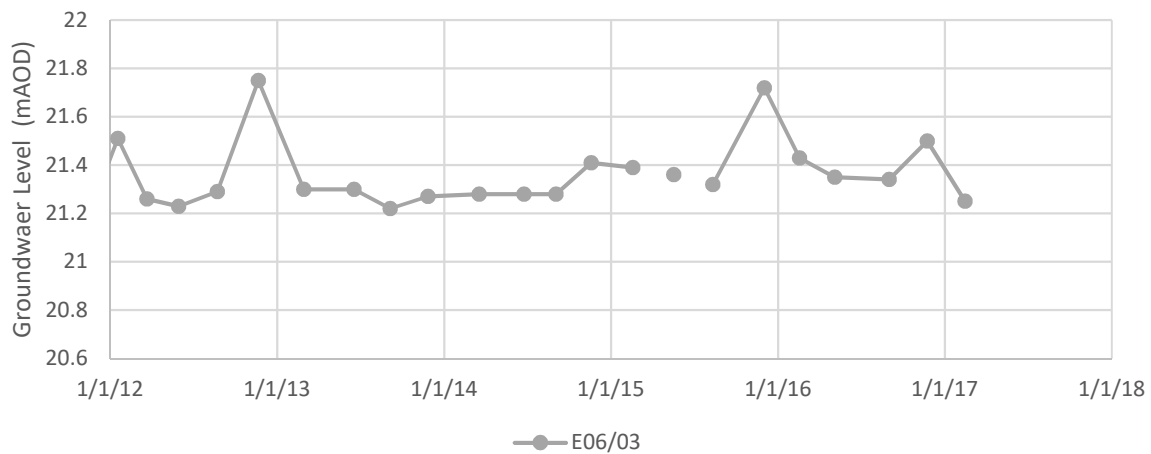
Hydrographs



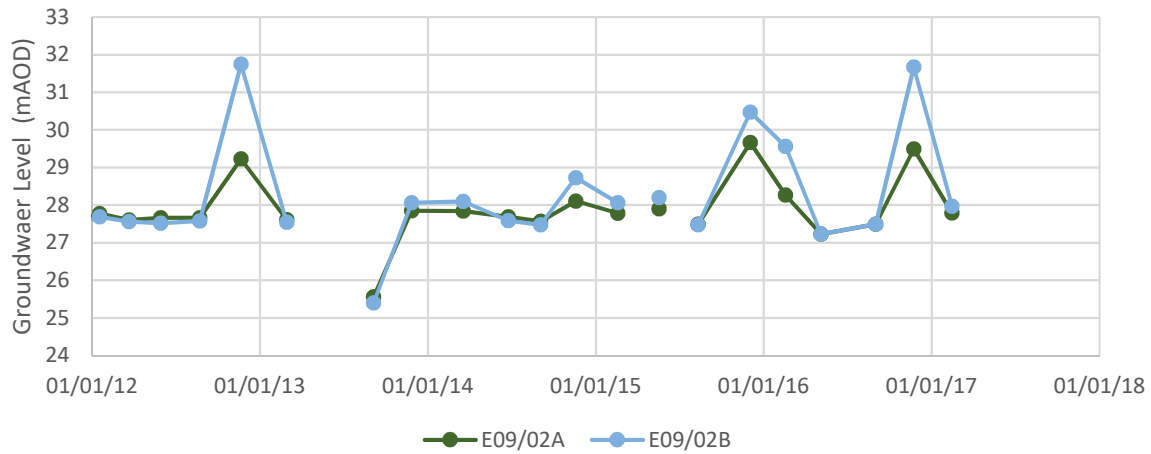
Aberthaw Quarry



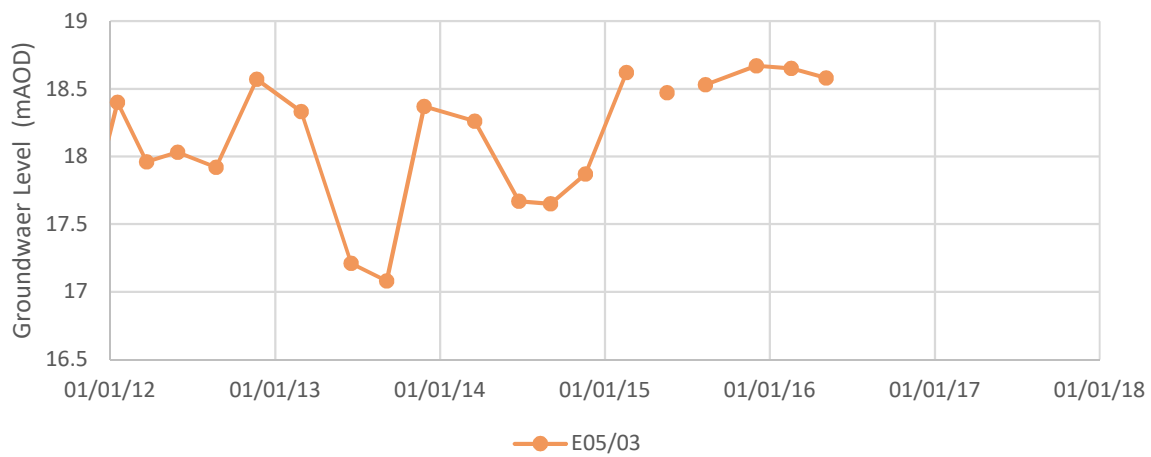
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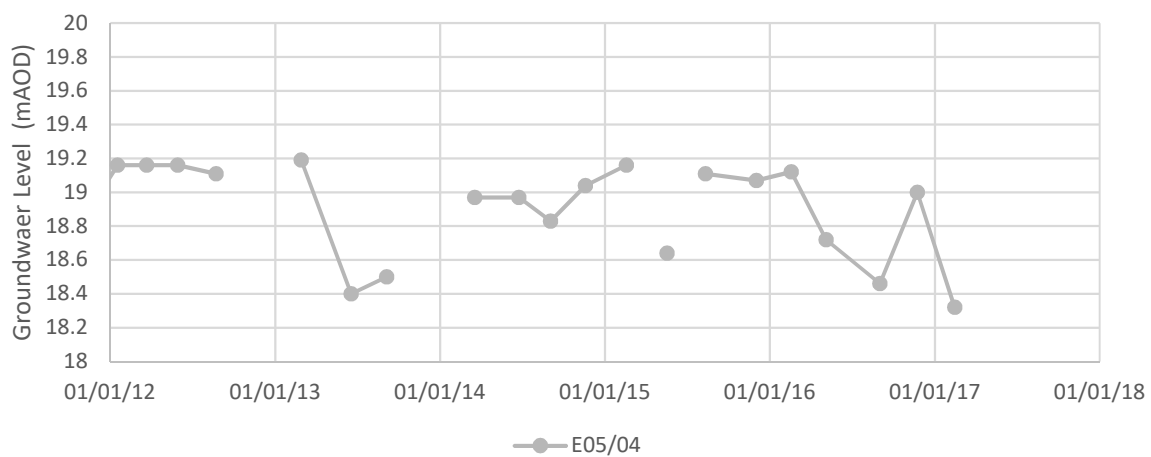
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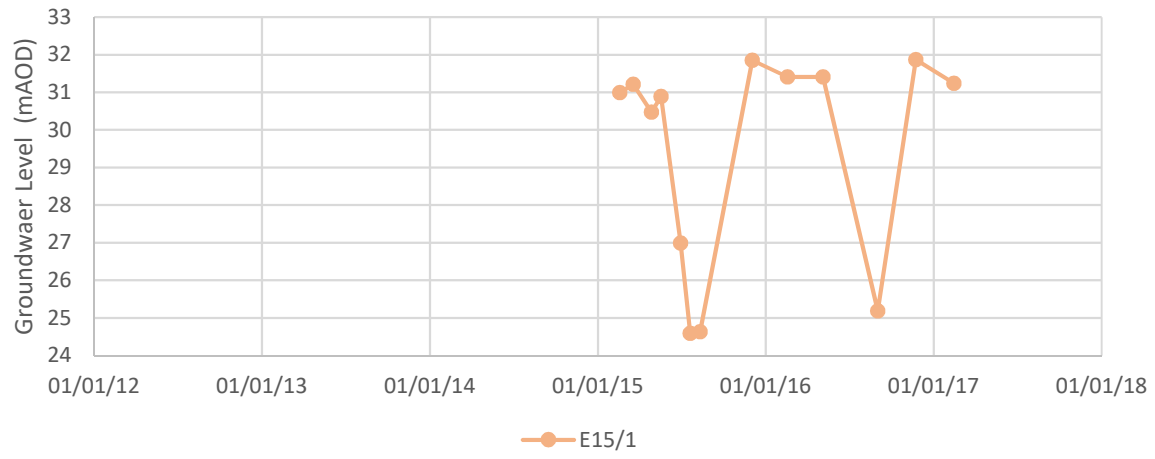
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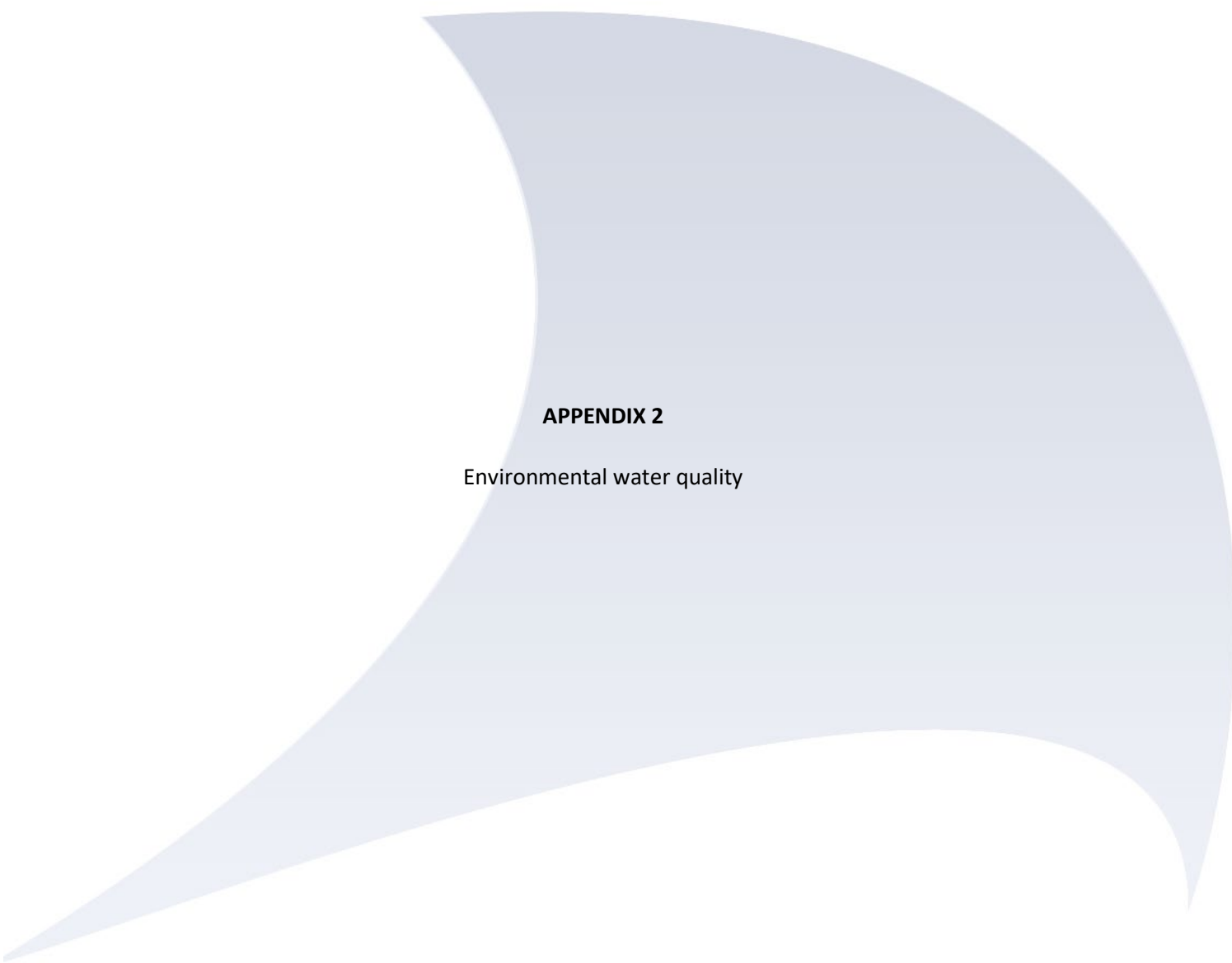


Hydrographs



Aberthaw Quarry

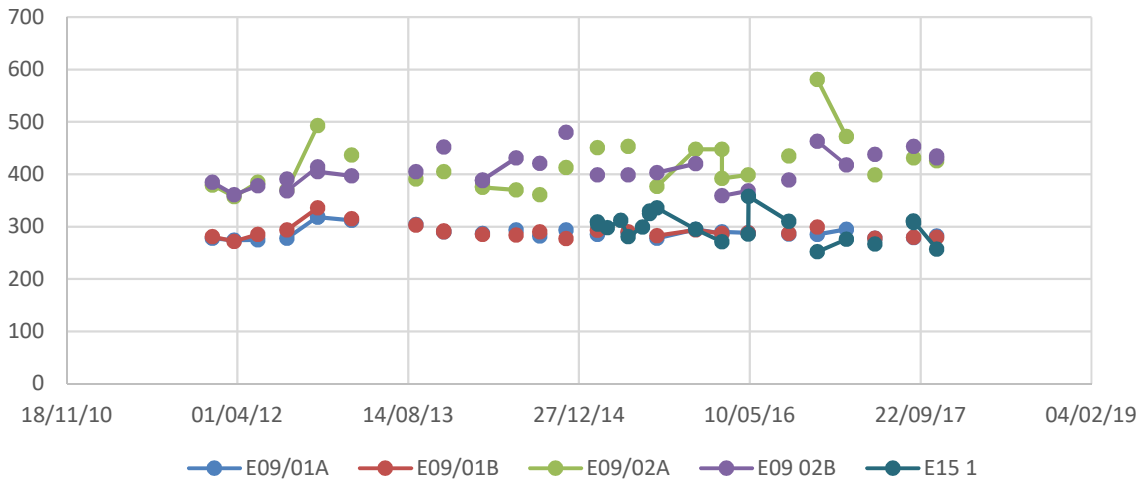




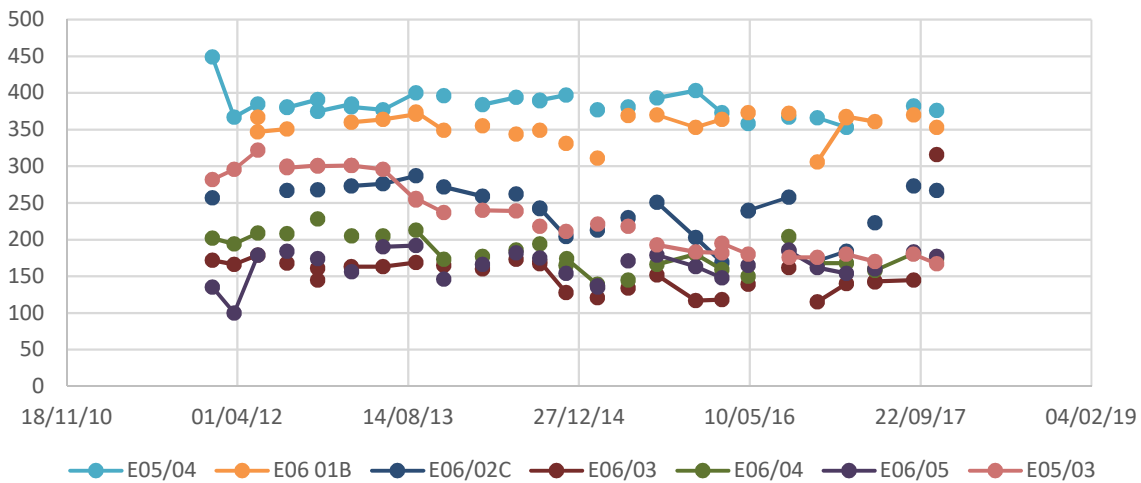
APPENDIX 2

Environmental water quality

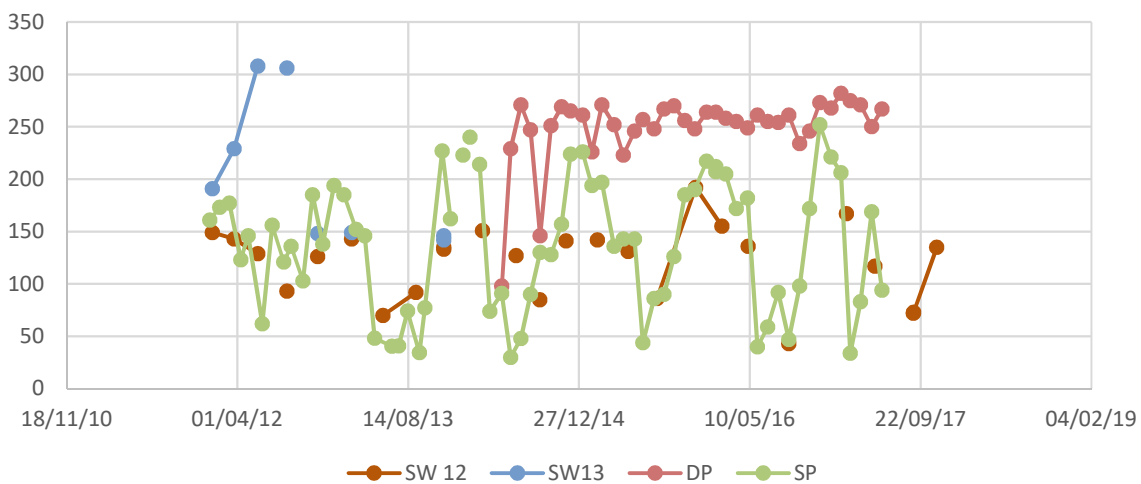
Alkalinity: Up gradient



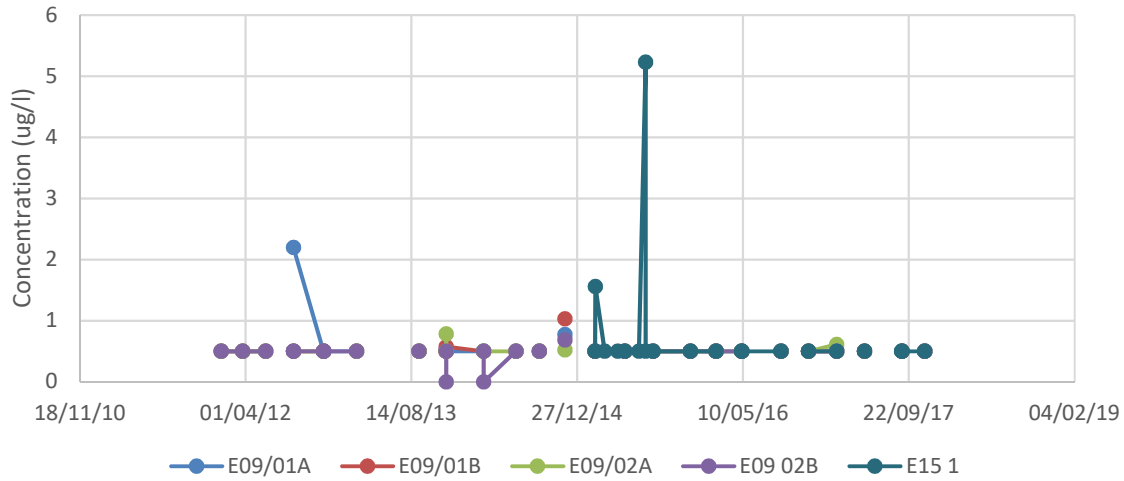
Alkalinity: Down gradient



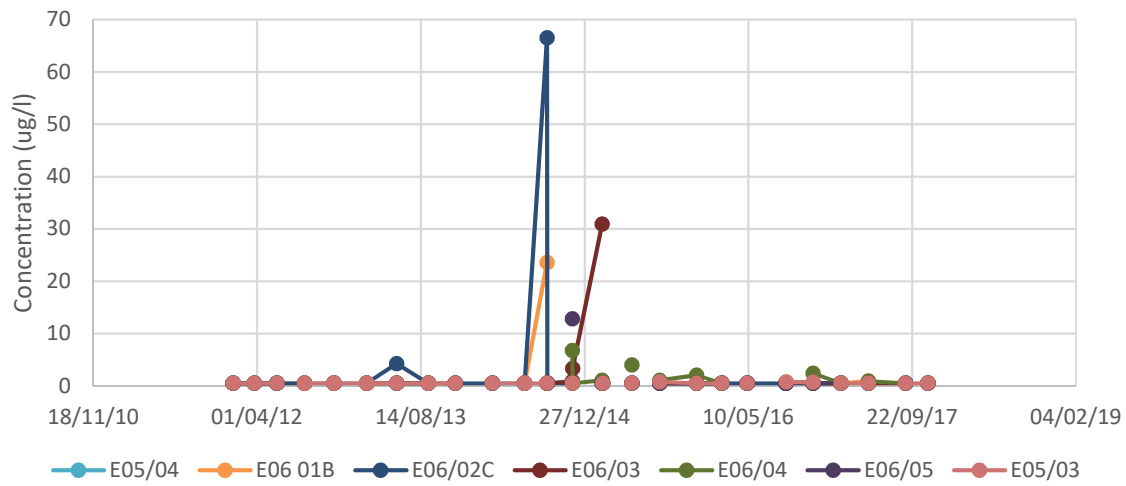
Alkalinity: Surface water



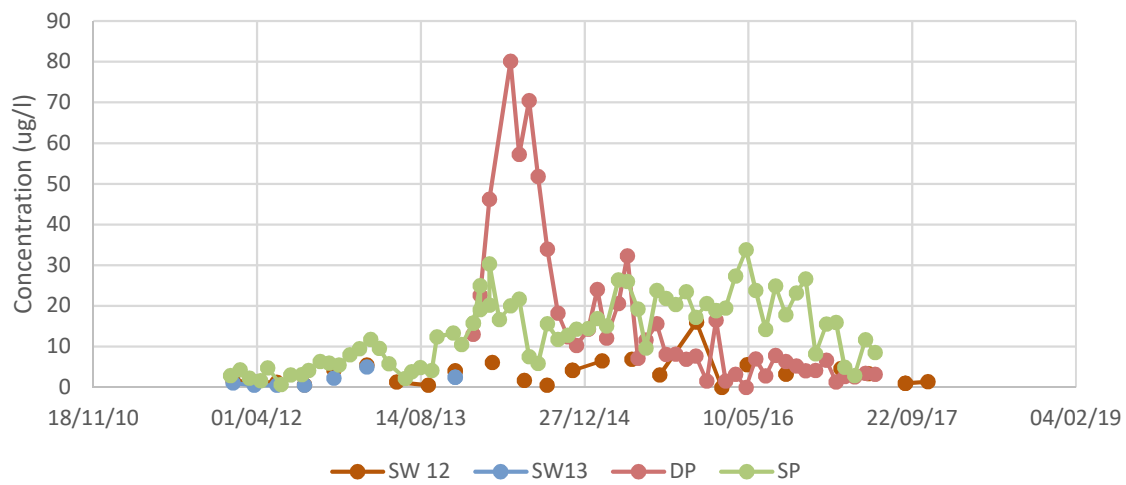
Chromium: Up gradient

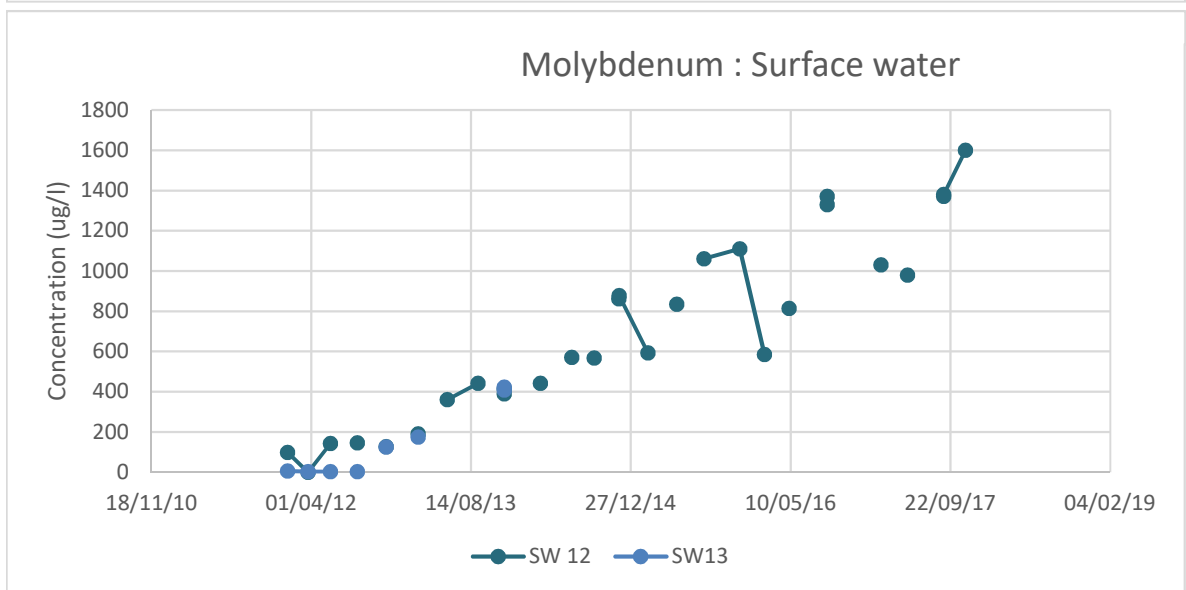
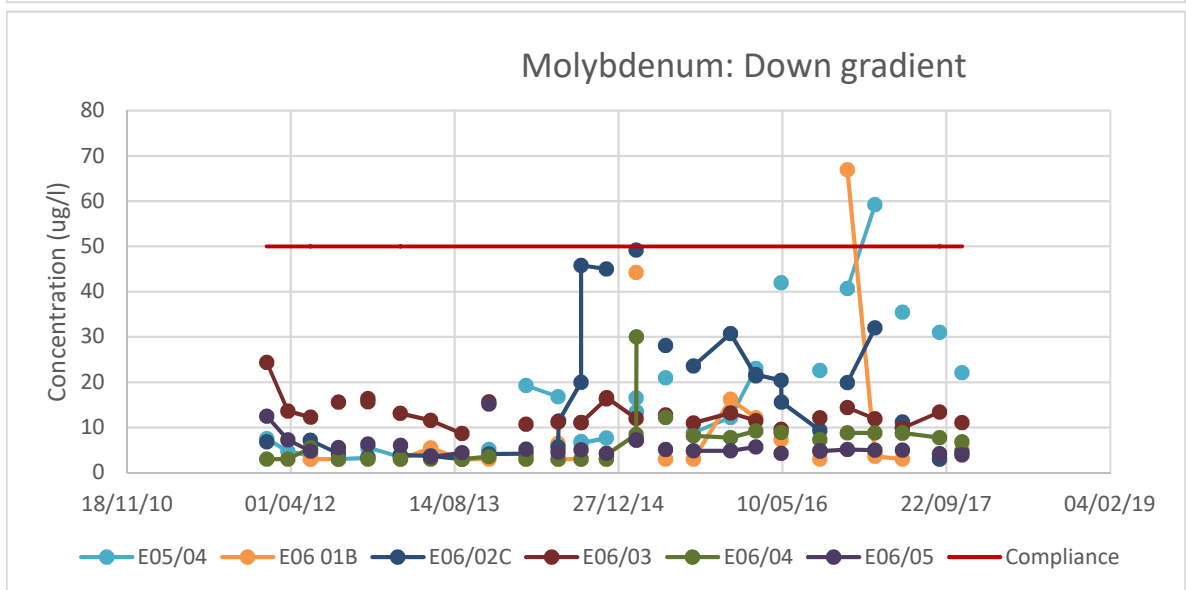
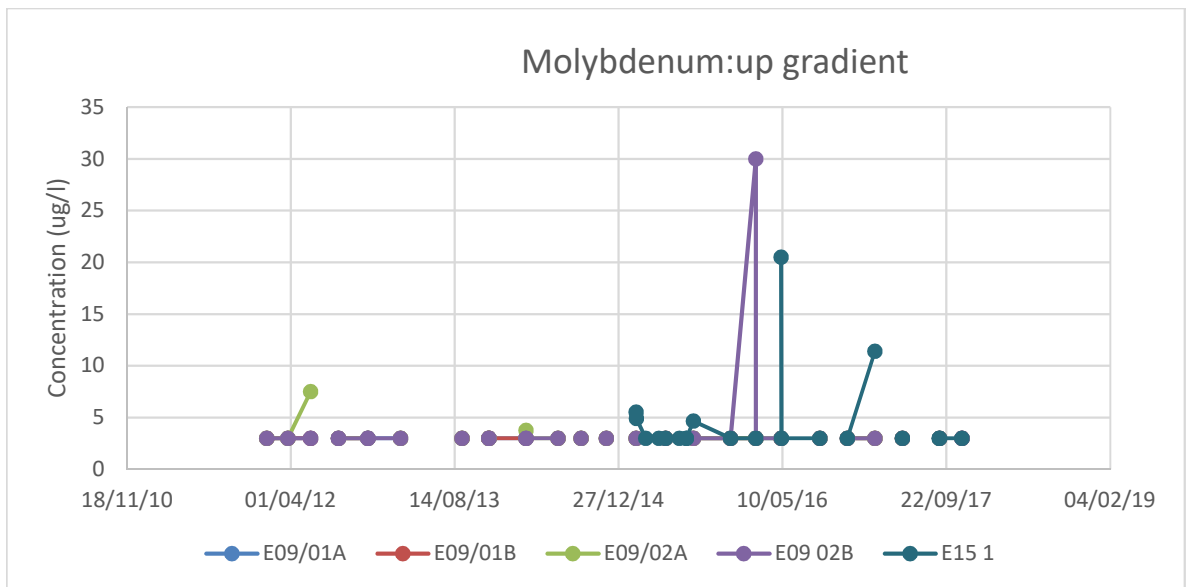


