

Wales and Borders Rail Service and South Wales Metro

TRAN01 - CVL Transformation

Taffs Well Depot Controlled Waters Risk Assessment | P02

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Executive Summary

Amey Infrastructure/Amey Seilwaith was commissioned by Transport for Wales (TfW) to undertake a Controlled Waters Detailed Quantitative Risk Assessment (CW-dQRA) using current available groundwater data for the site at Taff's Well. Groundwater sampling was undertaken between the 16th April 2019 and the 22nd August 2019, following the initial phase of ground investigation as detailed within Amey Infrastructure/Amey Seilwaith Phase II Land Assessment Report (ref. [TRAN01-KAW-R0-TAF-RPT-G-GE-000004](#)).

The site is located at Taff's Well, South Wales and covers an area of approximately 5.53ha. The OS grid reference of the site centre is ST 12554 83262 and the nearest postcode is CF15 7RN. Historically, the site has had various industrial land uses, namely an iron works/forge from the end of the 19th Century, followed by the manufacturing of lathes, drain covers and automotive parts, as well as less industrial uses within recent times. The site is located c. 100m up hydraulic gradient of the River Taff/Afon Taf at its closest point.

Exceedances of chosen evaluation criteria (hereafter referred to as GAC_{CW}), which are protective of Controlled Waters, were identified within the Phase II Assessment for groundwater. Exceedances of the following were identified; aliphatic fractions, PAHs, metals and metalloids, nitrate, phenol, chloroform and cyanide. On the whole, substances within groundwater are believed to be linked to the Made Ground across the site, with the exception of chloroform and cyanide. Reviewing the spatial distribution of substances, it is likely that multiple 'hotspots' are present which are impacting groundwater, some of which may be located off-site. In addition, the removal of Made Ground across the site for re-development will reduce any potential source within the Made Ground present on site.

Due to the sites proximity to the Taff, a detailed assessment was undertaken following the Environment Agency's Remedial Targets Methodology (RTM). An assessment using the 'Level 3 Groundwater' approach has been applied within the Remedial Targets Worksheet (RTW) spreadsheet. Modelled input parameters were based off average site or borehole specific data where available. Where assumptions were made, these were the most conservative, and as such would yield the highest concentrations at the compliance point. Despite such a conservative approach, the Level 3 assessment did not demonstrate any exceedances at the compliance point, which was set as that bank of the River Taff/Afon Taf closest to the exploratory location being assessed, down hydraulic gradient.

Sensitivity analysis was undertaken on the assumptions made within the RTM assessment, which indicated changes to input parameters do not significantly alter the predicted concentration at the compliance point. Hydraulic parameters were deemed to have a low sensitivity, with initial concentrations and half-lives deemed to be the most sensitive parameters with a medium sensitivity. However, the sensitivity analysis indicated the distance between the site and compliance point has

the biggest influence over modelled concentrations; the distance is sufficient to naturally attenuate substances over the pathway by natural processes, minimising the impact of other input parameters into the model.

Therefore despite remaining uncertainties over the source of the groundwater impacts, coupled with the conservative nature of the hydrogeological modelling, the CW-dQRA with respect to groundwater indicates impacts upon groundwater from substances below the Taff's Well site should not impact on the River Taff/Afon Taf, which is identified as the Controlled Waters receptor.

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1 Introduction

1.1 Instruction and Background

Amey Infrastructure/Amey Seilwaith were commissioned by Transport for Wales (TfW) to undertake a Controlled Waters Detailed Quantitative Risk Assessment (CW-dQRA) using current available groundwater data for the site of the former Taff's Well Depot (hereafter referred to as 'the site'). This report should be read in conjunction with Amey Infrastructure/Amey Seilwaith Phase 2 Geoenvironmental Interpretative Report (ref. [TRAN01-KAW-R0-TAF-RPT-G-GE-000004](#)), particularly relating to groundwater sampling and testing.

The site is located at Taff's Well, north of Cardiff, South Wales and covers an area of approximately 5.53ha. The OS grid reference of the site centre is ST 12554 83262 and the nearest postcode is CF15 7RN. Historically, the site has had various industrial land uses, namely an iron works/forge from the end of 19th Century, followed by the manufacturing of lathes, drain covers and automotive parts, as well as more commercial uses within recent times. Since its closure, the site has been subject to several phase I and phase II assessments, which are discussed in the aforementioned Amey Infrastructure/Amey Seilwaith Phase 2 Geoenvironmental Interpretative Report.

A site location plan is included in Figure 1.

It should be noted that due to the Coronavirus pandemic, it was not possible to undertake further groundwater monitoring at the site at the beginning of the year (2020). It was decided, therefore, to undertake an assessment using the groundwater data available to date from the initial ground investigation (GI) undertaken in 2019.

1.2 Aims and Objectives

This hydrogeological risk assessment was undertaken to demonstrate the robustness of the conclusions within the Phase 2 Geoenvironmental interpretative report. As some exceedances of the chosen controlled waters generic assessment criteria (GAC_{CW}) were identified within the initial report, this CW-dQRA assesses risks posed to the identified receptor (The River Taff/Afon Taf).

It is worth noting here that the underlying aquifers, the Principal (Hunts Bay Oolite Subgroup and Pembroke Limestone Group) and Secondary A (River Terrace Deposits) aquifers, are not considered as receptors within this assessment; as the only known abstraction point is currently inactive, and it is not known if there are any plans to retain this after the site has been redeveloped. The likely purpose for retention of the abstraction point would be to provide water for use for the cleaning of rolling stock, with

excess water being discharged to Welsh Waters infrastructure. The underlying aquifers, however, do provide baseflow to the River Taff/Afon Taf, so the River Taff/Afon Taf is considered the only Controlled Waters receptor for the purposes of this assessment.

The following substances were encountered in concentrations in excess of the chosen GAC_{CW} and are therefore assessed within this report:

- Aliphatics >EC10-EC12 hydrocarbon fractions;
- Aliphatics >EC16-EC35 hydrocarbon fractions;
- Benzo(a)pyrene;
- Benzo(b)fluoranthene;
- Benzo(g,h,i)perylene;
- Benzo(k)fluoranthene;
- Chloroform (and dichloromethane, which is a product of the dechlorination of chloroform);
- Chromium;
- Copper;
- Cyanide (free);
- Fluoranthene;
- Indeno(1,2,3-c,d)pyrene;
- Iron;
- Lead;
- Manganese;
- Nickel;
- Nitrate;
- Phenol, and;
- Zinc.

It should be noted that concentrations of pyrene and phenanthrene were detected within groundwater samples analysed. However, these were not assessed as there are no GAC_{CW} relating to these substances. Using a surrogate, such as benzo(a)pyrene to assess these substances is considered to be unnecessarily conservative due to the substance's relative toxicities. However, it is considered likely that the processes outlined in Section 5.3 would deal with these substances so that they would not impact on the River Taff/Afon Taf. This is demonstrated by the Dutch Serious Risk Values for ecological receptors, in this case for groundwater. The concentration for benzo(a)pyrene is 0.72 µg/L, and the concentration for phenanthrene is 30 µg/L. A Serious Risk Value was not produced for pyrene [1].

The assessment was undertaken using the Environment Agency's Remedial Targets Methodology (RTM) assessment [2] using the 'Tier 3 Groundwater' approach. This methodology applies to groundwater that is already impacted and where the original surface source of these impacts has ceased. Where substances were demonstrated to be in exceedance at this stage, a further, more detailed assessment of the substances was undertaken.

For more information on this approach, please see Sections 5 and 6. The works which have been undertaken in the development of the site have also been considered, principally the removal of Made Ground from the site, as well as the development of a potential drainage strategy (although the details of this drainage strategy are yet to be finalised).

For the tabular Conceptual Site Model (CSM) for the site, refer to the original Phase II investigation report [3].

1.3 Legislative Context

The assessment has been undertaken in general accordance with the procedures set out in the Environment Agency's 'Land Contamination Risk Management (LCRM)' [4]. LCRM provides the technical framework for structured decision making about land contamination and builds on previous work carried out by the Environment Agency and the former Department of the Environment.

The scope of this assessment is based upon the procedures for CW-dQRA as set out in Stage 1 of LCRM and comprises the following stages:

- Define and determine parameters to characterise the Conceptual Site Model (CSM) that forms the basis of the CW-dQRA; and,
- Undertake CW-dQRA using the Remedial Targets Methodology [2] and associated Worksheet.

This assessment has been undertaken using the above methodological process whilst following relevant Welsh Government guidance.

2 Groundwater Monitoring

2.1 Groundwater Sampling

Sampling of groundwater was undertaken over a period of several months during and after GI works at the site, between the 16th April 2019 and the 22nd August 2019. An exploratory location plan of all GI locations is included in Figure 2a and 2b. A plan of locations where groundwater was sampled from is included in Figure 3.

Originally, it was intended that further monitoring and sampling of the groundwater on-site would be undertaken. However, due to the coronavirus pandemic, it was not possible to undertake the further sampling at the time. A decision was taken to assess the data already available from the site, and to use this as a basis for the assessment as this was considered to represent a worse-case scenario for the site prior to development.

Exceedances of the substances outlined in Section 1 were detected during sampling. A summary of the sampling which was undertaken during this period is provided in Table 1 below. Four additional boreholes from previous investigations, undertaken by WYG in 2018 [5] were also monitored. Samples were only able to be recovered from BH101 as BH102-104 were either inaccessible due to site operations or dry during sampling events. CPBH213 was inaccessible due to site operations. Borehole logs from which groundwater samples were taken are included in Table 1.

Table 1 - Summary of boreholes with Geo-Environmental Related Testing

Borehole ID	Monitoring Well	Chemical Testing Results (Groundwater)	Strata Screened
CPBH211	✓	Samples not taken as borehole was dry	River Terrace Deposits
CPBH212	✓	✓	River Terrace Deposits
CPBH213	✓	Borehole not accessible	River Terrace Deposits
RBBH202	✓	✓	River Terrace Deposits
RBBH203	✓	✓	River Terrace Deposits
RBBH205	✓	✓	River Terrace Deposits
RBBH206	✓	✓	Penarth Group Limestone
RBBH209	✓	✓	River Terrace Deposits
RBBH210	✓	✓	River Terrace Deposits

Borehole ID	Monitoring Well	Chemical Testing Results (Groundwater)	Strata Screened
WS205	✓	Samples not taken as borehole was dry	River Terrace Deposits
WS208	✓	Samples not taken as borehole was dry	River Terrace Deposits
WS210	✓	Samples not taken as borehole was dry	River Terrace Deposits
WS212	✓	Samples not taken as borehole was dry	River Terrace Deposits
WS213	✓	Samples not taken as borehole was dry	Granular Made Ground
WS215	✓	Samples not taken as borehole was dry	Made Ground
WS218	✓	Samples not taken as borehole was dry	River Terrace Deposits (misinterpreted on the logs as Alluvium)
WS219	✓	Samples not taken as borehole was dry	River Terrace Deposits (misinterpreted on the logs as Alluvium)
WS223	✓	Samples not taken as borehole was dry	Made Ground
BH101*	✓	✓	River Terrace Deposits
BH102*	✓	Samples not taken as borehole was dry	River Terrace Deposits
BH103*	✓	Samples not taken as borehole was dry	River Terrace Deposits
BH104*	✓	Samples not taken as borehole was dry	River Terrace Deposits

*Historic WYG 2018 [5] boreholes

2.2 Groundwater Flow Direction

Within the original report, it was hypothesised that groundwater flow below the site was principally within the River Terrace Deposits. The groundwater below the site is likely to originate from the slopes of Craig yr Allt located to the east - northeast, and flowing downgradient towards the River Taff/Afon Taf in an approximate south-south-westerly direction, as well as from infiltration to the north of the site. At the time of the ground

investigation the site was covered with asphalt and other hard standing which would have significantly reduced infiltration on-site. There is also the potential for a small proportion of groundwater below the site to derive from the hypothesised source of a hydrothermal spring which is reported to be present at Taff's Well.

As included within the original interpretative report, a plan (reproduced here as Figure 4) demonstrates the hypothesised groundwater flow beneath the site. This was generally thought to be from the north flowing in a southerly direction, then moving to a NNE toSSW oriented direction.

Depth to bedrock was considered to influence the direction of groundwater flow; an analysis of the exploratory location records from previous GIs indicates that there is a bedrock "bulge" in the central eastern portion of the site, which is interpreted as likely being caused by either the movement of the River Taff/Afon Taf post glacial-era, or caused by glaciers themselves as they traversed the Taff's Well gorge. It is suspected it is this bulge which causes the deflection of groundwater, from the N-S direction groundwater appears to flow in the northern portion of the site, to the NNE-SSW direction groundwater appears to flow in the south western portion of the site.

2.3 Groundwater Levels

2.3.1 Groundwater Strikes

A perusal of the exploratory location records indicates that groundwater was only detected within several locations during their advancement; namely HP205 within Made Ground (at a depth of 1.2m BGL), and CPBH212, WS218, WS221, BH101, BH102, and BH104 within River Terrace Deposits. All other locations were noted as being dry.

Observations of groundwater rising following a strike during drilling were mostly slight, the only significant rise being within BH102, where groundwater was encountered at a depth of approximately 9.2m BGL, rising to 1.1m BGL. There was no obvious confining layer within this borehole according to the records, so it is assumed that, in this portion of the site, there is a small confining aquitard which is influencing the depth of groundwater across the south western boundary of the site. As this was not found in any other areas, it is assumed this is a local feature that is not replicated in other portions of the site.

All exploratory locations which encountered the bedrock did not record any groundwater strikes. This is true for both the Amey GI BHs, advanced using rotary, and the WYG GI BHs, advanced using cable percussion.

2.3.2 Groundwater Monitoring

Groundwater monitoring after the GI demonstrated that those BHs which were installed at shallow depths were generally dry, and that groundwater across the site is at a depth varying between 27-34m AOD; the average minimal and maximal heights were 29.04m AOD and 30.78m AOD respectively. A hydrograph using data across all monitoring visits has been included in Insert 1.

The average height variance across the site, within boreholes, is 1.74m. This would indicate that groundwater is present below within the River Terrace Deposits, with occasional small perched lenses within the Made Ground on-site.

It is considered that the groundwater detected within RBBH206, the only exploratory location which was installed into the limestone, is in hydraulic continuity with groundwater within the River Terrace Deposits. This is evidenced within the hydrograph in Insert 2-1 below, as groundwater trends mirror those of the River Terrace deposits. This refines the groundwater model provided in the Phase II report [3], where groundwater within the limestone was considered to have flowed down an incorrectly installed or damaged well.

Therefore, it is concluded that the groundwater monitored and sampled below the site resides within the River Terrace Deposits as well as the Pembroke Limestone Group/Hunts Bay Oolite Subgroup, and that the groundwater within these strata is in hydraulic continuity. It is not possible to determine whether there is any flow of groundwater between the superficial deposits and bedrock, but it is considered this flow, if present, will have no impact on the overall assessment of the risk posed by the site on the identified receptor. It would therefore stand to reason that the majority of the water within the River Terrace Deposits is sourced from the slopes of Craig yr Allt and land to the east – north east of the site, with a minor component from infiltration at the site (the site was generally hardstanding prior to the demolition of the works previously present). This implies that the contribution to groundwater from the source of hydrothermal water at Taff's Well is likely to be negligible.

Insert 1 – Taff's Well Hydrograph



2.4 Generic Assessment Criteria (Controlled Waters)

Considering the environmental setting of the site, the following controlled waters generic assessment criteria (GAC_{CW}) have been adopted in order of preference:

- Freshwater Environmental Quality Standards (EQS) [6];
- Inland Surface Water EQS [6];
- WHO 2008 - Petroleum Products in Drinking Water (WHO 2008) [7] ;
- UK Drinking Water Standards [8].

The GAC_{CW} concentrations are included in Table 2. Laboratory analysis results are included within Appendix B, with the screened groundwater results included within Appendix C.

2.5 Exceedances

Exceedances, varying in their presence, were identified in several locations throughout the sampling regime. A summary of the exceedances of substances related to the GAC_{CW} used is given in Table 2. A discussion of the exceedances is provided within the following sections, along with graphs showing the concentrations during the sampling visits per determinand.