Chromium: Down gradient

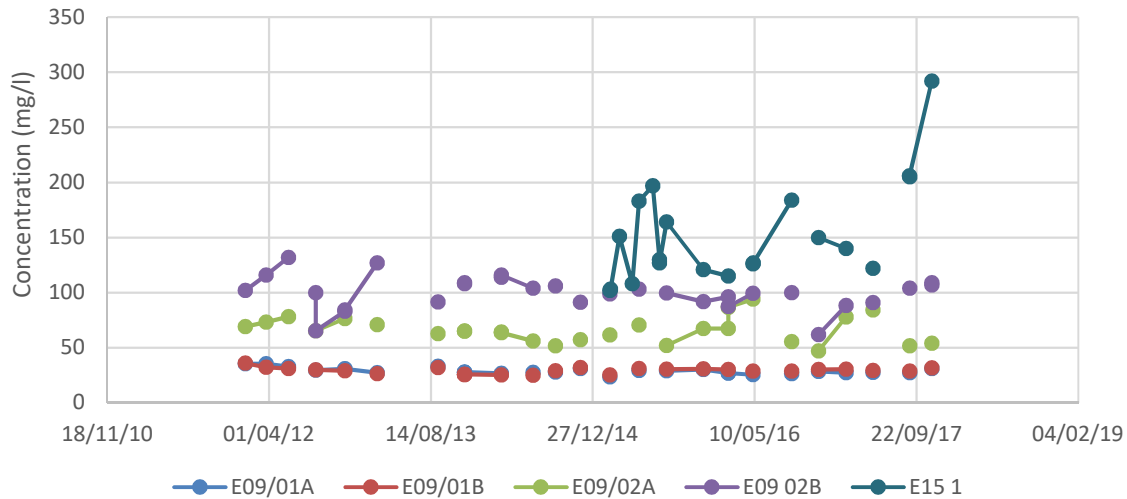


Chromium: Surface water

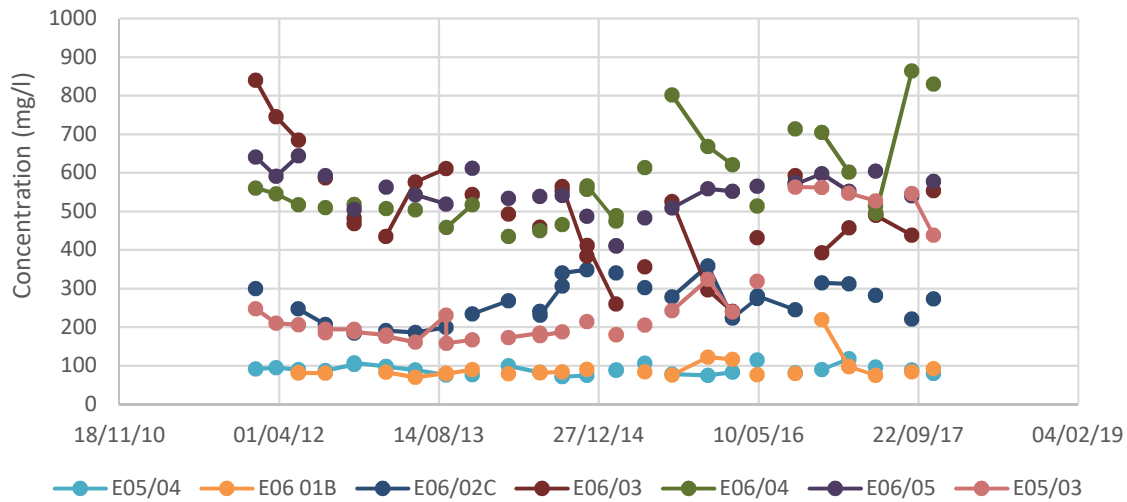




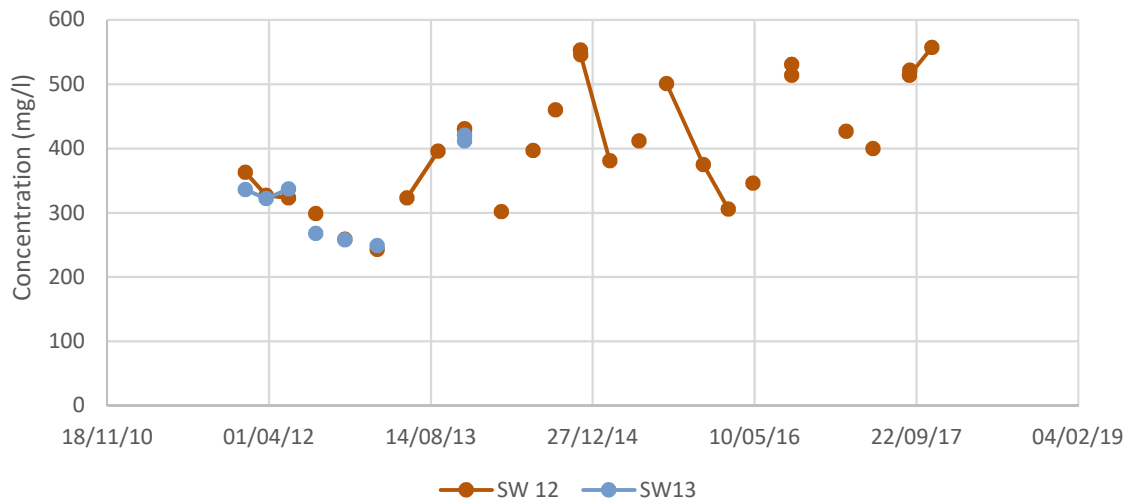
Suphate as SO4: Up gradient



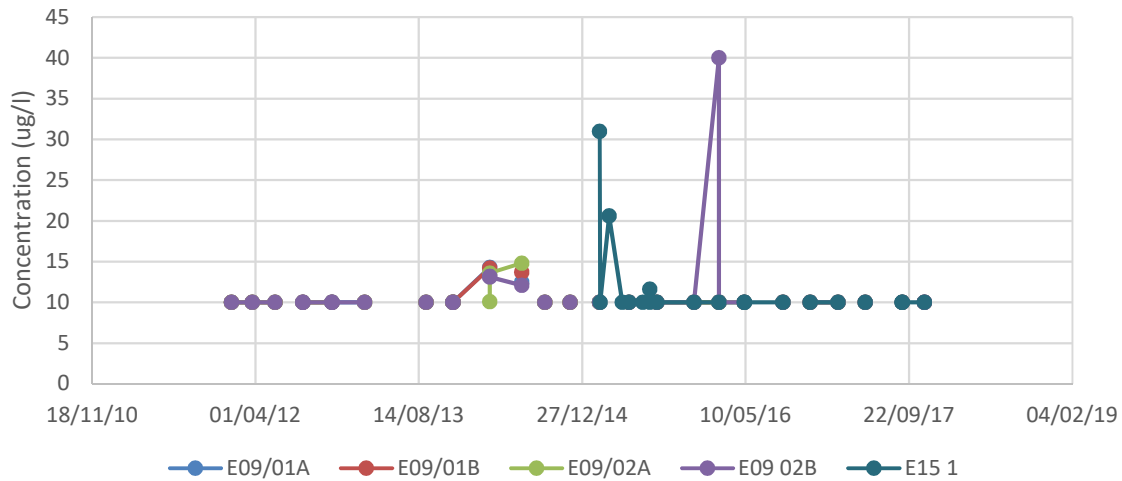
Suphate as SO4: Down gradient



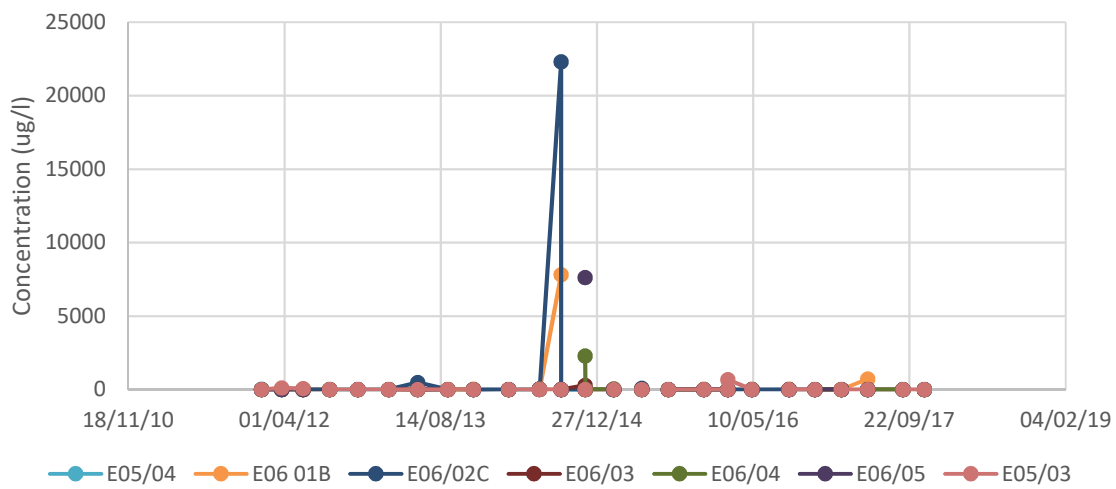
Suphate as SO4: Surface water



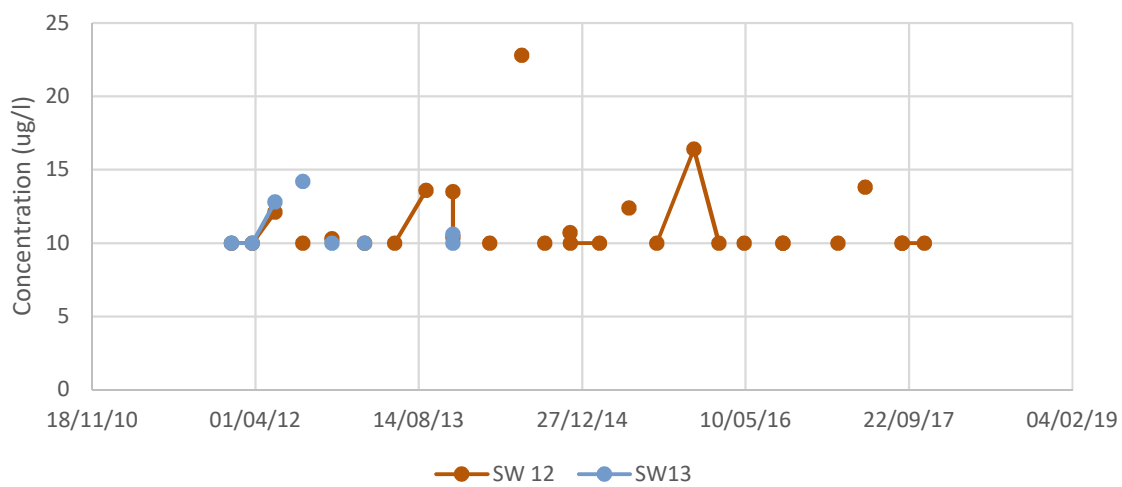
Aluminium: Up gradient



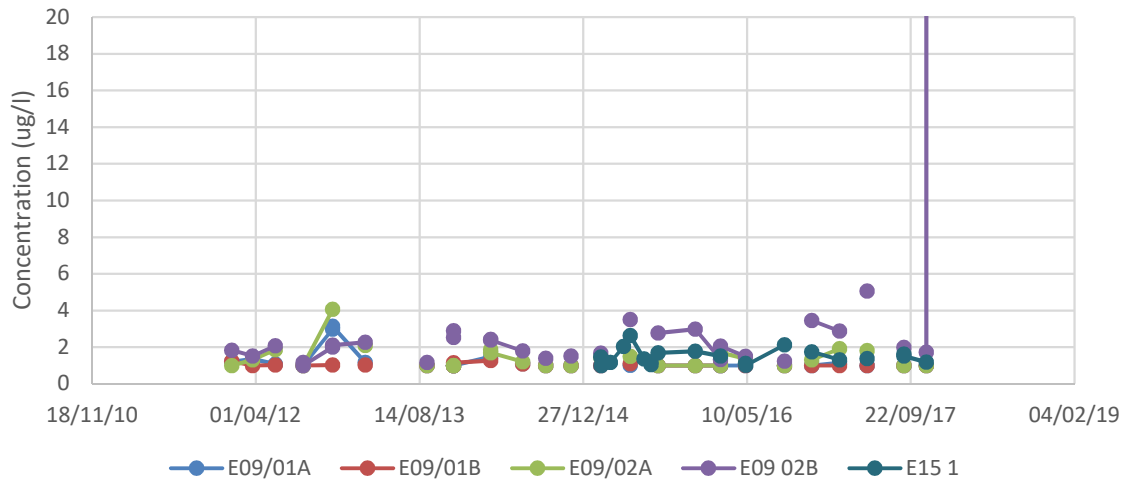
Aluminium: Down gradient



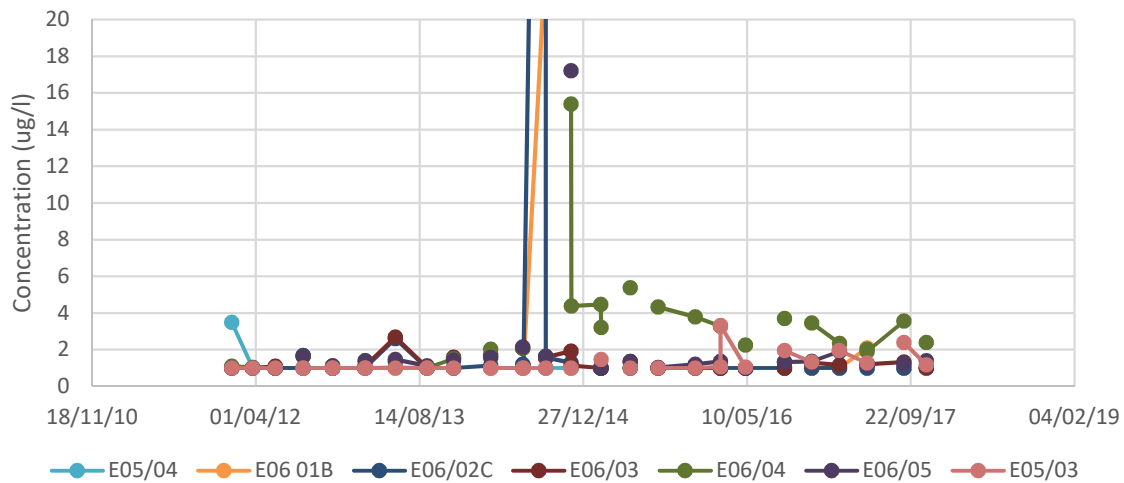
Aluminium: Surface water



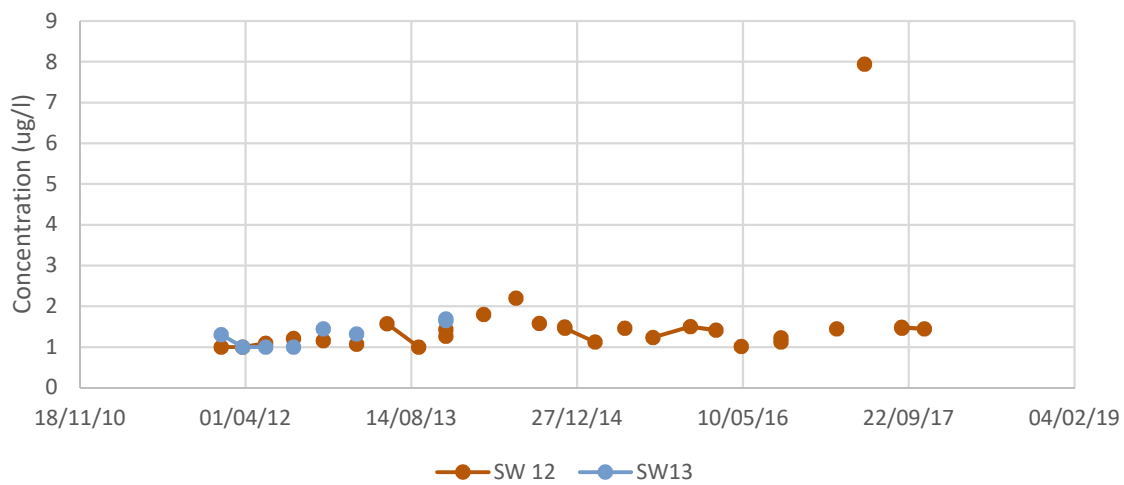
Copper: Up gradient



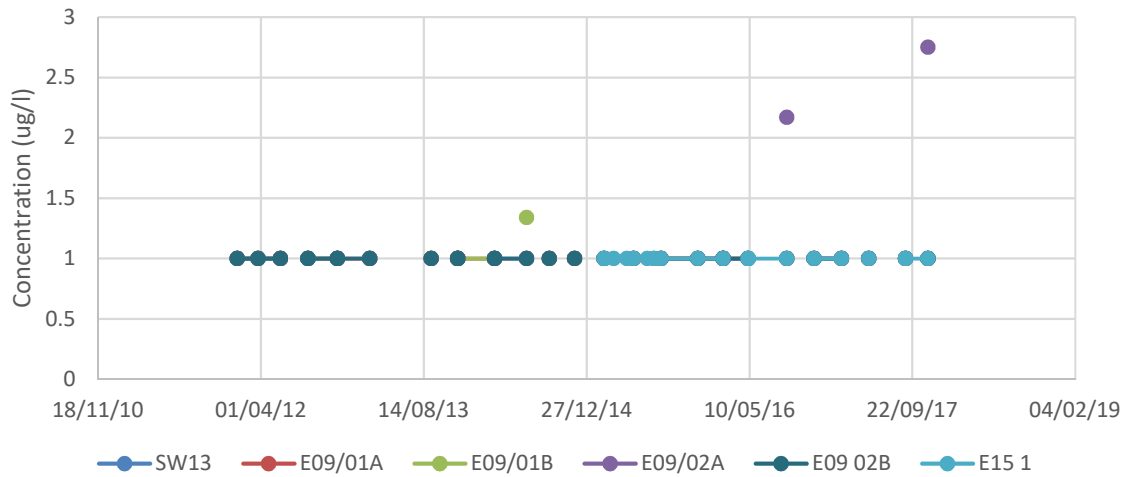
Copper: Down gradient



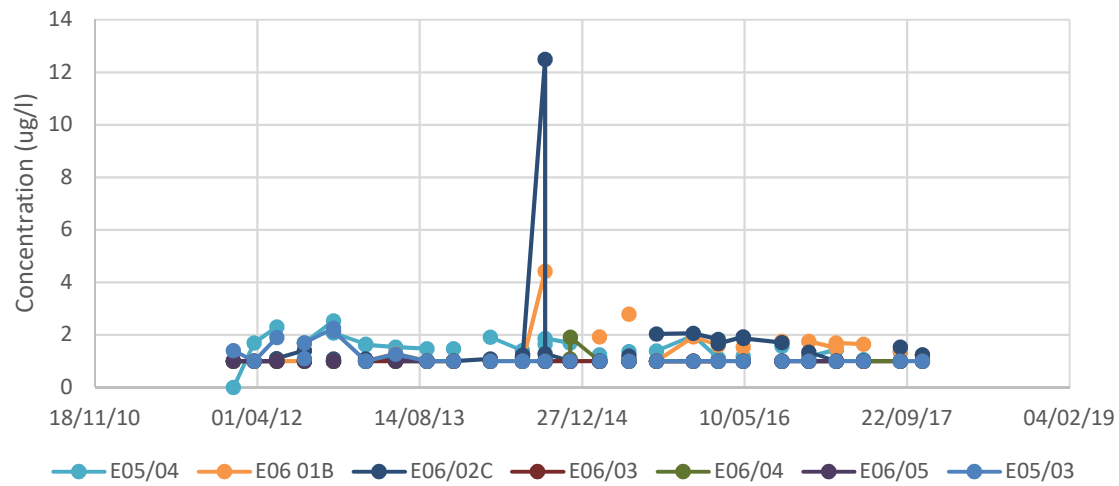
Copper: Surface water



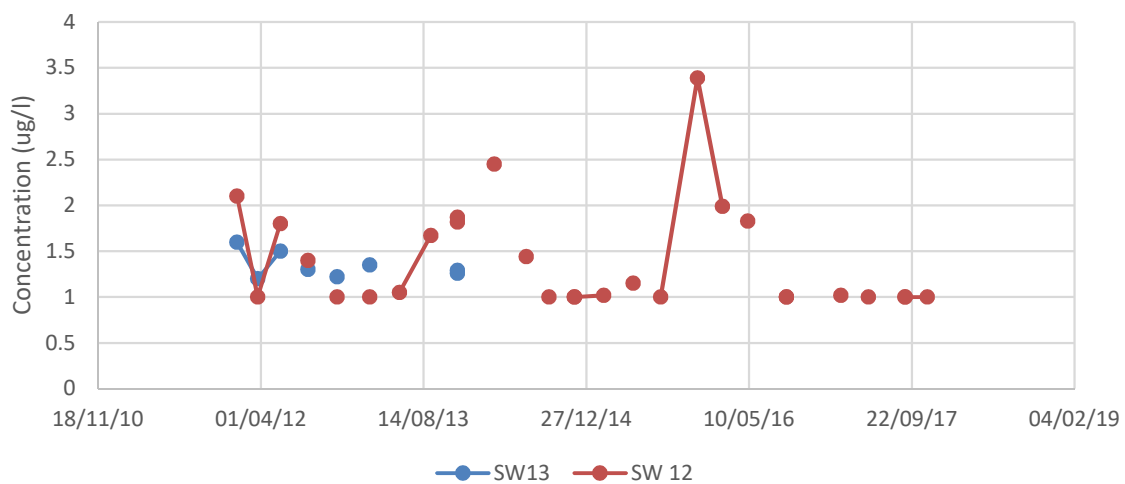
Arsenic: up gradient



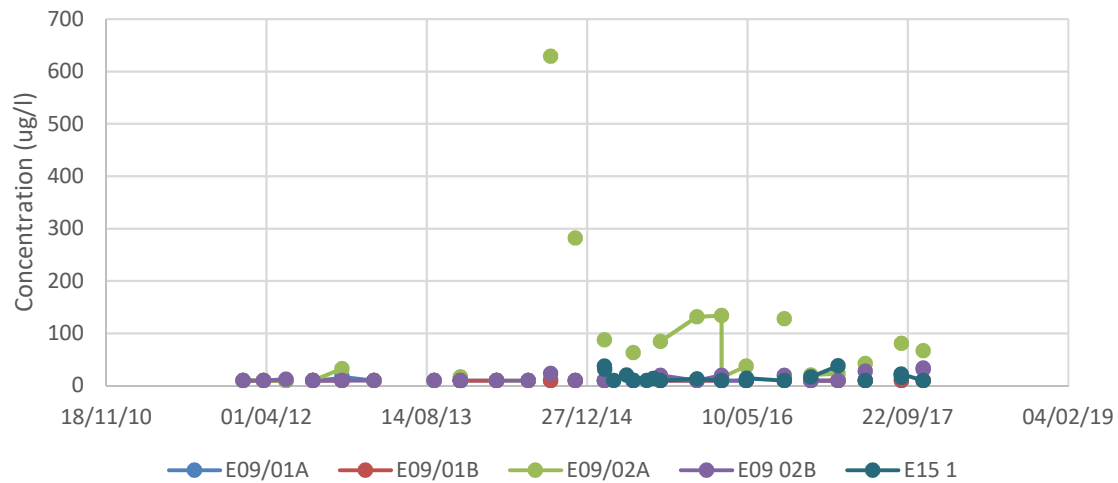
Arsenic: Down gradient



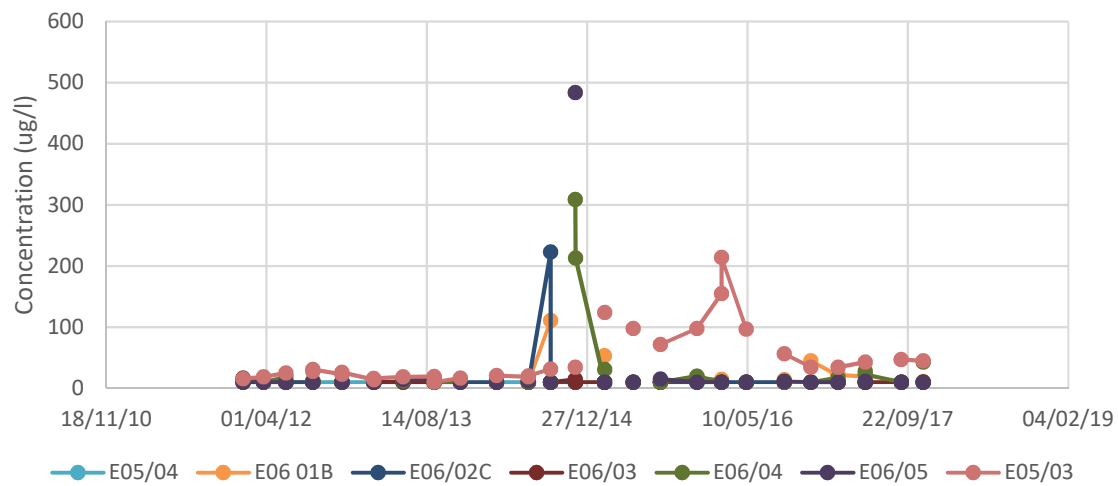
Arsenic: Surface water



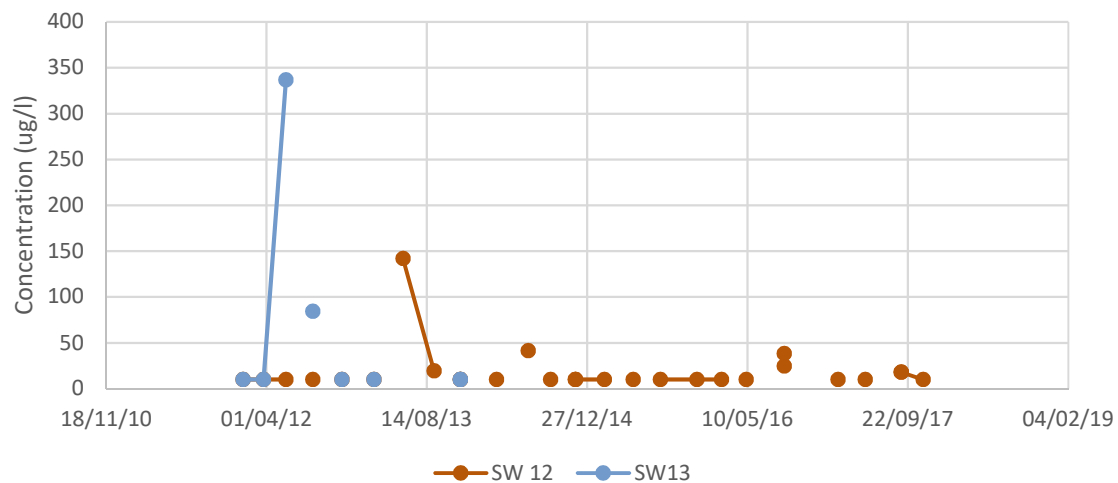
Manganese: Up gradient



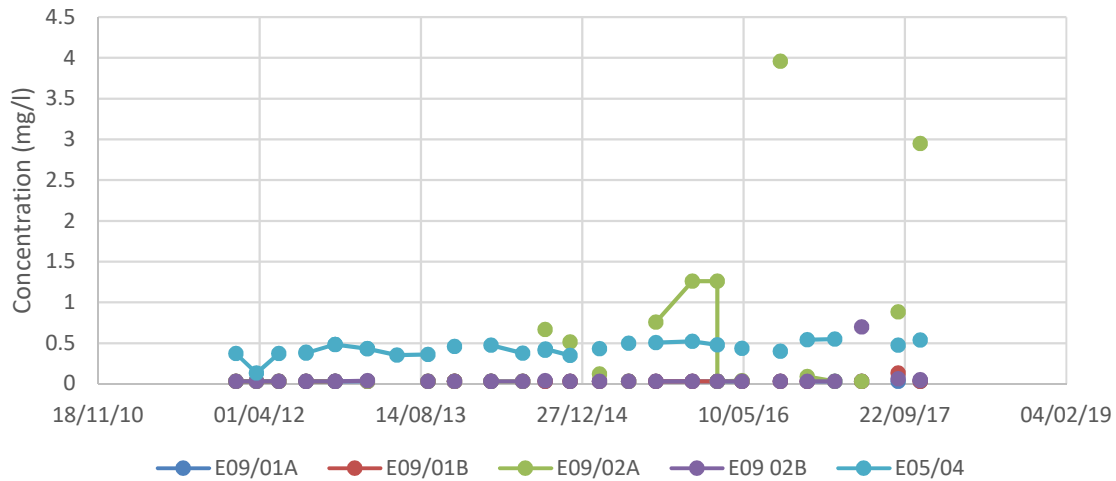
Manganese: Down gradient



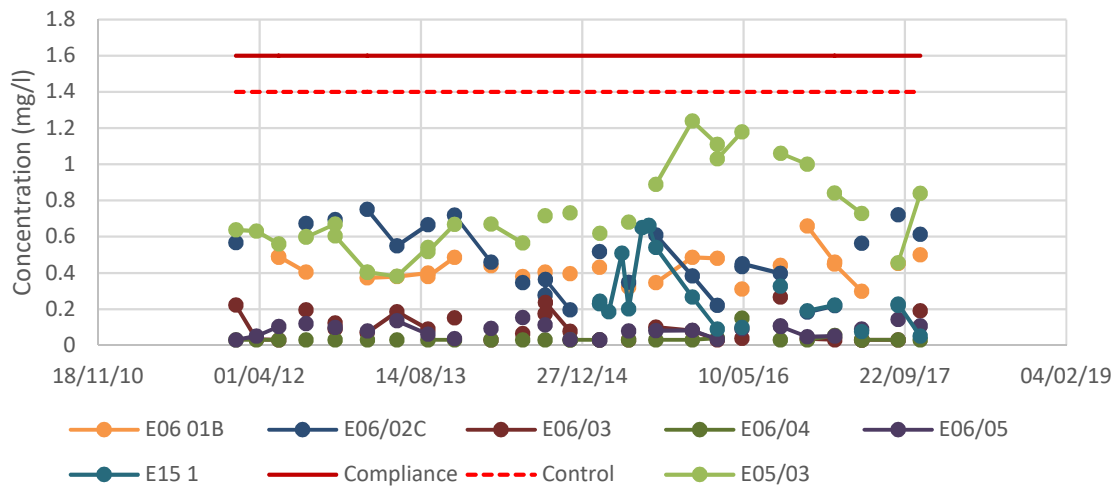
Manganese : Surface water



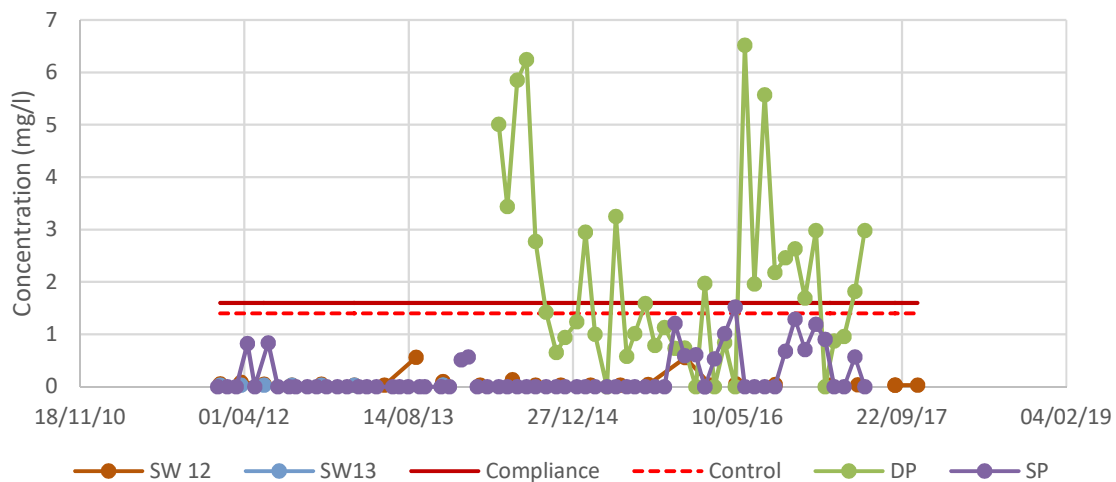
Ammoniacal Nitrogen: Up gradient



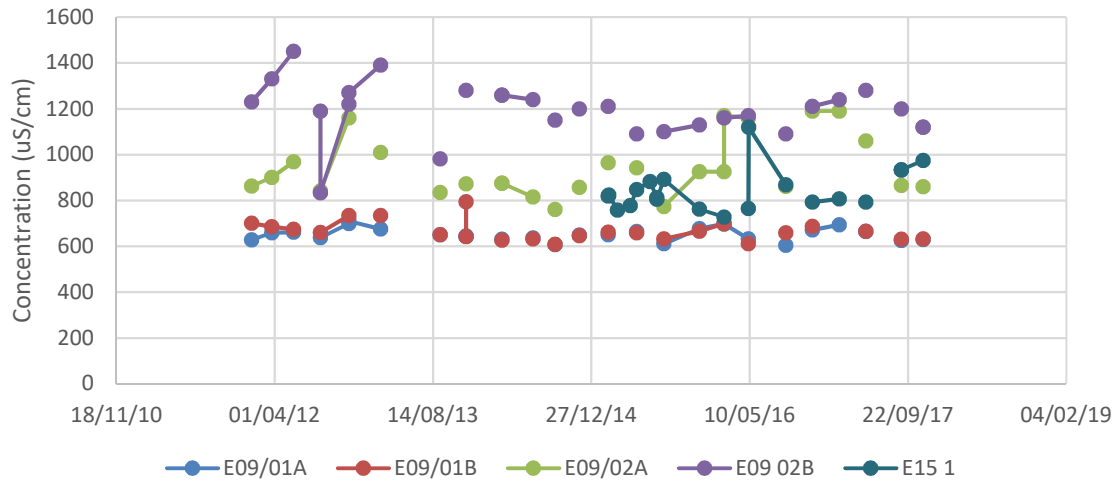
Ammoniacal Nitrogen: Down gradient



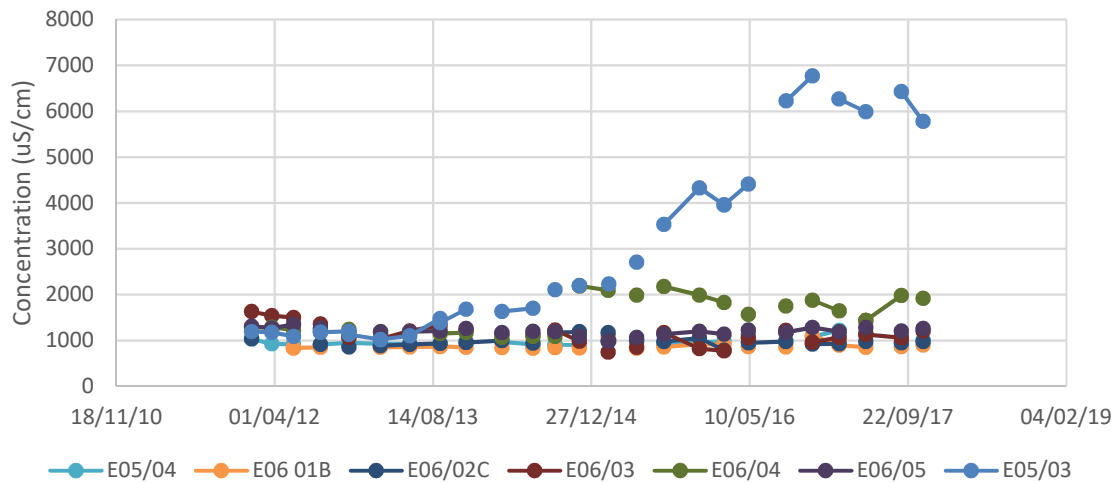
Ammoniacal Nitrogen: Surface water



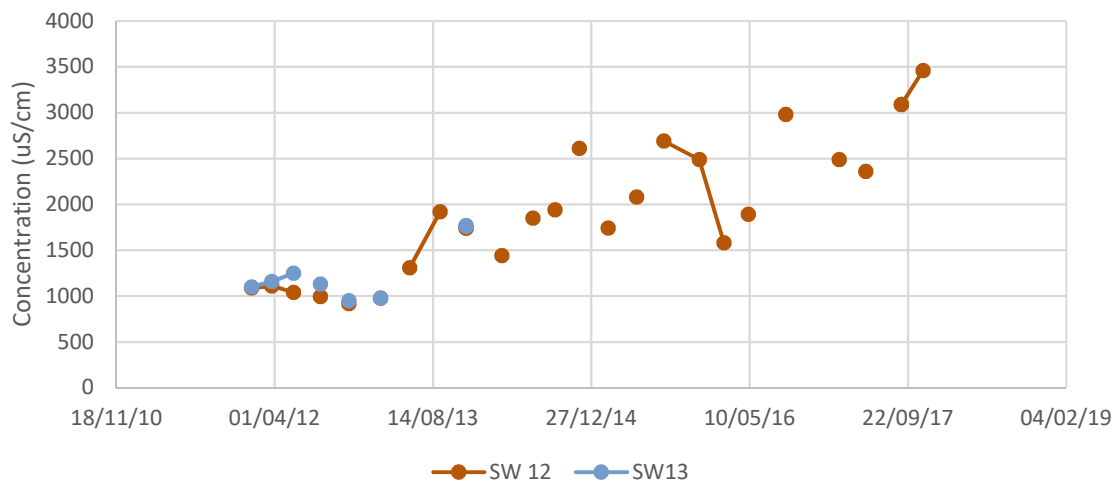
Conductivity: Up gradient

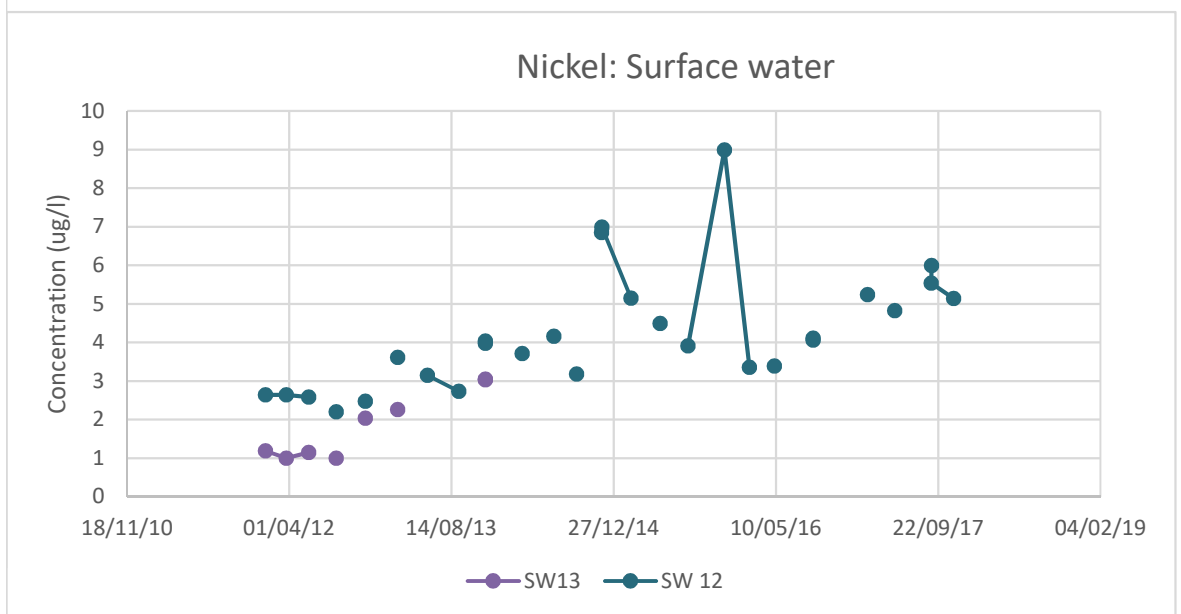
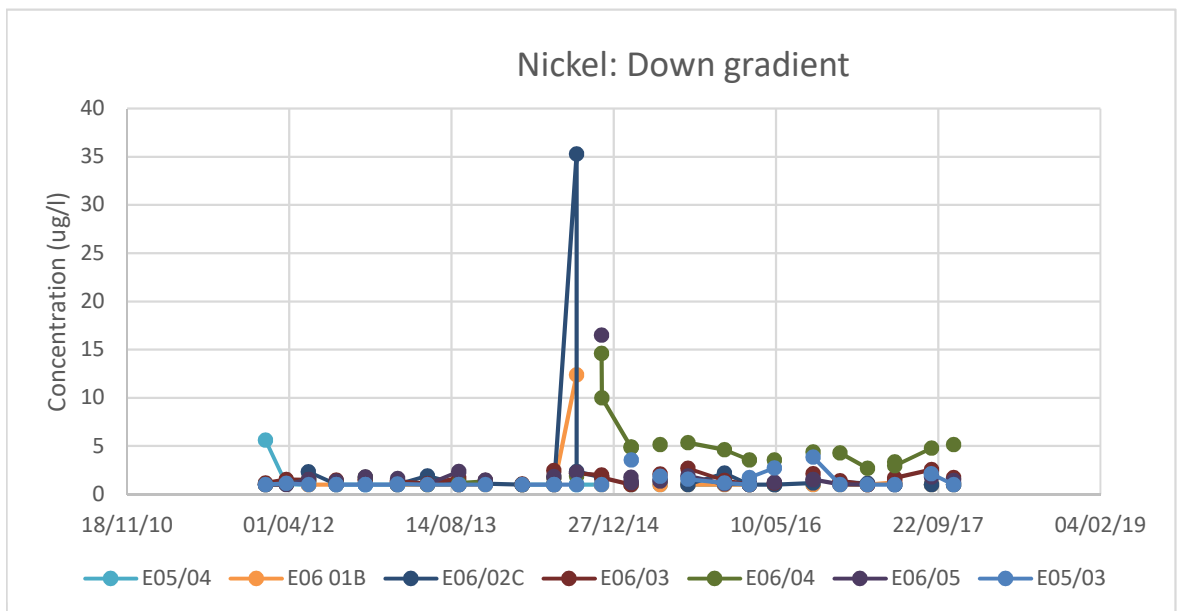
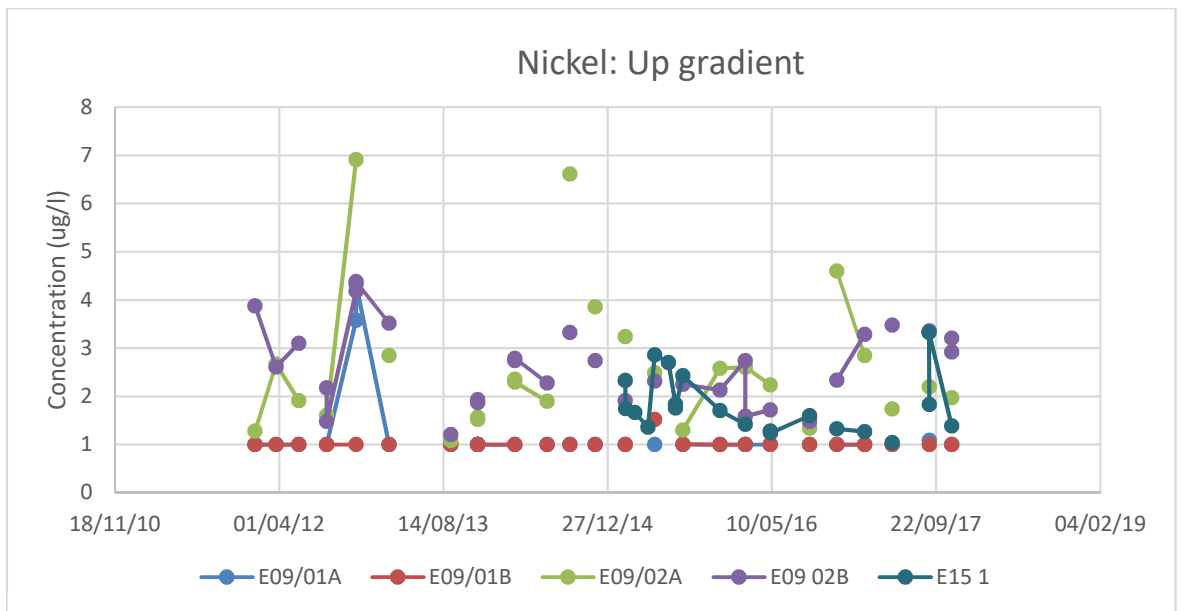


Conductivity: Down gradient

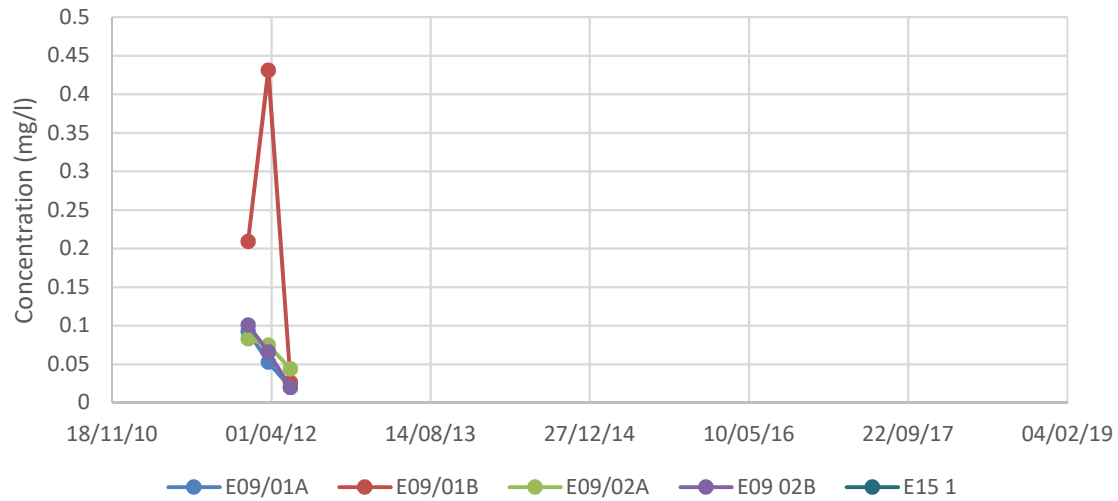


Conductivity: Surface water

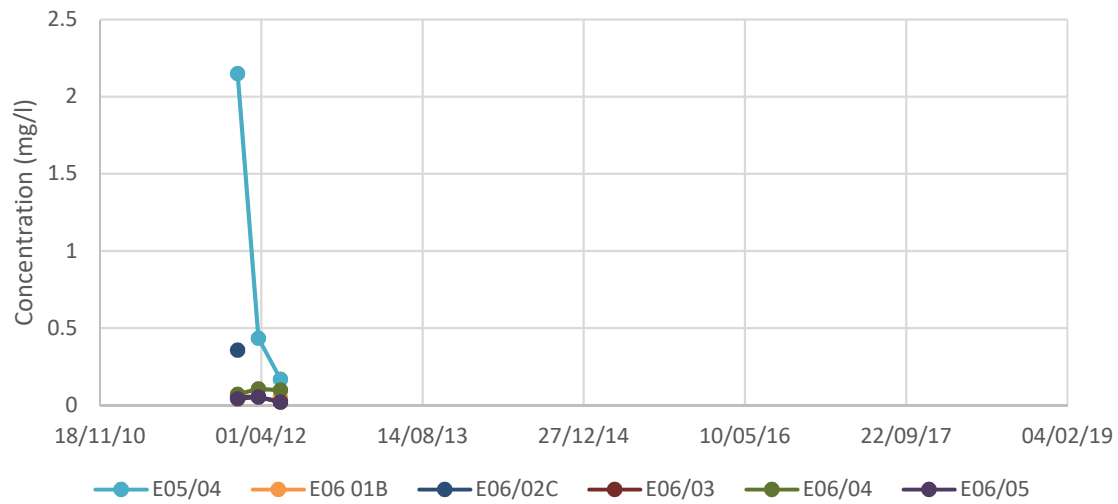




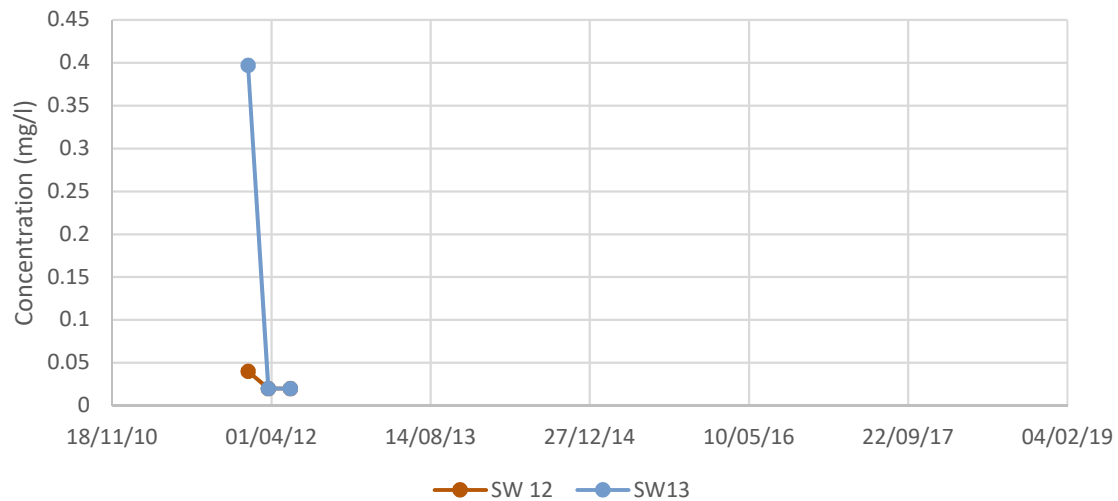
Phosphate: Up gradient



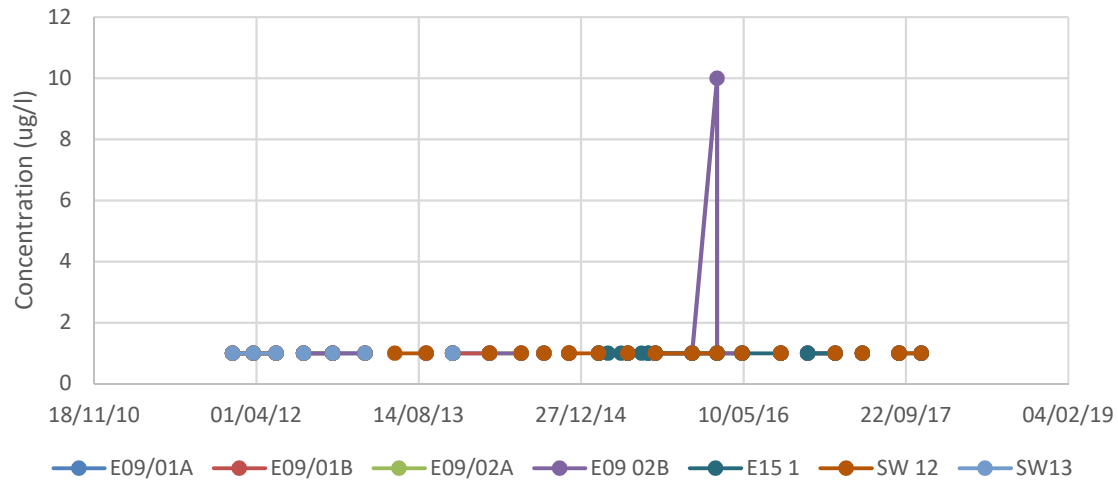
Phosphate: Down gradient



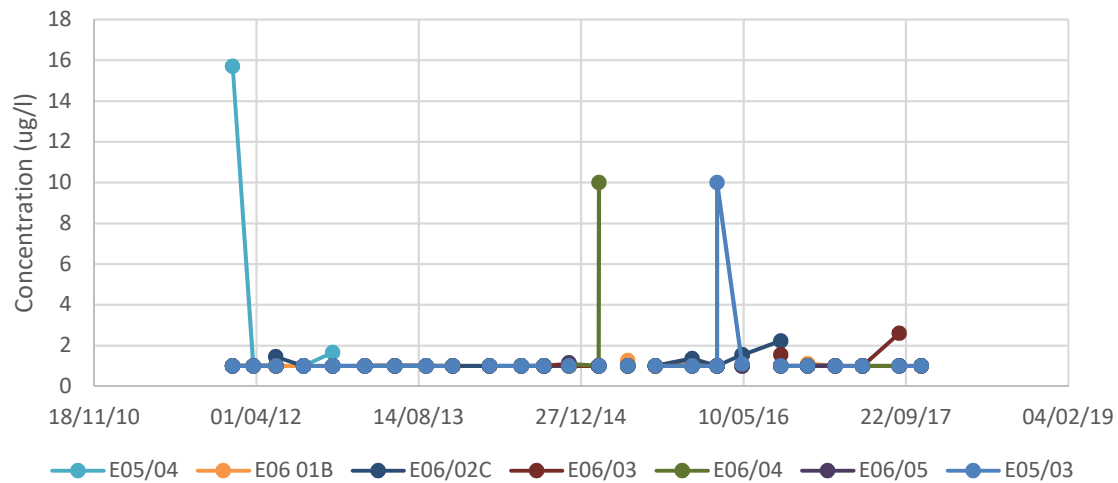
Phosphate : Surface water



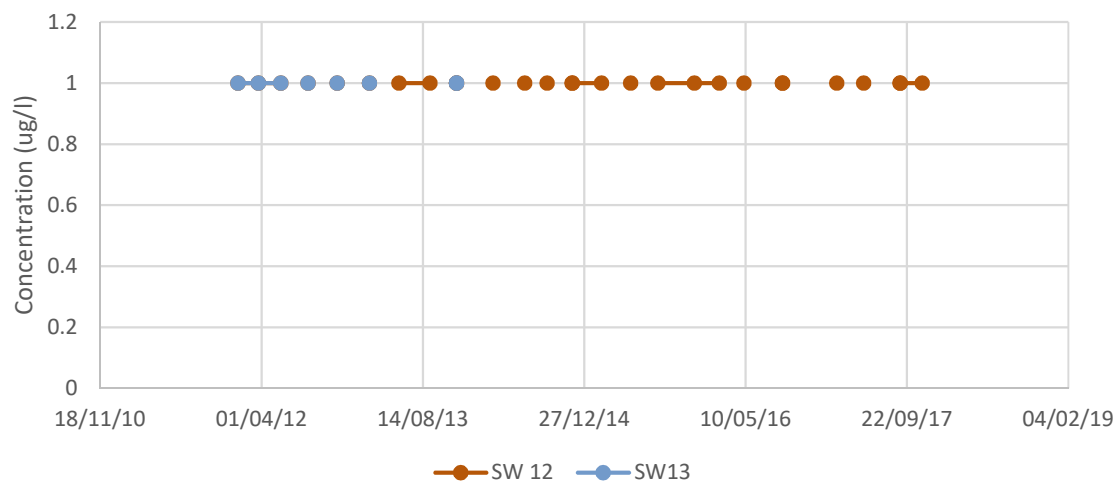
Antimony: Up gradient



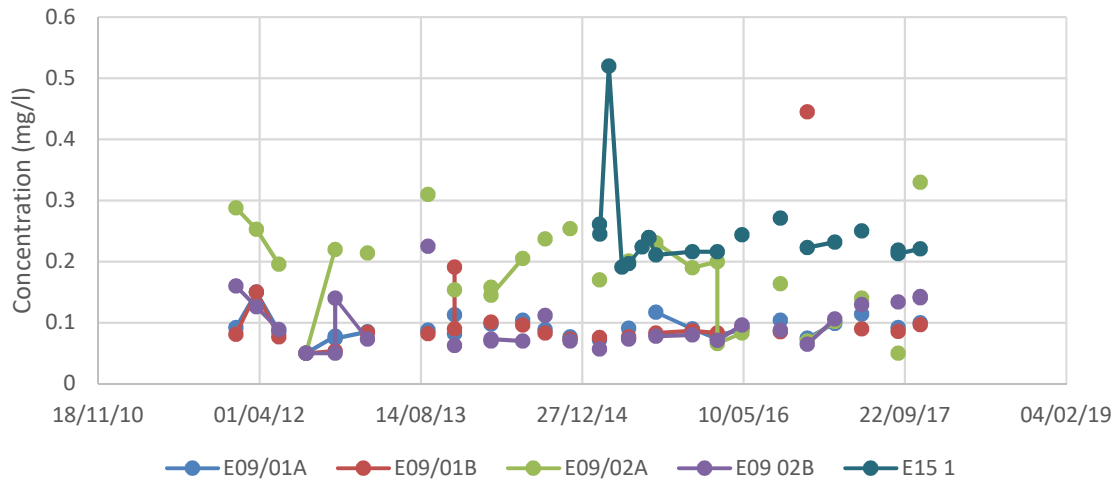
Antimony: Down gradient



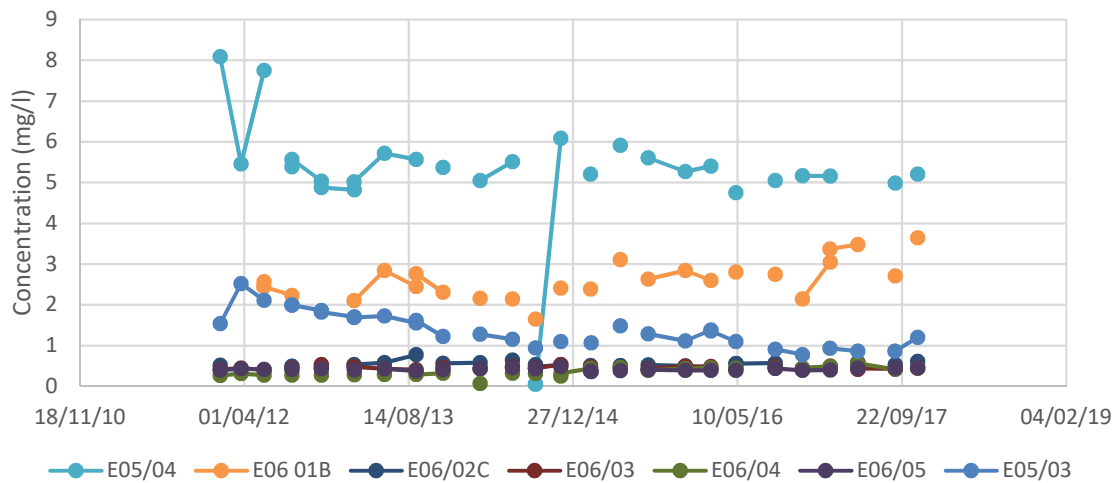
Antimony: Surface water



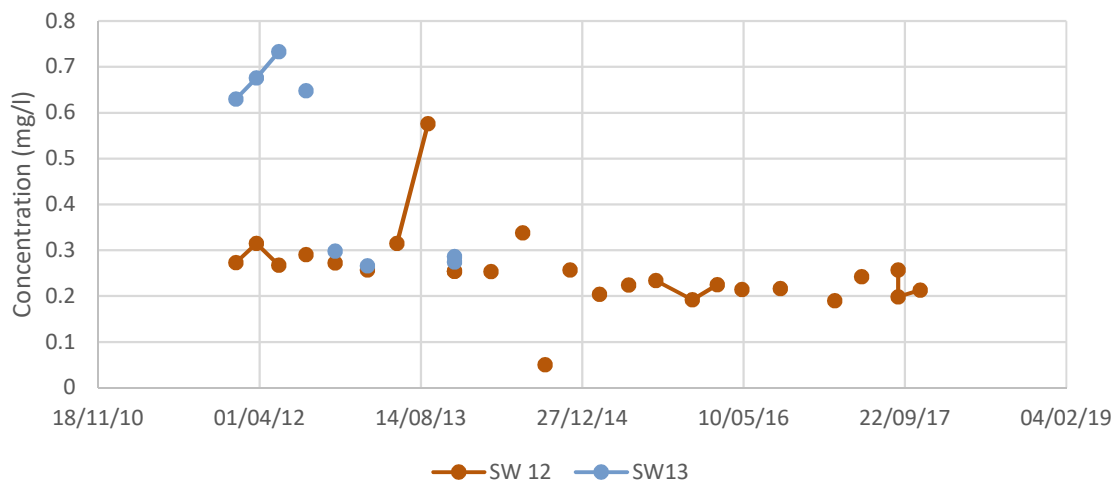
Fluoride: Up gradient

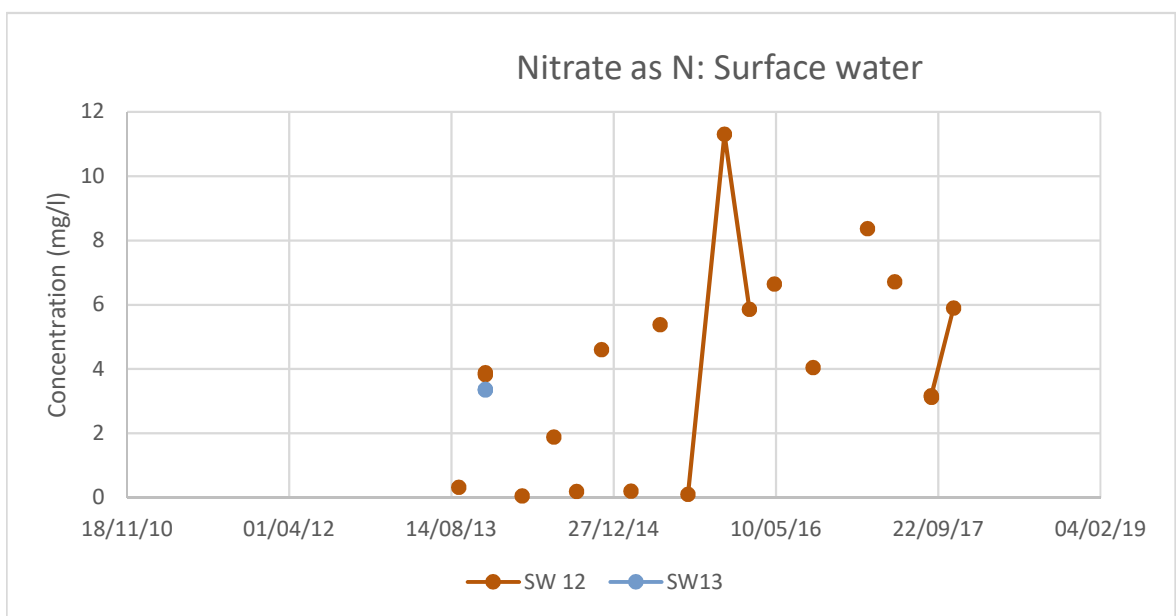
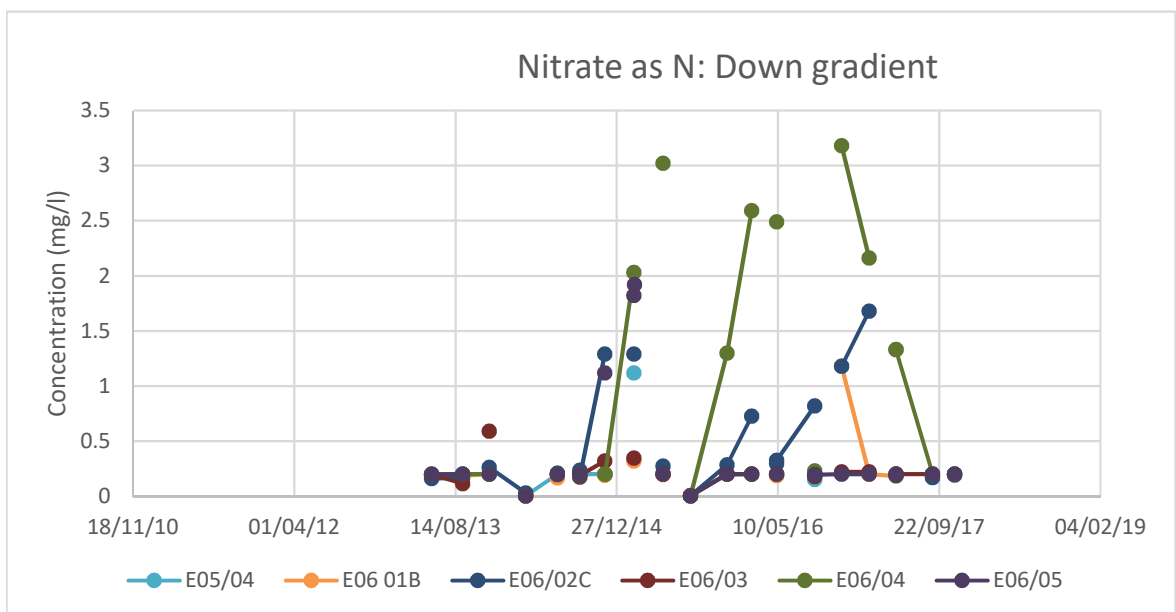
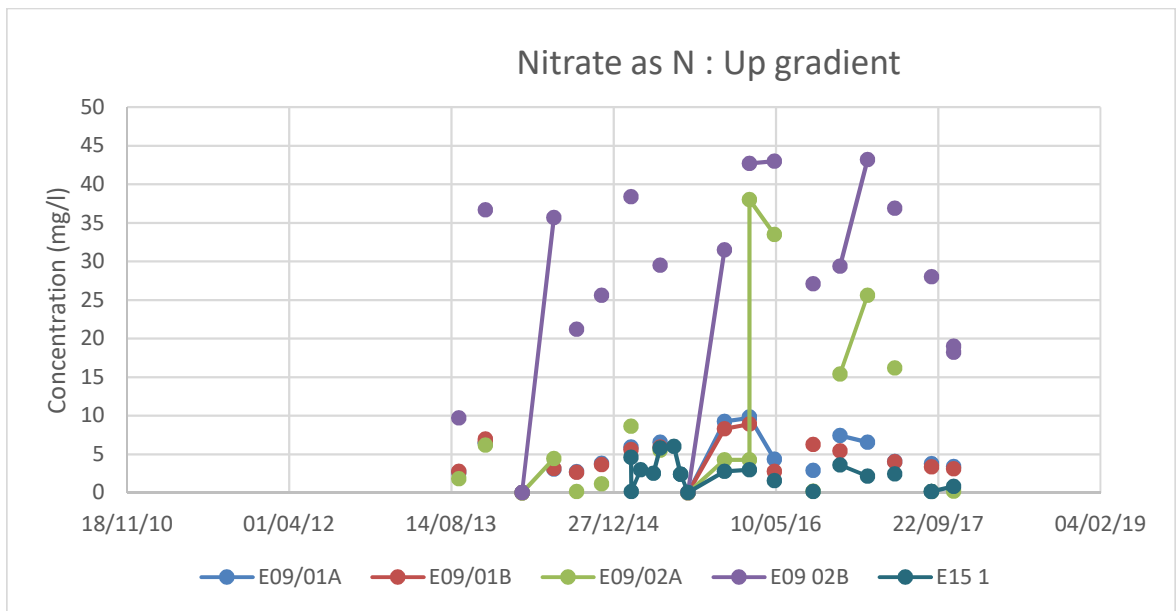


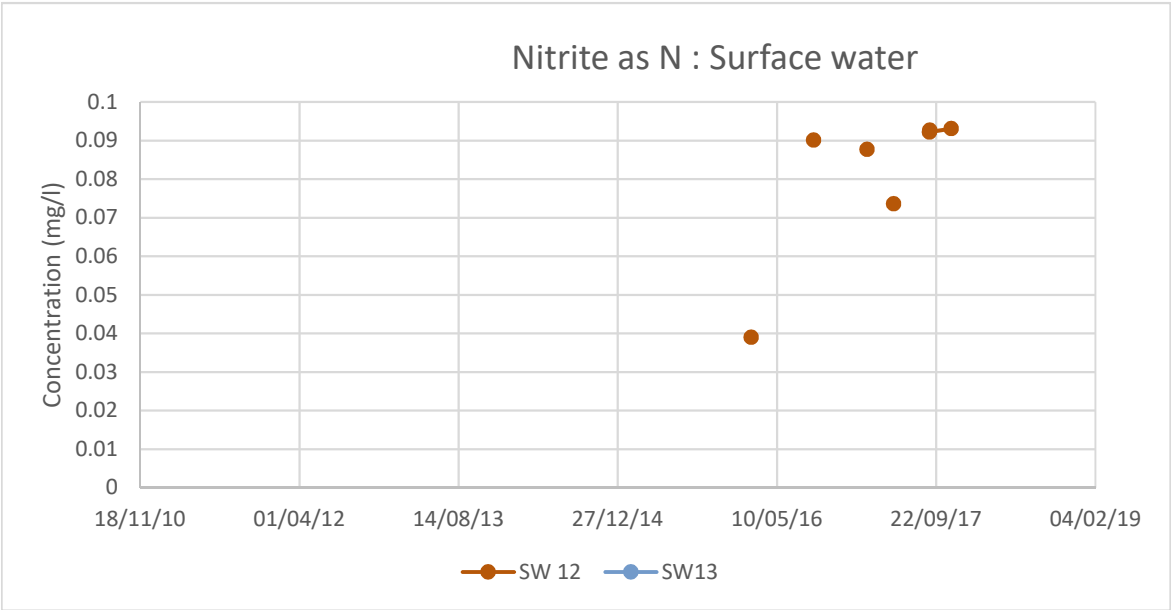
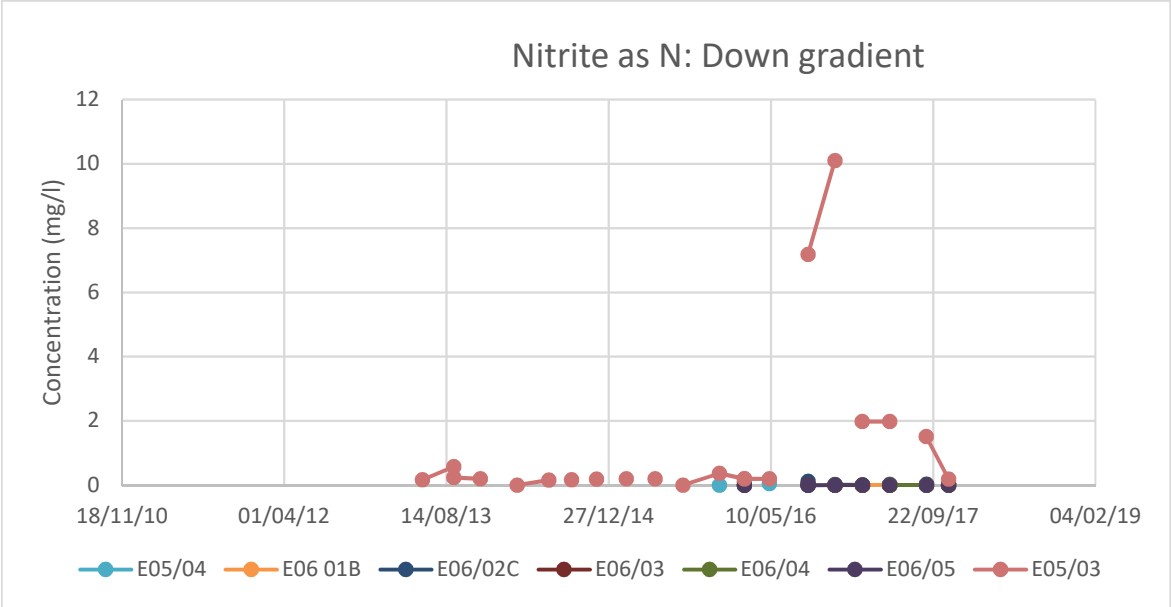
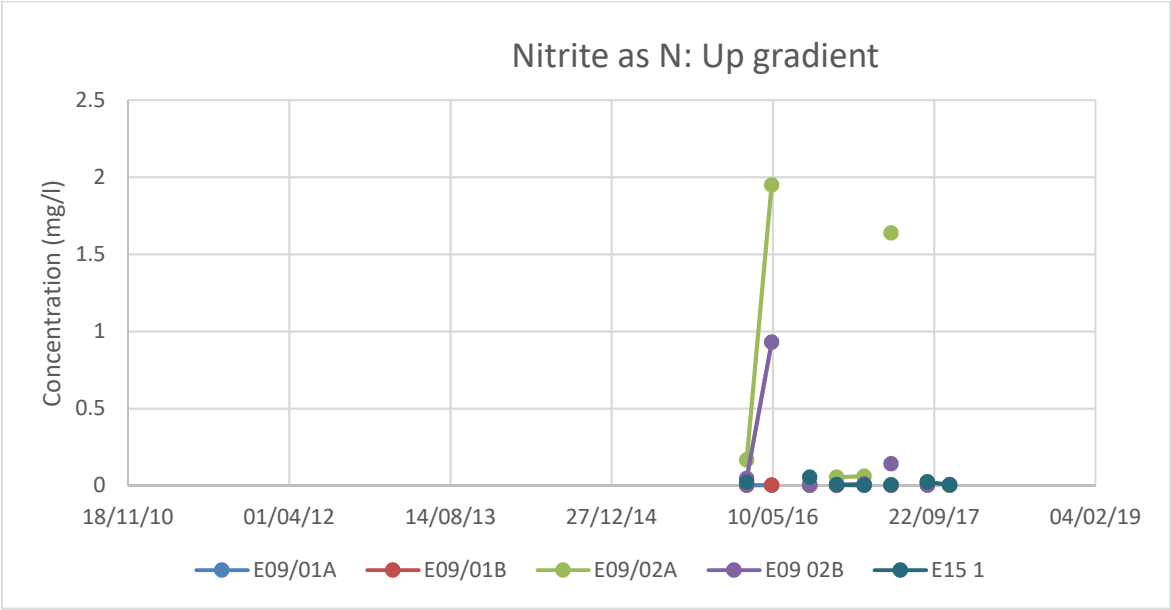
Fluoride: Down gradient