Table 2 - Summary of Exceedances of Substances within Groundwater Samples

Substance	Screening Value (µg/L)	Source of screening value	Borehole	Concentrations of Exceedances (µg/L) (in date order where more than one occurrence was identified)
Aliphatics >EC10-EC12	300	WHO Petroleum products in drinking-water	RBBH206	438
Aliphatics >EC16-EC35	300	See note below (1)	RBBH206	2,400
Benzo(a)pyrene	0.00017	Inland Surface Water EQS	BH101	0.03, 0.04
Benzo(b)fluoranthene	0.00017	See note below (2)	RBBH206 BH101	0.03, 0.03, 0.06 0.02, 0.08
Benzo(g,h,i)perylene	0.00017	See note below (2)	BH101	0.011, 0.02, 0.03
Benzo(k)fluoranthene	0.00017	See note below (2)	RBBH206 BH101	0.01 0.01, 0.02, 0.03
Chloroform (3)	2.5	Private Water Supplies (England) Regulations 2016	RBBH205 RBBH206	3 4, 19
Chromium (assumed as total Cr and assessed as Cr III; Cr IV was not detected in any soil testing above LoD)	4.7	Freshwater EQS	RBBH202 RBBH203 RBBH205 RBBH206 RBBH209 RBBH210 BH101	7.4 10.1 11.1 5.6, 9.4, 13.2 7, 15 6.9, 7.5 5.4
Copper	1	Freshwater EQS	RBBH202 RBBH203 RBBH205 RBBH206 RBBH209 RBBH210	4 8 6, 7, 11 4, 7, 10, 12 3, 7, 21 4, 6

Substance	Screening Value (µg/L)	Source of screening value	Borehole	Concentrations of Exceedances (µg/L) (in date order where more than one occurrence was identified)
			BH101	3, 4, 22
Cyanide (Free) (see 2.5.10)	1	Freshwater EQS	BH101	25
Fluoranthene	0.0063	Inland Surface Water EQS	RBBH205 RBBH206 BH101	0.016 0.034, 0.035 0.06, 0.07, 0.15, 0.179
Indeno(1,2,3-c,d)pyrene	0.00017	See note below (2)	BH101	0.02, 0.03
Iron	1,000	Freshwater EQS	RBBH202 RBBH203 RBBH206 RBBH209 RBBH210 BH101	1,117 1,083 2,014 2,120 1,124 1,677
Lead	1.2	Freshwater EQS	RBBH202 RBBH203 RBBH205 RBBH206 RBBH209 RBBH210 BH101	2.8 4.9 4.1 5.3 2.1, 4.4 2.3, 3.9 1.5, 52.4
Manganese	123	Freshwater EQS	RBBH202 RBBH203 RBBH205 RBBH206 RBBH209 RBBH210 BH101	178.6 168.8 198.3, 225.1 134.2 596.8, 1,186, 1,209, 1,411 2,519, 3,388, 3,763, 3,875, 3,937, 3,942 167.9, 226.1

Substance	Screening Value (µg/L)	Source of screening value	Borehole	Concentrations of Exceedances (µg/L) (in date order where more than one occurrence was identified)
Nickel	4	Freshwater EQS	RBBH209	9.1, 9.2, 9.3, 9.5
Nitrate	4,000	Groundwater-Dependent Terrestrial Ecosystems - Minimum Threshold	CPBH212	10,690
Phenol	7.7	Freshwater EQS	RBBH210	14
Zinc (4)	10.9	Freshwater EQS	CPBH212	12.6
			RBBH203	30.3
			RBBH205	22.4, 29.9
			RBBH206	13.3, 19.5, 21.7, 49.1
			RBBH209	11.3, 11.4, 31.8, 35.1
			RBBH210	20.4, 23.3, 25
			BH101	11.1, 21.8, 22.3, 23.5, 148.5

1 No GAC_{CW} for this TPH fraction, so the WHO Petroleum Products in Drinking-Water value for Aliphatics >EC12-EC16 is used as a surrogate. This is considered conservative as generally lower weight aliphatic compounds have a higher relative toxicity than heavier weight aliphatic compounds.

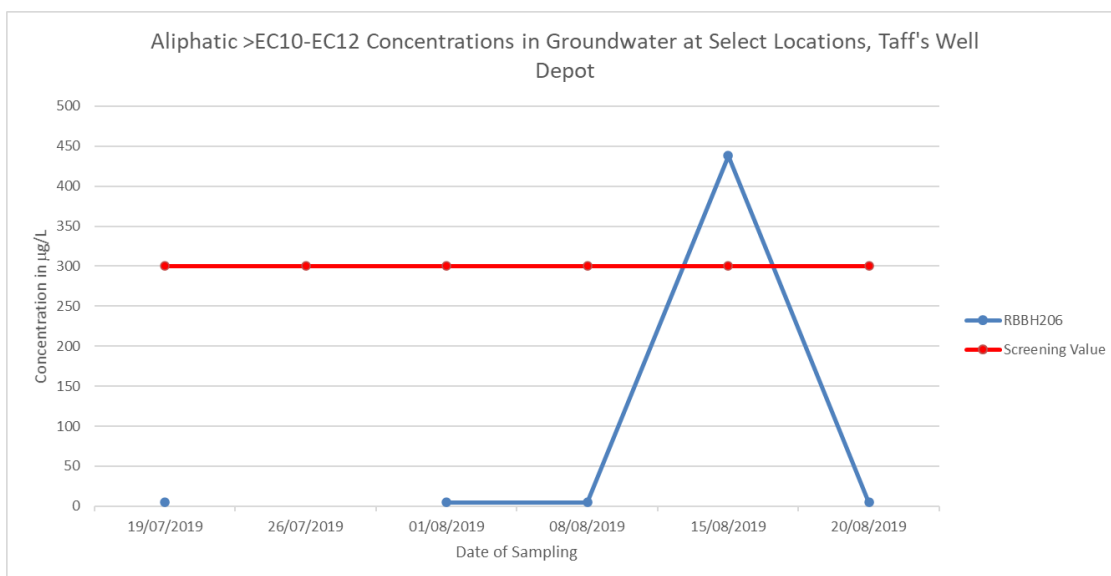
2 As there are no formal values with which to assess benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, and indeno(1,2,3-c,d)pyrene, the value for benzo(a)pyrene is used as a surrogate. It is noted this is likely exceedingly conservative as these PAHs are less toxic than benzo(a)pyrene.

3 As directed by the Environment Agency, breakdown products of substances are to be considered in this process. One of the breakdown products of chloroform is dichloromethane, which is also considered here, but there were no exceedances recorded within the sampling.

4 The value for zinc is meant to be amended using the bioavailable amount, as well as the Ambient Background Concentration. However, when undertaking a generic assessment, only the Freshwater EQS of 10.9 µg/L is used. The bioavailable amount has not been calculated, and the addition of the Ambient Background Concentration (2.8 µg/L) would increase the screening value, therefore the screening value of 10.9 µg/L is considered very conservative.

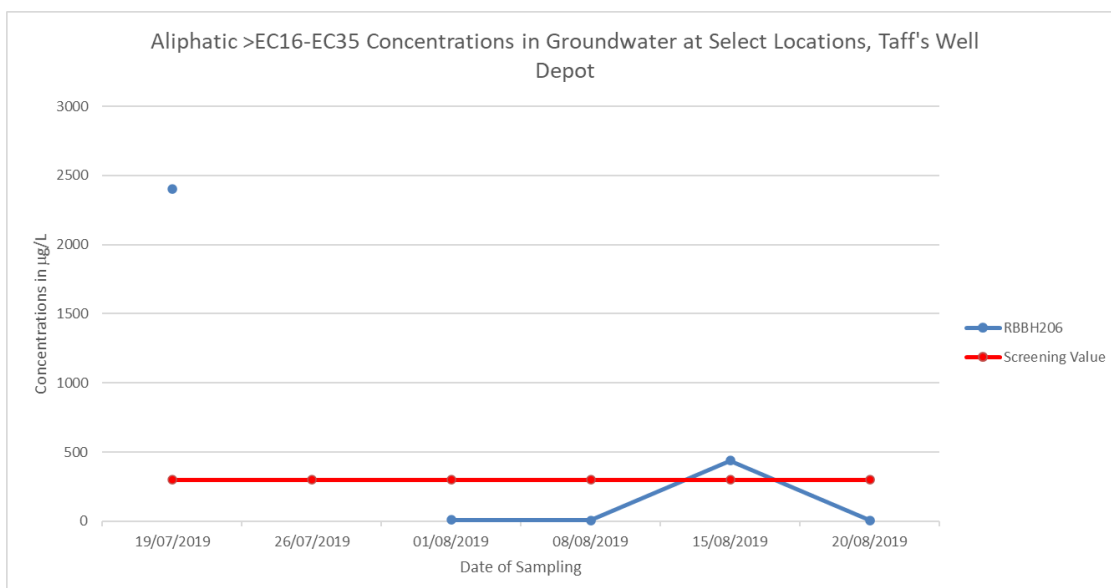
2.5.1 Aliphatics >EC10-EC12

Exceedances of aliphatic >EC10-EC12 compounds were detected in one borehole only, RBBH206, on the fifth round of sampling. Prior and subsequent to this date, the concentrations determined by analysis were below the limit of detection (LoD) (<5 µg/L).



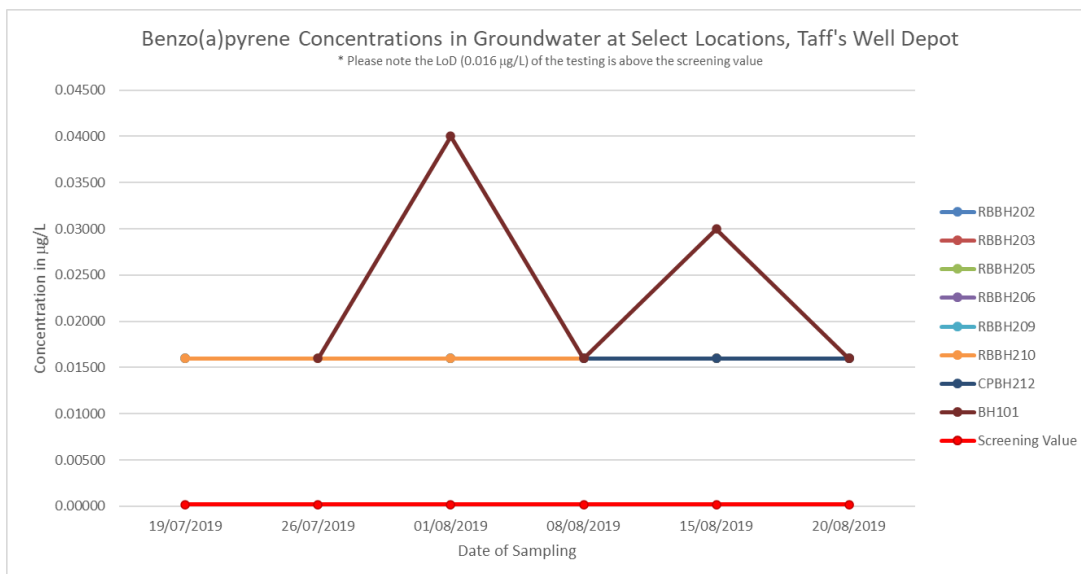
2.5.2 Aliphatics >EC16-EC35

Exceedances of aliphatic >EC16-EC35 compounds were detected in one borehole only, RBBH206, on the first and fifth sampling visits. Subsequent to, prior, and between these dates, the concentrations determined by analysis were below the limit of detection (LoD) (<10 µg/L).



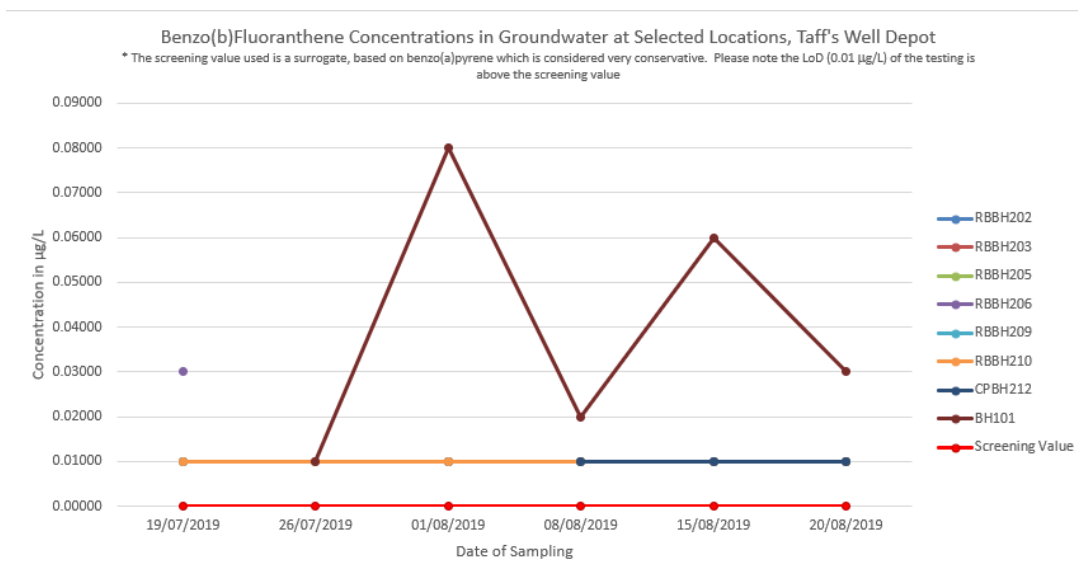
2.5.3 Benzo(a)pyrene

Detections of benzo(a)pyrene above the LoD were detected in one borehole only, BH101, on the third and fifth rounds of sampling. Subsequent to, prior, and between these dates, concentrations determined by analysis were below the LoD ($<0.16 \mu\text{g/L}$). It should be noted the LoD is above the GAC_{CW} .



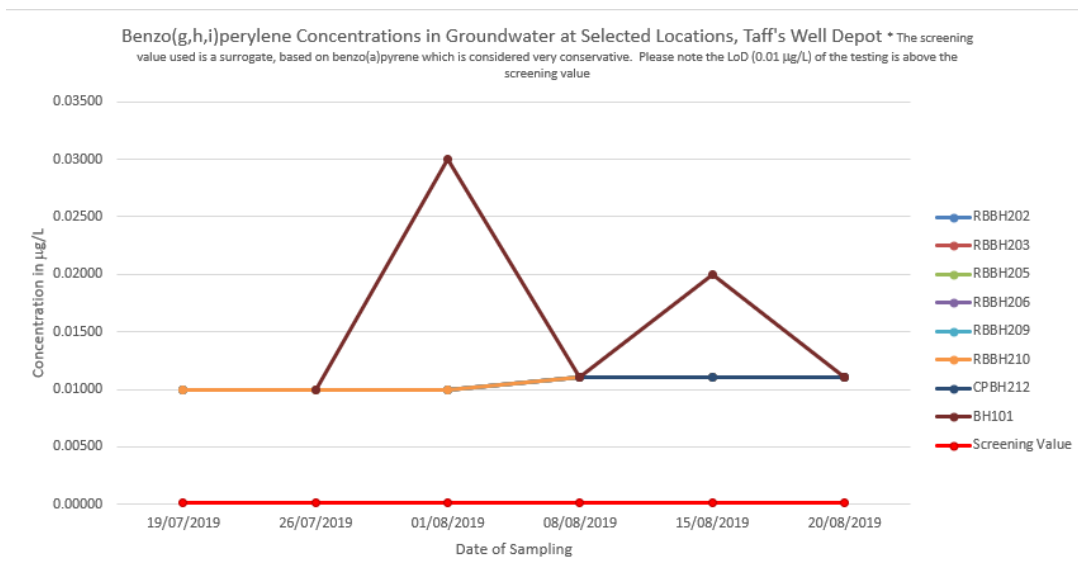
2.5.4 Benzo(b)fluoranthene

Detections of benzo(b)fluoranthene above the LoD were detected within RBBH206 and BH101. Exceedances within RBBH206 were only detected on the first sampling visit, whereas exceedances within BH101 were detected on the third, fourth, fifth, and sixth sampling visits. On the remaining dates, concentrations determined by analysis were below the LoD ($<0.01 \mu\text{g/L}$). It should be noted the LoD is above the surrogate GAC_{CW} . Please note graph is on the next page.



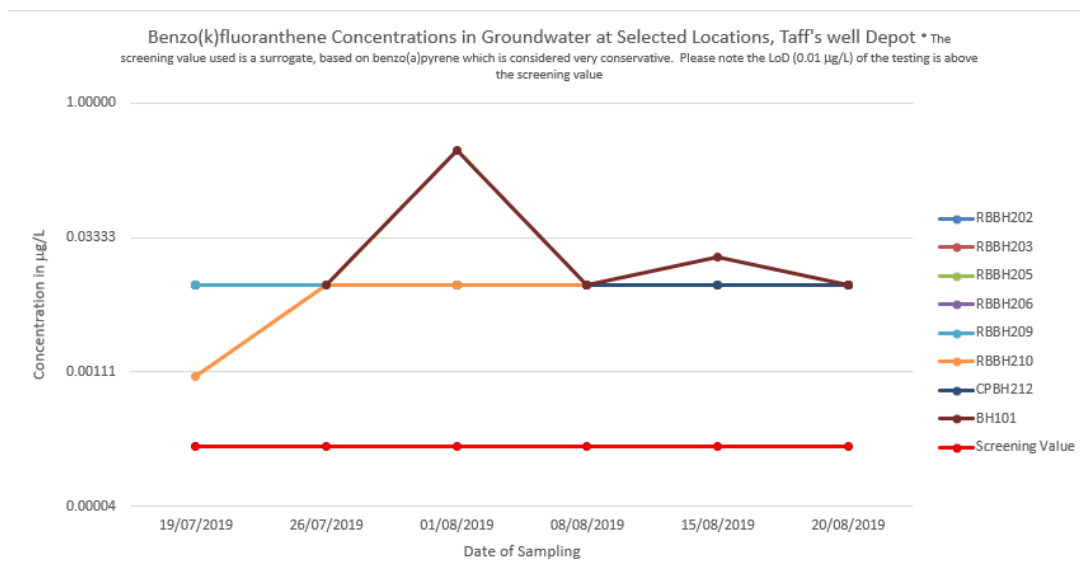
2.5.5 Benzo(g,h,i)perylene

As with benzo(a)pyrene, detections of benzo(g,h,i)perylene above the LoD were only found within BH101 on the third, fifth and sixth sampling rounds. On the remaining dates, concentrations determined by analysis were below the LoD (<0.011 µg/L). It should be noted the LoD is above the surrogate GAC_{CW}.



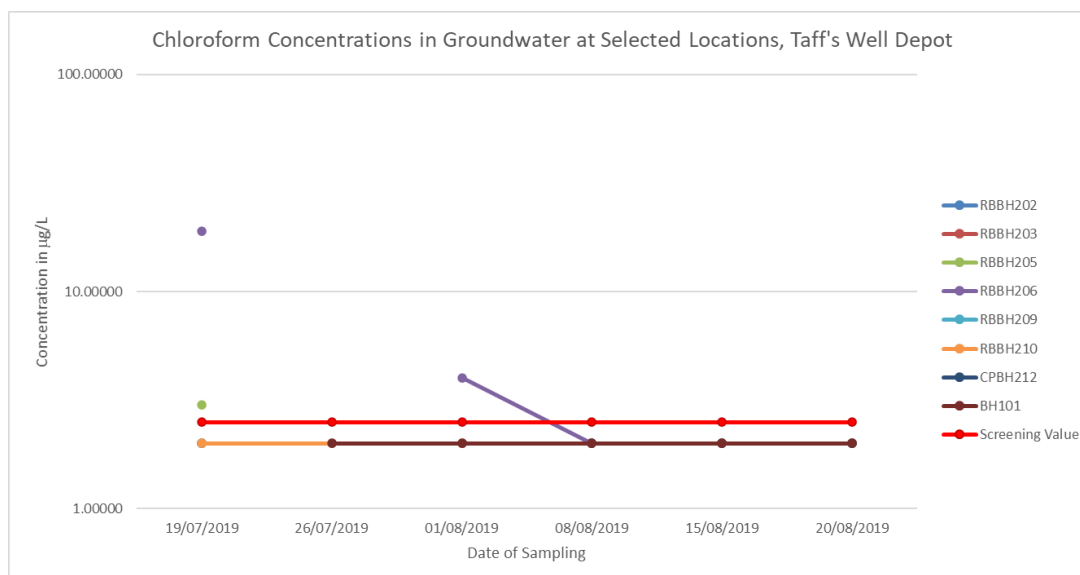
2.5.6 Benzo(k)fluoranthene

Detections of benzo(k)fluoranthene were detected above the LoD within both RBBH206 and BH101 on the first sampling visit, and detected within RBBH206 on the third, fifth, and the sixth sampling visit within BH101. On the remaining dates, concentrations determined by analysis were below the LoD (<0.01 µg/L). It should be noted the LoD is above the surrogate GAC_{CW}. Please note the graph is below.



2.5.7 Chloroform

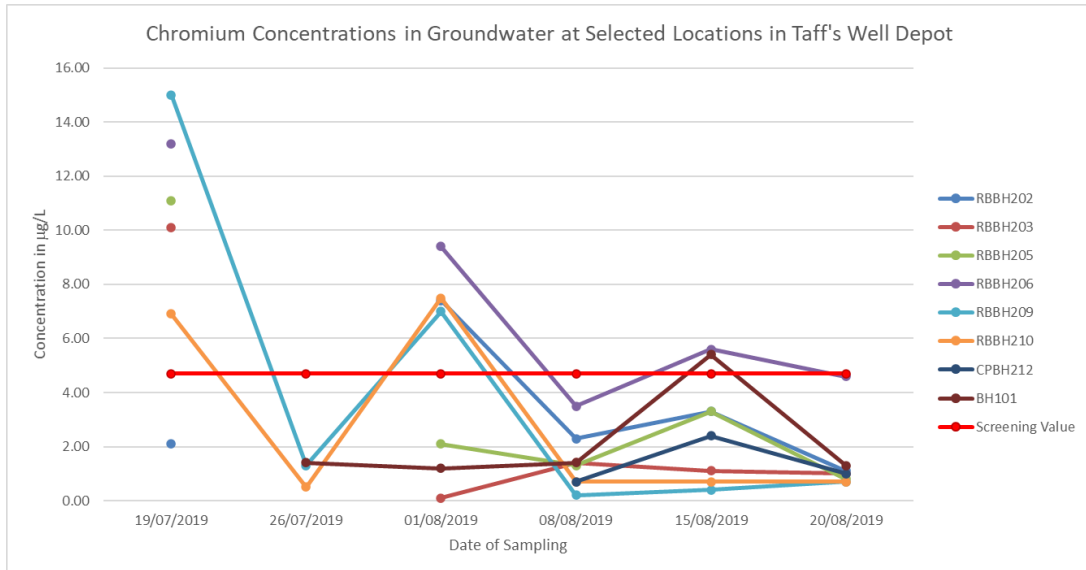
Exceedances of chloroform were detected within RBBH205 and RBBH206 on the first sampling visit, and within RBBH206 on the third sampling visit. Chloroform was detected within RBBH206 on the fourth sampling visit, but the concentration was below the GAC_{CW} used. Chloroform was below the limit of detection (<2 µg/L) on all other occasions.



2.5.8 Chromium

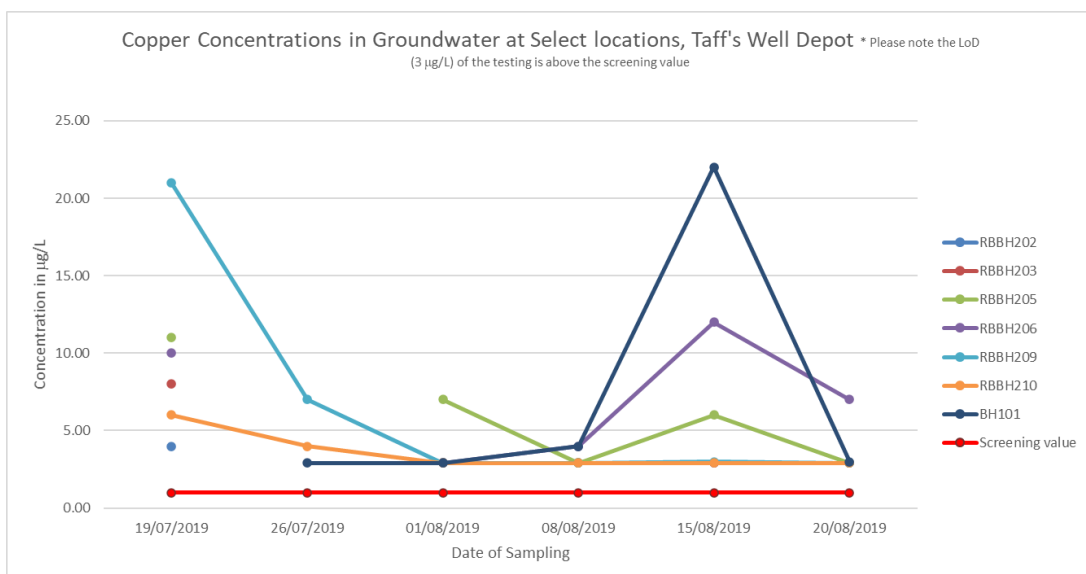
Exceedances of chromium were detected in several boreholes; in boreholes RBBH202, RBBH203, RBBH205 and BH101 on only one sampling visit, in RBBH209 and RBBH210 on two sampling visits, and in RBBH206 on three monitoring visits. Prior and subsequent to these visits, the concentrations determined by analysis were below

the GAC_{CW} , or below the limit of detection ($<0.2 \mu\text{g/L}$). As noted above, the assessment of chromium was based on chromium III, as no chromium IV was detected within soil testing results above the soil analytical LoD.



2.5.9 Copper

Exceedances of copper were detected in several boreholes; RBBH202 and RBBH203 on one occasion, RBBH210 on two occasions, RBBH205, RBBH209 and BH101 on three occasions, and RBBH206 on four occasions. The majority of the groundwater exceedances were detected after the installation of the monitoring standpipes during the first sampling visit, with subsequent concentrations fluctuating to, at, or below, the LoD ($<3 \mu\text{g/L}$) on the final visit.

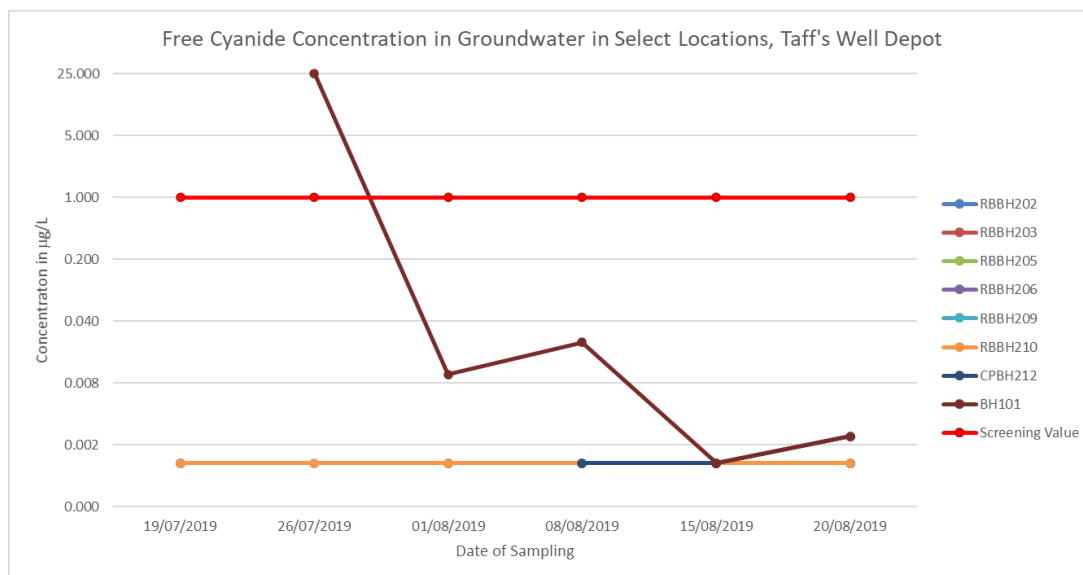


2.5.10 Cyanide (free)

Exceedances of both free and total cyanide were detected within several boreholes across the site. However, as suggested by the name, total cyanide is a combination of multiple different compounds which contain the cyano- group. Cyanide mostly occurs as inorganic metal-cyanide complexes, cyanate and thiocyanate species, as well as organo-cyanide complexes.

As such, it is not possible to assess the impact of total cyanide due to the large number of potential compounds present. It is, however, possible to assess the impact of free cyanide, which in essence is a combination of the free cyanide ion and hydrogen cyanide. Given the pH of the groundwater on site is less than the acid dissociation constant of hydrogen cyanide (between 9.3-9.4 pH units), it is most likely that all the “free cyanide” is present in the form of hydrogen cyanide, so where free cyanide has been assessed, it has been done so as hydrogen cyanide. Mention of cyanide or free cyanide from hereon is to be taken to refer to hydrogen cyanide, unless explicitly stated.

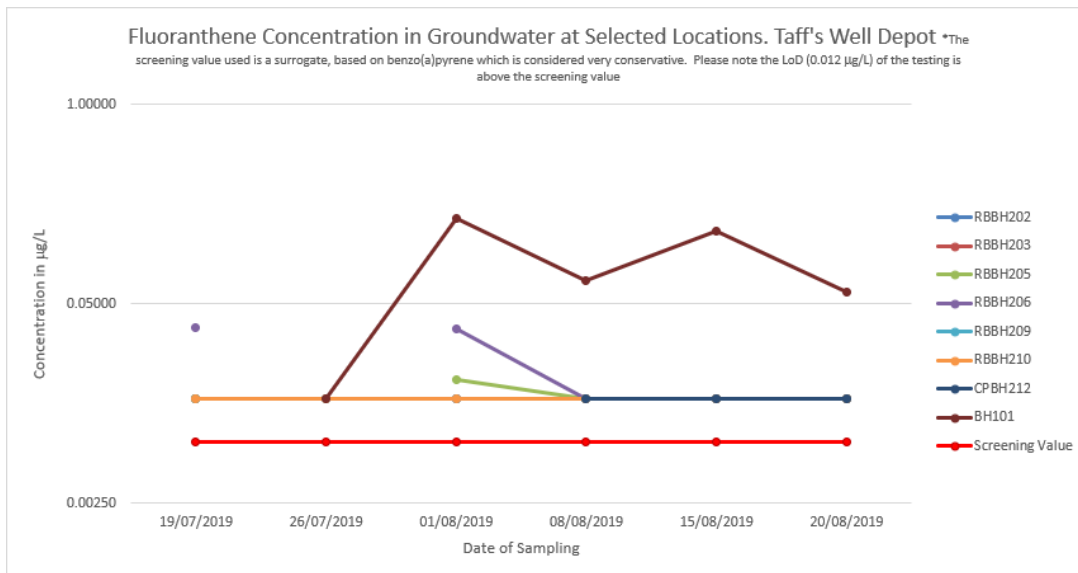
Cyanide was detected in one location during one monitoring visit (the same monitoring visit where total cyanide was detected at a concentration of 130 µg/l). This was in BH101 on the second monitoring visit. At all other monitoring visits, in all other locations, both free and total cyanide were below the GAC_{CW} or LoD (<0.001 µg/L). There is no obvious source of cyanide on site.