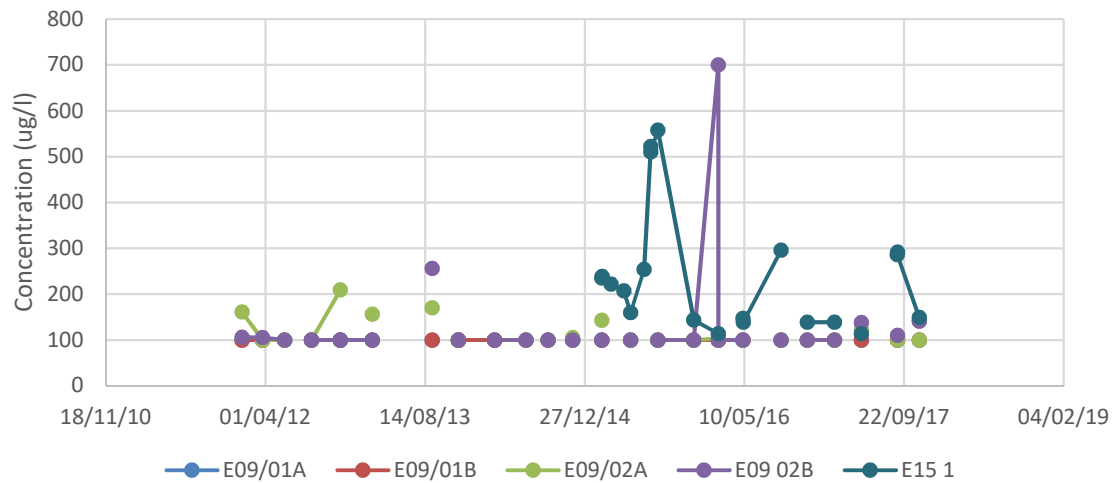
Fluoride: Surface water



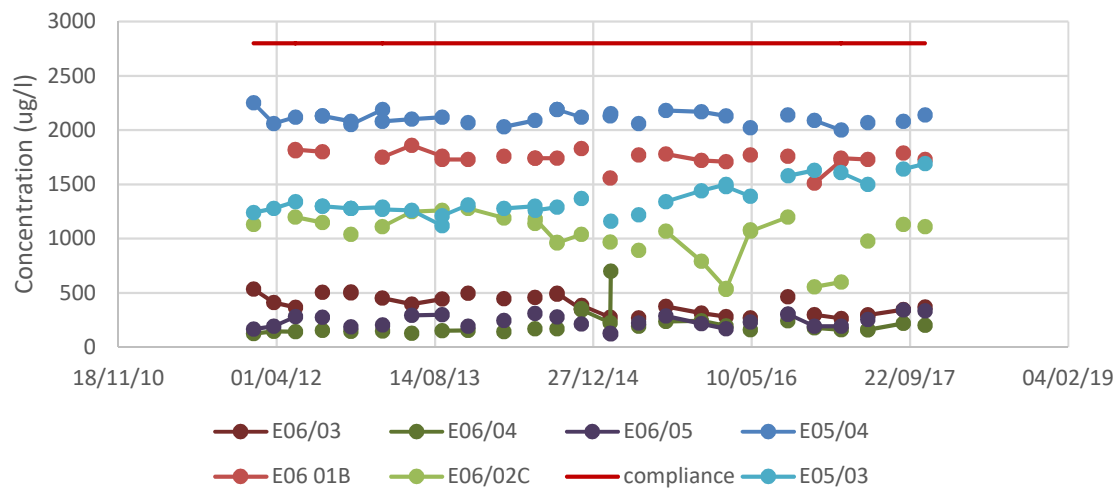




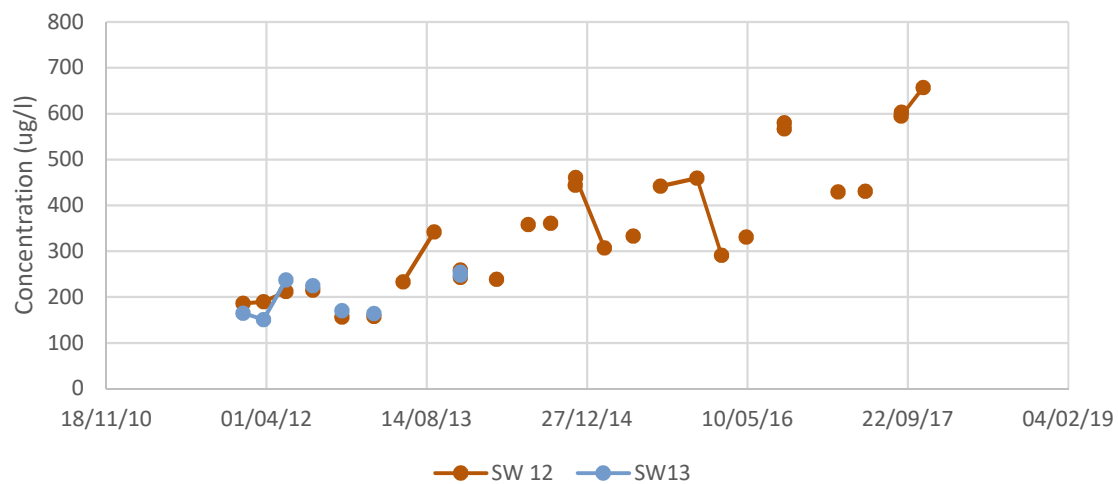
Boron Up gradient

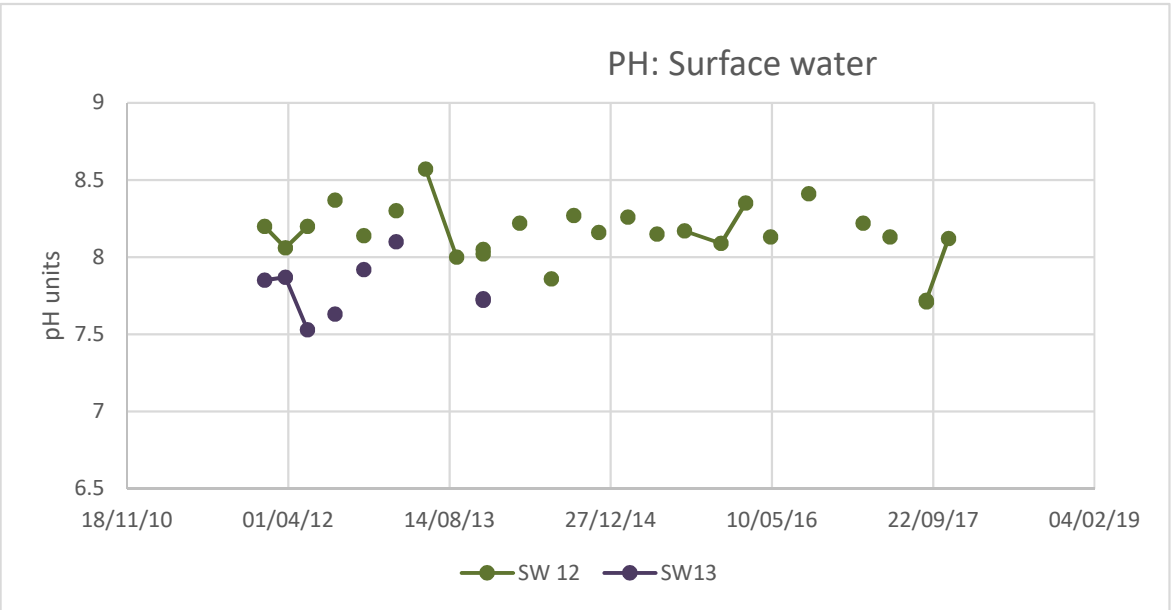
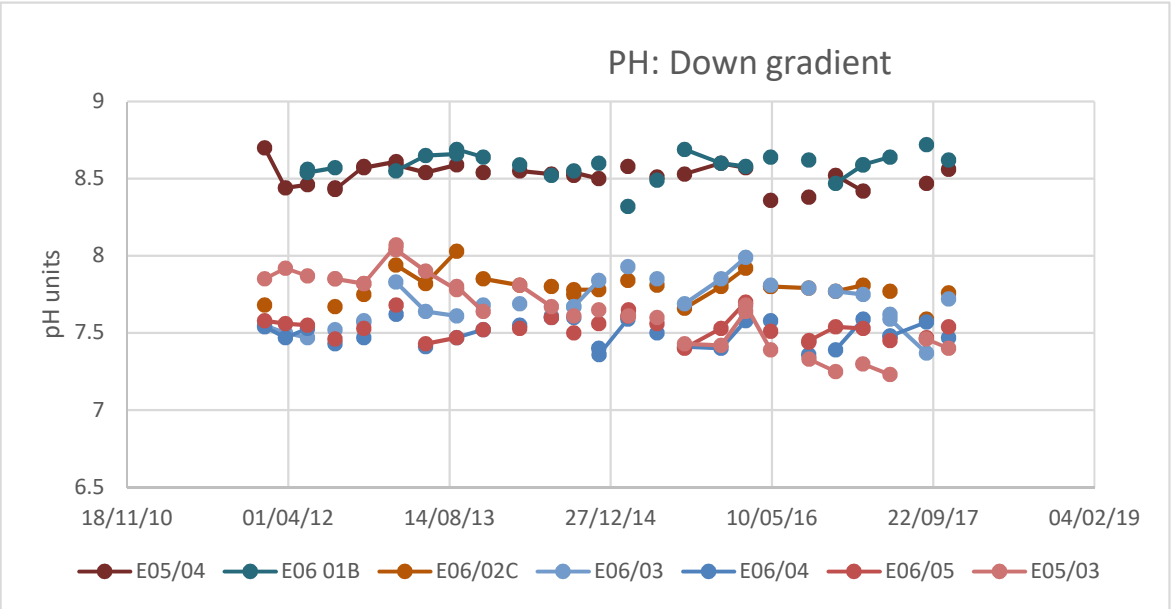
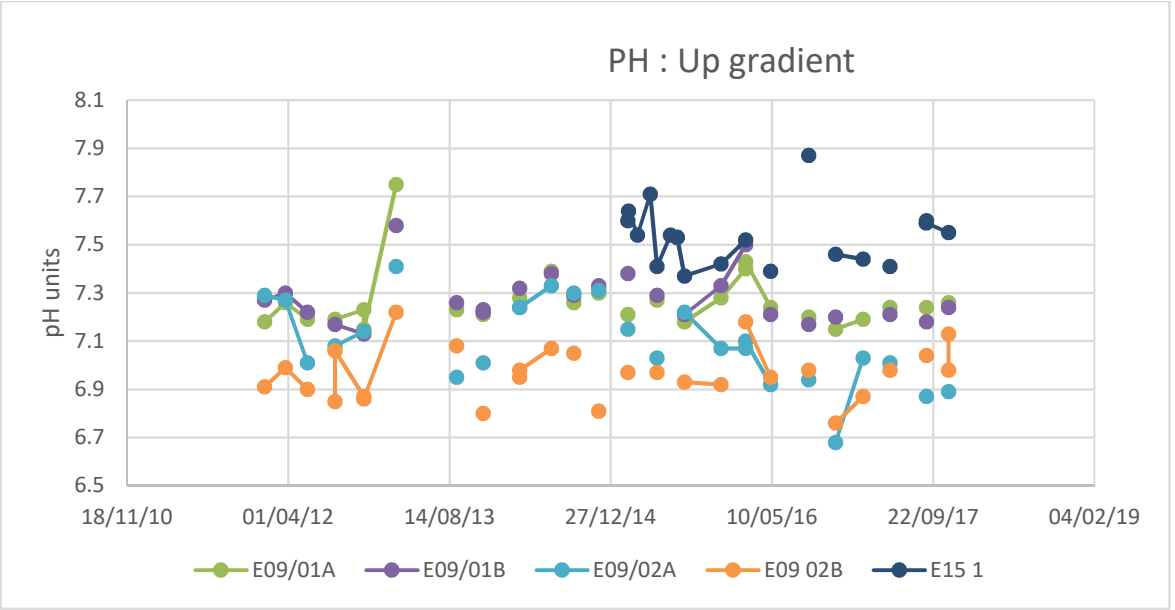


Boron: Down gradient

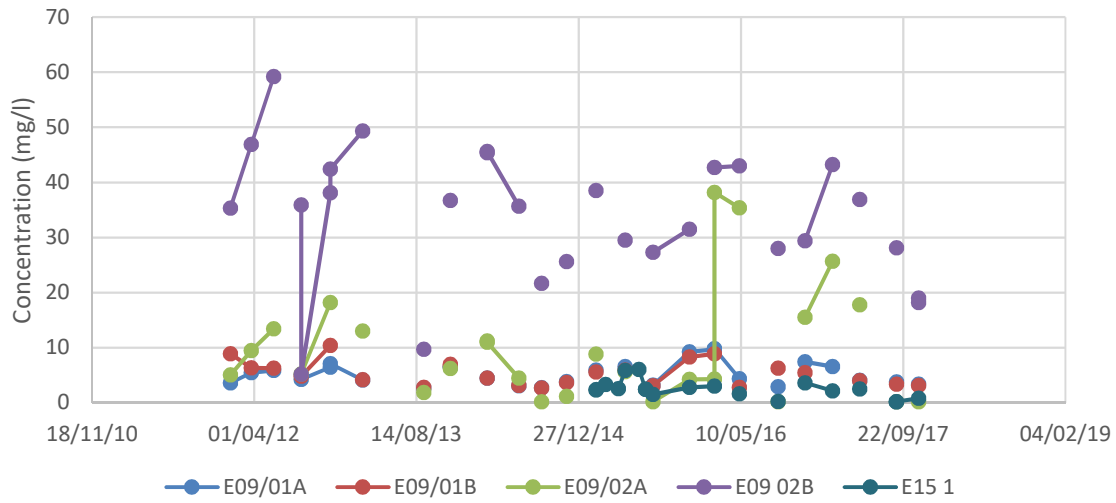


Boron Surface Water

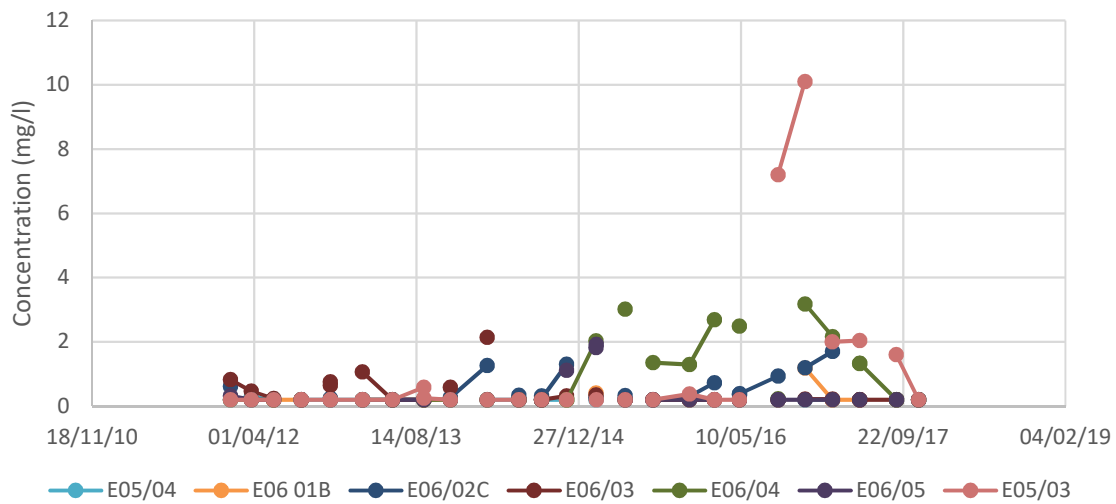




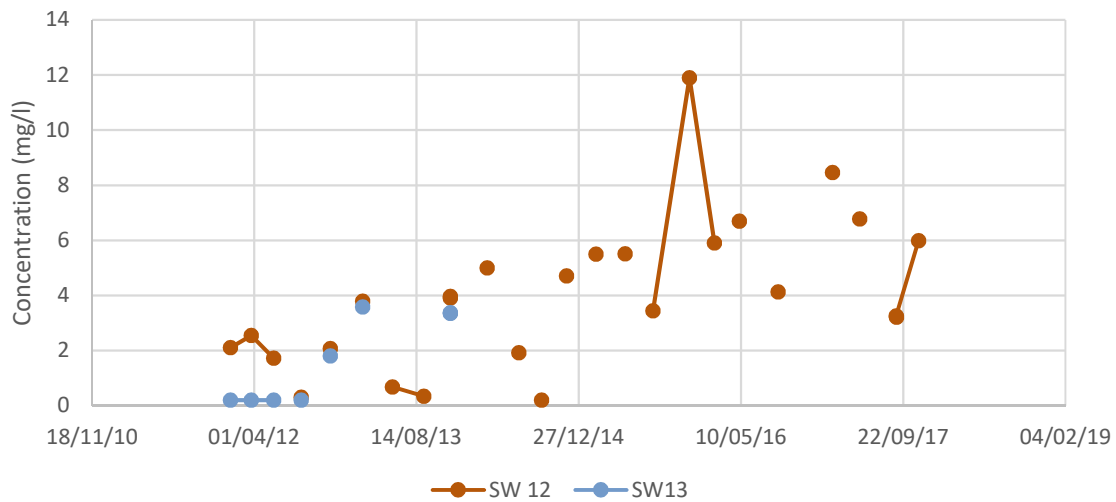
Total Oxidised Nitrogen as N: Up gradient



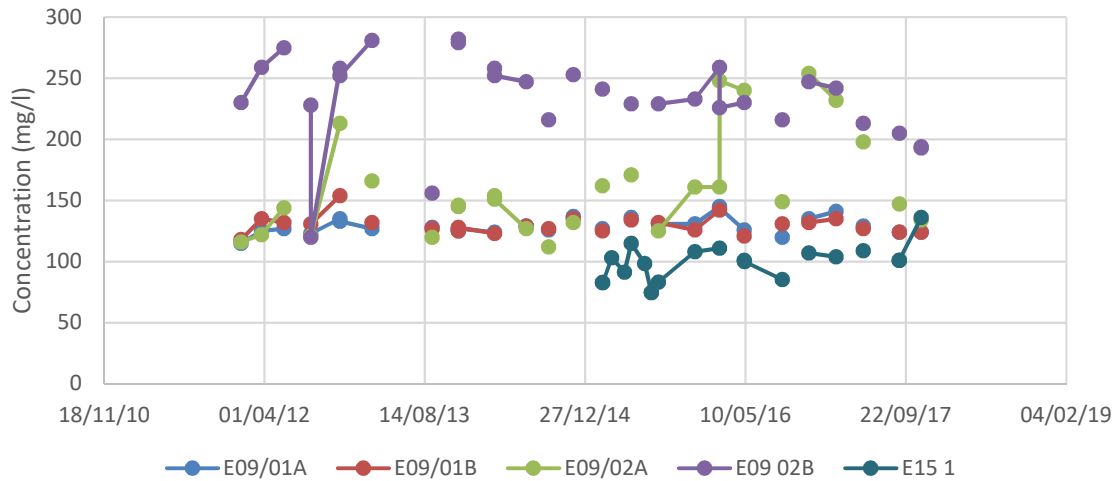
Total Oxidised Nitrogen as N: Down gradient



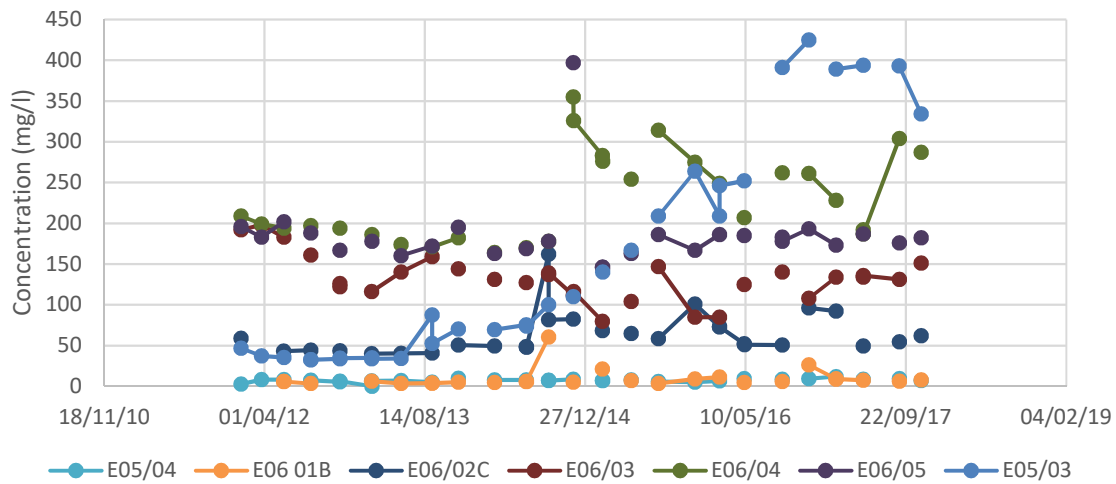
Total Oxidised Nitrogen as N: Surface water