2.5.11 Fluoranthene

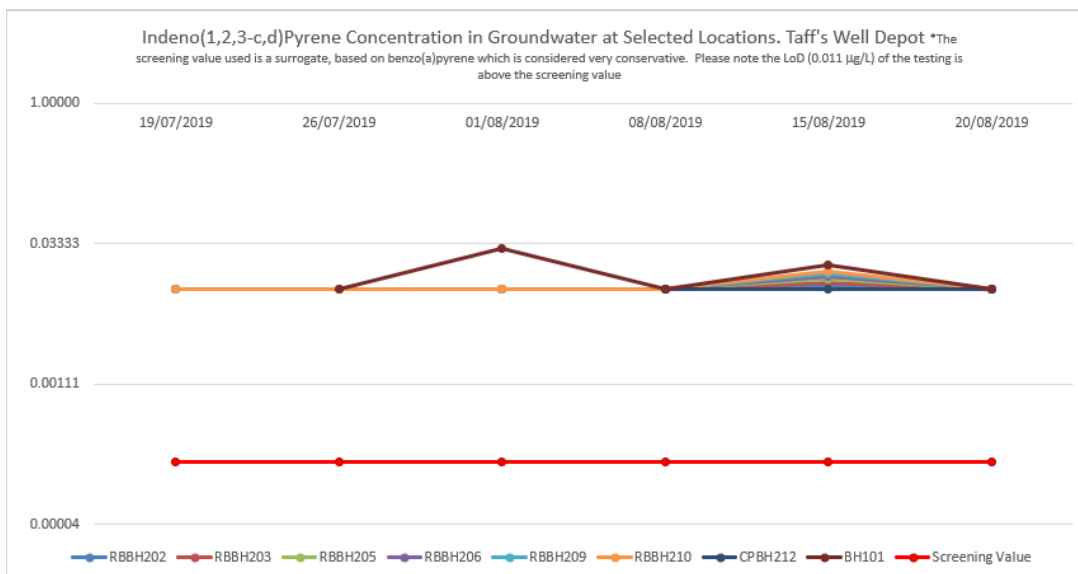
Detections of fluoranthene were detected within RBBH205, RBBH206, and BH101. The first detection was within RBBH206 on the first monitoring visit; with more detections within RBBH205 and RBBH206 observed during the third monitoring visit.

Detections in BH101 were first identified during the third monitoring visit and then on every monitoring visit after. On the remaining dates, concentrations determined by analysis were below the limit of detection ($<0.012 \mu\text{g/L}$). It should be noted the LoD is above the GAC_{CW} .



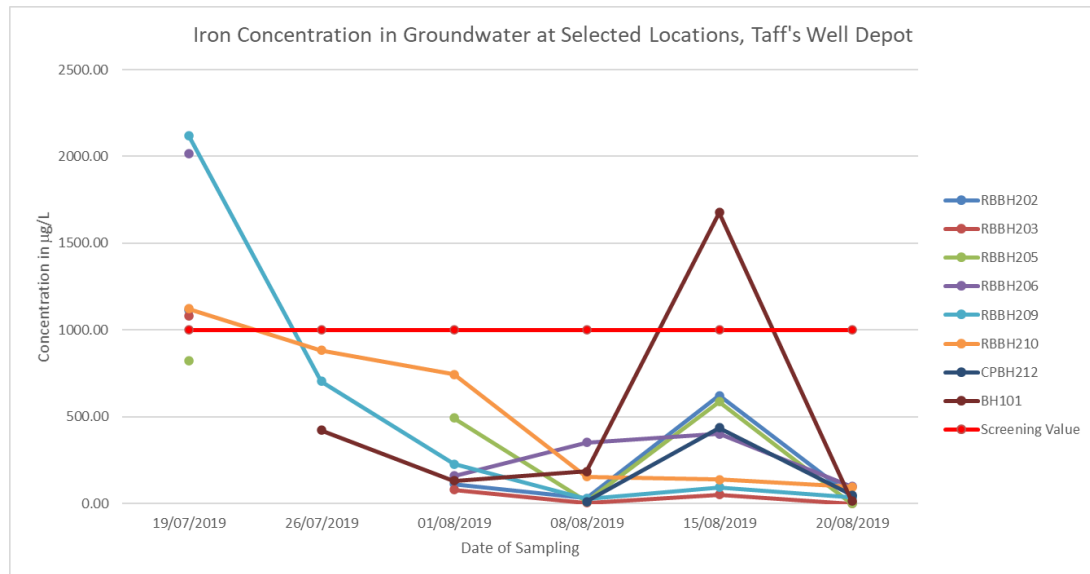
2.5.12 Indeno(1,2,3-c,d)Pyrene

Detections of indeno(1,2,3-c,d)pyrene above the LoD were only detected within BH101 on the third and fifth visits. On the remaining dates in all other locations, concentrations as determined by analysis were below the limit of detection (between <0.011 - $0.017 \mu\text{g/L}$). It should be noted the LoD is above the surrogate GAC_{CW} .



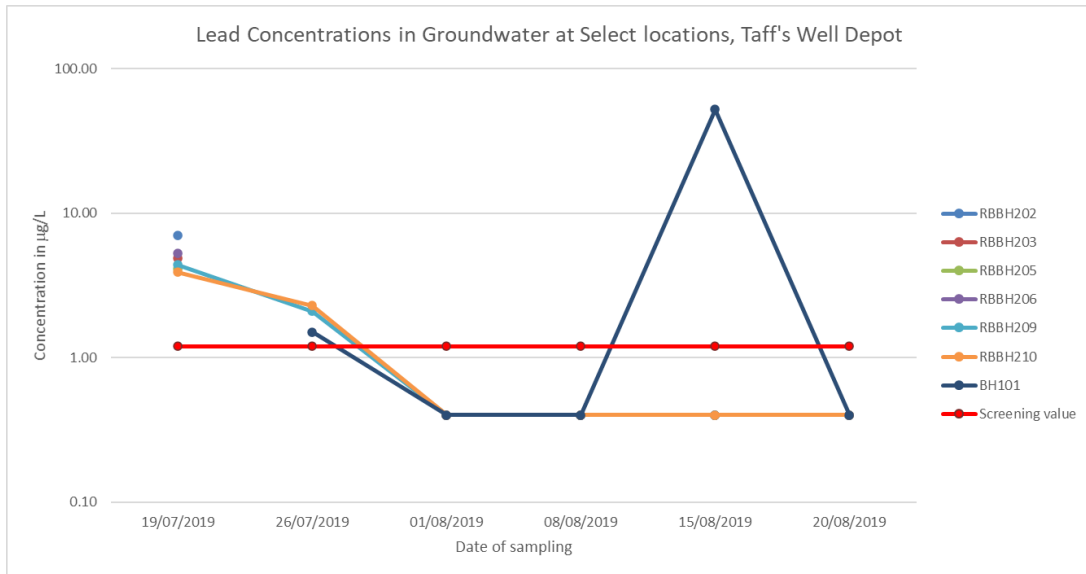
2.5.13 Iron

Exceedances of iron were detected within RBBH202, RBBH203, RBBH206, RBBH209, RBBH210 and BH101. The exceedances within RBBH202, RBBH203, RBBH206, RBBH209, and RBBH210 were only detected on the first monitoring visit, with the remaining exceedance within BH101 detected during the fifth monitoring visit. On the remaining dates, concentrations determined by analysis were below the GAC_{CW}, or below the limit of detection (<0.0047 µg/L).



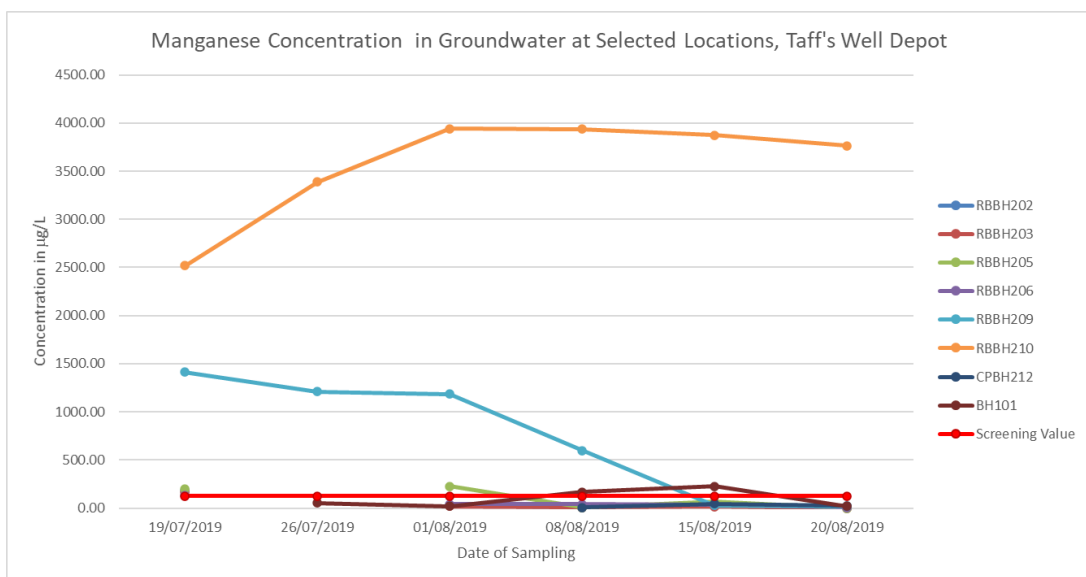
2.5.14 Lead

Exceedances of lead were detected within RBBH202, RBBH203, RBBH206, RBBH209, RBBH210, and BH101. Exceedances within RBBH202, RBBH203, and RBBH206 were only detected on the first sampling visit. Exceedances within RBBH209 and RBBH210 were detected on the first and second visit. Exceedances within BH101 were detected in the second and fifth visits only. On the remaining dates, concentrations determined by analysis were below the limit of detection (<0.4 µg/L). Please note, the graph is on the next page.



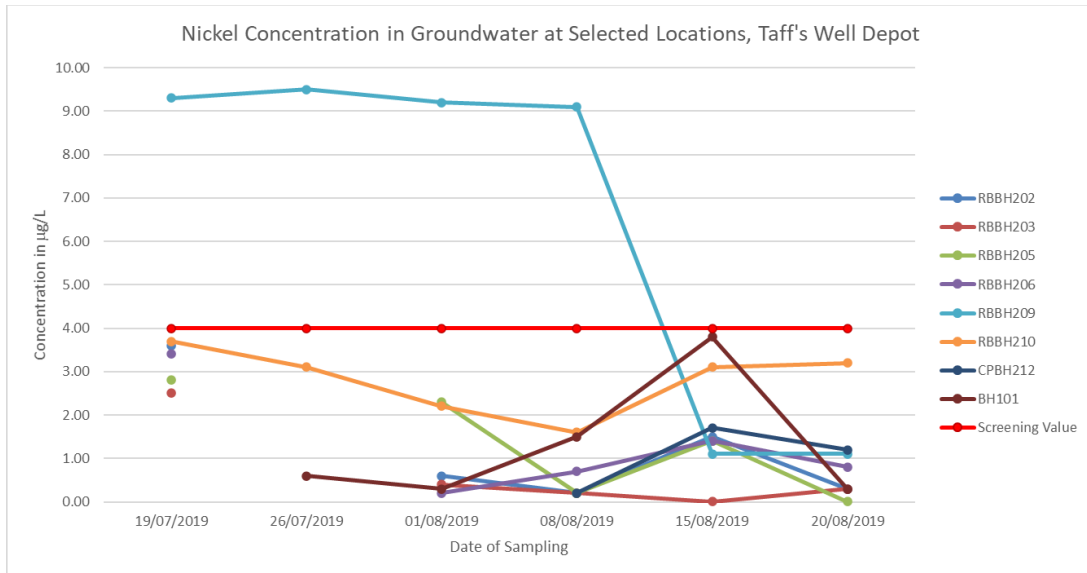
2.5.15 Manganese

Exceedances of manganese were detected within RBBH202, RBBH203, RBBH205, RBBH206, RBBH209, RBBH210 and BH101. Exceedances within RBBH202 and RBBH203 were only detected during the first sampling visit. Exceedances within RBBH205 were detected within the first, second and third monitoring visits. Exceedances within BH101 were detected within the fourth, fifth and sixth sampling visits. Exceedances within RBBH209 were detected within the first, second, third and fourth monitoring visits, and exceedances within RBBH210 were detected within all six monitoring visits. On the remaining dates, concentrations determined by analysis were below the GAC_{CW}, or below the limit of detection (<0.0015 µg/L).



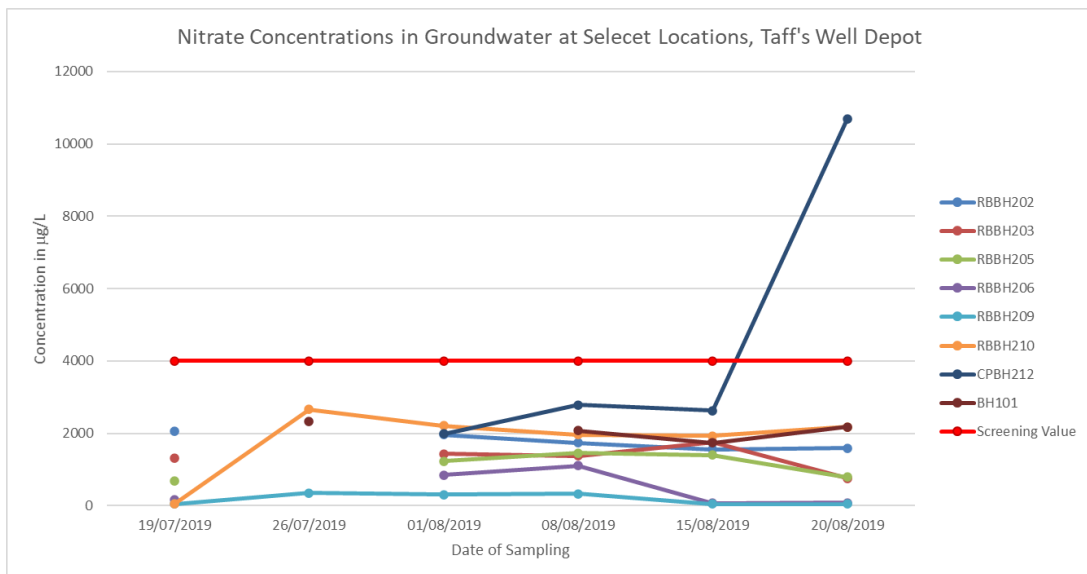
2.5.16 Nickel

Exceedances of nickel were detected within RBBH209 only, during the first, second, third and fourth monitoring visits. On the remaining dates, concentrations determined by analysis were below the GAC_{CW}, or below the limit of detection (<0.0002 µg/L).



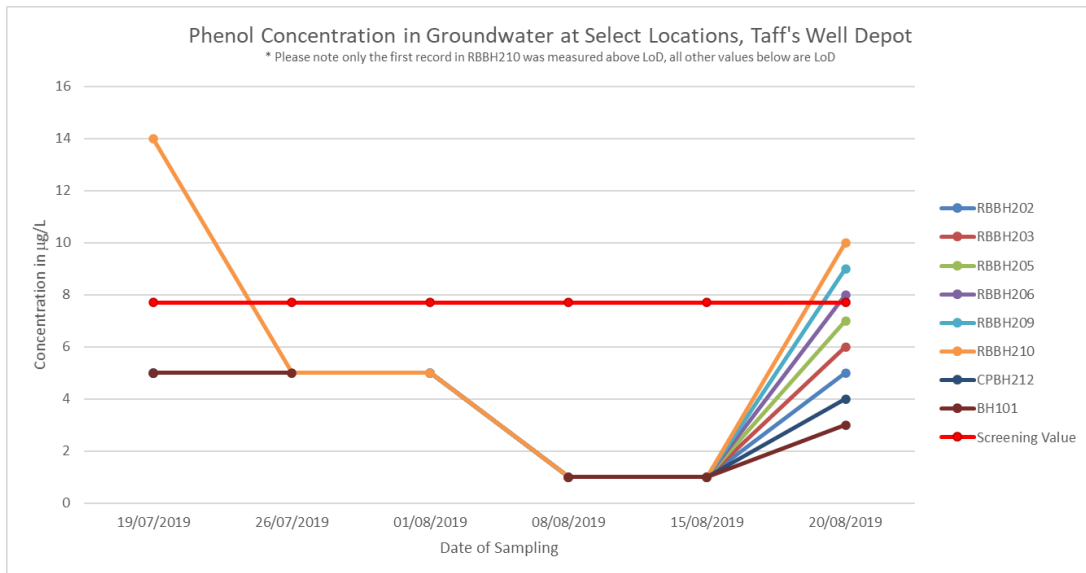
2.5.17 Nitrate

An exceedance of nitrate was only detected within CPBH212 on the sixth monitoring visit. Prior to this, all other sampling visits at this location, and all other locations, determined via analysis that the concentrations of nitrate were below the GAC_{CW} or below the limit of detection (<0.05 µg/L).