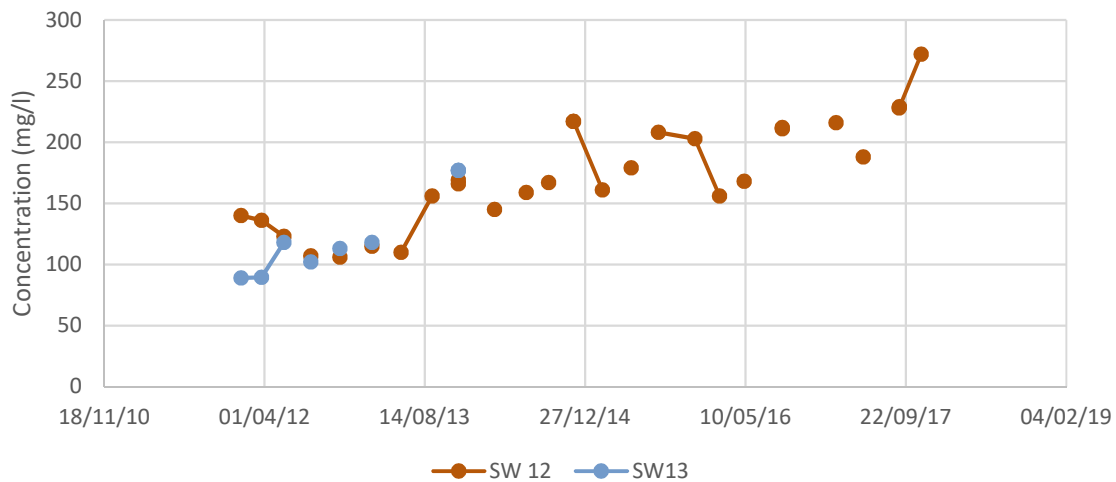
Calcium: Up gradient



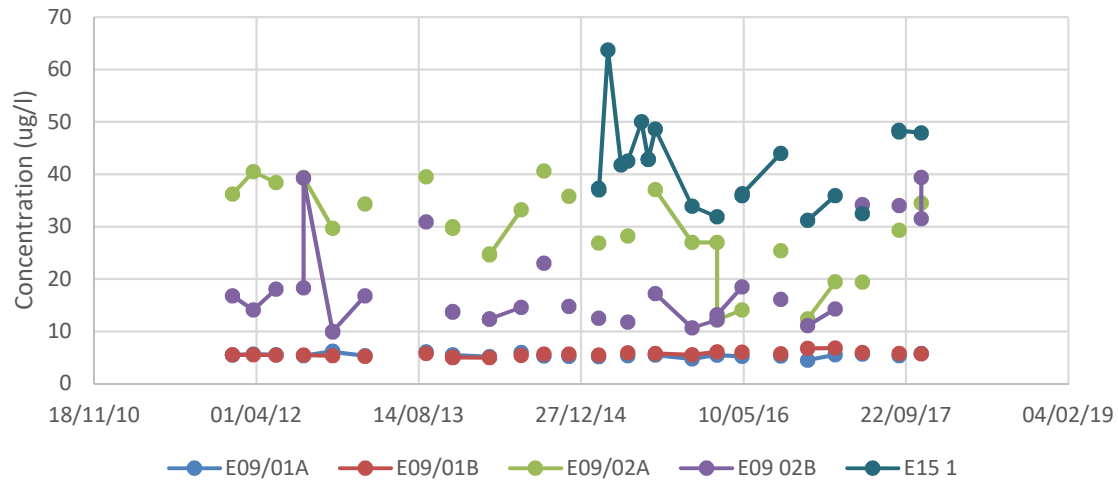
Calcium: Down gradient



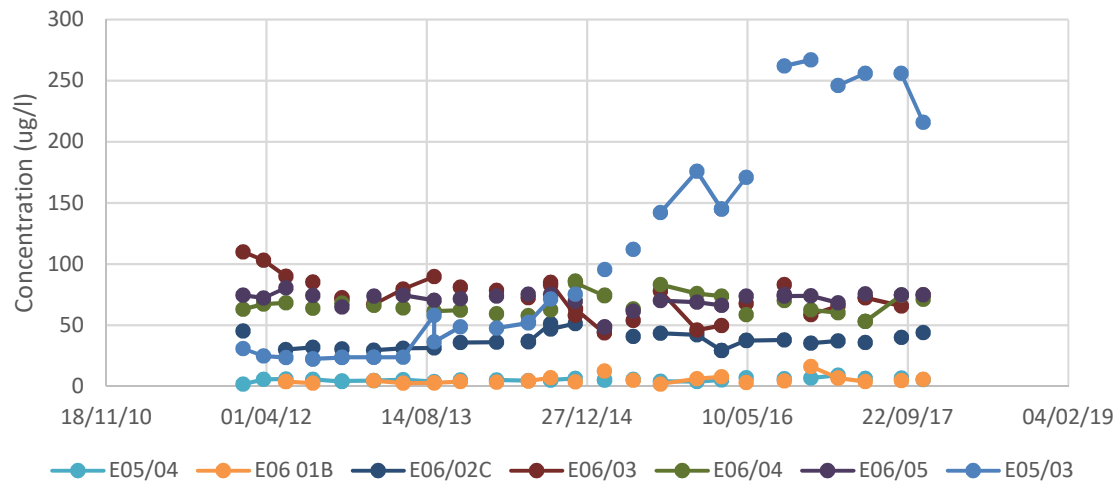
Calcium : Surface water



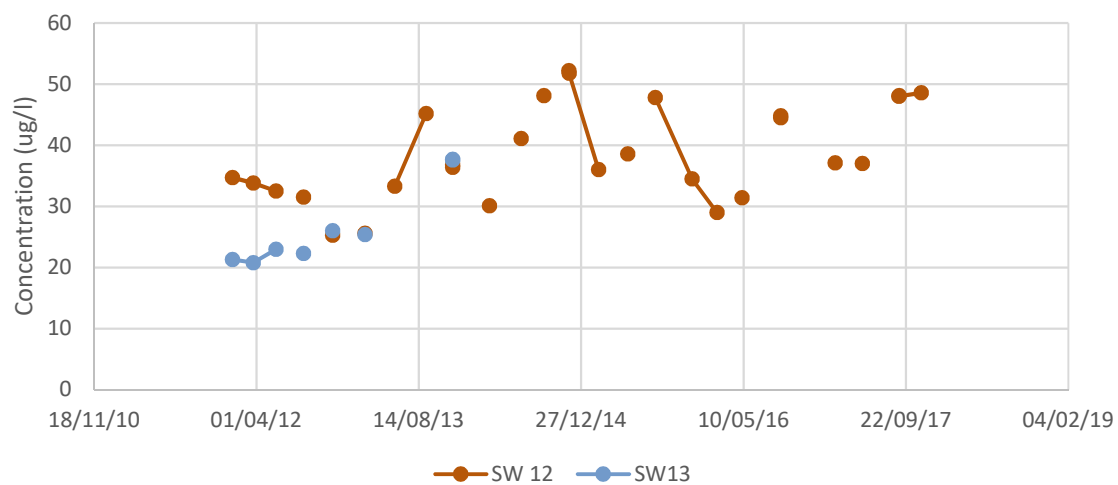
Magnesium: Up gradient



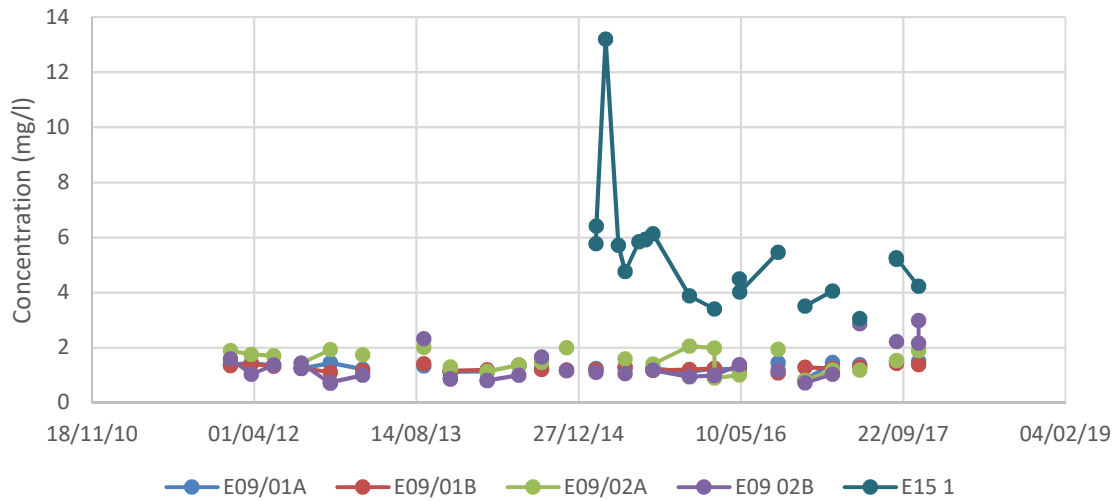
Magnesium: Down gradient



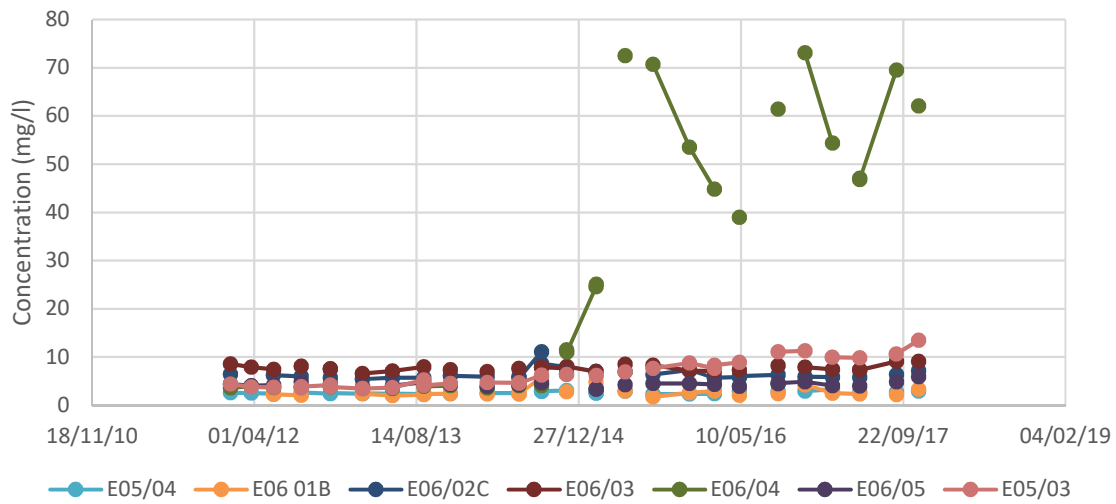
Magnesium: Surface water



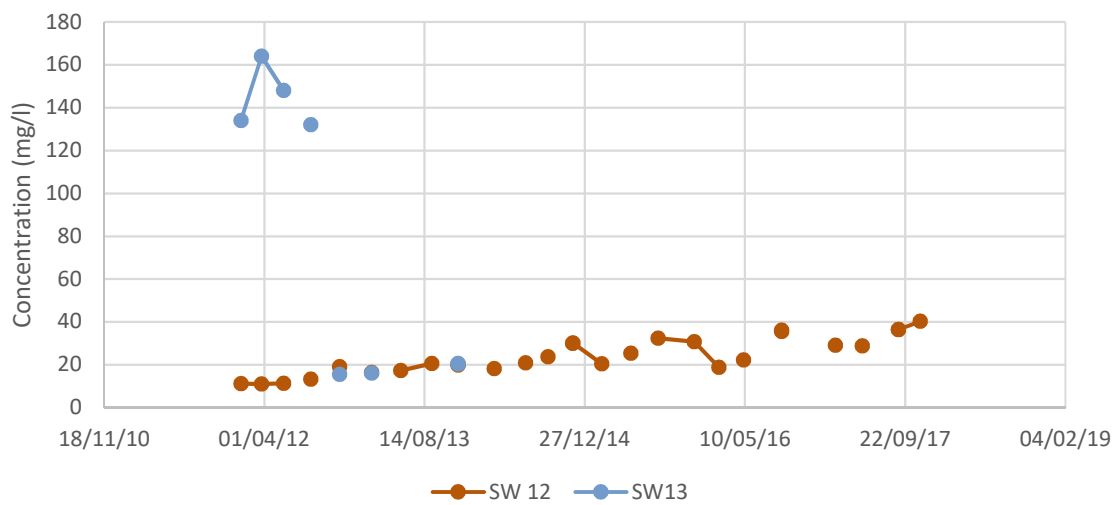
Potassium: Up gradient



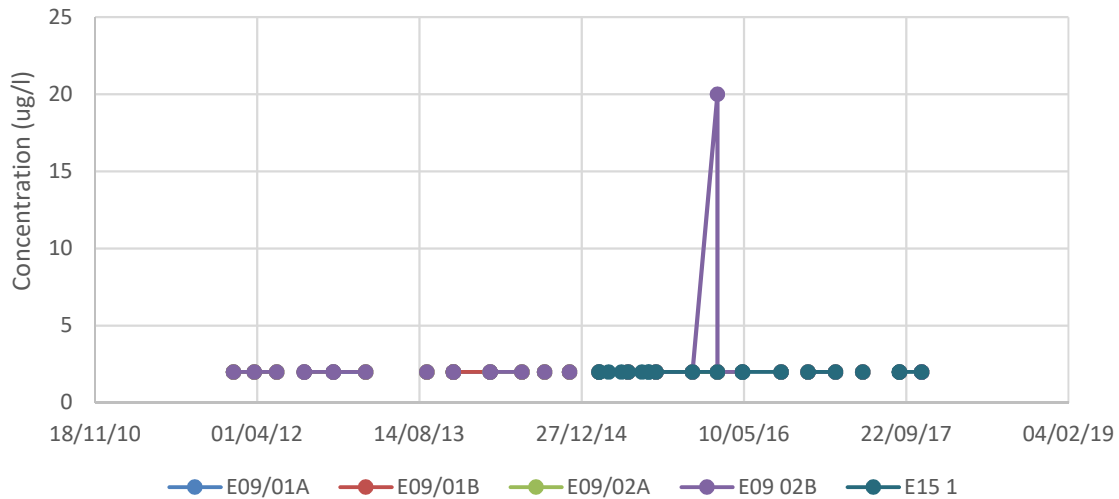
Potassium: Down gradient



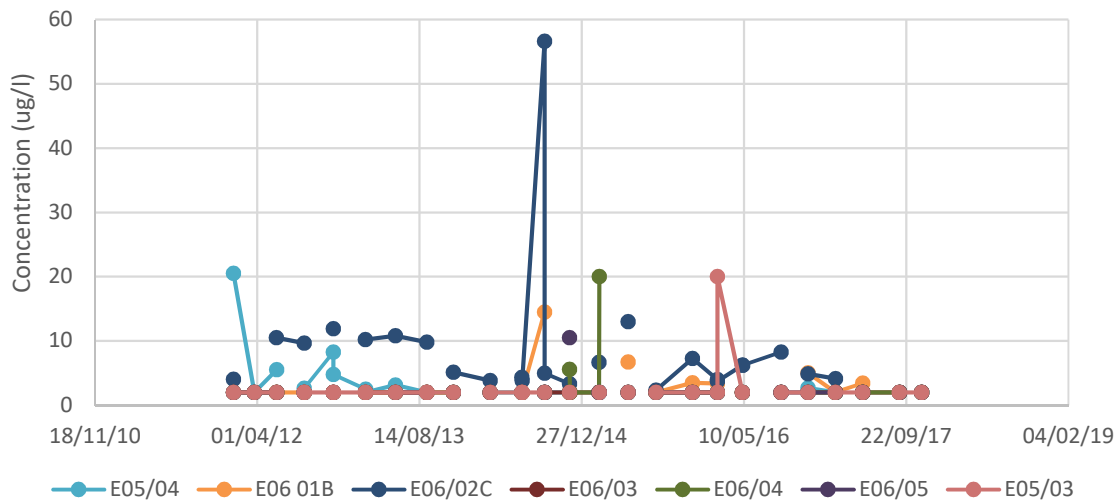
Potassium: Surface water



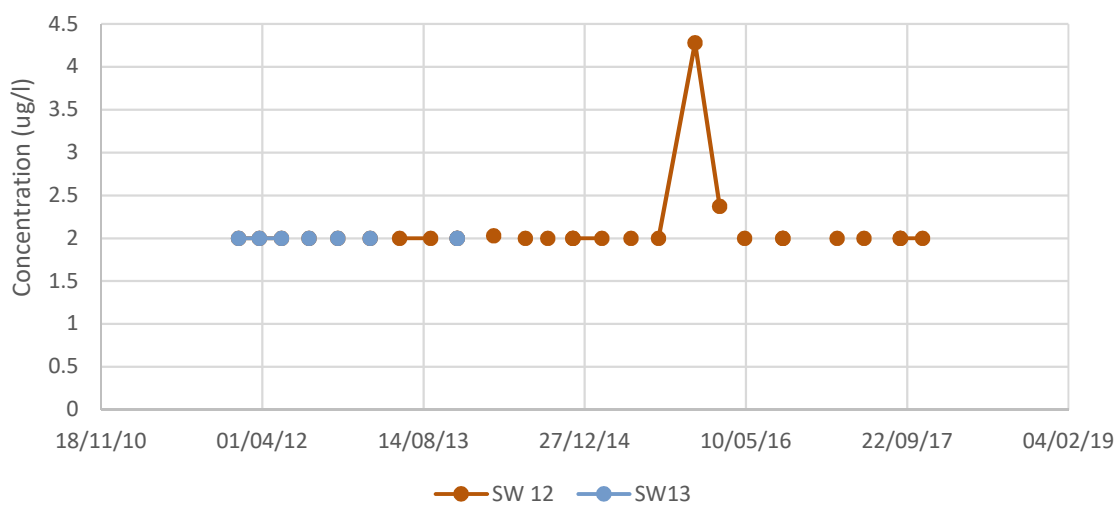
Vanadium: Up gradient



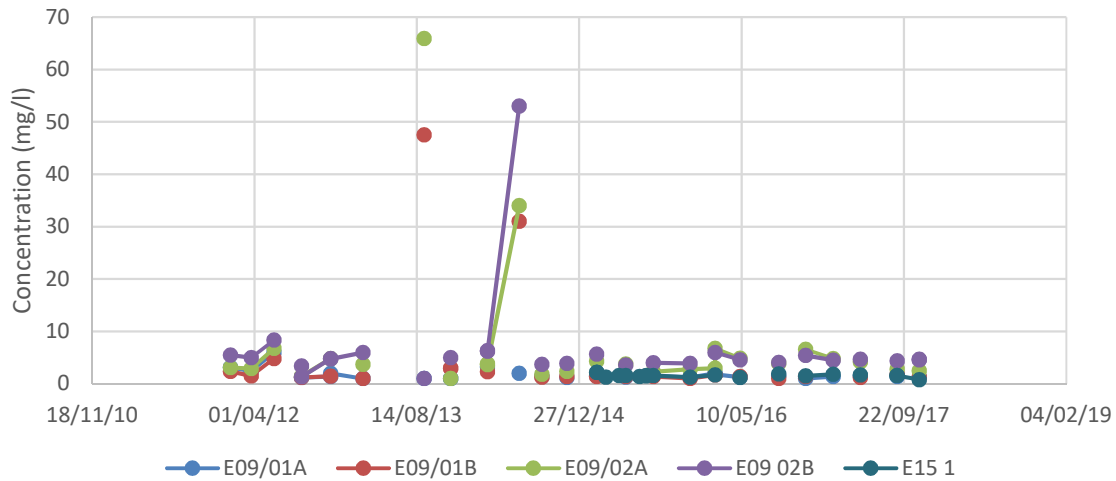
Vanadium : Down gradient



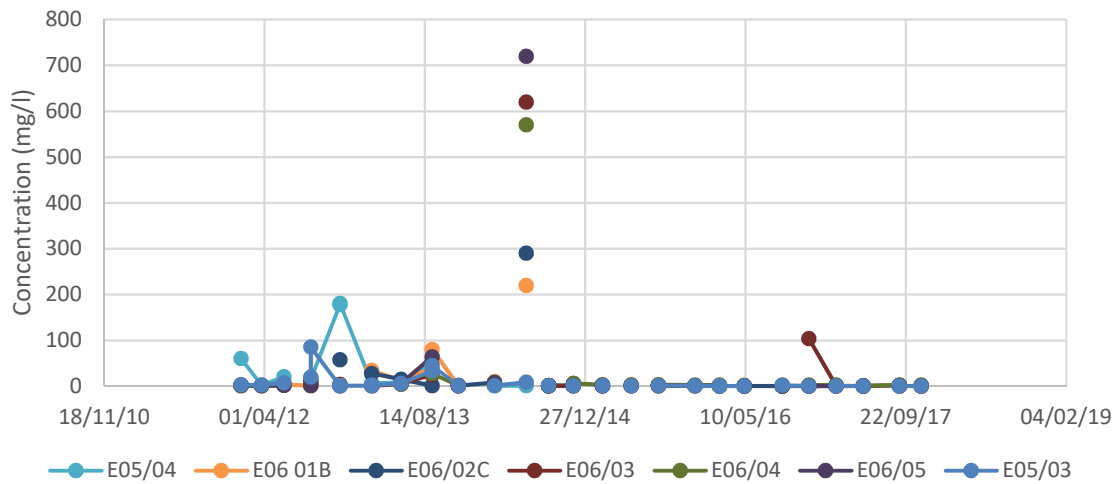
Vanadium : Surface water



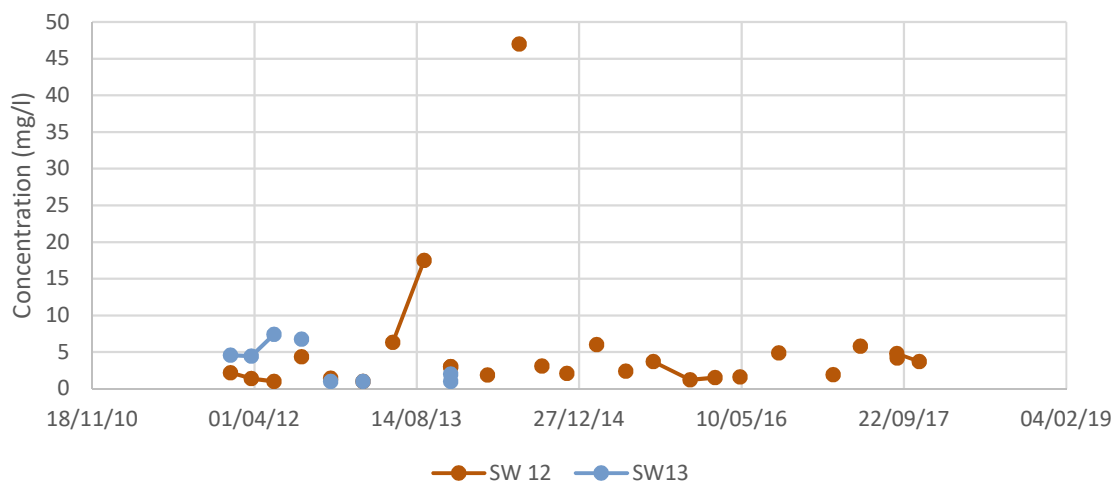
Total Organic Carbon: Up gradient

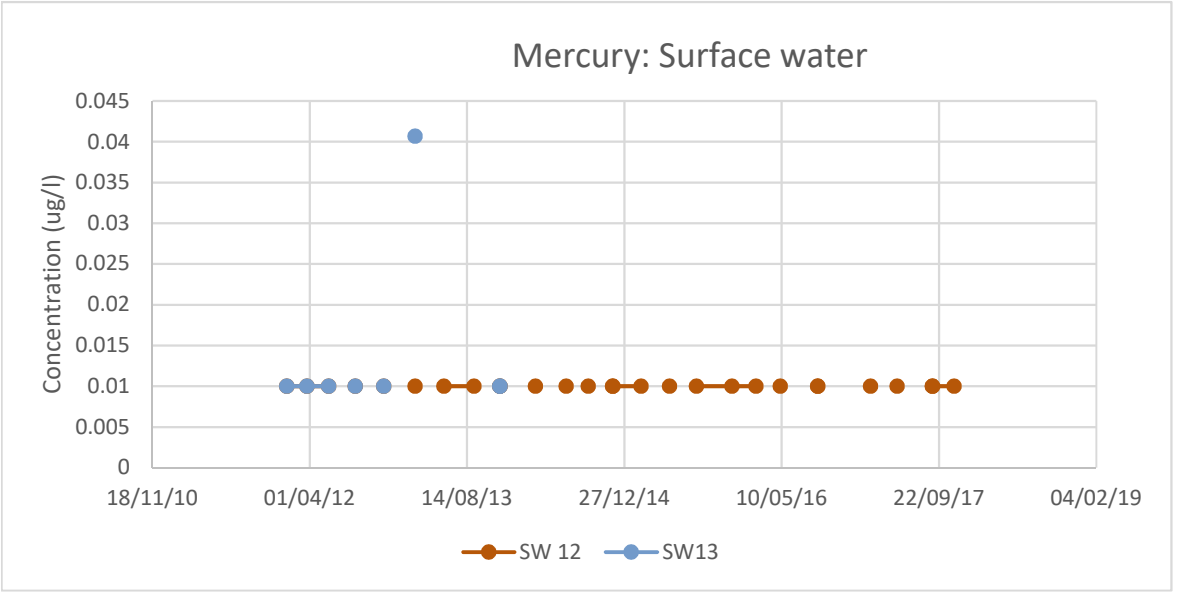
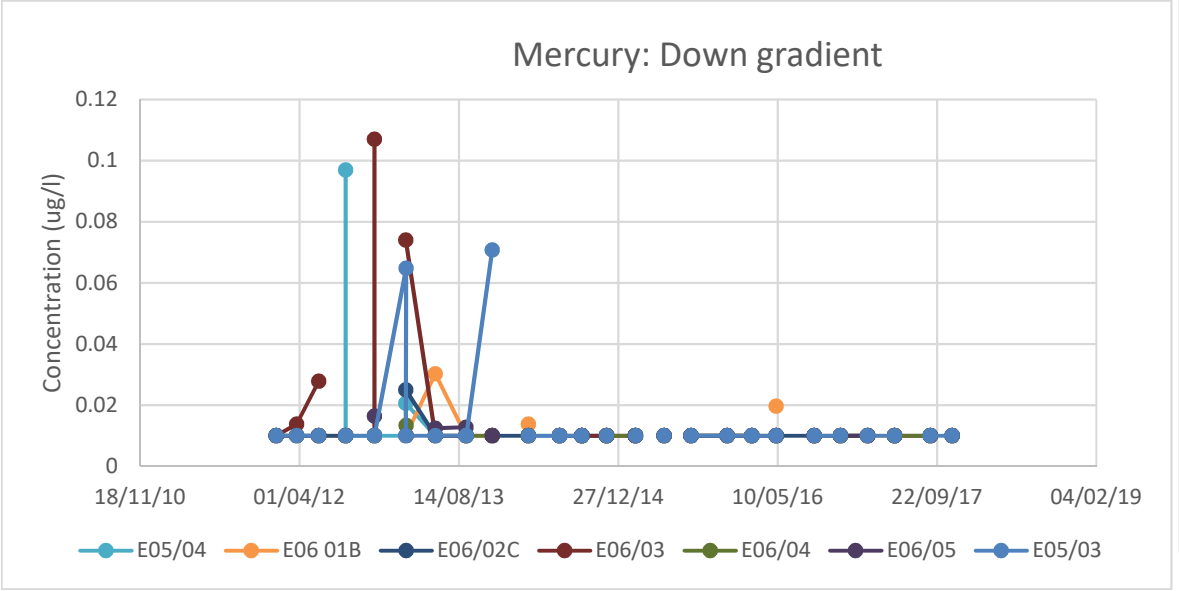
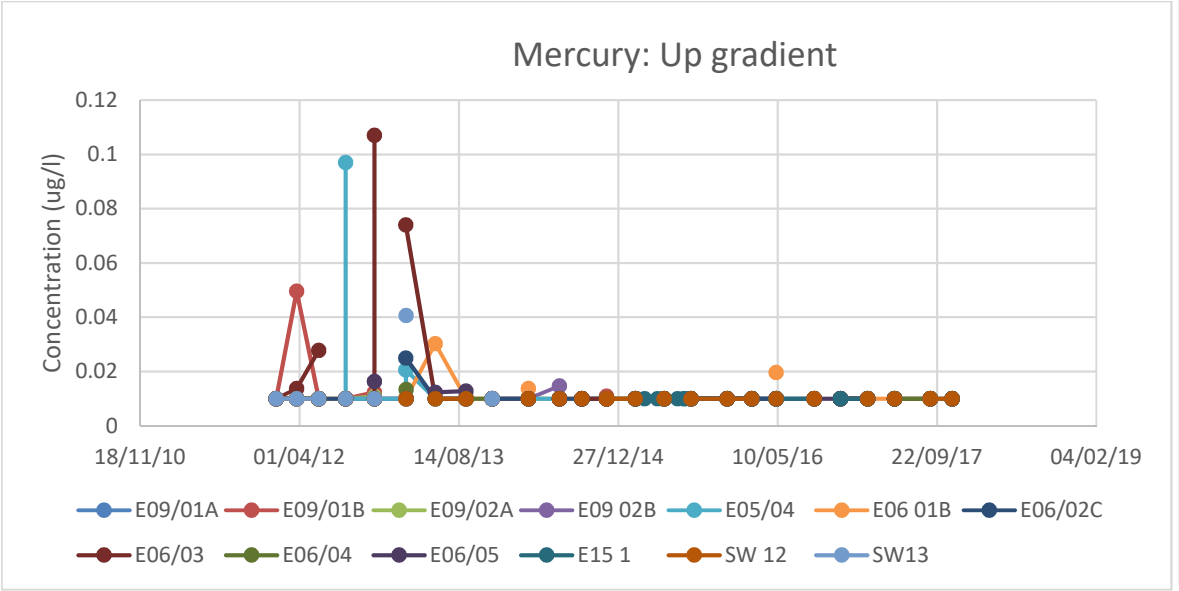