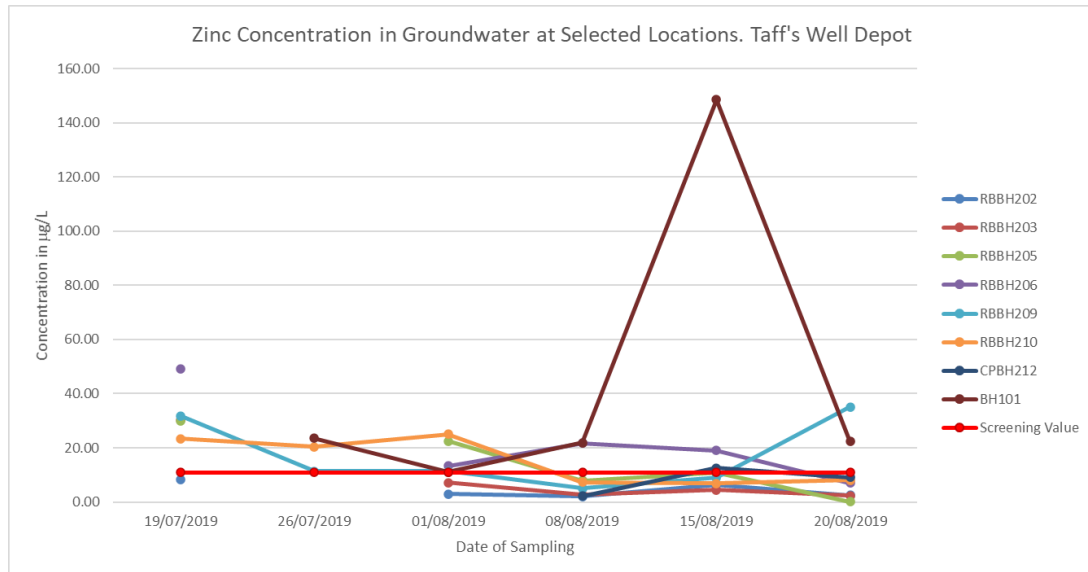
2.5.18 Phenol

An exceedance of phenol was only detected within RBBH210 on the first monitoring visit. Subsequent to this, all other sampling visits at this location, and all other locations, determined via analysis that the concentrations of nitrate were below the GAC_{CW} or below the limit of detection (between $<1-10 \mu\text{g/L}$). The three exceedances noted in week six below are present due to the varying LoDs used by the laboratory in those tests.



2.5.19 Zinc

Exceedances of zinc were detected within RBBH203, RBBH205, RBBH206, RBBH209, RBBH210, BH101 and CPBH212. The exceedance within CPBH212 was only detected during the sixth sampling visit. Exceedances within RBBH205 were only detected on the first and third sampling visits. Exceedances within RBBH210 were only detected on the first, second and third sampling visits. Exceedances within RBBH206 and RBBH209 were detected during the first, third, fourth and fifth sampling visits, and the first, second, third, and sixth sampling visits respectively. Exceedances within BH101 were detected during the second, third, fourth, fifth and sixth sampling visits. Please note the graph is on the next page.



2.5.20 Compounds detected where a GAC_{CW} was not available

It should be noted that phenanthrene and pyrene have not been evaluated within this assessment. Although identified above the LoD, using benzo(a)pyrene as a surrogate GAC_{CW} was considered to be too onerous given the relative toxicity of phenanthrene and pyrene compared to benzo(a)pyrene. As such it is assumed that the conclusions relating to the PAHs discussed below will apply to phenanthrene and pyrene.

2.6 Permeability Testing

Infiltration tests (falling head tests) undertaken within each of the main horizons on site; namely:

- Made Ground,
- River Terrace Deposits (formerly identified as Alluvium), and
- the Pembroke Limestone Group.

Note the bedrock is identified as the Pembroke Limestone Group on the exploratory location records, but the British Geological Survey (BGS) map indicates the southern portion of the site is underlain by the Hunts Bay Oolite Subgroup. These recorded permeabilities of 1.97×10^{-7} , 3.00×10^{-7} and 1.60×10^{-7} m/s respectively. All strata tested had relatively low permeabilities, falling into the hydraulic conductivity range of silts [9].

3 Surface Water Sampling

Within the scope of the Phase 2 Geo-Environmental Interpretive Report ([TRAN01-KAW-R0-TAF-RPT-G-GE-000004](#)), two surface water samples were taken for chemical analysis; one upstream (SW01) and one downstream (SW02) of the site. Figure 3 demonstrates the surface water locations in relation to the site.

The surface water samples were submitted for the same laboratory testing as groundwater samples and screened against the hierarchy of GAC_{CW} identified in Section 2.4. The surface water testing results are included in Appendix C.

This testing indicated one slight exceedance of copper and two slight exceedances of zinc. The exceedance of copper was located upstream of the site, and therefore not believed to be connected to the site. Zinc exceeded adopted GAC_{CW} both upstream and downstream of the site which may be indicative of naturally occurring elevated concentrations, or other sources of anthropogenic contamination, within surface waters of the River Taff/Afon Taf.

Groundwater concentrations below the site showed that copper and zinc were recorded in excess of adopted GAC_{CW} . As such, the site has been considered within the assessment as presenting a potential source of metal and metalloids in the River Taff/Afon Taf, although in the Phase 2 Geo-Environmental Interpretive Report ([TRAN01-KAW-R0-TAF-RPT-G-GE-000004](#)) this was originally deemed unlikely.

4 Substance Sources

4.1 Introduction

Significant research has been undertaken to determine the likely sources of substances within the River Terrace Deposits below the site, which exceed the relevant GAC_{CW} used, as outline above in Table 2. Logically, the principal source would be assumed to be on-site Made Ground; indeed, this was the assumption made within the initial interpretative report produced following the initial GI towards the end of 2019 [3]. However, in the production of this report, it became clear this was not necessarily the case. As such, a detailed assessment of the site's history was undertaken using available resources (historical OS and other maps, online trade directories and guides, as well as "grey literature" such as non-academic or commercial websites).

Furthermore, a series of substance distribution plots have been generated using Surfer® modelling software, in order to spatially assess distributions. These are included within Appendix D; although these plots were generated using the same data, the data presentation is different to those presented in the original Phase 2 [3] due to a different approach in assessing the data.

4.2 Sources of Aliphatics >EC10-EC12 and >EC16-EC35

Aliphatic >EC10-EC12 compounds within groundwater were detected in exceedance of water quality standards within RBBH206 on one sampling visit only (438µg/l). Aliphatic >EC16-EC35 also greatly exceeds the Amey quality standard on another sampling visit, with a measured concentration of 2400µg/l. The standard for the heavier aliphatics is detailed in Table 2. For reference RBBH206 is located centrally within the site.

An assessment of soil analysis results for RBBH206 indicated low levels of TPH (201 mg/kg of total of Aromatic fractions) at a depth of 0.6m. There was one minor concentration of Aliphatics >EC21-EC35 within this location, detected at a concentration of 16 mg/kg. All other TPH fractions were below the LoD. As such, the hydrocarbon concentration detections within groundwater are not reflected within the soils analysed within this exploratory location, and there are no indications on exploratory location records which imply a hydrocarbon source at RBBH206.

An analysis of historical Ordnance Survey maps indicates that the location of RBBH206 was central within former industrial site, and was close to a building and an internal rail line (1878-1880), an area of raised ground likely relating to the route of a former rail line which connected to the main rail network to the south of the site (1900-1901), and

on the southern edge of a large building oriented approximately east-west (1937-1943). By 1954-1971, another building had been constructed to the south of this location, and an internal rail line was several metres to the east. Tanks were not noted to be present within the vicinity of the site.

An assessment of soil concentrations within WS214, located c. 20m west of RBBH206, recorded elevated concentrations of aromatic fractions >EC10, particularly the >EC21–EC35 fraction. The aliphatic >EC10-EC12 fraction was not detected within soils analysed from WS214. This location is also perpendicular to the hypothesised flow of groundwater. Due to these two reasons alone, the soils in the location of RBBH206 and WS214 are considered unlikely to be the source.

Upgradient of RBBH206, soils within TP104 were not tested during the WYG GI. Soils within WS12 were tested during the Intégral Géotechnique GI in 2012, although TPH was not tested for. The only PAH detected above limit of detection was phenanthrene, at a concentration of 0.012 mg/kg. Total Organic Carbon (TOC) was tested for and was found to be at a value of 8.7%. Soils at this location at a depth of 0.3m BGL are recorded within the log as being a pink very sandy fine to medium angular to sub-angular gravel. It is not known why this location recorded a high TOC; strata below include coal fines, but the TOC concentrations may be the result of cross contamination from another location. If the source is soils to the north of RBBH206, it is not within the immediate vicinity.

Groundwater monitoring within RBBH206 indicated a groundwater depth of 29.09m AOD, or 4.64 m BGL. Levels prior to and subsequent to this date indicated slight variation on the order of several centimetres, both higher than, and lower than the level on the 15th August 2019. This means that, were this location to be the source, that hydrocarbons would be leaching downwards, largely driven either by infiltration and percolation of rainwater or leaks from drainage. The location of RBBH206 is a former car park, so it is considered that the most plausible source of this aliphatic fraction is leaks from drainage which have been impacted with hydrocarbons due to leaking engines, spillages etc.

It is therefore thought that the hydrocarbons within this location are related to vehicles using the car park on a daily basis for work.

4.3 Sources of Polyaromatic Hydrocarbons (PAHs)

4.3.1 Benzo(a)pyrene

BH101 is located within the central northern portion of the site, recording a maximum concentration of benzo(a)pyrene within groundwater of 0.04µg/l on 01/08/2019 and 0.03µg/l on the 15/08/2019. All other locations were recorded at the LoD (0.016 µg/L). Groundwater monitoring on the dates of exceedances indicated that groundwater was at a depth 30.50m AOD (1st August 2019) and 30.36 m AOD (15th August 2019), or 3.08 and 3.22 m BGL respectively, which was within the screened section of Alluvium (re interpreted here as River Terrace Deposits) and River Terrace Deposits as per the WYG log.

Soils from BH101 were not analysed during the original GI undertaken by WYG. The nearest historical location for which soil results are available is WS22 (14m to the south), from the Intégral Géotechnique investigation undertaken in 2012. This indicates concentrations of benzo(a)pyrene at 0.17 mg/kg at a depth of 0.4m BGL, within a layer described as containing *'loose black with occasional white gravelly sand of coal fines; sands of mainly coal with some clinker and rare fragments of iron'*. A similar layer (with ash, but no coal fines) was identified within the log for BH101. It is possible that the benzo(a)pyrene concentrations are related to the clinker and ash within the layer. However, it is considered unlikely this layer is the source given benzo(a)pyrene's relative immobility due to low solubility and tendency to sorb to organic matter. The most likely source of the benzo(a)pyrene is considered to be the hydrocarbon odour noted between 4.00 - 7.20m BGL within River Terrace Gravels in the log for BH101, which is below monitored groundwater levels. One sample of groundwater was taken from this location at the time of the WYG ground investigation, where a concentration of 1.05 µg/L was recorded. This is significantly higher than the concentrations detected in 2019 as indicated in Section 2.5.3.

An analysis of historical Ordnance Survey maps indicates the area surrounding BH101 was originally open fields (1878-1880 to 1900-1901), although there was a feature, interpreted as a land-raise of some sort, approximately 30m to the southeast in the 1900-1901 historical OS maps. By 1919-1920, the site was still open field, with an allotment to the north and the land-raise to the southeast. By 1937-1943 the location was within the boundary of the overall site but was still open space itself; a small building was located just to the north of the site. By 1954-1971, the location was situated on the SW corner of a large rectangular building, to the north of a "Works" located in the western - central portion of the site.

4.3.2 Benzo(b)fluoranthene

The distribution trend for benzo(b)fluoranthene is the same as for benzo(a)pyrene. As discussed above, there are no apparent sources from the historical maps. The concentrations detected within BH101 are likely related to the “hydrocarbon odour” on the log for this location, and it is assumed the source in RBBH206 is from the soil; testing of soils from RBBH206 recorded concentrations of 3.82 mg/kg at 0.6 m BGL, 0.71 at 1.4m BGL, and 0.19 mg/kg at 2.6m BGL.

4.3.3 Benzo(g,h,i)perylene

As discussed, soils from BH101 location were not analysed during the WYG investigation, but it is thought the presence of PAHs are related to the presence of a “hydrocarbon odour” noted on the log for this location.

4.3.4 Benzo(k)fluoranthene

As discussed above, benzo(k)fluoranthene was noted within RBBH206 and BH101. It is thought the presence of benzo(k)fluoranthene within groundwater is sourced from Made Ground within RBBH206, and from the area of “hydrocarbon odour” identified within the log of BH101.

4.3.5 Indeno(1,2,3-c,d)pyrene

As discussed, the exceedances recorded in groundwater samples within BH101 are thought to originate from to the presence of a “hydrocarbon odour” noted on the log.

4.3.6 Fluoranthene

The presence of Fluoranthene within groundwater is believed to originate from the Made Ground within RBBH205 and RBBH206, and from the area of “hydrocarbon odour” identified within the log of BH101 as previously indicated.

4.4 Sources of Chloroform

The location and historic land-uses surrounding RBBH206 are described above in Section 4.2. RBBH205 is located in the extreme southern portion of the site, adjacent to Ffordd Bleddyn. In 1878-1888, the borehole was located on the edge of a long, linear feature, interpreted as a track but with no obvious access or egress, which runs N-S parallel to the current Ffordd Bleddyn. By 1900-1901, RBBH205’s location was situated at the junction of two rail tracks, the westerly rail track joining the main line to the east of Taff’s Well Station, the easterly line extending to the north, which terminated

on site. Land-use was identical by 1919-1920, although some further industrial development had occurred around the location in the form of further rail lines. By the 1954-1971 maps, the location was now at the SE corner of what is interpreted as dedicated areas for stockpiling, possibly of coal.

Chloroform was detected in Made Ground soils during the 2019 investigation at the following locations; TP202 at 0.5m BGL (0.006 mg/kg), WS208 at 0.8m BGL (0.092 mg/kg), and WS216 at 0.5m BGL (0.008 mg/kg) and 1.0m BGL (0.005 mg/kg). TP202 is located approximately 30m to the E-SE of RBBH205, WS208 is located approximately 55m to the N-NW of RBBH205 and 115m to the south of RBBH206, and WS216 is 66m to the N-NE of RBBH206. In late 2019, further investigation was undertaken in support of the design of the track bed at the site. Chloroform was not detected in any location tested above the limit of detection ($<1 \mu\text{g/kg}$). It is considered unlikely that the soils in these locations is the source of the chloroform encountered. Chloroform was not tested for in the WYG investigation in 2018. The 2012 Intégral Géotechnique investigation detected chloroform above the limit of detection in groundwater ($<1 \mu\text{g/L}$) in one location, BH3 at a concentration of $1.3 \mu\text{g/L}$. Chloroform was not detected in soils above the varying limits of detection within the analytical results ($<5.2 \mu\text{g/kg}$, $<6.5 \mu\text{g/kg}$, $<7.1 \mu\text{g/kg}$, and $<8.5 \mu\text{g/kg}$).

BH3 is referred to in the testing results but is not a location mentioned within the Intégral Géotechnique report and is assumed to equate to CP3 which is referred to within the Intégral Géotechnique report. CP3 is located approximately 60m to the west of RBBH206.

The Agency for Toxic Substances & Disease Registry (ATSDR) [10] lists numerous uses for chloroform; they state its major use (98%) is in the manufacture of HCFC-22, which is a refrigerant. Other minor uses include its use as an extraction solvent, a dry-cleaning spot remover, in fire extinguishers, as an intermediate in the manufacture of dyes and pesticides, and as a fumigant. It was also used in products packaging and as an anaesthetic. Chloroform is not listed as an individual substance within the following industry profiles:

- engineering works: mechanical engineering and ordnance works [11];
- railway engineering works [12];
- metal manufacturing, refining, and finishing works: iron and steel works [13];
- railway land [14];and
- road vehicle fuelling, service and repair: transport and haulage centres [15].

However, chlorinated and halogenated solvents are mentioned in all of these Industry Profiles, of which chloroform is one. A perusal of companies previously based at the site does not indicate any industry where chloroform is likely to have been used.