Total Organic Carbon: Down gradient

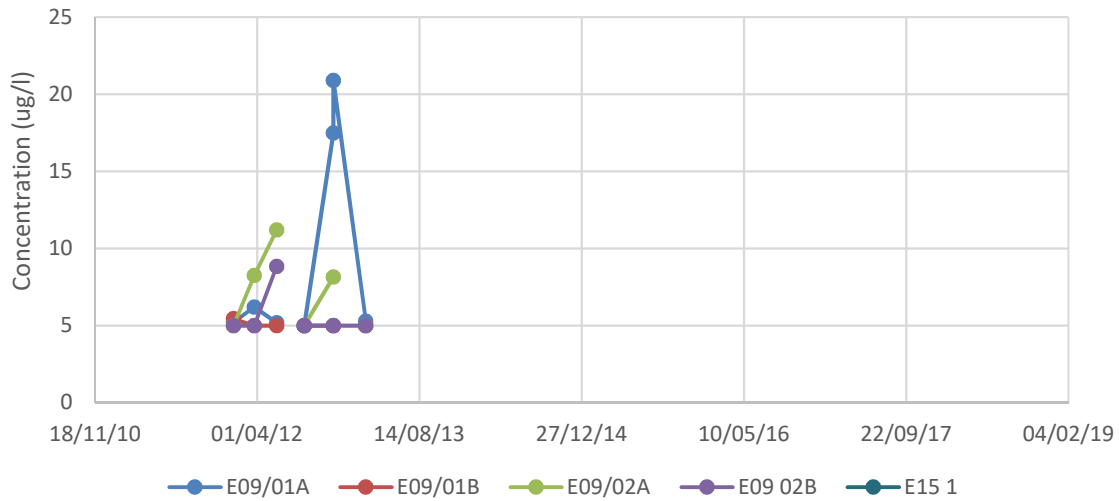


Total Organic Carbon : Surface water

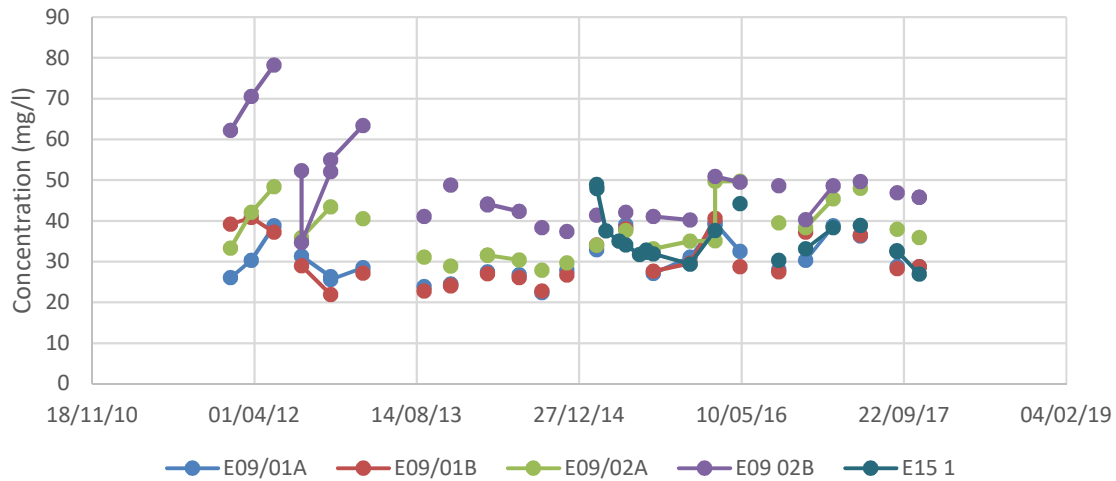




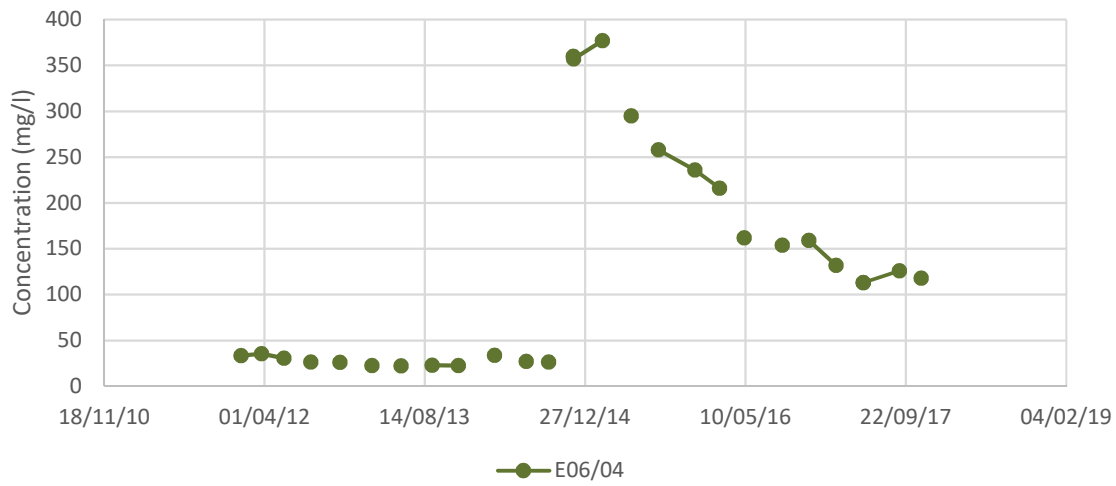
Zinc: Up gradient



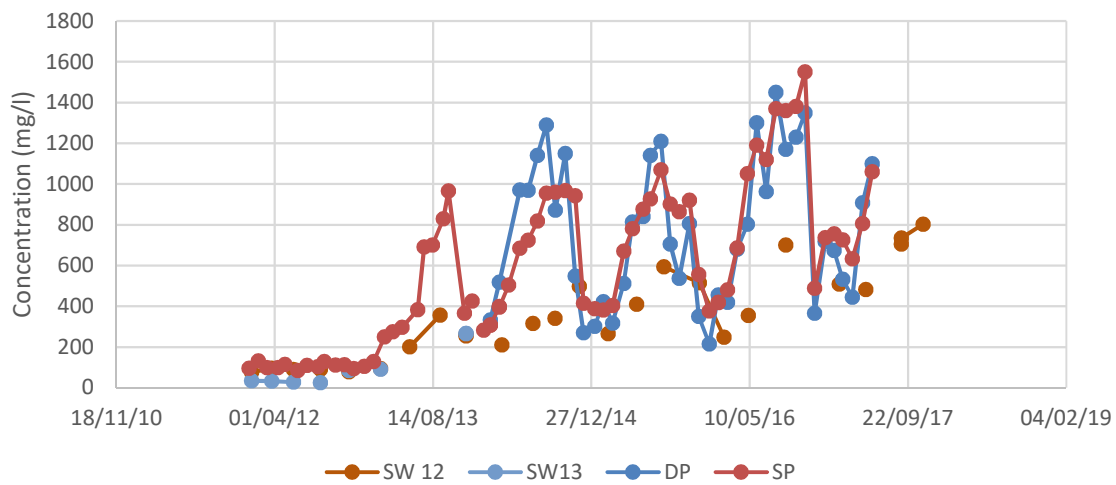
Chloride: Up gradient



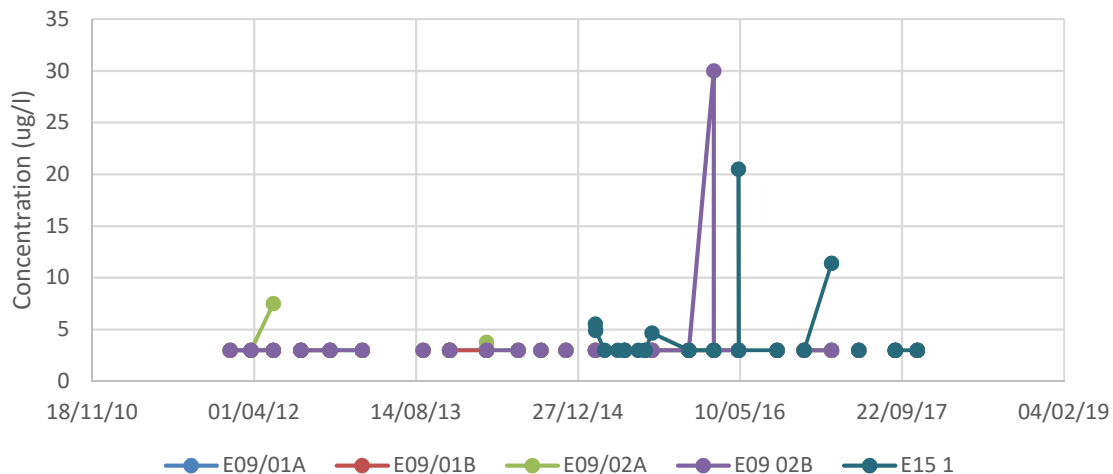
Chloride



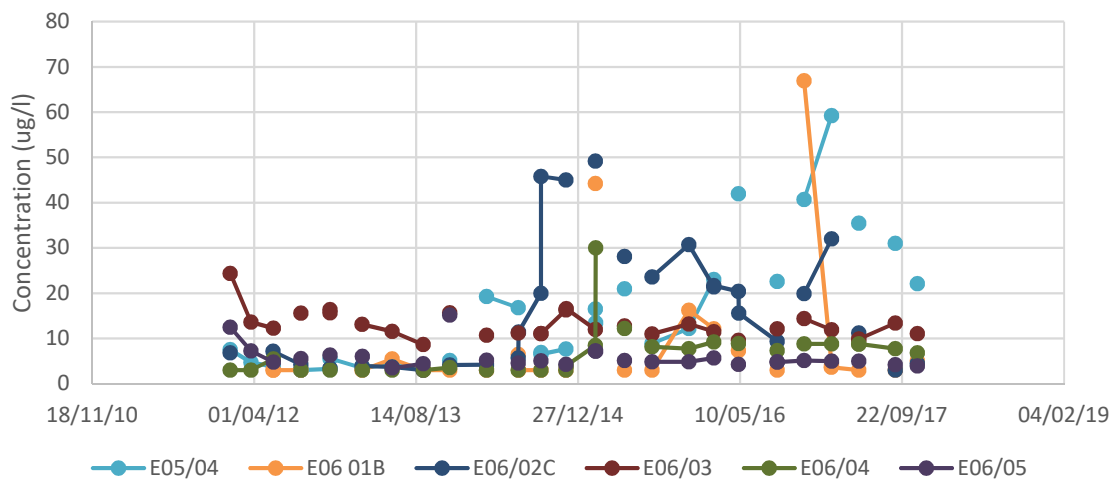
Chloride: Surface water



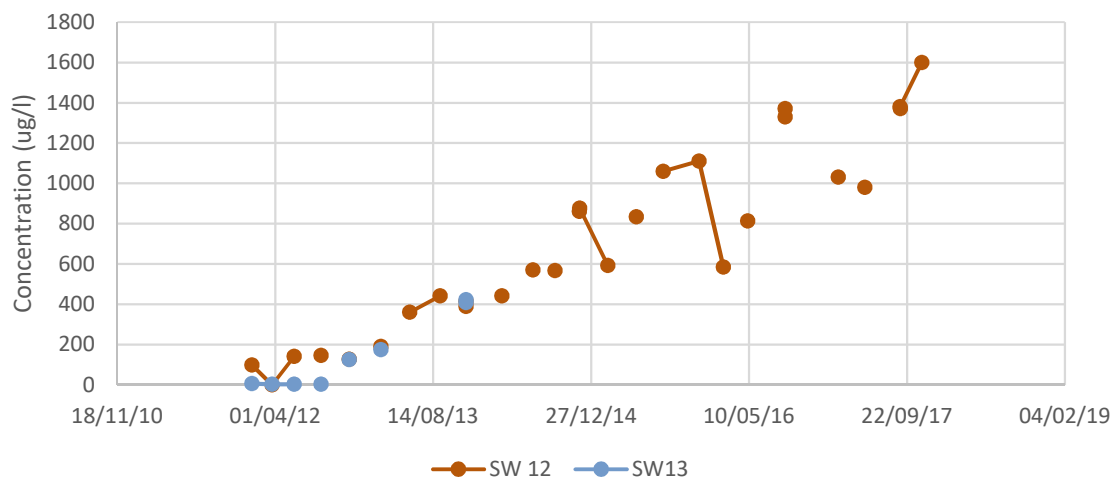
Molybdenum : Up gradient



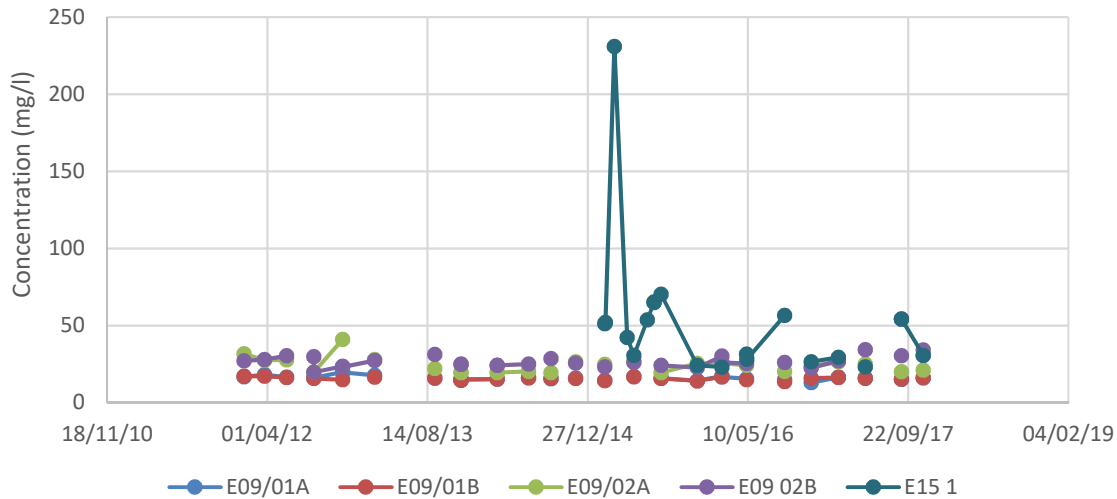
Molybdenum : Down gradient



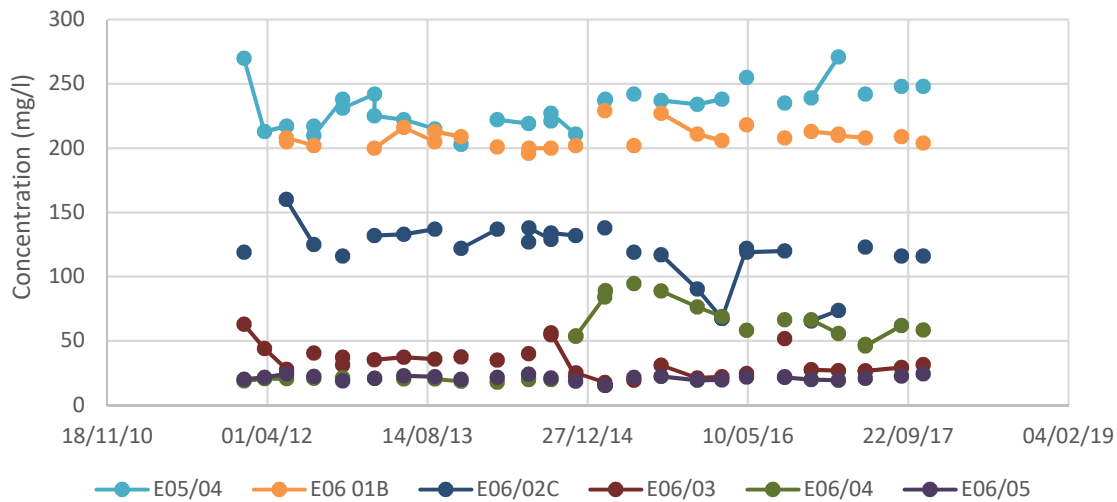
Molybdenum: Surface water



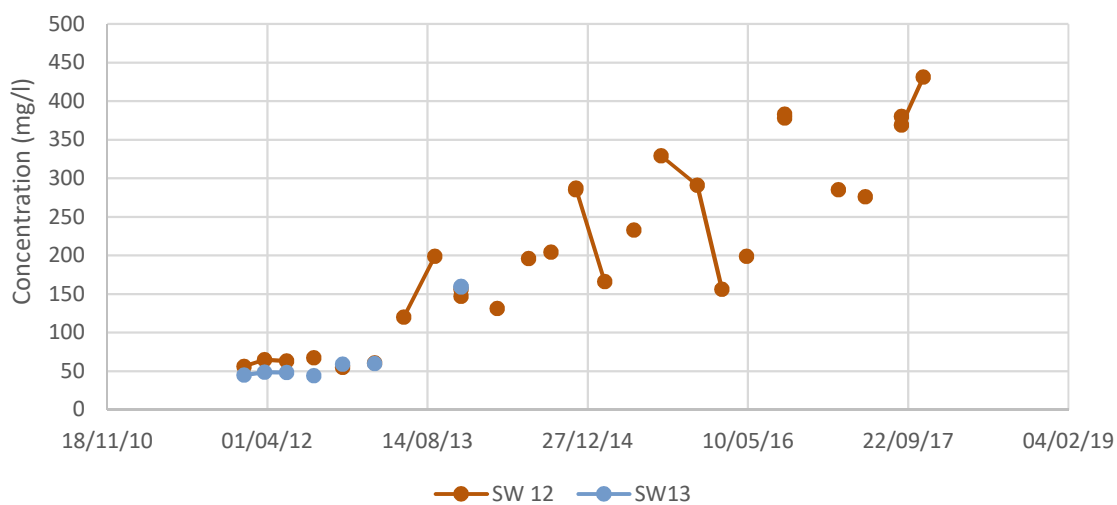
Sodium: Up gradient



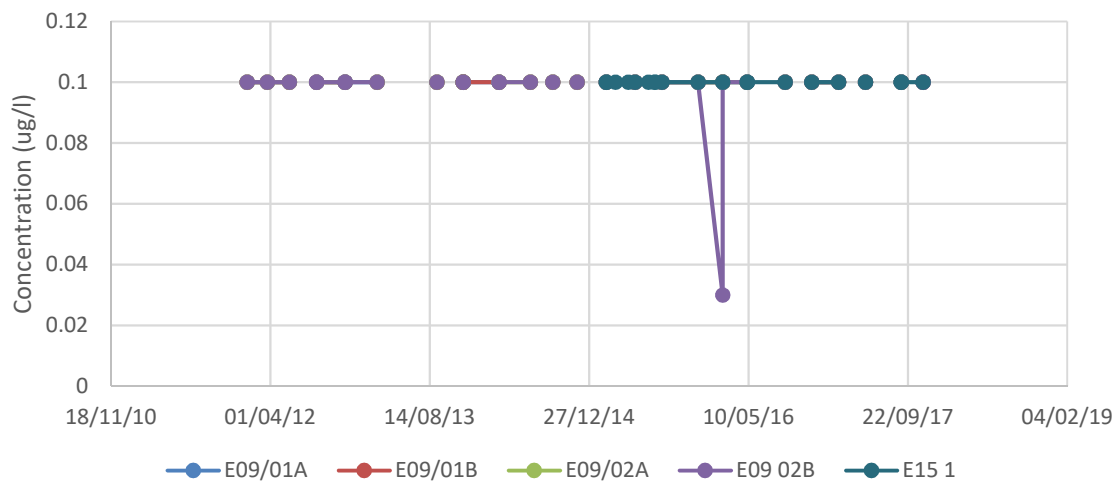
Sodium: Down gradient



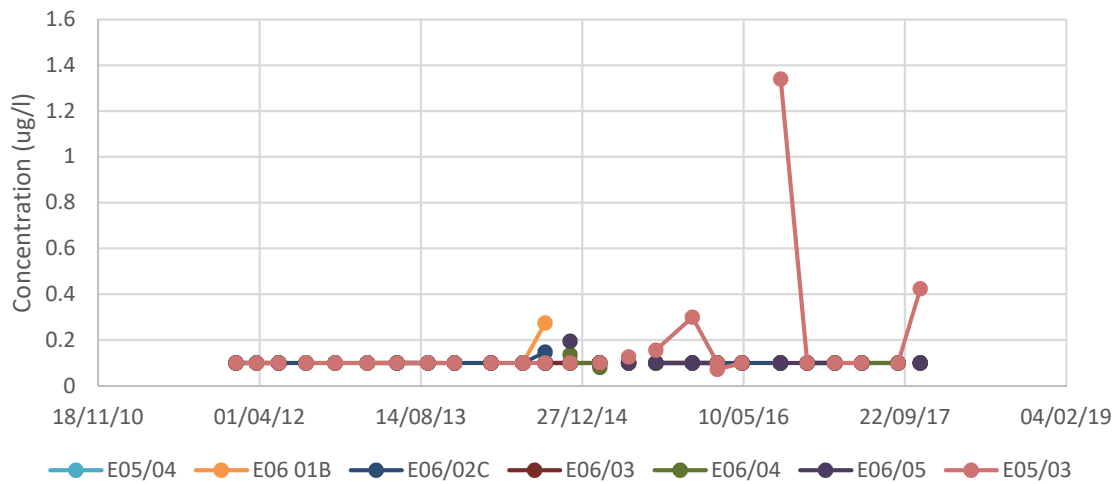
Sodium : Surface water



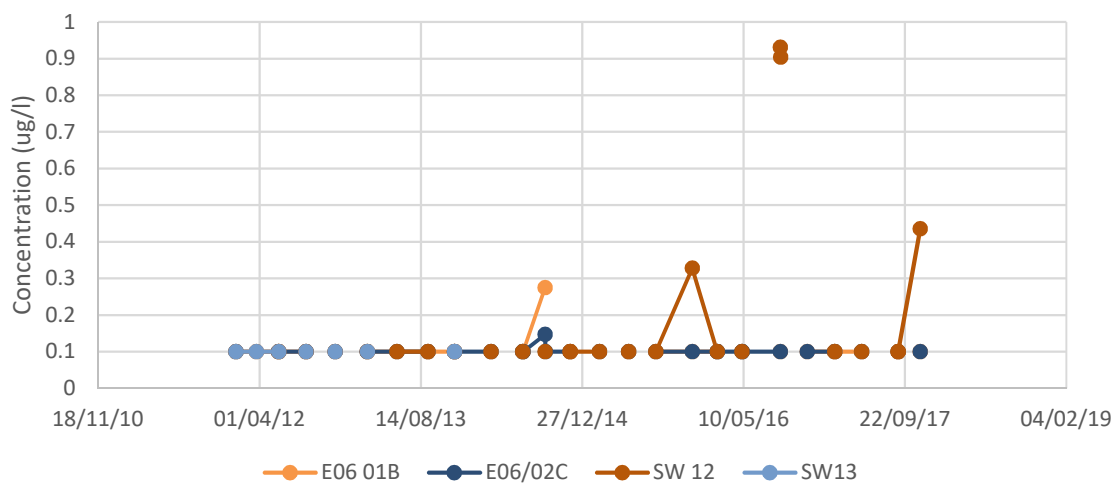
Cadmium: up gradient

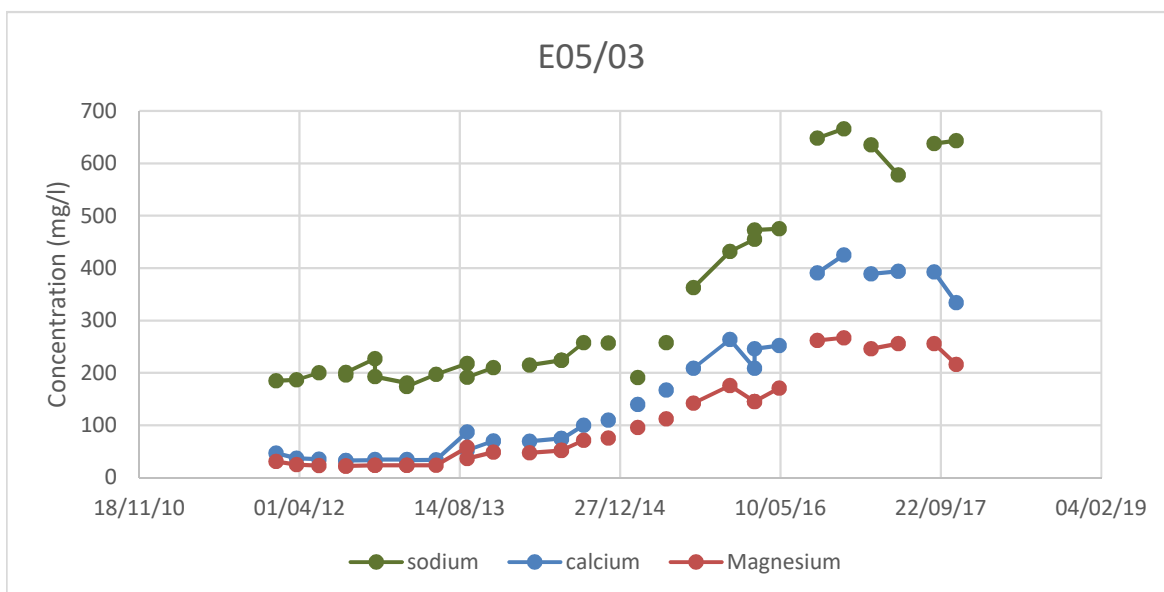
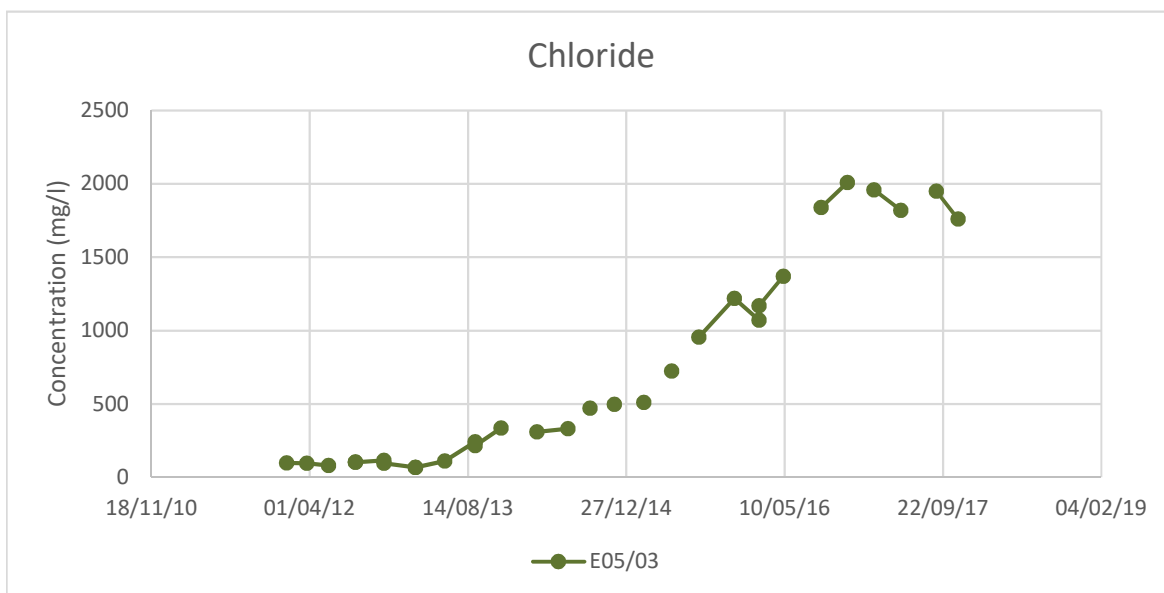
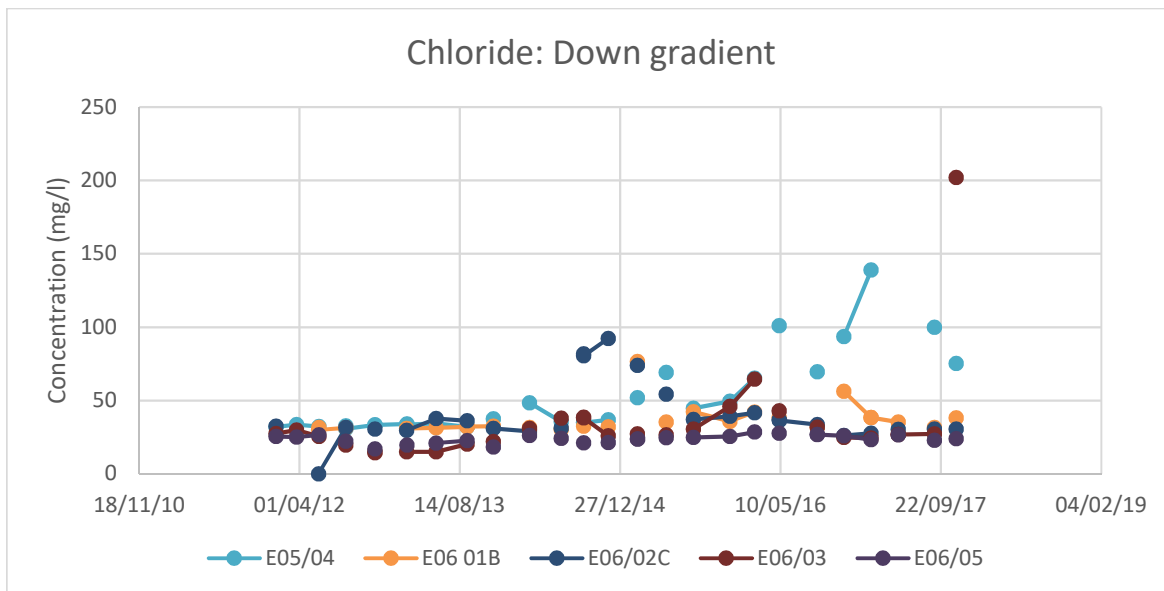


Cadmium: down gradient



Cadmium: Surface water

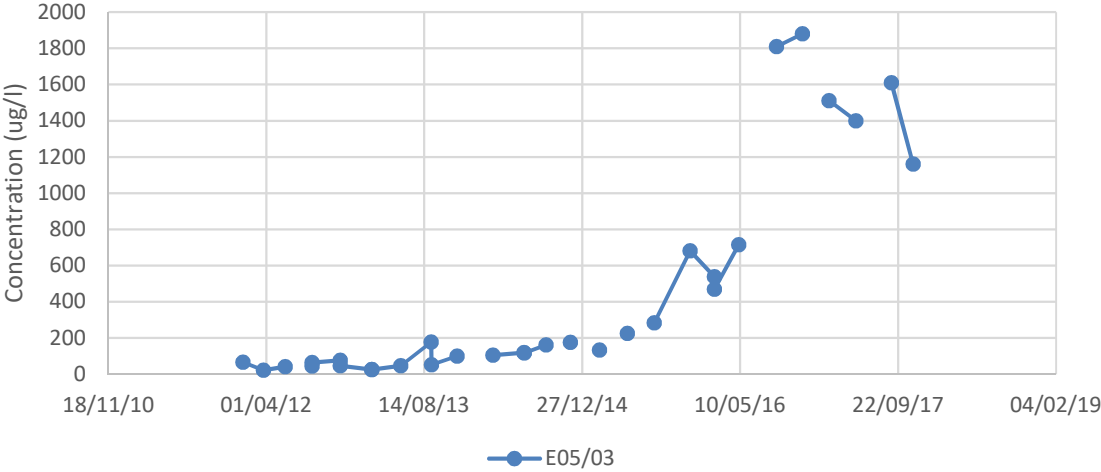




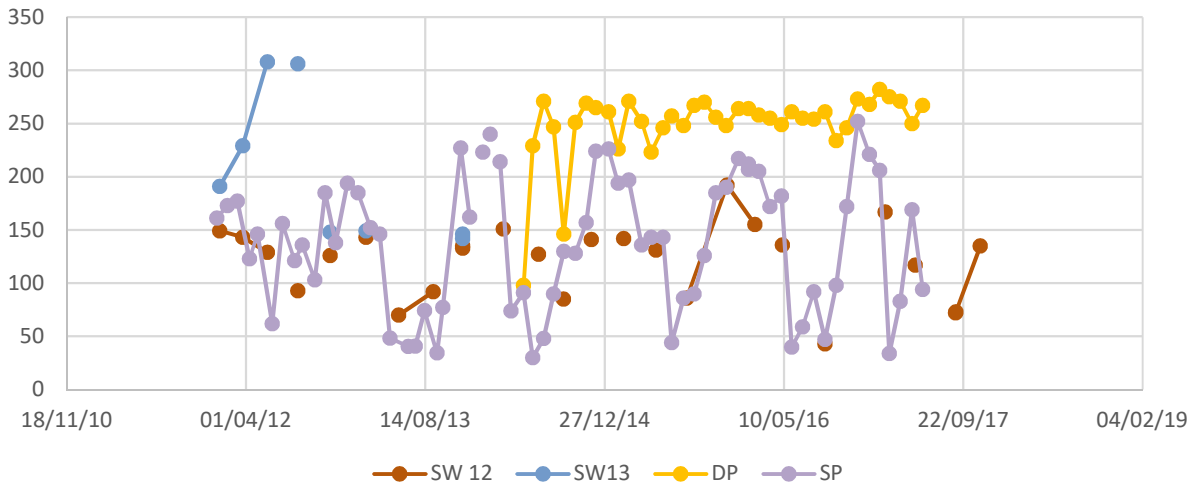
56.61972 cl- (meq) 21.23938 Ca meq)
 28.95652 Na (meq) 20.5 Mg (Meq)

Not just saline - ion exchange occuring

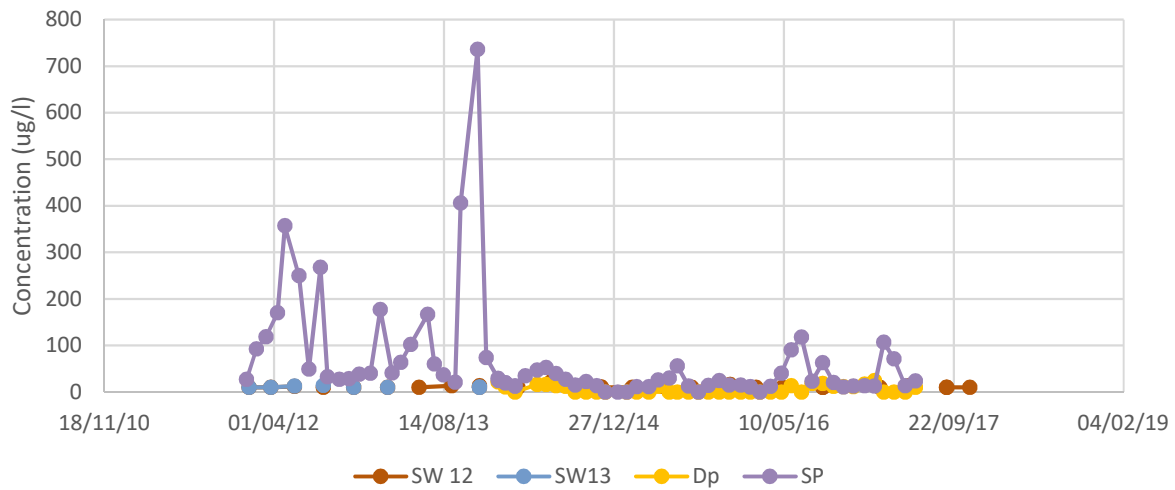
Molybdenum



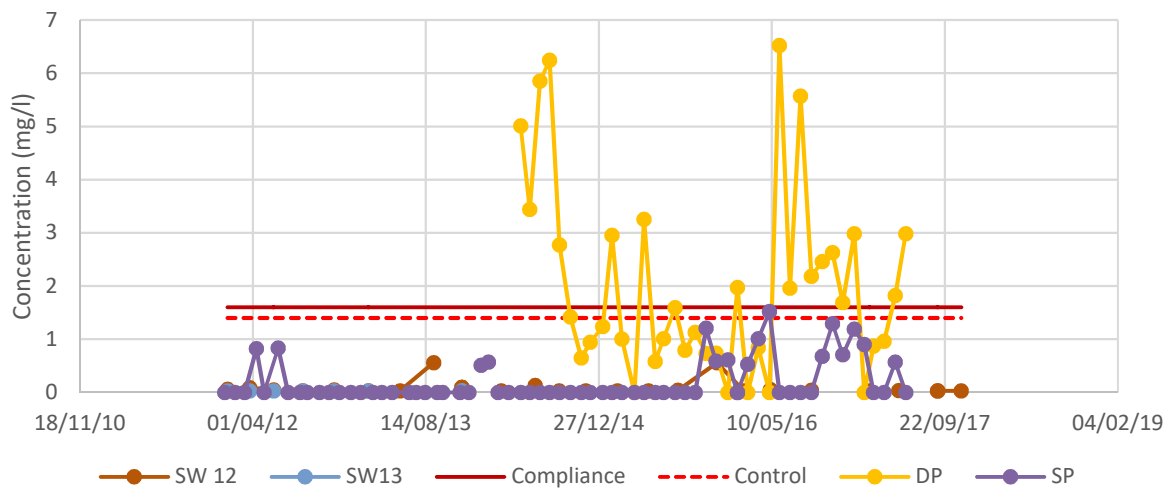
Alkalinity: Surface water



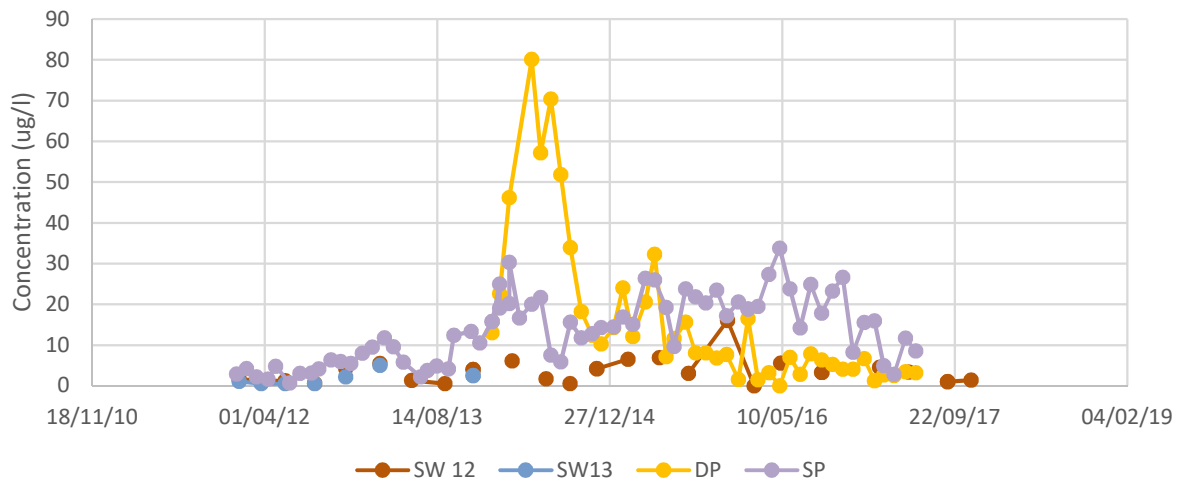
Aluminium: Surface water



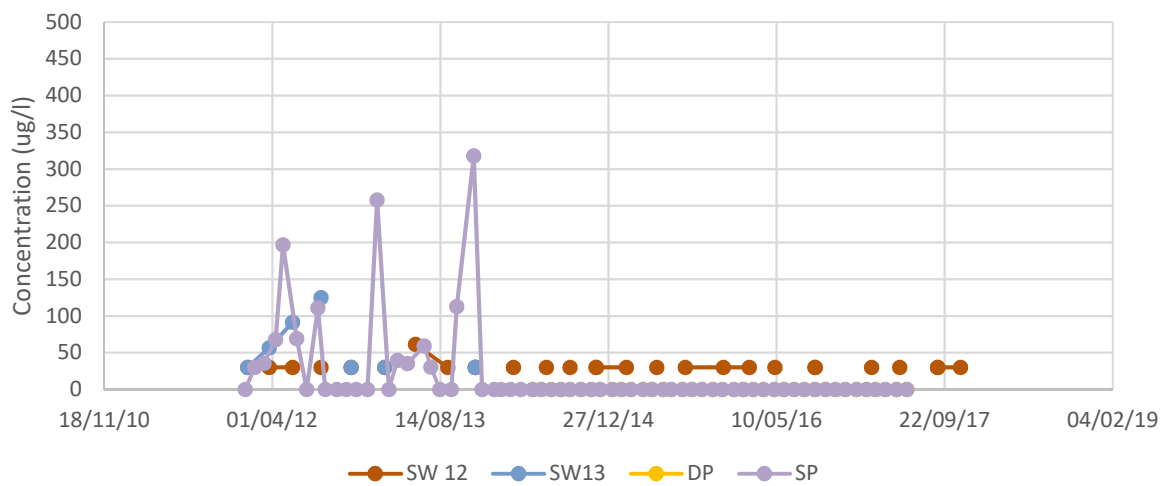
Ammoniacal Nitrogen: Surface water



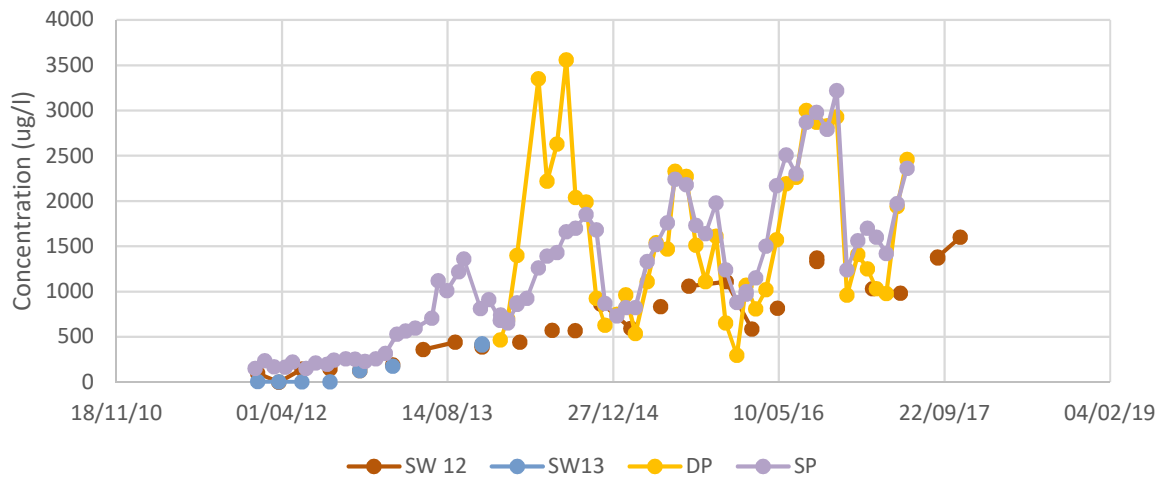
Chromium: Surface water



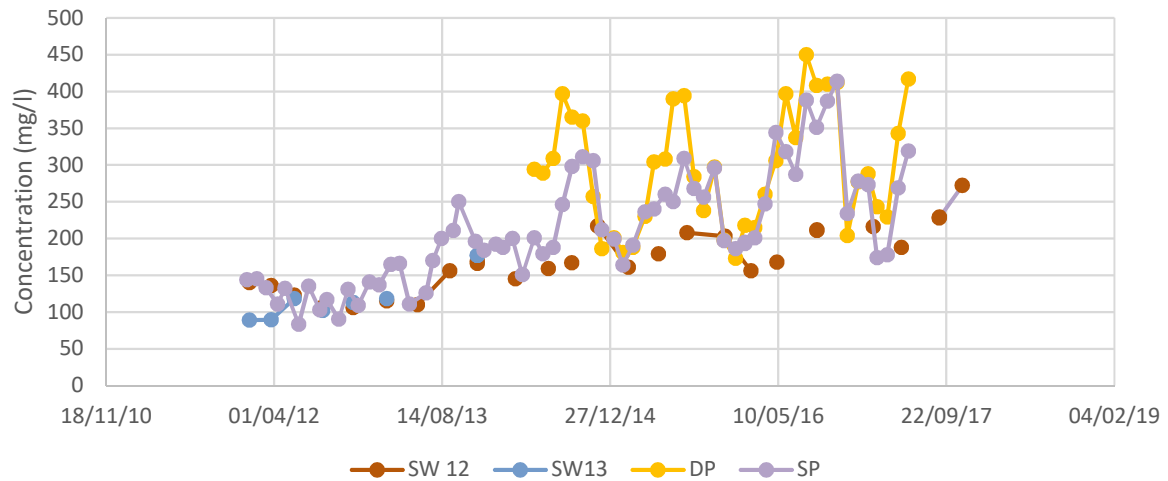
Iron: Surface water



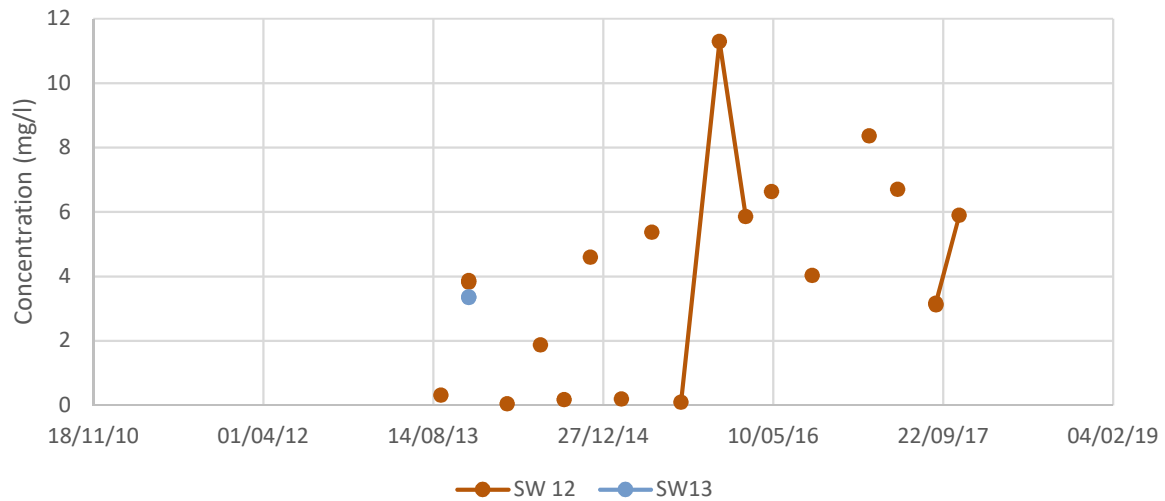
Molybdenum: Surface water



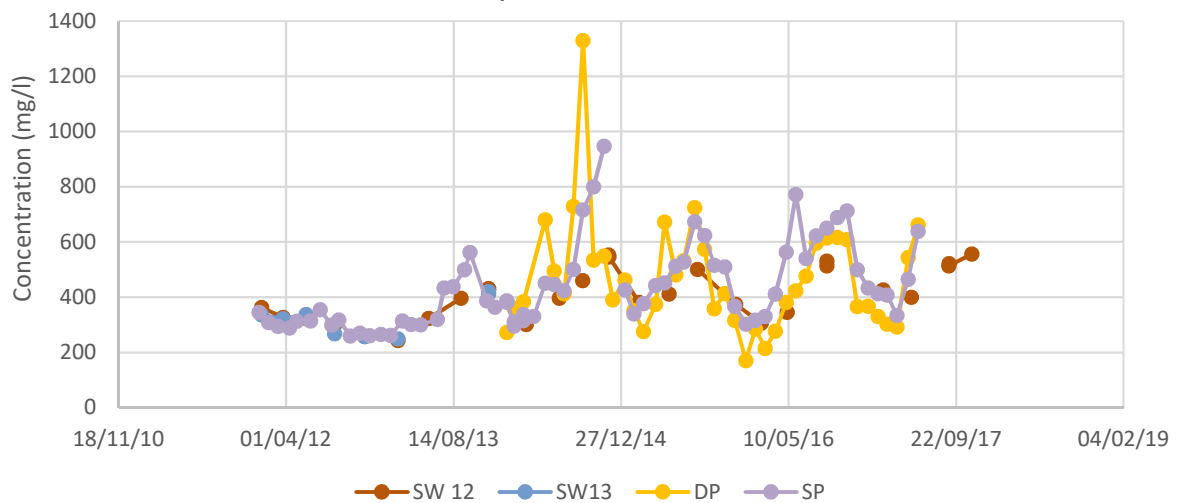
Calcium : Surface water

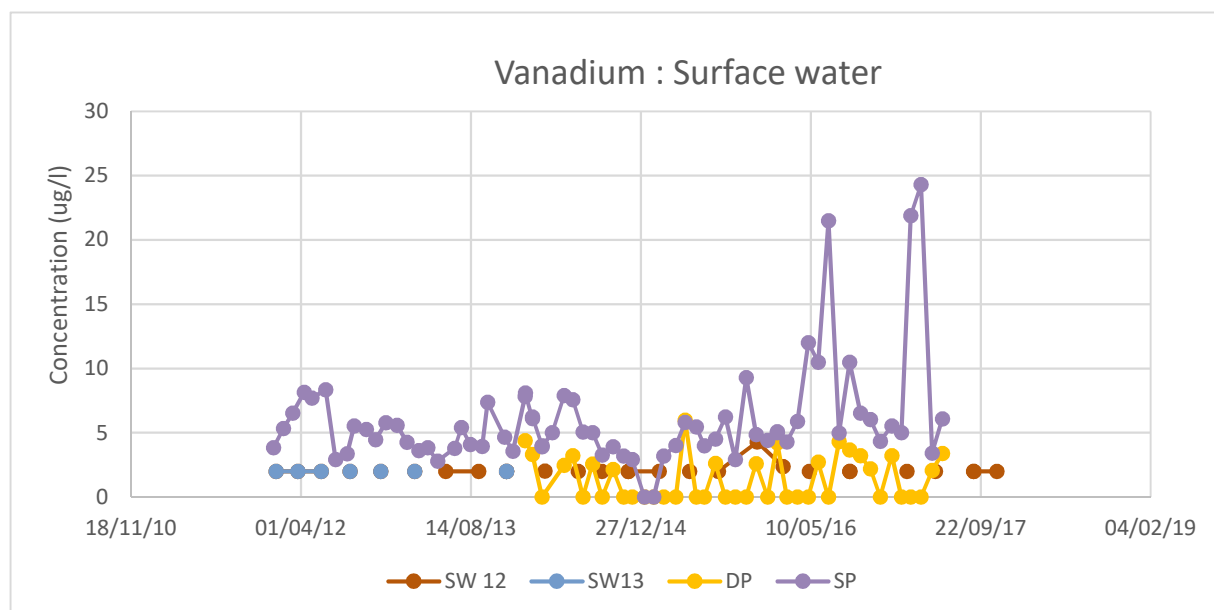
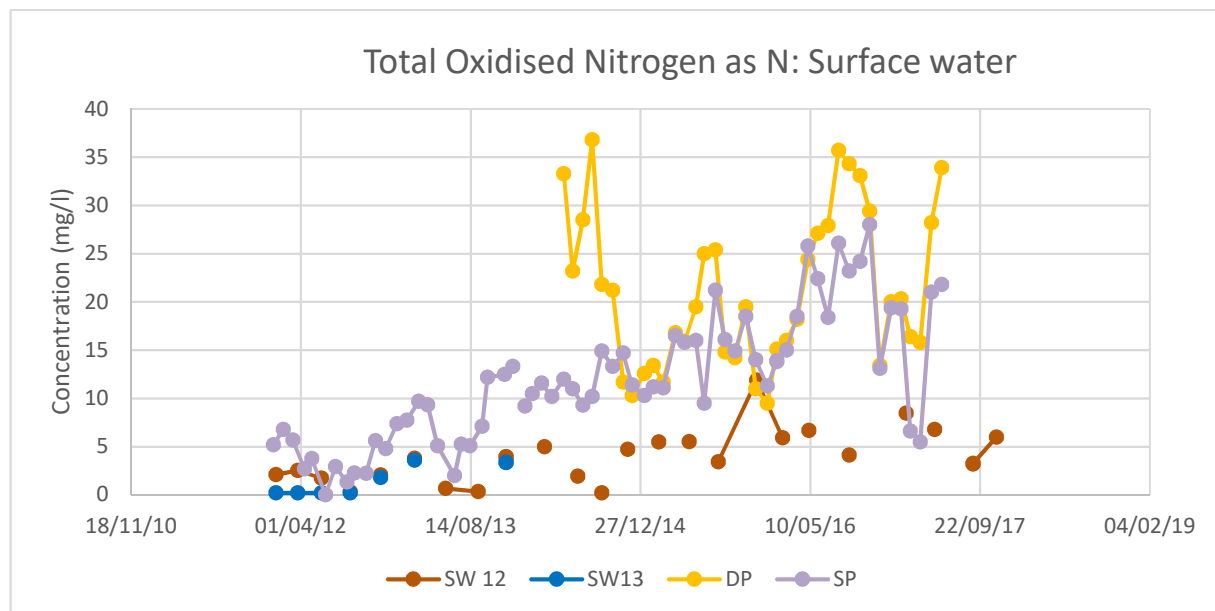
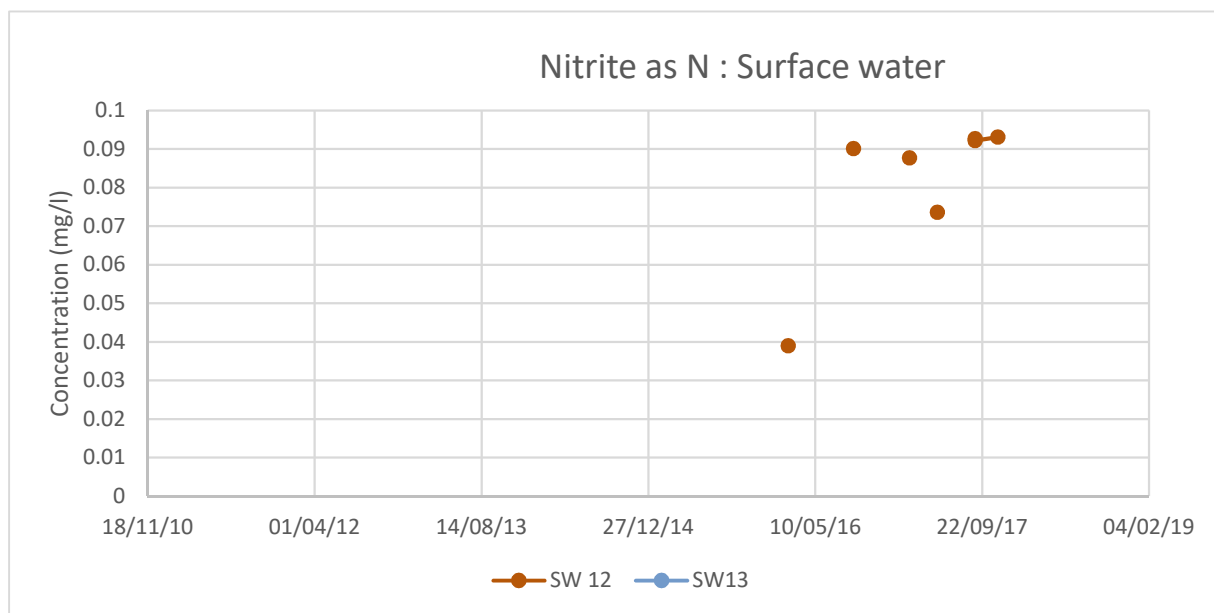