Chloroform is also a naturally occurring compound, with its production in nature being significantly more than via anthropogenic processes [16]; studies have indicated that chloroform can be formed in soils of forests via the incubation of chloroperoxides and hydrogen peroxide with organic acids and glucose (chloroform is the principal reaction product of this process), the decarboxylation of trichloroacetic acid, or in a Fenton-like process [17]. One way to distinguish between anthropogenic and naturally occurring chloroform is via isotopic analysis, but this is outside the scope of this report. Ground cover to the north-east and east of the site comprises a significant proportion of wooded land. It is possible that this is the source of chloroform within groundwater beneath the site, and not from the on-site shallow soils. This would account for the lack of correlation between locations where chloroform was detected in soils in comparison to where chloroform was detected in groundwater. RBBH206 was located within a car park, and RBBH205 was located within an area of hardstanding. RBBH206 had trees growing in close proximity to the borehole, where RBBH205 did not.

The detections around the site appear to have no correlation between soil locations and groundwater locations. Although chloroform was detected in very small concentrations within shallow soils on site, it is not possible to attribute a source to the chloroform in either soils or groundwater with any degree of confidence. It is possible that unspecified historical industrial activities may account for the sporadic distribution in soils. It should also be noted that chloroform is generally non-reactive in the atmosphere [10], and so its presence could be as the result of aerial deposition.

It is not considered possible to identify a source for the chloroform on site. As such, for the sake of this assessment, the source is assumed to be groundwater in the vicinity of RBBH206 as this is where the highest concentration in groundwater was recorded.

It is also worth noting that dichloromethane, a decay product of chloroform, was not detected in any groundwater samples. However, for the sake of this assessment, and in line with guidance within RTM [2], dichloromethane has been considered within the risk assessment.

4.5 Sources of Metals and Metalloids

4.5.1 General

The relationships between concentrations of metals and metalloids within groundwater are notably more complex than the TPH and PAH concentrations. In order to assess the sources of metals and metalloids, concentrations within the soil have been split between Made Ground and River Terrace Deposits. In addition, groundwater concentrations on the monitoring rounds of the 19th July 19 and 1st August 2019 have been scrutinised, with the former generally having the highest concentrations of metals and metalloids, and the latter having the greatest distribution of boreholes unless otherwise stated.

Substance concentrations in groundwater have also been informed by groundwater levels closest to the sampling dates above (18th of July 2019 and 15th of August 2019) where possible, though the records are largely sporadic.

4.5.2 Chromium

The highest concentrations of chromium within soil samples are located centrally and in the southern portions of the site, with a 'hotspot' of chromium identified along the north western boundary (in the vicinity of WS219 and WS210). Chromium concentrations generally appear to increase in concentration and spatial coverage with depth in those boreholes where exceedances were detected. Relatively high levels of chromium were detected in soils within RBBH203 (61.3 mg/kg at a depth of 2.5m BGL), WS209 (62.5 mg/kg at a depth of 0.2m BGL), and WS205 (62.3 mg/kg at a depth of 1.5m BGL). All other borehole locations indicated a concentration of chromium in soils no greater than 47.2 mg/kg (RBBH205). It should be noted that none of the soil concentrations exceeded the relevant GAC.

An analysis of historical maps at these locations shows that in 1878-1880, all the locations (apart from BH101) were adjacent to rail-lines, with BH101 being located in an area devoid of structure, assumed to be open space. By 1900-1901, the proximity to rail was still present, but the structure of the rail-lines had moved somewhat. This remained the case until the maps published in 1937-1943, where the locations of BH101 and RBBH206 are now shown to be close to buildings. These are not labelled so their use is unknown, but it is considered likely they were part of the iron forge.

In 2004, the BGS undertook a geochemical baseline survey of the Cardiff area [18]. Samples were taken of surface soils (0.05 – 0.20m bgl) and profile soils (0.35 – 0.50m bgl). Concentrations of Chromium within glaciofluvial deposits to the south of the site

record values between 58 to 84 and 74 to 109 ppm for surface and profile soils respectively. The median values for chromium throughout Cardiff are 72 mg/kg and 81 mg/kg for surface and profile soils. The BGS also records a median value of 92 mg/kg of chromium within 18,927 stream sediment samples across the entirety of Wales. It is considered by the BGS that the elevated concentrations of chromium within profile soils relates to the different sized fractions which were tested (<2mm of surface soils, and <15µm for profile soils). A comparison of the BGS report [18] with the site won data indicates that the soil concentrations of chromium are generally within those values found within the wider Cardiff area. The distribution map of chromium within soils within the BGS report [18] shows that the highest concentrations of chromium are concentrated along the coast, and generally decrease inland. The distribution of chromium also generally shows a decrease from east to west. Concentrations within areas considered to be rural (areas represented by white on the distribution map within the BGS report) range from 53-125 ppm. Some of the elevated concentrations are likely one of land uses related to some anthropogenic process. Removal of these suggests that background chromium concentrations in the west of Cardiff vary between 53-84 ppm, which is where the concentrations detected at the site are between. It could be argued that the underlying chromium concentrations on site are more likely to be naturally occurring than related to processes which occurred on site, and that hotspots are related to anthropogenic processes.

It is apparent when comparing chromium concentrations within groundwater on the 19th July 19 and 1st August 2019 that the highest groundwater concentrations are located centrally within the site, which is broadly where the highest elevations in soils are found (particularly within the Made Ground). However, when comparing groundwater from the 19th July 2019, concentrations are particularly elevated around RBBH109, with a concentration recorded of 15 µg/L; such a 'hotspot' doesn't appear to relate to sampling undertaken on 1st August 2019, and as such may represent an offsite source.

Therefore, despite levels detected in soils beneath the site considered to be representative of soil within the area, the presence of relatively small concentrations of chromium (the highest concentration detected was 15 µg/L within groundwater), would likely indicate that this chromium is derived from a combination of naturally occurring chromium within Superficial deposits and elevated concentrations within 'hotspots' within the Made Ground.

4.5.3 Copper

The locations where elevated concentrations of copper were identified are broadly the same as discussed in Section 4.5.2. However, soil concentrations are centred in 'hotspots' rather than being as widespread as those recorded for chromium. Although soil concentrations do not exceed the GAC, they are elevated in the vicinity of CPBH208, WS219 and RBBH202, with the highest concentration of 550mg/kg within the Made Ground of CPBH208. Concentrations within the Superficial deposits are negligible, ranging between 5 – 34mg/kg, but show relative elevations similar to the overlying Made Ground. Baseline concentrations of copper of 23-480ppm in profile soils over the glaciofluvial deposits are similar concentrations to that detected within the soils on site [18].

There appears to be little to no correlation between concentrations of copper within groundwater to those recorded within the soil; concentrations within groundwater are elevated above GAC_{CW} in every location during the 19th of July visit, with the concentrations at their highest at RBBH109 of 21.0µg/l which is located in the west of the site. Furthermore, there is little to no relationship indicated between temporal groundwater concentrations e.g. RBBH205 records a concentration of 11.0mg/l on the 19th of July which decreases to 7.0µg/l on the 1st August but is below LoD on other rounds. Therefore, it is difficult to disentangle the source or sources of copper exceedances within groundwater. However, it is assumed the elevated concentrations within groundwater are related to the distribution of Made Ground, with the initial concentration within RBBH209 assumed to be an offsite source of Made Ground associated with the former railway line to the north.

4.5.4 Lead

The spatial distribution of lead concentrations within soil across the site is broadly similar those of copper, whereby the greatest concentrations are located within shallow Made Ground, with concentrations decreasing with depth. The highest concentration of 801mg/kg was recorded within Made Ground of WS223. A second area of elevated concentrations is located around HP205, located centrally within the southern portion of the site, with a maximum of 370mg/kg. Note that neither of these concentrations exceeded the GAC. The geochemical baseline [18] for Taff's Well indicated a concentration of between 147 – 400ppm and 124 – 327ppm within surface and profile soils respectively. Thus, concentrations within the Made Ground on site exceed the baseline values for the area.

WS223 is located centrally within the site, adjacent to RBBH206, which is located adjacent to a historic internal rail line until c. 1945 when the rail line was removed. HP205 was also located adjacent to a series of internal railway lines which remained in situ until c. 1969.

Concentrations of lead between 6–26mg/kg were also encountered within superficial deposits across the site. The spatial distribution of the maximum concentrations within superficial deposits don't necessarily correspond with those maximum concentrations detected in the overlying Made Ground. However, the elevated concentrations within groundwater recorded on the 19th July do correspond with elevated concentrations within the Made Ground.

Looking at the groundwater sampling round which was undertaken on the 15th August 2019, the highest recorded concentration of lead within groundwater was recorded (52µg/l within BH101) in the northern tip of the site. Soils from BH101 were not submitted for laboratory testing by WYG in 2018 although soil samples within WS22 and WS23 were submitted for testing by Intégral Géotechnique in 2012. This recorded lead concentrations of 95mg/kg at 0.40mbgl and 55mg/kg at 0.23mbgl respectively. Soils and groundwater were also submitted for laboratory testing within WS21, which was located c. 35m south east of BH10; lead concentrations within Made Ground (0.90mbgl) yielded concentrations of 9.1mg/kg, and a groundwater concentration as below LoD (<0.006mg/l).

The map from 1900-1901 shows an area of stippling along the north-eastern boundary of the site. This indicates an area of tipping, possibly of waste from the foundry. This is considered more likely to be boiler waste and other general waste produced by the works. Furthermore, the previous cruciform inner rail lines are no longer depicted by the time of the 1900-1901 1:2500 mapping, and instead a series of curved rail lines are depicted which appear to provide access to and from both the up and down lines of the Taff Vale Railway; the northern branch runs parallel to the western boundary of the site, and terminates within an unlabelled building, assumed to be an engine shed. These buildings are depicted as being modified and extended, as represented by the 1940 mapping, and subsequently also labelled as 'Works' by the 1959 1:1250 scale mapping. It may also be worth considering an offsite source directly north of the site; the Glamorganshire Canal ran along the northern and eastern boundaries of the site. The majority of the canal was infilled by the time the area was surveyed for the mapping dated 1964, with the stretch of the canal adjacent to the northern tip of the site shown to be drained by 1959 – 1969 mapping. A stretch of the old canal running along the northern and eastern boundary of the site did not look to be infilled until the construction

of the A48, from 1971 – 1989 mapping onwards. Due to the heavy industry located around Taff's Well, including a gas works, it is possible that backfill material within the canal may be leaching onto the site. However, this is highly speculative. It is considered the Glamorganshire Canal would only act as a source if there was no clay lining present, or it had been removed prior to filling. This is unknown at this time, but consideration does need to be given to the potential of the infilled canal as a source. The stretch of the canal which ran along the eastern boundary was likely infilled with inert waste later in the 1980s and therefore isn't thought to represent a significant source of impact.

It appears that Made Ground is the most likely source of lead in the southern and central portions of the site. However, the source of lead in BH101 cannot be confirmed due to lack of testing within this location. However, given the historic land use within this part of the site, impacted soils seem the most likely source, whether located on or off site.

4.5.5 Manganese

Manganese was not tested for in soil samples submitted for laboratory testing during the most recent GI phase by Amey Infrastructure/Amey Seilwaith in 2019, nor previous phases. However, groundwater samples submitted for laboratory testing were analysed for manganese, recording the greatest concentration of 3,942µg/l within RBBH210, which is located in the west of the site and installed into River Terrace Gravels. Concentrations decrease by an order of magnitude further to the east, past RBBH109. The geochemical baseline of manganese in soil to the south of the site is 0.193 - 0.260 wt.% (1,930 – 2,600ppm) and 0.197 – 0.263 wt.% (1,970 – 2,630 ppm) within surface and profile soils respectively [18]. The BGS also record a median value 0.18 wt.% (1,800 ppm) within stream sediments across Wales and West Central England.

RBBH109 and RBBH110 are located adjacent to Taff's Well Train Station, within a parcel of land sandwiched between the existing railway line (Taff Vale Railway) and a historic branch to the north (dismantled by 1971 – 1981 1:1250 mapping). This parcel of land contains two areas of raised ground marked from 1971 – 1996 mapping. Both these areas were levelled or re-profiled in recent years, as the area is now an asphalt carpark. As there is no obvious source of manganese, it is assumed to derive from the Made Ground associated with the dismantled branch further to the north of the site, or the previous areas of raised ground.

4.5.6 Nickel

The distribution of nickel concentrations in soils is concentrated in the east of the site; the highest concentration of nickel from the soil analysis results was 259.31mg/kg recorded in WS109 at 0.20mbgl within Made Ground, though this does not exceed the GAC. The concentration of nickel reduces to 37.6mg/kg at 1.50 – 1.70mbgl within superficial deposits in WS109. WS216 recorded the highest nickel concentration within the superficial deposits of 59.8 mg/kg at 1.60m BGL. These concentrations are slightly elevated when compared with surface and profile soil concentrations, which were between 26 – 34ppm and 28 – 37ppm respectively [18], but are likely reflective of the naturally occurring concentrations of nickel within the area.

The highest groundwater concentrations (and only exceedance of the GAC_{CW} within groundwater) are recorded in RBBH209, located in the west of the site. The groundwater concentrations within RBBH209 were consistently between 9.10 – 9.50µg/l, until nickel concentrations dropped below the GAC_{CW} , which occurred on the 15th July 2019. Furthermore, there appears to be little to no correlation between the highest soil concentrations of nickel and groundwater exceedances on the site. However, as for copper and manganese, the source of nickel in groundwater is assumed to be Made Ground associated with the dismantled railway line which ran to the north.

4.5.7 Iron

Iron was not tested for in soil samples submitted for laboratory testing during the most recent GI phase by Amey Infrastructure/Amey Seilwaith in 2019, nor previous phases. The geochemical baseline of iron to the south east of Taff's Well indicates a concentration between 5.90 – 6.89wt% (59,000 mg/kg to 68,900 mg/kg) for both surface and profile soils [18]. These concentrations exceed the median iron oxide (Fe_2O_3) concentration in soils for both surface and profile soils across Cardiff.

Concentrations of iron in groundwater were recorded in excess of GAC_{CW} at all locations (with the exception of RBBH205) on the 19/07/19. The greatest concentrations of 2,120µg/l and 2,014µg/l were recorded within RBBH209 and RBBH206 respectively. Following this initial sampling round, the concentration of iron in groundwater does not exceed GAC_{CW} , with the exception of BH101 on the 15th July 2019 (1,677µg/l).

Due to the lack of testing within soil samples, the source of iron within groundwater below the site is unclear. However, based on the spatial distribution of other

substances, it can be assumed the source of iron in the west of the site is Made Ground associated with the dismantled railway line to the north. Furthermore, the exceedance of iron in BH101 is assumed to be the same as that of lead, which may relate to the infilled material of the Glamorganshire Canal located at the northern tip of the site. It is also a strong possibility that diffuse iron is present within Made Ground due to the use of the site as a forge.

4.5.8 Zinc

The highest concentrations of zinc identified in Made Ground samples are concentrated along the south western boundary, parallel to the existing railway line within RBBH210 (1,016mg/kg), RBBH204 (939mg/kg) and WS207 (795mg/kg). Elevated concentrations are also present within WS223, recorded at 349mg/kg and 426mg/kg. However, it should be noted that no zinc concentrations exceeded GAC for soils.

Concentrations of zinc within the Superficial Deposits indicate a largely different trend, with concentrations relatively elevated in the north and eastern portions of the site. WS216 records the highest concentration of 211 mg/kg, but those locations along the eastern boundary range in concentrations from 86mg/kg (WS218) to 145mg/kg (WS209). Concentrations are also relatively elevated within TP208, located in the north of the site, with a concentration of 79mg/kg.

Concentrations of zinc in groundwater exceeded GAC_{CW} in several locations across the site on several occasions. However, the exceedances are not consistent spatially or temporally, and thus determining a primary source is challenging. The highest concentration of 148.50µg/l was recorded within BH101 on 15th July 2019. However, on monitoring rounds either side of the peak in BH101, concentrations are consistently between 22.5µg/l and 11.10µg/l. Groundwater concentrations also appear consistently elevated in RBBH206 and RBBH209.