Nitrate as N: Surface water

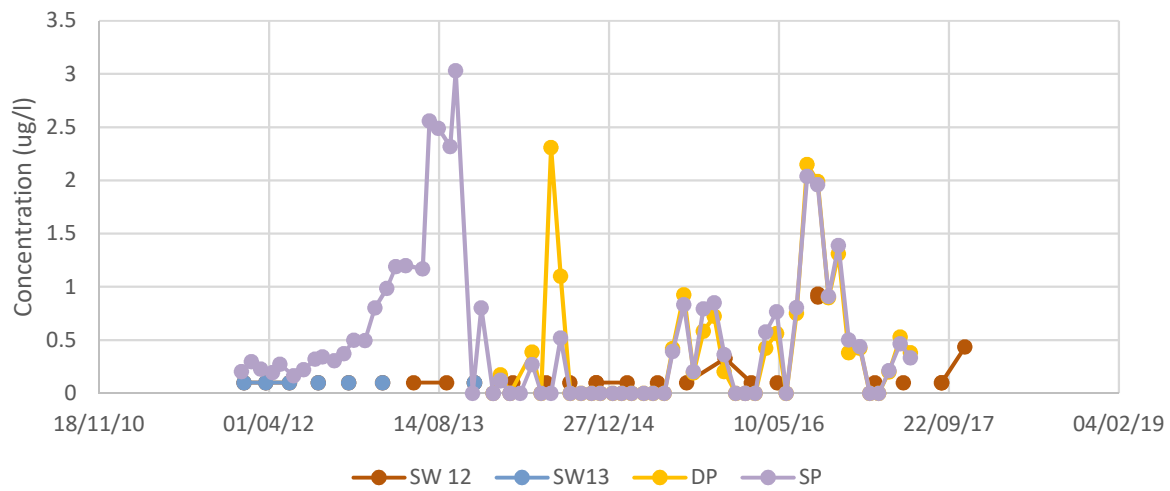


Suphate as SO4: Surface water

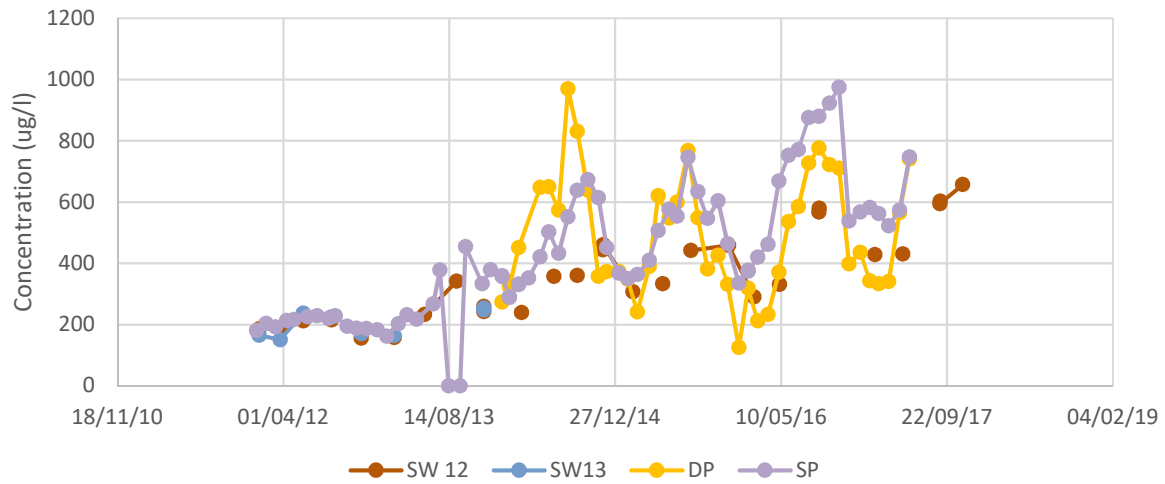




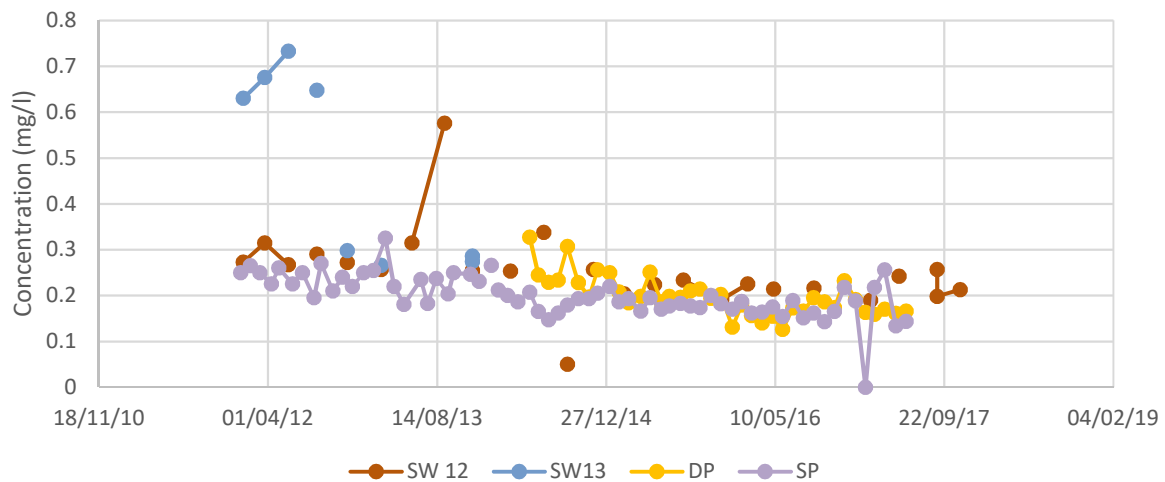
Cadmium: Surface water



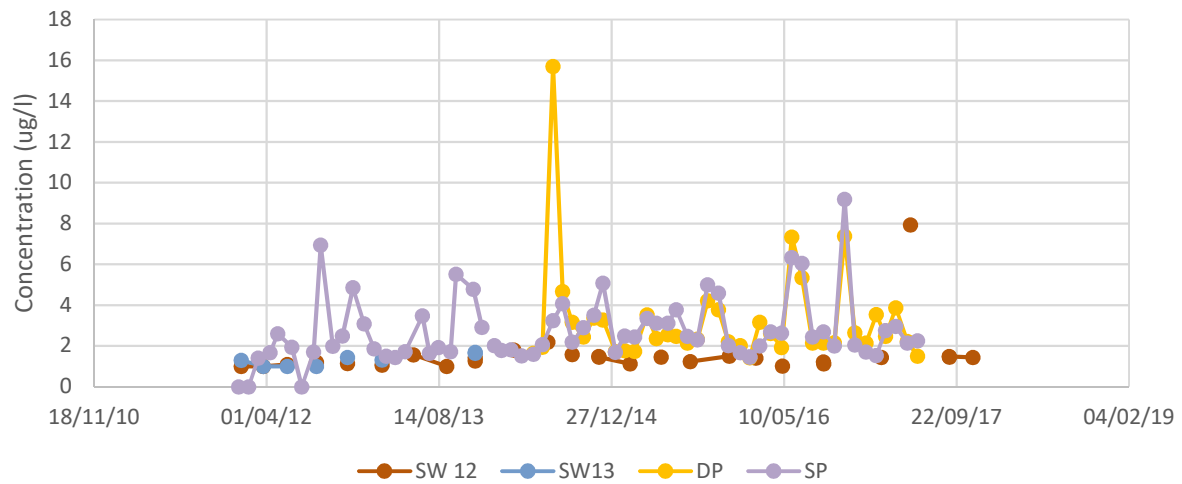
Boron Surface Water



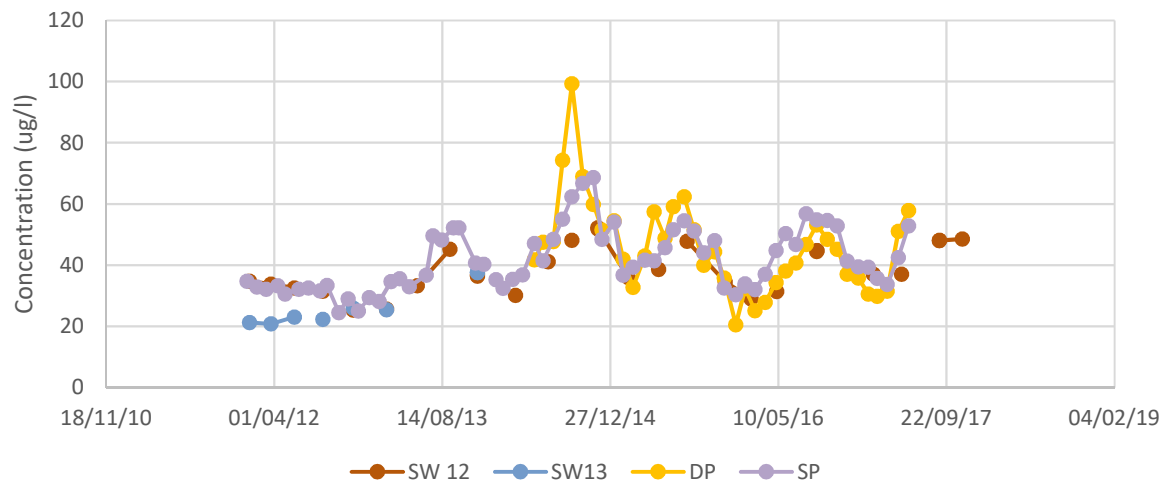
Fluoride: Surface water



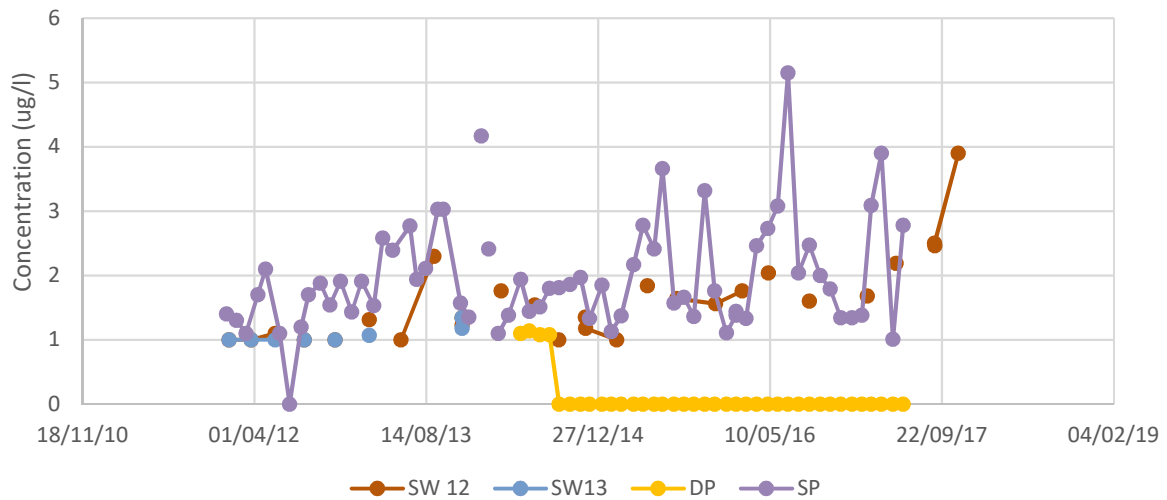
Copper: Surface water



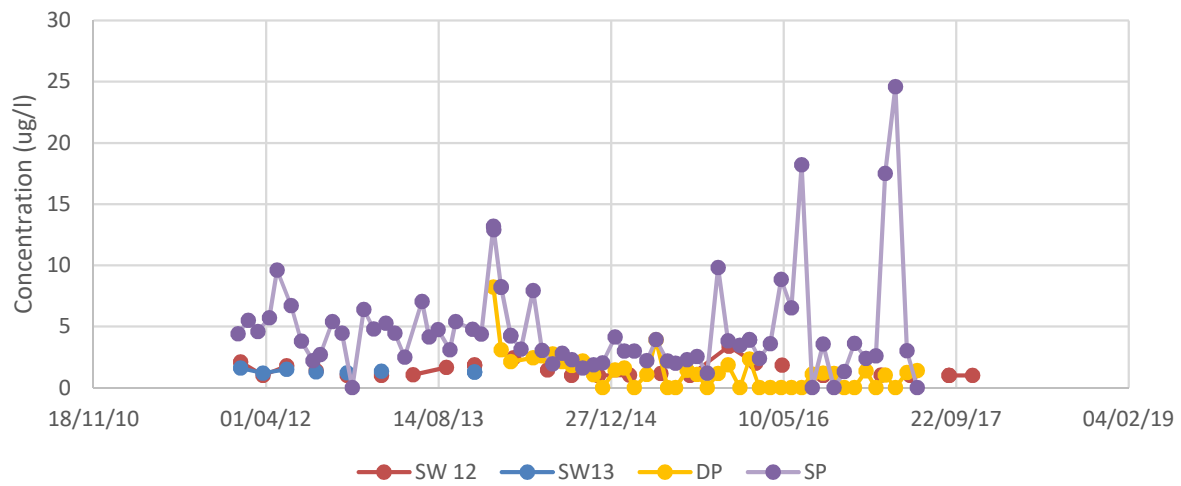
Magnesium: Surface water



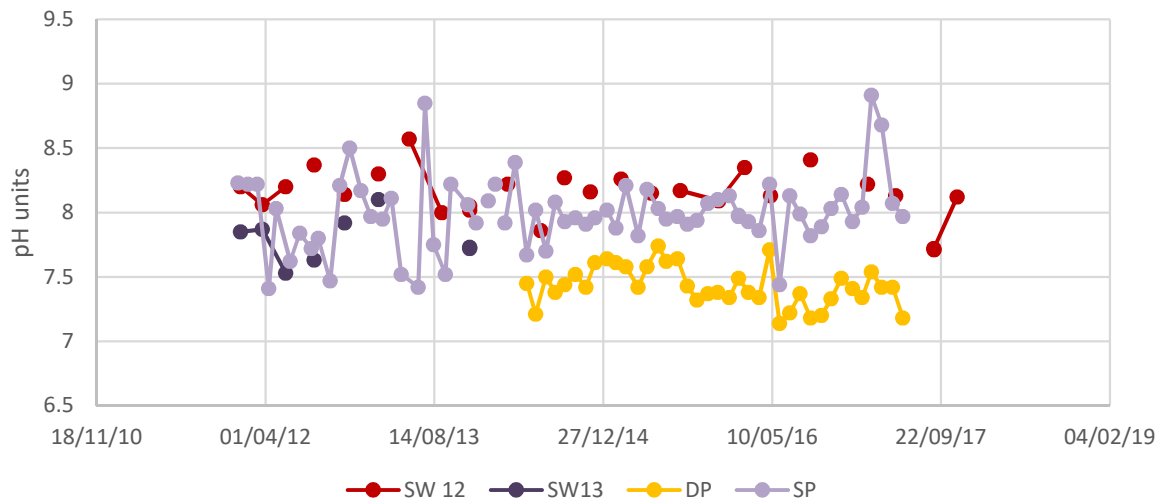
Selenium: Surface water



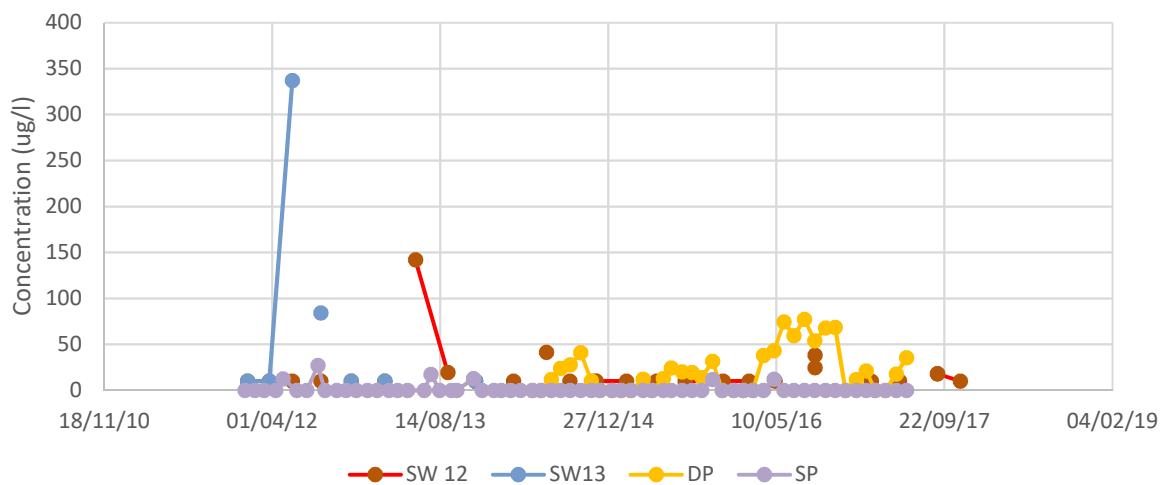
Arsenic: Surface water



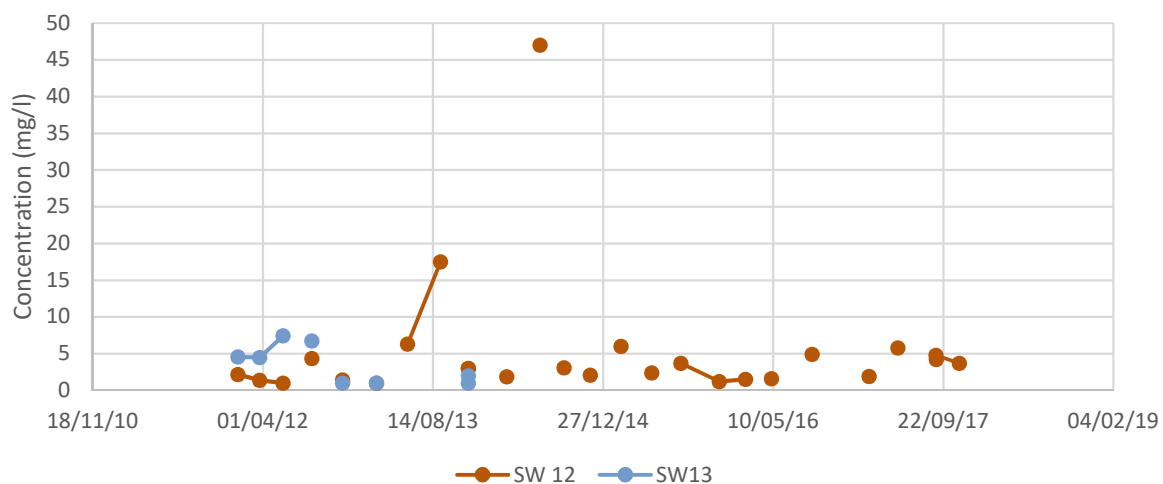
PH: Surface water



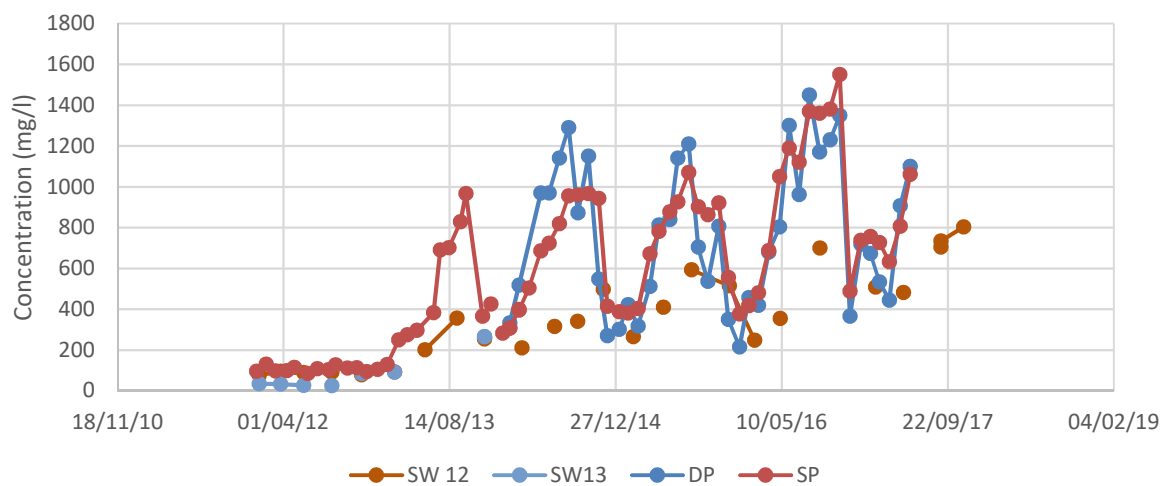
Manganese : Surface water



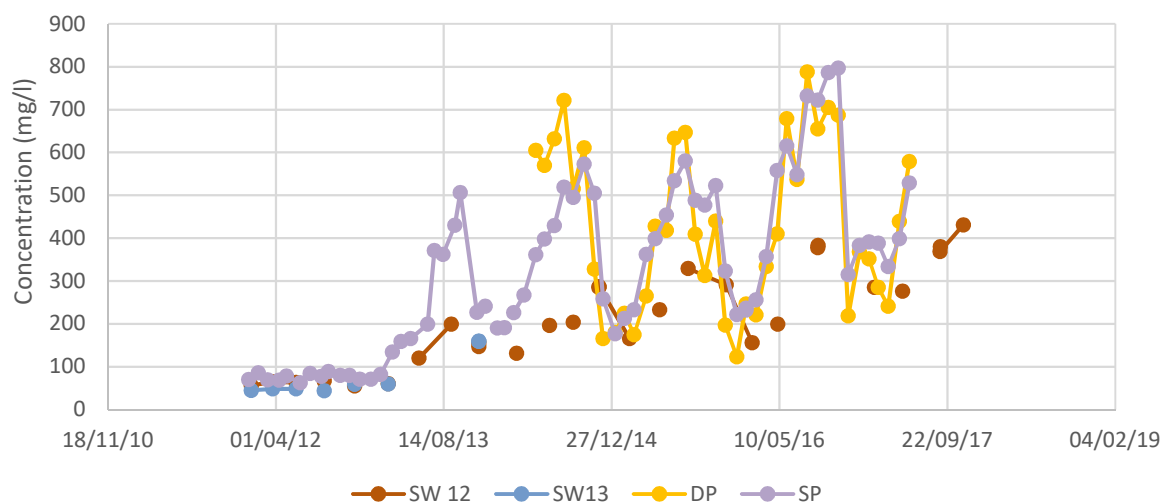
Total Organic Carbon : Surface water



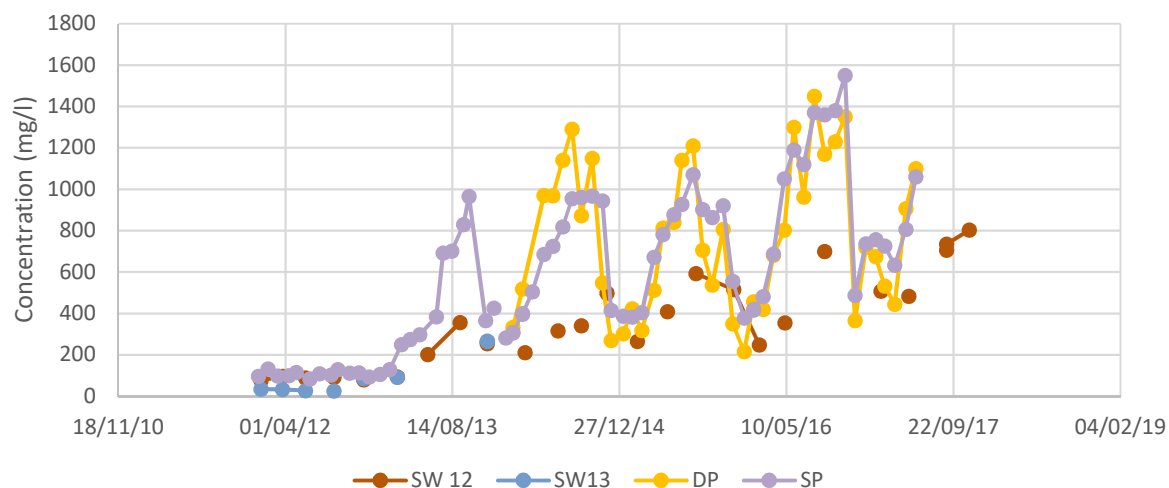
Chloride: Surface water



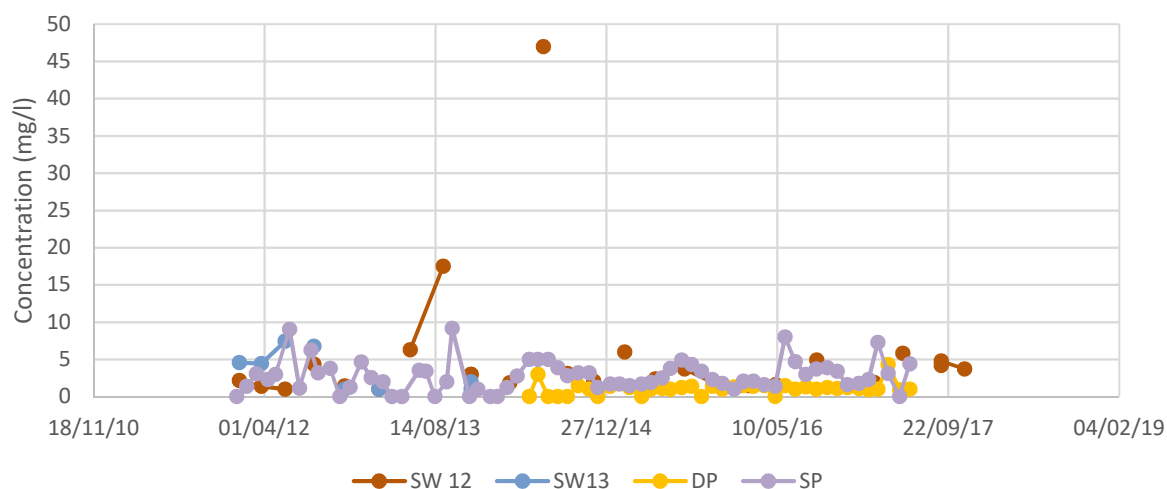
Sodium : Surface water



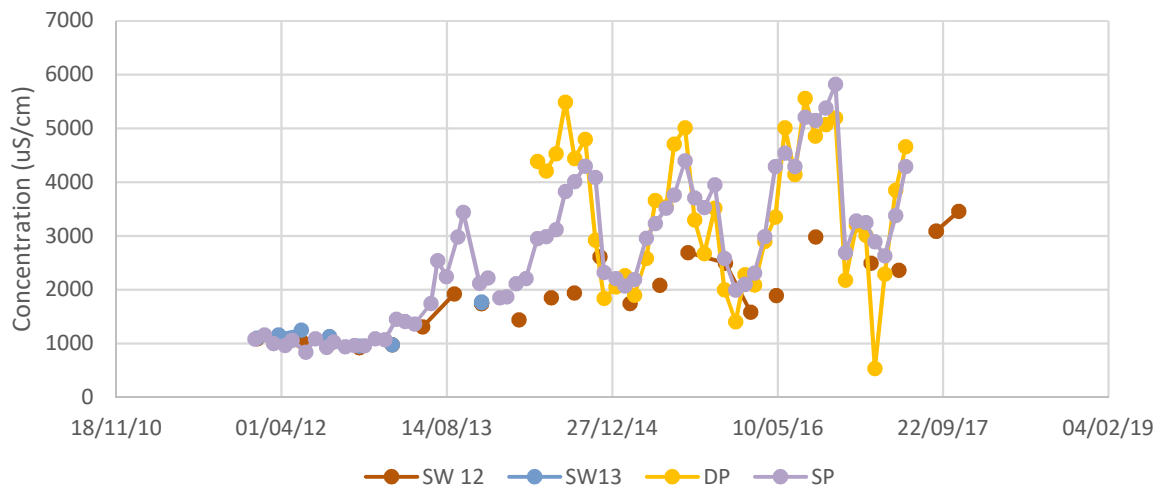
Chloride: Surface water



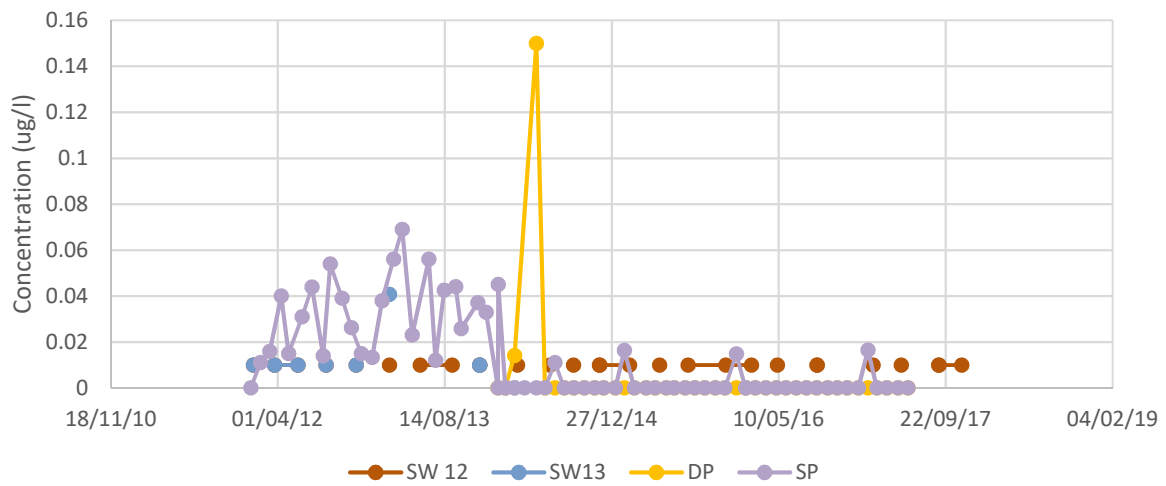
Total Organic Carbon : Surface water



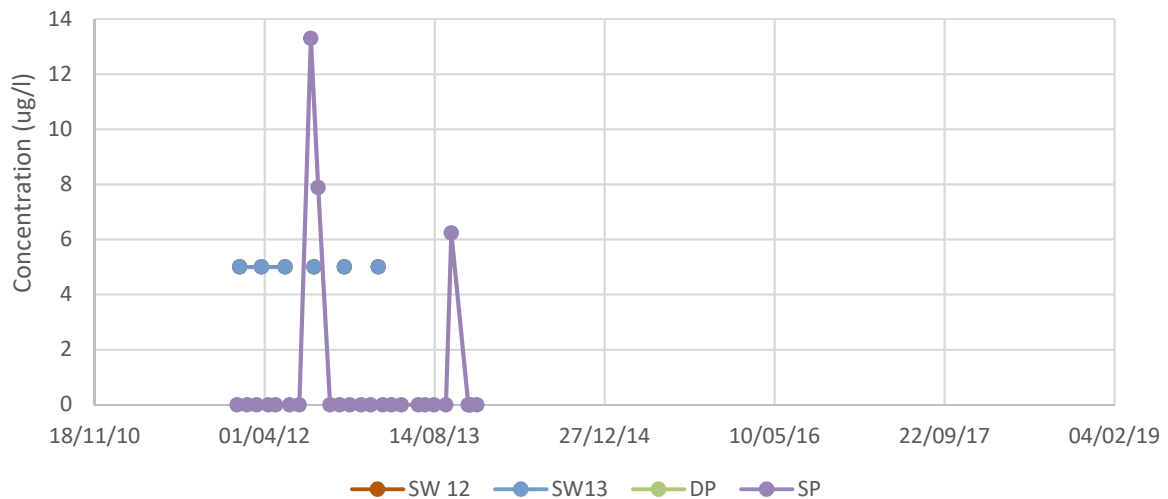
Conductivity: Surface water

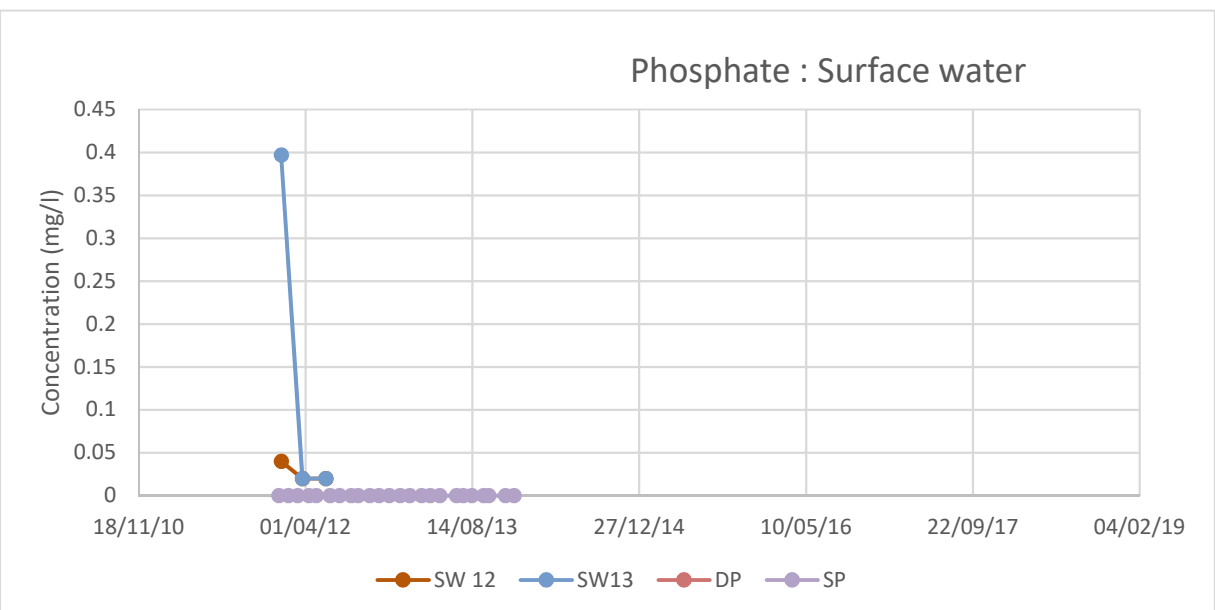
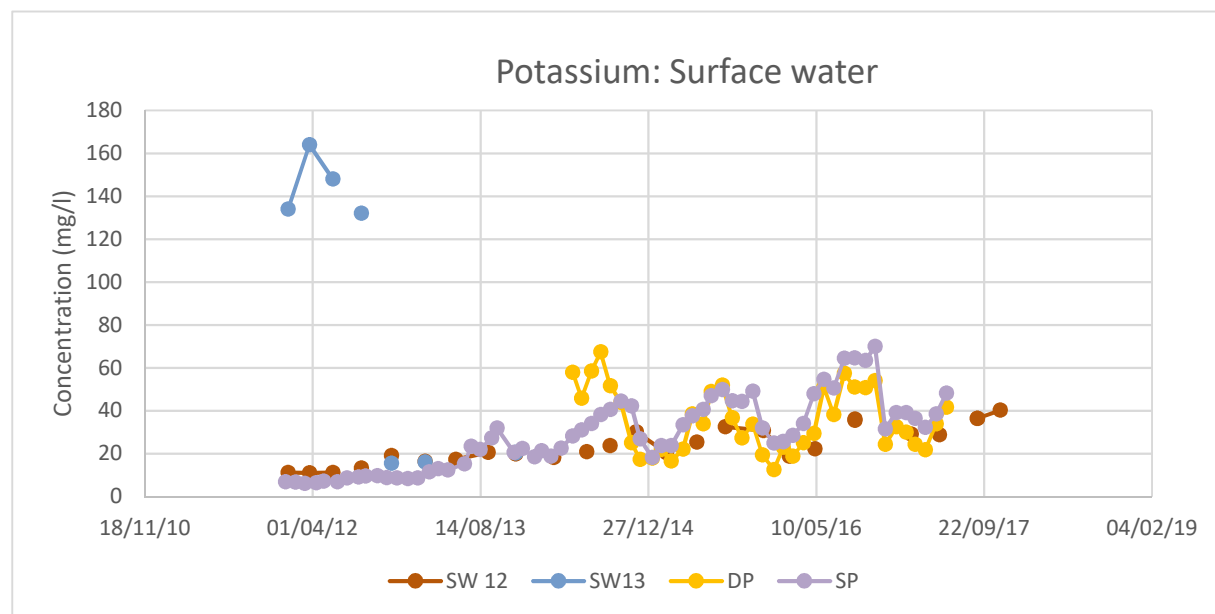
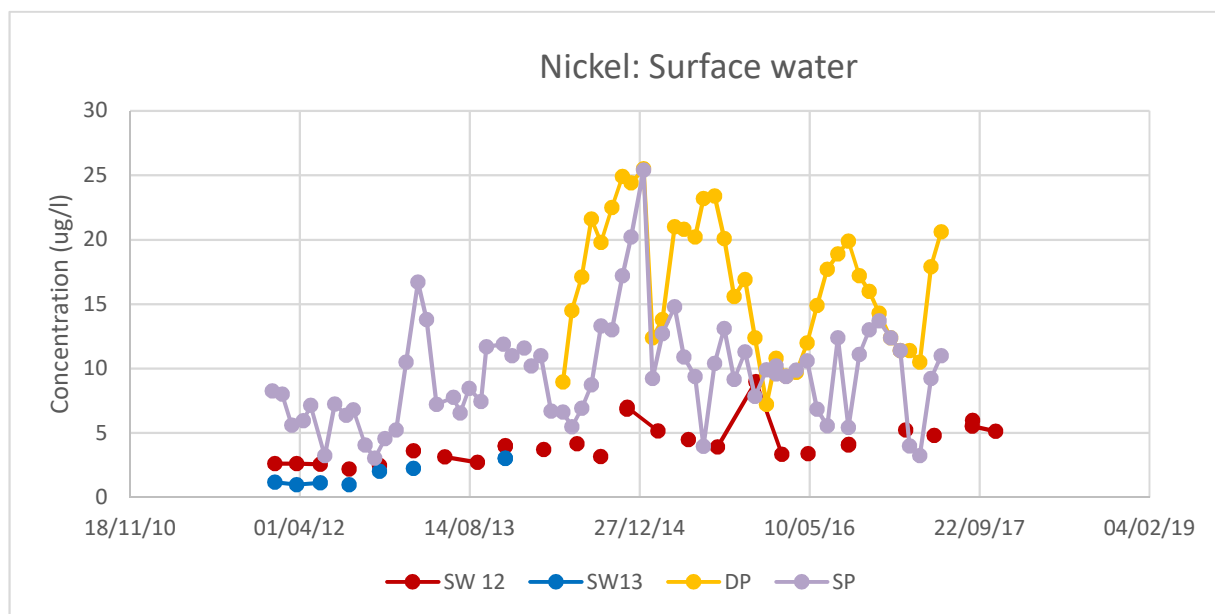


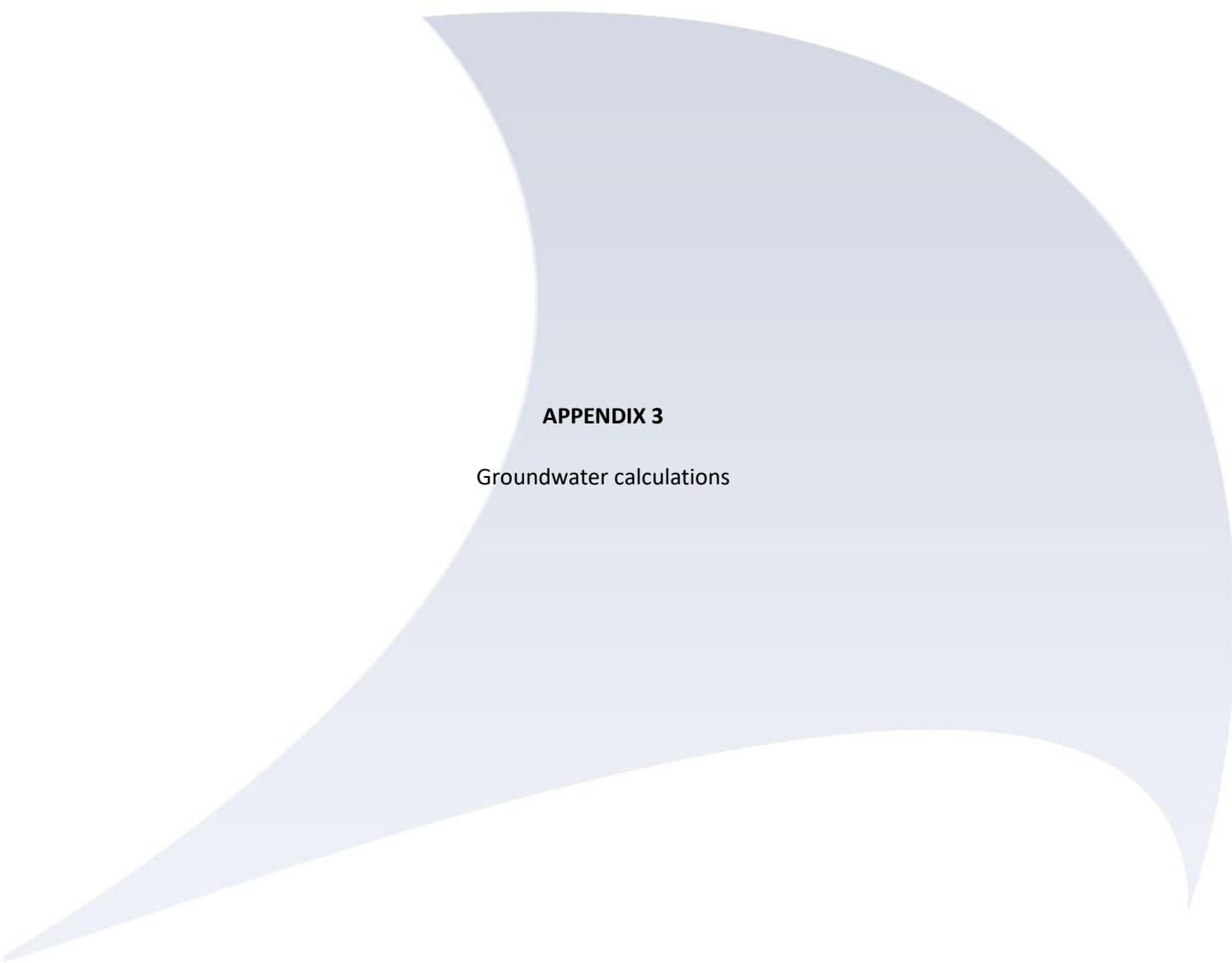
Mercury: Surface water



Zinc: Surface water







APPENDIX 3

Groundwater calculations

Step 1: Calculation of Flow in Aquifer

		Max K	Ave K	MinK	
K	m/s	7.00E-06	1.50E-07	2.00E-08	Range of values Site specific
l	-	0.04	0.04	0.04	Site specific Feb 2017
flow depth	m	10	10	10	Estimate of flow depth
flow width	m	500	500	500	Site specific Feb 2017
Q	m3/day	120.96	2.59	0.35	Darcy's Law

Step 2: Calculation of volume of seepage

On the basis of steady state flow where infiltration equates to leakage

Parameter	unit	Min Value	Max value		Comment
Area	Ha	23			
	m3	230000			
effective p	mm/yr	488			
Percentage	%	5%	30%		
	mm/yr	24.4	146.4		

Volume	m3/day	15.36	5612		
	m3/day	92.19	33672		

Step 3: Dilution Calculations

Standard contaminant mass balance approach

Ranges of values assessed

Min = maximum groundwater discharge with maximum concentrations into minimum groundwater flow resulting in Minimum dilution and maximum potential impact

Max = minimum groundwater discharge with minimum concentrations to maximum groundwater flow resulting in maximum dilution and minimum impact

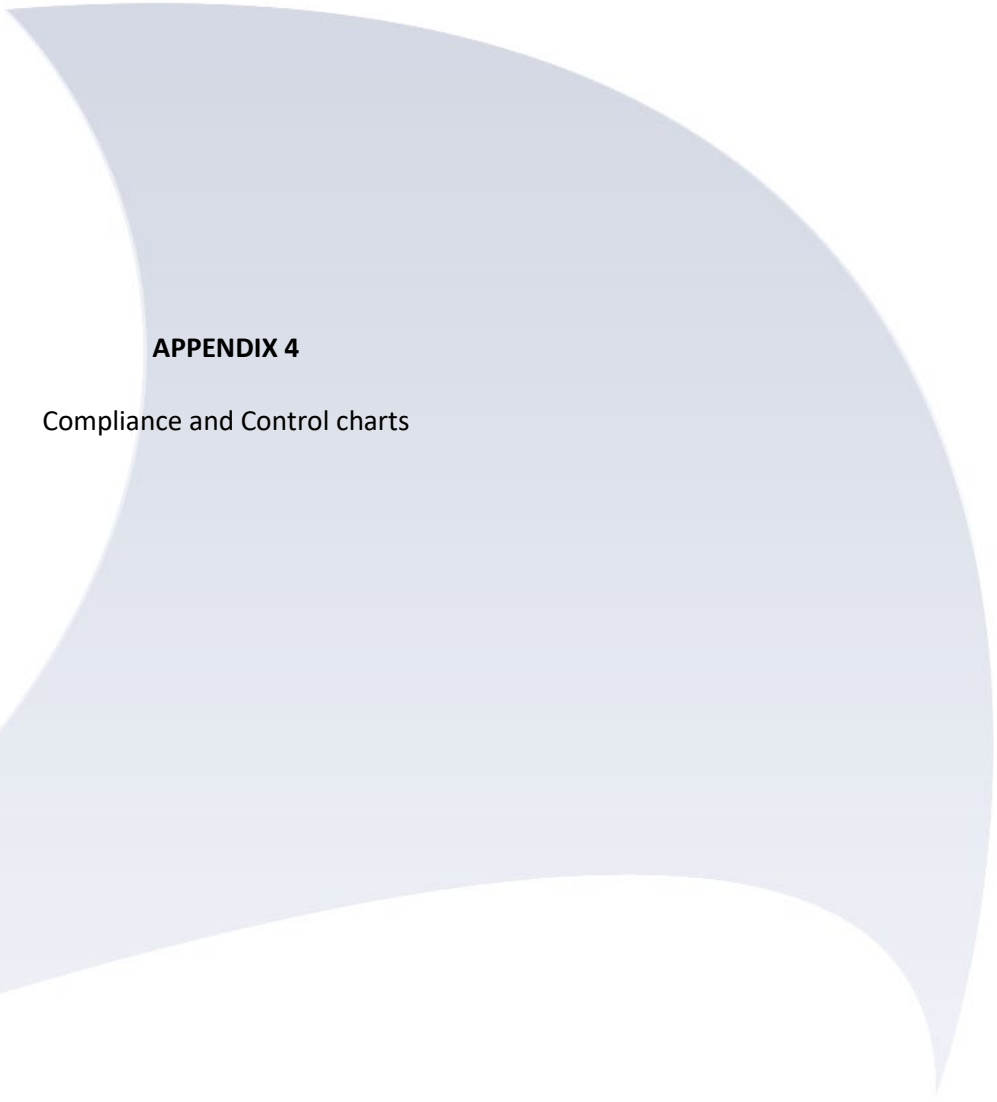
Ave = minimum groundwater discharge with minimum concentrations to average groundwater flow

Ave (2) = minimum groundwater discharge with minimum concentrations to average groundwater flow

Dilution calc	Min	Min	Average	Average (2)	max
NH4	mg/l	19.9	9.7	8.6	1.4
B	mg/l	10.0	3.9	3.5	0.7
Mo	mg/l	4.0	1.9	1.7	0.2
As	ug/l	99.7	48.8	43.8	11.8
Cd	ug/l	2.0	0.3	0.3	0.1
Hg	ug/l	2.0	0.3	0.3	0.1
Se	ug/l	298.9	97.4	86.1	14.4
So4	mg/l	1594.3	585.5	523.5	129.7

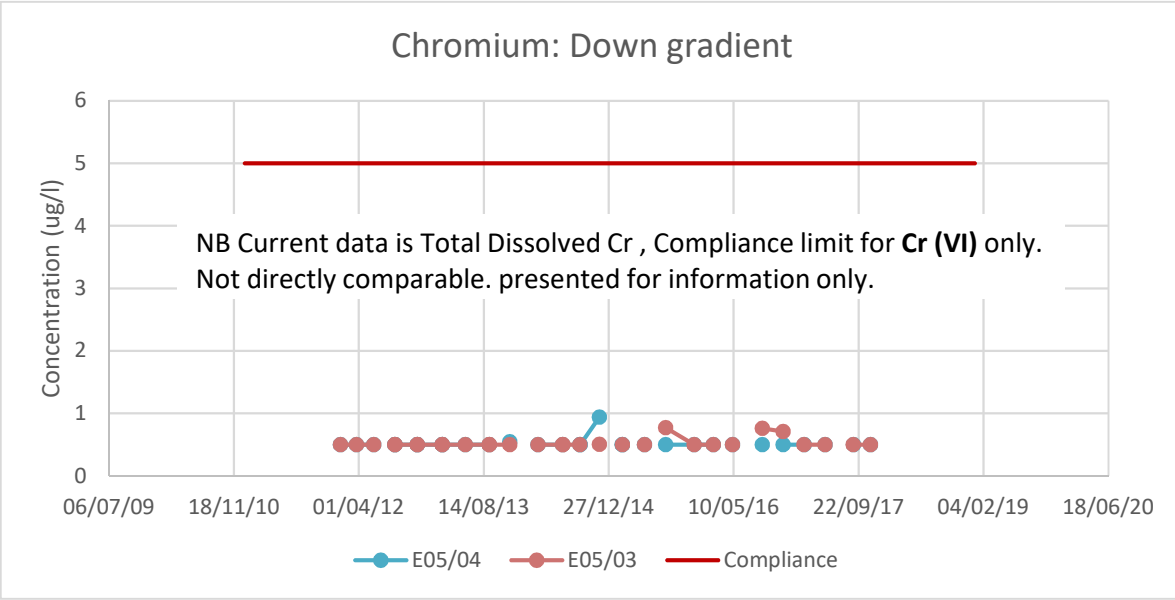
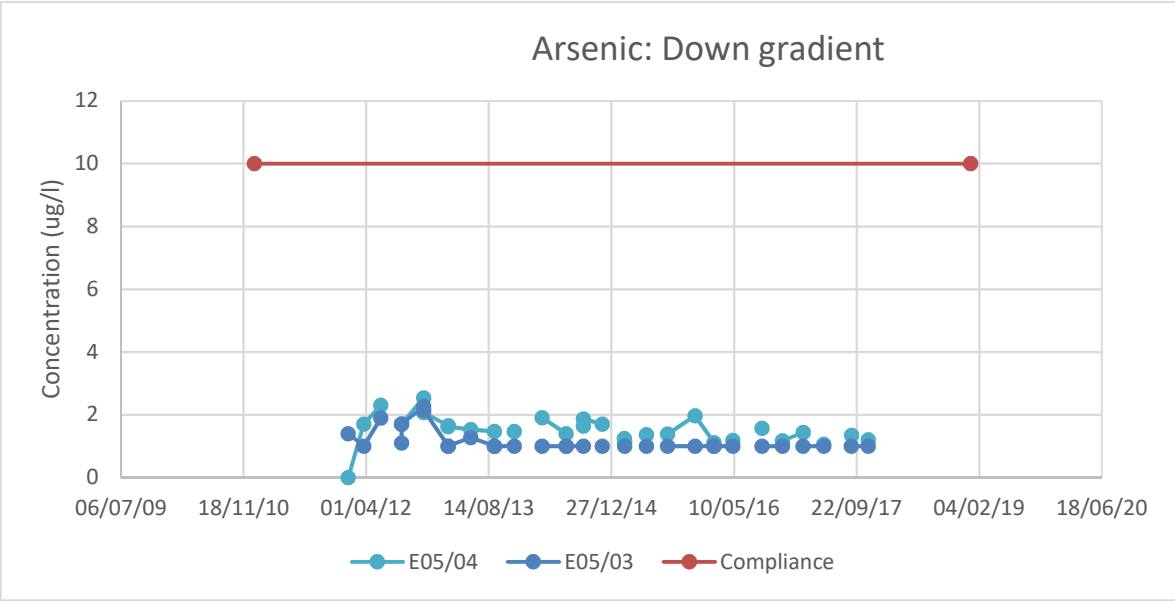
Source term and background MMI 2012 report

		Min	Max	background
NH4	mg/l	10	20	0.3
B	mg/l	4	10	0.28
Mo	mg/l	2	4	0.003
As	ug/l	50	100	7
Cd	ug/l	0.3	2	0.12
Hg	ug/l	0.3	2	0.03
Se	ug/l	100	300	3.5
SO4	mg/l	600	1600	70



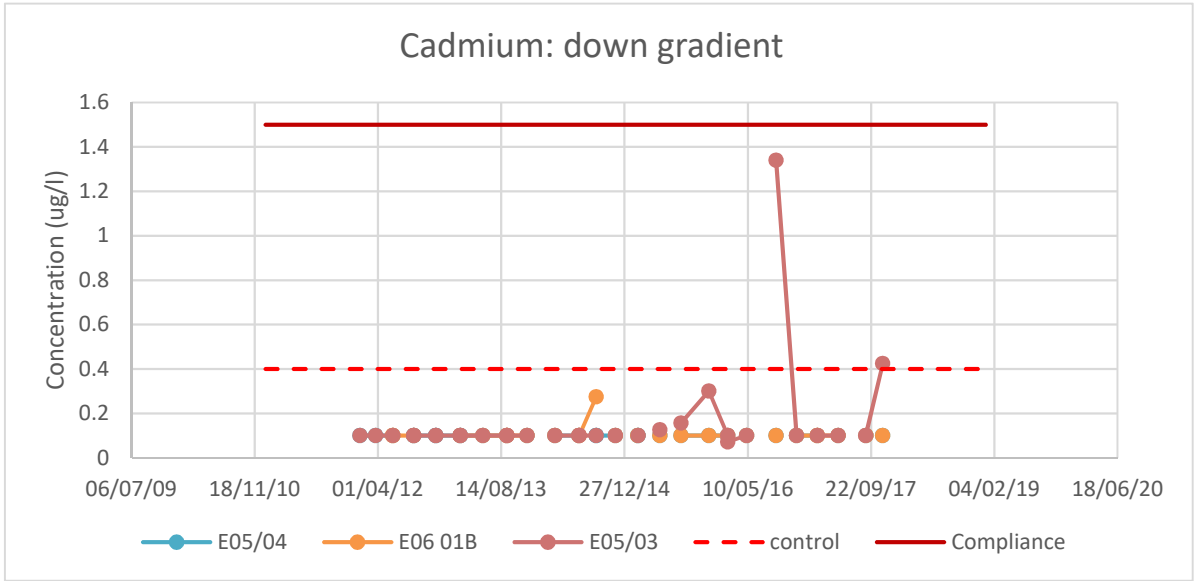
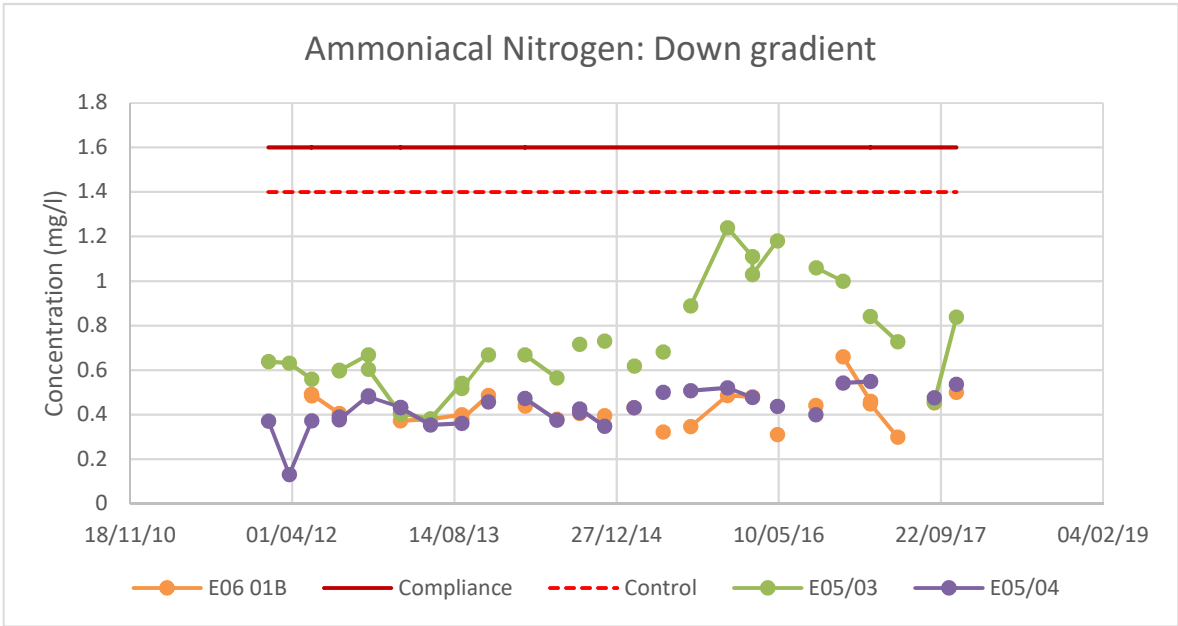
APPENDIX 4

Compliance and Control charts

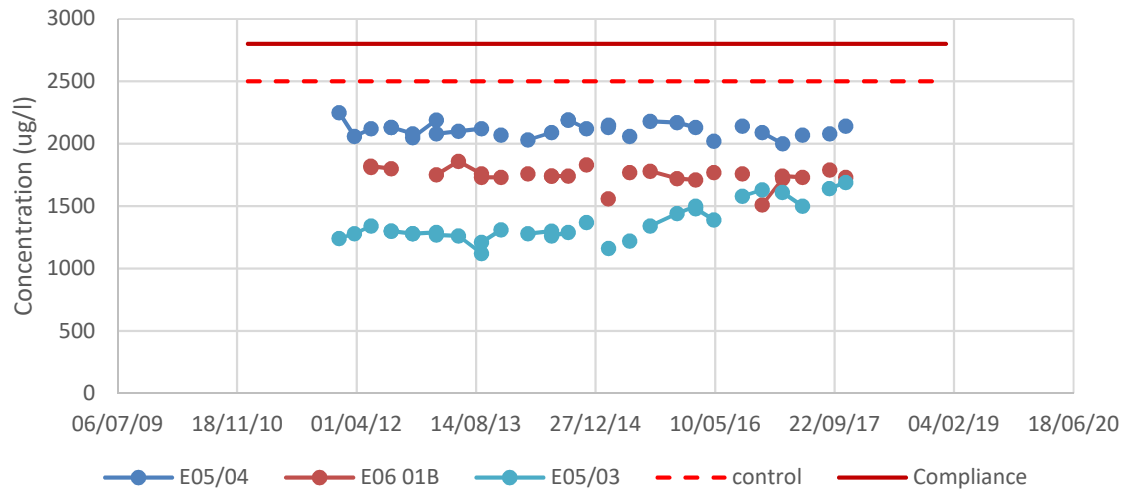


Parameter	Units	Reference Values				Up gradient Groundwater Background (E09/01A E09/01B)	Compliance Limits	
		AA	MAC	Source				
Hazardous Substances:								
Arsenic*	µg/l	50	-	EQS	1	10	E05/03 & E05/04	
Mercury	µg/l					0.03		
Chromium (VI)	µg/l		5	GW	0.7	5		

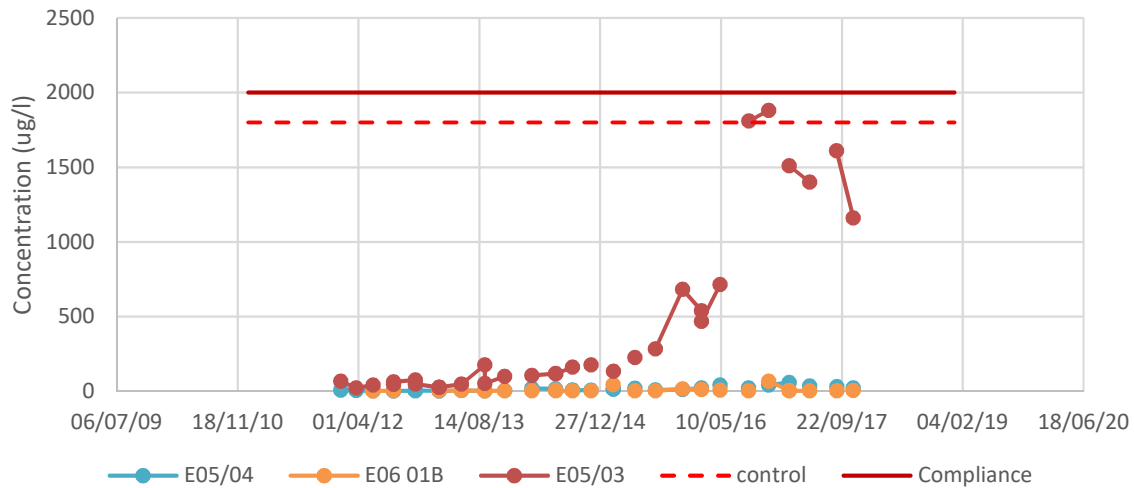
Parameter	Reference Values				Up gradient Groundwater Background (E09/01A E06/01B)	Control Levels	Compliance Limits	
	AA	MAC	Source					
	Non-Hazardous Substances:							
Ammoniacal Nitrogen as N (mg/l)	(unionised EQS 21 ug/l)		EQS	0.3	1.4	E06/01 E05/03 & E05/04	1.6	E05/03 & E05/04
Cadmium (dissolved) ug/l	0.25	1.5	EQS	0.1	0.4		1.5	
Boron mg/l	2		EQS	0.01	2.5		2.8	
Molybdenum ug/l	70		WHO	3	1800		2000	
Sulphate as SO4 mg/l	400		DWS	20	400		600	



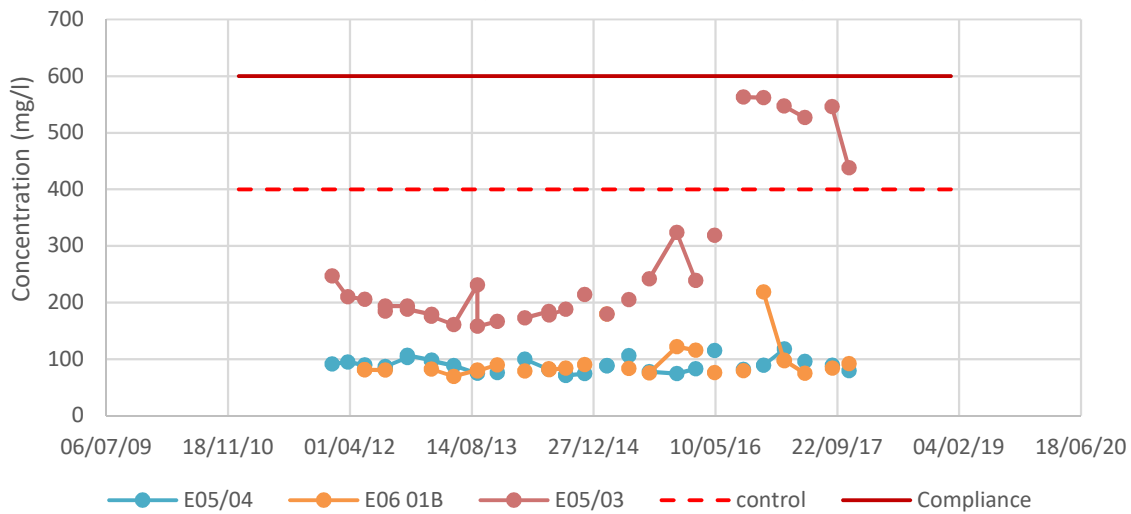
Boron: Down gradient

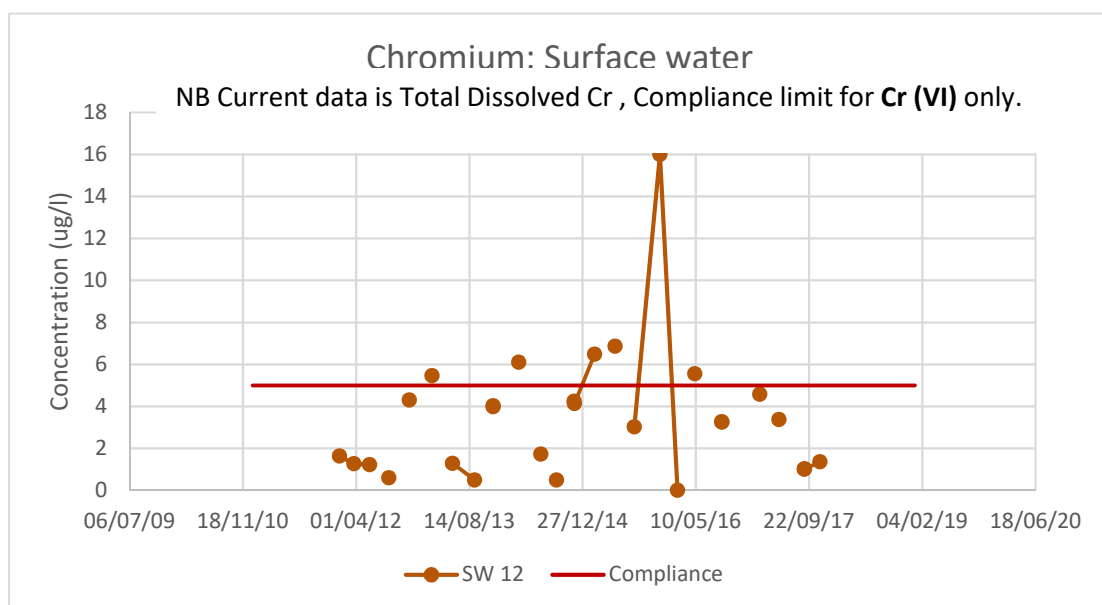
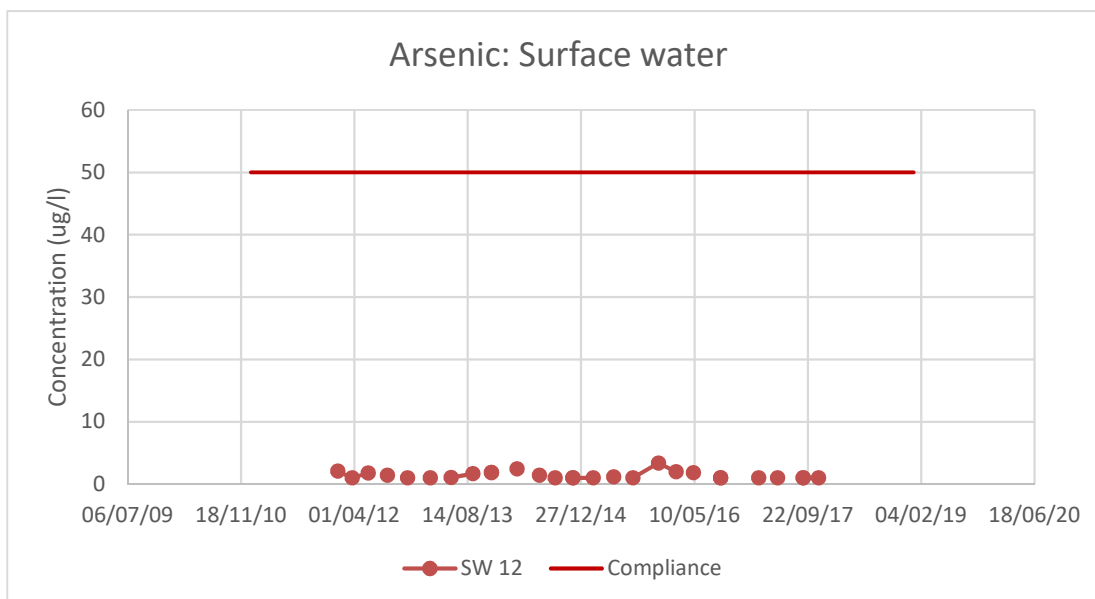


Molybdenum: Down gradient



Suphate as SO4: Down gradient



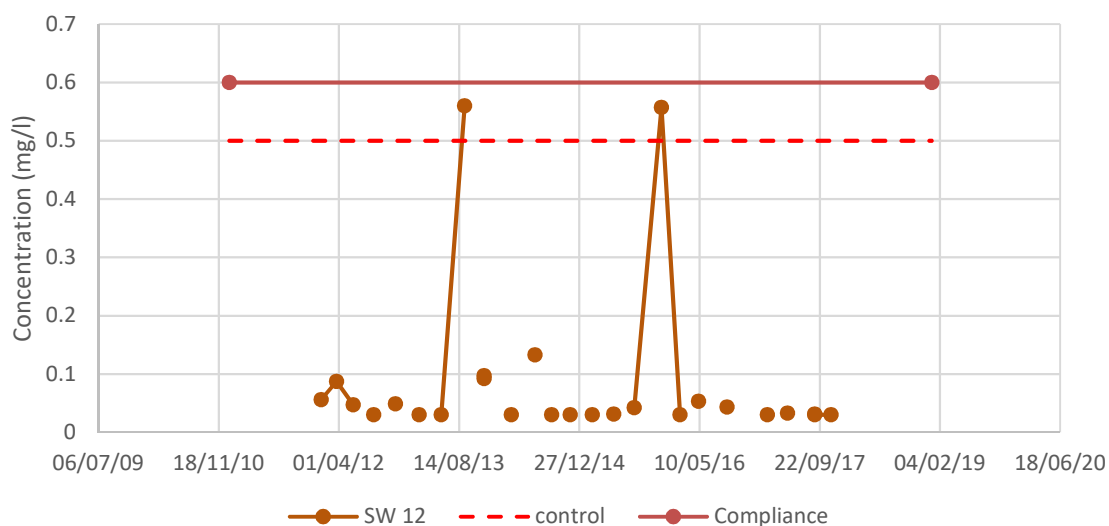


Parameter	Units	Reference Values			Control Levels		Compliance Limits	
		AA	MAC	Source				
Hazardous Substances:								
Arsenic*	µg/l	50	-	EQS	N/A	N/A	50	SW12
Chromium (VI)	µg/l		5	GW	N/A	N/A	5	

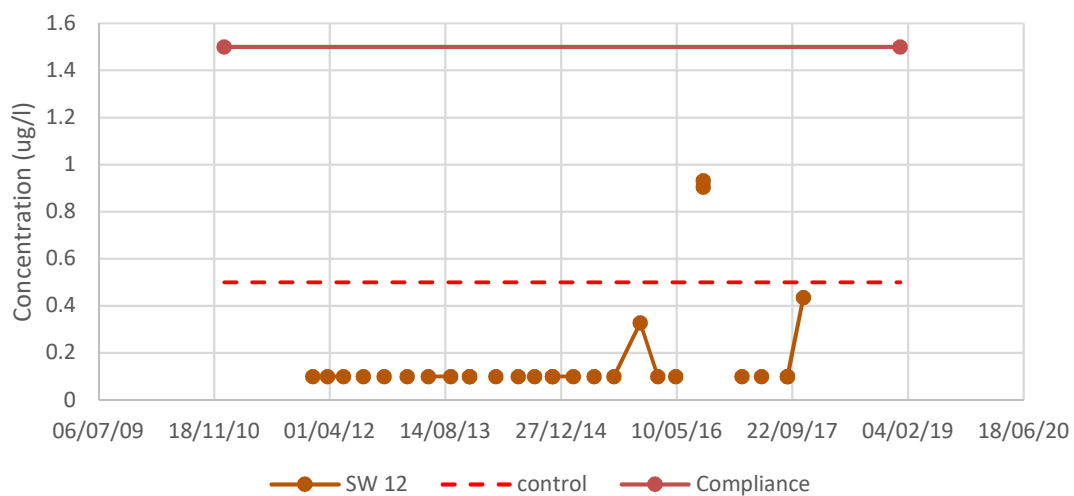
Parameter	Units	Reference Values			Control Levels	Compliance Limits
		AA	MAC	Source		
Non-Hazardous Substances:						

Ammoniacal-Nitrogen as N	mg/l	(unionised EQS 21 ug/l)		EQS	0.5	SW12	0.6	SW12
Cadmium (dissolved)	µg/l	0.25	1.5	EQS	0.5		1.5	
Boron	mg/l	2		EQS	1		2	
Molybdenum	µg/l	70		WHO	1800		2000*	
Sulphate as SO4	mg/l	400		DWS	600		700	

Ammoniacal Nitrogen: Surface water



Cadmium: Surface water





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