Due to the distribution and variation of exceedances of zinc within groundwater, it is probable that there are multiple sources across the site. Elevated concentrations identified within the Made Ground of WS223 likely account for exceedances in groundwater concentrations within the adjacent RBBH206. Furthermore, Made Ground (or 'stippled area' referred to in Section 4.5.4 above) is assumed to be a possible source for zinc within BH101, based on the same assumptions made for lead in Section 4.5.4. However, it is equally possible the source in BH101 is offsite such as the infilled canal directly north. Elevated concentrations of zinc within RBBH209 may also be attributed to an offsite source, similarly to chromium, copper, iron which are believed to relate to the railway line directly north.

4.6 Sources of Free Cyanide

Cyanide was only detected in excess of GAC_{CW} on the 26th of August 2019, with free cyanide measuring 25mg/l.

The ATSDR [19] state that cyanide is used principally within the steel, electroplating, mining and chemical industries. It is used, generally in salt form (such as sodium cyanide), in combination with barium chloride. Whilst it is possible that electroplating may have occurred at the forge, it is considered unlikely given what is known about the history of the site. It is possible that electroplating has occurred to the north-west of the site at the Glan-y-Llyn Industrial estate, but this direction is not in keeping with the hypothesised groundwater flow and would not explain the sole occurrence of cyanide within BH101. In mining, cyanide is used to leach metal from ore; given the sites previous use, it is considered that this process did not occur on site. There is no known chemical works on site, and none were identified on the historical maps.

It is also considered that the Glamorganshire Canal, infilled at the northern tip of the site by c.1960s, may also present an offsite source. As discussed in Section 4.5.4, a gas works was located 1km from the site until the 1938 mapping, which could present a source of cyanide, particularly if wastes were used to infill the canal, although it is noted this is nearly perpendicular to the hypothesised groundwater flow, although it is possible that a concentration gradient could drive some contamination “up” hydraulic gradient.

Cyanide is produced naturally by vascular plants during cyanogenesis, and cyanide can be stored within the plants tissues as a source of nitrogen. However, this too is unlikely to account for the elevated concentration recorded within groundwater within BH101.

Therefore, the source of cyanide on site cannot be determined with any level of certainty. Consequently, the source of cyanide has been modelled as a groundwater source on-site for the sake for this assessment.

4.7 Summary of Pollutant Linkages

As indicated within this section, there are likely multiple sources of the substances detected in groundwater samples across the site. Despite the former historical use of the site, the main source of on-site impacts is believed to originate from impacted soils surrounding both the existing railway line, running along the south western boundary of the site, and historical internal and peripheral railway lines, which are no long present on site. It is worth noting however that the level of the site is set to be reduced 33.6m

AOD, thus removing a substantial volume of Made Ground. **Figure 5** indicates the

locations and thickness of Made Ground which will remain. In some areas of the site, reduction of levels will remove Made Ground from the site entirely, these being in the north and north west portion of the site, and a band across the southern portion of the site. The remaining parts of the site have between 0 and 0.5m of Made Ground remaining, with greater than 0.5m remaining within the central and central eastern, and southern portions of the site. Therefore, the source, although poorly defined in some instances, is to be greatly reduced.

In addition to the Made Ground on-site acting as a source there also appears to be off-site sources which may account for groundwater exceedances in the north and west of the site.

The pollutant linkages are summarised in Table 3 for ease.

Table 3 - Summary of Pollutant Linkages

Contaminants	Source(s)	Pathway	Receptor
TPH (Aliphatics >EC10-EC12, >EC16-EC35)	<ul style="list-style-type: none"> Vehicular parking on site via drainage within Made Ground in the vicinity of RBBH206 	<ul style="list-style-type: none"> Infiltration and percolation of vehicle fuels through unsaturated ground an into groundwater, and; Infiltration and percolation of rainwater through impacted soil within Made Ground, potentially infilled ground or Superficial Deposits. 	Controlled waters comprising: Groundwater (Principal and Secondary A aquifers) and Surface Waters (the River Taff/Afon Taf)
PAHs (benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-c,d)pyrene, fluoranthene)	<ul style="list-style-type: none"> 'Hydrocarbon Odour' recorded at 4.0 – 7.20m BGL in BH101 assumed to be predominant source; Made Ground including 'clinker and rare fragments of iron' within BH101, and; Made Ground within RBBH205 and RBBH206. 	<ul style="list-style-type: none"> Infiltration and percolation of rainwater through impacted soil within Made Ground, potentially infilled ground or Superficial Deposits; Leaching of substances into groundwater, and; Baseflow of impacted groundwater down hydraulic gradient towards receptor 	
Chloroform/Dichloromethane	No obvious source based on historical site activities. Most likely sources are: <ul style="list-style-type: none"> Off-site forested soils; Groundwater in the vicinity of RBBH205 and RBBH206, and; Made Ground in located in/around TP202, WS208 and WS216. 		
Cyanide (free)	No obvious source based on historical site activities. Most likely sources are: <ul style="list-style-type: none"> Made Ground associated with previous site uses; Vascular plants, and; Possible material within infilled Glamorganshire Canal to the north. 		

Contaminants	Source(s)	Pathway	Receptor
Chromium	<ul style="list-style-type: none"> River Terrace Deposits (minimal Cr concentrations in Made Ground) 	<ul style="list-style-type: none"> Infiltration and percolation of rainwater through impacted soil within Made Ground, potentially infilled ground or Superficial Deposits; Leaching of substances into groundwater, and; Baseflow of impacted groundwater down hydraulic gradient towards receptor. 	
Copper, Manganese, Nickel, Zinc	<ul style="list-style-type: none"> Offsite source such as Made Ground located around former railway lines 		
Iron	<ul style="list-style-type: none"> Naturally occurring elevated concentrations of Iron; Possible material within infilled Glamorganshire Canal to the north; Former potential tip area in north of site, and Widespread presence due to site history as forge. 		
Lead, Zinc	<ul style="list-style-type: none"> Made Ground associated around former railway lines. 		

5 Controlled Waters Detailed Quantitative Risk Assessment

5.1 Introduction

This section summarises the methodology and results of the Controlled Waters Detailed Quantitative Risk Assessment (CW-dQRA).

5.2 Modelling Approach

The Environment Agency's (EA) Remedial Targets Methodology (RTM) defines a tiered system to assess risks to Controlled Waters from impacted soils and groundwater [2]. These tiers can be summarised as follows:

- Level 1 assesses the partitioning of a substance from the solid phase into the aqueous phase and compares calculated substance concentrations in 'pore water' to the target concentration;
- Level 2 considers dilution by the receiving groundwater and whether this is sufficient to reduce substance concentrations to acceptable levels, and;
- Level 3 considers whether natural attenuation (including dispersion, retardation, and degradation) of the substance as it moves through the unsaturated and saturated zones to the receptor are sufficient to reduce substance concentrations to acceptable levels.

A Level 3 groundwater assessment has been undertaken within the Remedial Targets Worksheet (RTW) here using site specific parameters from the 2019 Amey Infrastructure/Amey Seilwaith ground investigation and subsequent monitoring.

The full list of input parameters is included in Appendix E.

5.3 Transport Mechanisms

The Level 3 Groundwater assessment considers the following substance transport mechanisms:

- **Advection:** The main process driving the migration of substances in the subsurface and involves the transport of dissolved substances (solutes) by groundwater under a hydraulic gradient;
- **Dispersion:** Redistribution of the substance within the mobile phase. Fluid mixing occurs due to groundwater movement and aquifer heterogeneities. The

process causes longitudinal, transverse and vertical spreading of the plume, reducing the substance concentration;

- **Dilution:** Dilution will occur when substances reach the water table (Level 2 Assessment);
- **Retardation:** Transfer of the substance from a mobile to an immobile phase. This is a measure of the reduction in solute velocity relative to the velocity of the advecting groundwater caused by processes such as adsorption, and;
- **Degradation:** Processes resulting in a loss in substance mass; transformation of a substance that results in a change in chemical structure mass within the environment.

5.4 Adopted Water Quality Criteria

The adopted GAC_{CW} within this CW-dQRA are the same as the initial GAC_{CW} included in Section 2.4.

5.5 Modelled Source

As indicated in Section 4, despite an evaluation of possible sources of groundwater impacts, the spatial and temporal distribution of such impacts is complex and largely inconsistent between on-site soil sources and groundwater concentrations; possible on and off-site sources have been determined. Consequently, the sources within this assessment have been modelled within the groundwater only.

However, to best model the heterogeneous nature of impacts upon the receptor, concentrations have remained specific to the borehole in which they were sampled.

5.6 Initial Concentration

The modelled initial concentrations were selected from the highest recorded concentration for each substance within groundwater, in exceedance of the GAC_{CW} , within each borehole. Therefore, only the saturated pathway has been considered within this assessment as this poses the greatest risk to Controlled Waters.

Table 4 - Modelled Initial Concentrations

Substance	Borehole and Concentrations	Modelled Concentration (µg/l)
Copper	RBBH202 4/-/-/-/-/-	4
	RBBH203 8/-/-/-/-/-	8
	RBBH205 11/-/7/-/6/-	11
	RBBH206 10/-/-/4/12/7	12
	RBBH209 21/7/-/-/3/-	21
	RBBH210 6/4/-/-/-/-	6
	BH101 -/-/-/4/22/3	22

NB; a – indicates either a concentration below the GAC_{CW}, or when sampling did not occur. For actual relevant concentrations, please see Section 2.5. The / indicates the separation between the weeks, so for RBBH210, the concentration was 6 µg/L in week one, and 4 µg/L in week two, etc.

RTM recommends that the breakdown products of substances in groundwater should also be modelled. An investigation into the breakdown products of organic compounds was undertaken. The breakdown products of PAHs are generally PAH metabolites; it was not possible to source sufficient relevant information, so these were not modelled. One of the breakdown products of chloroform is dichloromethane. It has been assumed that the concentration of dichloromethane is 1:1 with chloroform; it's assumed that all chloroform will be converted to dichloromethane as a conservative measure. Therefore, the initial modelled concentrations for chloroform and dichloromethane are the same.

5.6.1 Source Area

The source is assumed to be impacted groundwater for the sake of the assessment. Consequently, the modelled source area is taken as the borehole and an area of soil/groundwater 5m either side of the installation, as a highly conservative assessment. Therefore, the width of the theoretical plume is taken as being 10m at each borehole location.

5.6.2 Aquifer and Plume Thickness

The saturated aquifer thickness has been taken as the thickness of the Superficial deposits; calculated as the depth from the bottom of the Made Ground to the top of bedrock. In cases where the boreholes did not penetrate the bedrock, such as

RBBH209, then the average thickness of Superficial deposits from across the whole site, from available data, was applied as the aquifer thickness.

Within the RTM, plume thickness has to be less than that of aquifer thickness. However, as a highly conservative measure, the plume thickness has been set to the maximum allowed within the model when considering dispersion parameters.

5.6.3 Half Lives

As a highly conservative first measure, all half-lives for modelled substances were set to the maximum allowed within the model (9×10^{99} days). However, where exceedances were recorded after the initial run (for cyanide and PAHs), the maximum half-life sourced from literature was applied. Whilst the second run remained highly conservative, the half-lives are deemed more representative of 'real world' conditions.

The half-lives of PAHs were set to the maximum within the ranges outlined by Howard *et al* (1991) [20]. The half-life for cyanide was set at 15 days as per WFD-UKTAG Guidance; this was greater than that outlined by the US Environmental Protection Agency for Hydrogen Cyanide (8.21 days) [21].

5.7 Modelled Pathway Parameters

5.6.4 Bulk Density

The bulk density was calculated using site specific data for the River Terrace Deposits (RTG) from locations WS219, CPBH212 and WS217. The average bulk density was applied within the RTW, which was calculated as 1.2 g/cm^3 .

5.6.5 Effective Porosity

Porosity was calculated using the porosity calculator included within the RTW; assuming total porosity is equal to the effective porosity, natural moisture content (NMC) and dry bulk densities were used for the RTW as shown in Table 5.

Table 5 - Calculated Porosities

BHID	Depth (mbgl)	Strata	NMC (%)	Dry Bulk Density g/cm^3	Porosity (total)
CP212	1	RTG	20	1.72	0.381
WS217	0.7	RTG	5.8	2.19	0.212
W219	0.8	RTG	30	1.48	0.468

The modelled porosity was chosen to be the average of the three calculated porosities from the site-specific values. This was an assumed effective porosity of 35%.

5.6.6 Hydraulic Gradient

Hydraulic gradient was calculated using the minimum groundwater elevation in individual boreholes compared to the elevation of the River Taff/Afon Taf, which was taken as 26.78m AOD (based on NRW lidar data), divided by the horizontal distance between the individual borehole location and the edge of the Taff in the direction of determined groundwater flow direction.

5.6.7 Hydraulic Conductivity

Although three falling head tests were undertaken on the site, only one test was undertaken within the River Terrace Gravels deposits. This hydraulic conductivity was undertaken within WS205, with a calculated permeability of 3.00×10^{-7} m/s (2.59×10^{-2} m/d). As such, this is the permeability modelled within the RTW.

5.6.8 Retardation

Retardation processes are likely to occur within the clay and silt rich layers of the Superficial Deposits. Substances will likely be subject to sorption processes such as adsorption, chemisorption, absorption and ion exchange. Sorption is commonly expressed in terms of the soil water partition coefficient (K_d) for inorganic substances, or the organic carbon partition coefficient (K_{oc}) for organic substances. Sorption for organics substances also considers the fraction of organic carbon (F_{oc}) within the soil.

5.8 Compliance Points

Welsh Government guidance on setting compliance points has been followed in this assessment [22]. The compliance points used in the assessment ensure the protection of any groundwater dependent receptors identified that exist down hydraulic gradient of the source area.

Compliance points have been set for individual boreholes, the location of which has been established where the River Taff/Afon Taf is intercepted by the anticipated groundwater flow direction.

5.9 Level 3 RTW Assessment

Initially, every measured groundwater concentration of each substance that was in excess of the GAC_{CW} within each borehole was individually assessed. In order to refine the model, borehole specific parameters were used where possible.

This initial assessment (Run One) did not consider substance half-lives, and thus was highly conservative. Although the majority of substances were shown to not exceed GAC_{CW} at the respective compliance point, there were a small number of exceedances (namely cyanide and PAHs) due to the effective removal of degradation within the model. Some metals (copper and manganese) also exceeded GAC_{CW} at some compliance points.

Further assessment (Run Two) for some substances which exceeded the GAC_{CW} at the compliance point had their half-lives adjusted from Run One (PAHs and cyanide). The result of this was that the concentration was significantly reduced or shown to have 'no impact' at the respective compliance point.

The initial manganese and copper concentrations which were shown to exceed GAC_{CW} were also re-assessed during Run Two. However, the initial concentration of the metals within the boreholes (the modelled initial concentration) were considered in the context of the bioavailability of the substance which can be calculated using the Rivers and Lakes - Metal Bioavailability Assessment Tool (M-BAT) [23]. The M-BAT tool was developed by the UK Technical Advisory Group on the Water Framework Directive (WFD - UKTAG). The spreadsheet applies $EQS_{bioavailable}$ criteria, which were developed under the Water Framework Directive (WFD), calculating bioavailability by assessing the concentrations of calcium and Dissolved Organic Carbon (DOC) as well as the pH of the sample. Consequently, when manganese and copper were considered within the context of their respective bioavailability, Run Two of the RTW did not yield any exceedances of the relevant GAC_{CW} .

A summary of the RTW inputs is provided in Appendix E. The RTW outputs are provided in Appendix F and Appendix G.

As such, the exceedances of copper and zinc within surface water samples taken from the River Taff/Afon Taf (as described in Section 3) are not shown to be related to sources associated with the impacted groundwater at Taff's Well.

6 Sensitivity Analysis

6.1 Introduction

Altering one or more of the input parameters into the model has the potential to drastically alter substance concentrations at the receptor. Therefore, a sensitivity analysis should be undertaken in line with the RTM Guidance [2]. The analysis determines which parameters have the greatest influence on the results of a numerical model, and therefore indicates if further data is required to better constrain the most sensitive parameters. Conducting a sensitivity analysis therefore increases confidence in the modelled outputs.

A range of inorganic and organic substances were selected in order to assess the model's sensitivity. The following substances were selected for this sensitivity analysis:

- Aliphatic EC10-EC12 (TPH);
- Benzo(k)fluoranthene (PAH);
- Chloroform (trichloromethane) (organics); and
- Copper (metals).

These substances represent a cross section of modelled impacts and are expected to behave slightly differently from each other within the natural environment. In order to assess the impact of altering certain input parameters, all modelled concentrations are those recorded within RBBH206. RBBH206 was selected for the sensitivity analysis as concentrations of the selected substance groups was the higher than other locations. Furthermore, input parameters have also been increased and decreased by the same amount (10%), unless otherwise stated, in order to compare the relative impact upon the model. Adjusted input parameters are included in Table 6, with outputs from the analysis included in Appendix H.

Table 6 – Sensitivity analysis Parameters and Ranges

Parameter	Modelled Parameter	Sensitivity Range	Sensitivity			Justification/ Comment
			Low	Med	High	
Hydraulic conductivity (m/day)	0.00356	0.00320 - 0.00392	X			No change observed in 3 of 4 substances. Only BkF marginally effected.
Hydraulic Gradient (fraction)	0.0043	0.00387 - 0.00473	X			No change observed in 3 of 4 substances. Only BkF marginally effected.

Parameter	Modelled Parameter	Sensitivity Range	Sensitivity			Justification/ Comment
			Low	Med	High	
Porosity (fraction)	0.028	0.0252 - 0.0308	X			No change observed in 3 of 4 substances. Only BkF marginally effected.
Half-life (Aliphatic EC10-EC12) days	9E+99	1000		X		Half-life already set at max, so reduced to maximum literature value. Reduction in half-life value approximately proportional to change.
Half-life (BkF) days	4270.5	3843.45 - 4697.55	X			Predicted concentration of BkF like that caused by altering aquifer properties.
Half-life (Chloroform) days	9E+99	27.2		X		Half-life already set at max, so reduced to maximum literature value. Reduction in half-life value approximately proportional to change.
Initial Conc (Copper) mg/L	0.012	0.0108 - 0.0132		X		Increase and decrease in initial concentration results in proportional change in resultant concentration.
Initial Conc (Aliphatic EC10-EC12) mg/L	0.438	0.3942 - 0.4818		X		Increase and decrease in initial concentration results in proportional change in resultant concentration.
Initial Conc (BkF) mg/L	1.00E-05	9.00E-06 - 1.09E-05		X		Increase and decrease in initial concentration results in proportional change in resultant concentration.
Initial Conc (Chloroform) mg/L	0.02	0.017 - 0.021		X		Decrease in initial concentration results in proportional change in resultant concentration. Increase results in slight increase in resultant concentration.

6.2 Aquifer Properties

6.2.1 Hydraulic Conductivity

A 10% reduction and increase in hydraulic conductivity had no effect on the resultant predicted concentration at the compliance point (272m from RBBH206) for TPH, organics or metals.

The predicted concentration for benzo(k)fluoranthene decreased by c. 80% and increased by c.270% and therefore were not proportional relative to the increase of the model, or each other. Crucially however, the concentration for benzo(k)fluoranthene is

well below GAC_{CW} , even with increasing hydraulic conductivity by 10%; in fact an exceedance of GAC_{CW} is only achieved by increasing conductivity by two orders of magnitude, which would constitute a permeability comparable to that of a pure sand, which is not representative of site conditions.

6.2.2 Hydraulic Gradient

A 10% reduction and increase in hydraulic gradient had no effect on the resultant predicted concentration at the compliance point for TPH, organics or metals.

The predicted concentration for benzo(k)fluoranthene decreased by c. 80% and increased by 270%, similarly to the change of predicted concentration for hydraulic conductivity; an increase of hydraulic gradient by c. two orders of magnitude would result in an exceedance of GAC_{CW} . To achieve this, the change in hydraulic head between RBBH206 would have to be c.118m.

6.2.3 Effective Porosity

A 10% reduction and increase in porosity had no effect on the resultant predicted concentration at the compliance point for TPH, organics or metals.

By increasing the effective porosity by 10%, the predicted concentration for benzo(k)fluoranthene decreased by c. 80%, whilst decreasing porosity resulted in a c. 320% increase in predicted concentration. Though the relationship is the opposite to that demonstrated by hydraulic gradient and hydraulic conductivity, the percentage increase is approximately the same.

6.3 Substance Half Lives

All substances, with the exception of benzo(k)fluoranthene, were modelled to have the maximum value the spreadsheet allows (9E+99 days). Note that the half-life for copper was unchanged within the sensitivity analysis.

As the half-lives for chloroform and TPH were already set at the maximum permitted value, only a reduction has been assessed. Both chloroform and TPH were set at the maximum half-lives found in literature:

- Aliphatic EC10-EC12 at 1000 days [24]; and
- Chloroform at 27.2 days after USEPA CompTox OPERA Model [21].

A reduction in half-lives for both groups reduced predicted concentrations at the receptor by c. 23 orders of magnitude for TPH and >150 orders of magnitude for chloroform.

The half-life modelled in the spreadsheet for benzo(k)fluoranthene was set at the literature value (as per Run Two). As such, this value was increased and decreased by 10%, resulting in a c. 80% reduction and c.270% increase in predicted concentrations respectively.

6.4 Initial Substance Concentration

Initial substance concentrations were increased and decreased by 10% for all four modelled substances. All changes resulted in a 9 – 10% increase or decrease in the resultant concentration, with the exception of chloroform which recorded a c. 6% increase in resultant concentration when initial concentration was increased by 10%. Therefore, initial and resultant concentrations show a roughly proportional relationship.

6.5 Discussion of Sensitivity

As the initial models have been set up based on very conservative parameters initially, the sensitivity of the model to changes in input parameters doesn't alter the predicted concentration at the compliance point greatly, if at all.

Initial concentrations and half-lives are deemed to be the most sensitive parameters across the board, with any changes most amplified for benzo(k)fluoranthene, chosen to represent PAHs. However, even with benzo(k)fluoranthene, unrealistic alterations of hydraulic properties must be applied in order for an exceedance to be calculated at the compliance point.

As such, the alterations to the model inputs based off site specific data are not deemed sensitive. This is due to the distance of the site from the compliance point; such that any substances are suitably attenuated by natural processes (advection, dispersion, dilution, retardation) largely irrespective of input parameters. Therefore, the hydrogeological model generated for this assessment is deemed to be appropriate.

7 Conclusion

7.1 Regulatory Context

This Controlled Waters detailed Quantitative Risk Assessment (CW-dQRA) has been conducted in line with guidance within Land contamination Risk Management (LCRM) [4], which incorporates the methodologies from the Remedial Targets Methodology (RTM) [2] and Land Contamination Groundwater Compliance Points [22].

By following such guidance, the duty to monitor, protect and enhance the environment (including water resources) can be satisfied under the Water Resources Act 1991 [25].

7.2 Model Outcomes

Despite elevated concentrations of PAHs (benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-c,d)pyrene, fluoranthene), TPH (Aliphatics >EC10-EC12, >EC16-EC35), chloroform, cyanide, metals (chromium, copper, iron, lead manganese, nickel and zinc) recorded within groundwater below the site at Taff's Well, the CW-dQRA undertaken here indicates that the site is not believed to pose a risk to the River Taff/Afon Taf (Controlled Waters).

Despite undertaking a sensitivity analysis, the numerical model used within the Remedial Targets Worksheet (RTW) is deemed to be a conservative representation of hydrogeological conditions below the site; the model showed limited sensitivity to changes in aquifer properties, substance concentrations and half-lives. It is therefore considered that the transport mechanisms within the aquifer (advection, dispersion, dilution, retardation, and degradation) are sufficient to negate the risk to Controlled Waters, largely due to the distance between the site and River Taff/Afon Taf. Consequently, no further work is recommended from the outcomes of this assessment.

7.3 Uncertainties

The largest uncertainty within this risk assessment are the number of potential sources on site. For the purposes of this assessment, the source of impacts within groundwater is assumed to be Made Ground (though in some cases this is poorly constrained by laboratory soil analysis as there seems to be a mismatch between site soil concentrations and groundwater concentrations). However, due to the length of the pathway, substance concentrations within groundwater are predicted to be negligible by the time the groundwater reaches the receptor.

It is also worth highlighting that the redevelopment of the site at Taff's Well involves the reduction of a substantial thickness of Made Ground across the site. Proposals are to

remove soils across the majority of the site to a depth of 33.6m AOD. The discussion in Section 4.7 above indicates where Made Ground is expected to remain on the main body of the site, and how thick this Made Ground is likely to be, based off the logs.

Furthermore, there is some uncertainty as to possible off-site sources located to the north and north east of the site. Obvious off-site sources of groundwater contamination include Made Ground associated with the dismantled railway or the Glamorganshire Canal, as well as previous land-uses. Identifying the potential off-site sources would require further ground investigation outside the boundary of the site, which is beyond the scope of this assessment. Consideration also needs to be given that some of the substances detected (for example, chloroform) maybe present on site as the result of naturally occurring processes.

However, the effect of potentially impacted groundwater from any potential on-site or off-site sources has been assessed within this risk assessment, and that too has been demonstrated to have a negligible risk on Controlled Waters, with no exceedances of GAC_{CW} predicted. This is supported by surface water sampling within the Taff.

7.4 Concluding Comments

The Detailed Quantitative Risk Assessment for the site at Taff's Well indicates that recorded concentrations of certain substances within groundwater (TPH fractions, individual PAHs, chloroform, cyanide and some metals) below the site are not predicted to exceed GAC_{CW} at the modelled compliance point, taken as the bank of the River Taff/Afon Taf.

The uncertainty of the likely source(s) for the impacted groundwater is suitably negated over the pathway as to have no or little predicted measurable impact on Controlled Waters. Dilution of groundwater entering the River Taff/Afon Taf has not been accounted for in this assessment, but is likely to have a significant effect, dramatically reducing the concentrations per volume, given the rate of flow within the River Taff/Afon Taf. As such, no further assessment is deemed necessary based on the recorded groundwater concentrations.

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Figures

[TRAN01-KAW-R0-TAF-RPT-G-GE-000027 Taffs Well Hydrogeological Risk Assessment Figures Combined.pdf](#)

Figure 1 – Site Location

Figure 2a – Exploratory Hole Locations Northern Portions

Figure 2b – Exploratory Hole Locations Southern Portions

Figure 3 –Groundwater and Surface Water Sampling Locations

Figure 4 –Groundwater Flow

Figure 5 –Made Ground Remaining Post Excavation

Appendix A: Borehole Logs

[TRAN01-KAW-R0-TAF-RPT-G-GE-000027 Taffs Well Hydrogeological Risk Assessment
Appendix A Borehole Logs.pdf](#)

Appendix B: Lab Results

[TRAN01-KAW-R0-TAF-RPT-G-GE-000027 Taffs Well Hydrogeological Risk Assessment
Appendix B Lab Results.pdf](#)

Appendix C: Screened Groundwater and Surface Water Results

[TRAN01-KAW-R0-TAF-RPT-G-GE-000027 Taffs Well Hydrogeological Risk Assessment Appendix C Screened Groundwater and Surface Water](#)

Appendix D: Substance Distribution Plots

[TRAN01-KAW-R0-TAF-RPT-G-GE-000027 Taffs Well Hydrogeological Risk Assessment
Appendix D Substance Distribution Plots.pdf](#)

Appendix E: Remedial Targets Worksheets (RTW) Inputs

[TRAN01-KAW-R0-TAF-RPT-G-GE-000027 Taffs Well Hydrogeological Risk Assessment Appendix E Remedial Targets Worksheets \(RTW\) Input](#)

INITIAL SUBSTANCE CONCENTRATIONS

Dates sampled; 19/07/2019, 26/07/2019, 01/08/2019, 08/08/2019, 15/08/2019, 20/08/2019

Substance	BH & Conc (µg/l)	Modelled Conc (µg/l)
Copper	RBBH202 4/-/-/-/-/-	4
	RBBH203 8/-/-/-/-/-	8
	RBBH205 11/-/7/-/6/-	11
	RBBH206 10/-/-/4/12/7	12
	RBBH209 21/7/-/-/3/-	21
	RBBH210 6/4/-/-/-/-	6
	BH101 -/-/-/4/22/3	22
Lead	RBBH202 2.8/-/-/-/-/-	2.8
	RBBH203 4.9/-/-/-/-/-	4.9
	RBBH205 4.1/-/-/-/-/-	4.1
	RBBH206 5.3/-/-/-/-/-	5.2
	RBBH209 4.4/2.1/-/-/-/-	4.4
	RBBH210 3.9/2.3/-/-/-/-	3.9
	BH101 -/1.5/-/-/52.4/-	52.4
Manganese	RBBH202 178.6/-/-/-/-/-	178.6
	RBBH203 168.8/-/-/-/-/-	168.8
	RBBH205 198.3/-/225.1/-/-/-	225.1
	RBBH206 134.2/-/-/-/-/-	134.2
	RBBH209 1,411/1,209/1,186/596.8/-/-	1,411
	RBBH210 2,519/3,388/3,942/3,937/3,875/3,763	3,942
	BH101 -/-/-/167.9/226.1/-	226.1
Chromium	RBBH202 -/-/7.4/-/-/-	7.4
	RBBH203 10.1/-/-/-/-/-	10.1
	RBBH205 11.1/-/-/-/-/-	11.1
	RBBH206 13.2/-/9.4/-/5.6/-	13.2
	RBBH209 15/-/7/-/-/-	15
	RBBH210 6.9/-/7.5/-/-/-	7.5
	BH101 -/-/-/5.4/-	5.4
Zinc	CPBH212 -/-/-/-/12.6/-	12.6
	RBBH203 30.3/-/-/-/-/-	30.3
	RBBH205 29.9/-/22.4/-/-/-	29.9
	RBBH206 49.1/-/13.3/21.7/19.5/-	49.1
	RBBH209 31.8/11.4/11.3/-/-/35.1/	35.1
	RBBH210 23.3/20.4/25/-/-/-	25
	BH101 -/23.5/11.1/21.8/148.5/22.3/	148.5

Iron	RBBH202 1,117/-/-/-/-/-/	1,117
	RBBH203 1,083/-/-/-/-/-/	1,083
	RBHB206 2,014/-/-/-/-/-/	2,014
	RBBH209 2,120/-/-/-/-/-/	2,120
	RBBH210 1,124/-/-/-/-/-/	1,124
	BH101 -/-/-/-/1,677/-/	1,677
Nickel	RBBH209 9.3/9.5/9.2/9.1/-/-/	9.5
Nitrate	CPBH212 -/-/-/-/-/10,690/	10,690
Phenol	RBBH210 14/-/-/-/-/-/	14
Free cyanide (hydrogen cyanide)	BH101 -/25/-/-/-/-/	25
Aliphatics >EC10-EC12	RBBH206 -/-/-/-/438/-/	438
Aliphatics >EC16-EC35	RBBH206 2,400/-/-/-/-/-/	2,400
Benzo(a)pyrene	BH101 -/0.04/-/0.03/	0.04
Benzo(b)fluoranthene	RBBH206 0.03/-/-/-/0.06/0.03/	0.06
	BH101 -/-/0.08/0.02/-/-/	0.08
Benzo(g,h,i)perylene	BH101 -/-/0.03/-/0.02/0.011/	0.03
Benzo(k)fluoranthene	RBBH206 0.01/-/-/-/-/-/	0.01
	BH101 -/-/0.03/-/0.02/0.01/	0.03
Fluoranthene	RBBH205 -/-/0.016/-/-/-/-/	0.016
	RBBH206 0.035/-/0.034/-/-/-/-/	0.035
	BH101 -/-/0.179/0.07/0.15/0.06/	0.179
l123cdP	BH101 -/-/0.03/-/0.02/-/-/	0.03
Chloroform	RBBH205 3/-/-/-/	3
	RBBH206 19/-/4/-/	4



Appendix F: Remedial Targets Worksheets (RTW) Outputs Run 1

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Appendix G: Remedial Targets Worksheet (RTW) Outputs Run 2

[TRAN01-KAW-R0-TAF-RPT-G-GE-000027 Taffs Well Hydrogeological Risk Assessment Appendix G Remedial Targets Worksheets \(RTW\) Output](#)



Appendix H: Sensitivity Analysis Output

[TRAN01-KAW-R0-TAF-RPT-G-GE-000027 Taffs Well Hydrogeological Risk Assessment Appendix H Sensitivity Analysis Output.pdf](#)

