ARUP

BAM Nuttall Ltd

Victoria North HIF Infrastructure Works

Controlled Waters Detailed Quantitative Risk Assessment

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Executive Summary

This report has been prepared by Arup on behalf of BAM Nuttall Ltd (BAM) to present the results of additional ground investigation for per- and polyfluorinated substances (PFAS) and a detailed assessment of the risks to controlled waters associated with ground contamination at the Victoria North HIF Infrastructure site. It should be read in conjunction with previous ground investigation factual and interpretative reports.

This report aims to present sufficient information to discharge the first part of Condition 7a of planning consent 133143/VO/2022, namely the submission of further site investigation and risk assessment and to support the development of a Remediation Strategy for the proposed HIF Infrastructure works.

Proposed development

Manchester City Council (MCC) and Far East Consortium International Ltd (FEC) have obtained planning consent for the HIF Infrastructure works, which include: earthworks and remediation to create suitable development platforms for future residential-led development; the construction of new internal access roads; new utility and services connections; and the provision of green infrastructure including green links and the first phase of a new city river park.

A series of ground investigations have been completed to inform the redevelopment of the area for housing by a joint venture between MCC and FEC. A detailed review of the history of the site and the findings of the ground investigations are presented in the Arup Ground Investigation Report (GIR).

This report references three primary site areas, known as: Red Bank plateau (an area constructed by filling during the late 1800s to create railway sidings); St. Catherine's Wood (an area comprising wooded slopes extending down to the banks of the River Irk); and Red Bank terrace (a generally flat area currently occupied by a variety of commercial operations and car parking).

Emerging water

During site clearance by BAM in February 2022, emerging water was discovered in the north of the site. Some of this emerging water had pooled on the surface of the ground and may also have infiltrated through the largely granular made ground soils of the Red Bank plateau. Laboratory testing of the emerging water identified the presence of per- and polyfluoralkyl substances, also known as PFAS. Although the site has a long history of industrial uses, the majority of uses pre-date the widespread use of PFAS. Given the established history of the site together with the site setting, only the Red Bank plateau area is considered to have the potential for PFAS contamination.

PFAS ground investigations

Following detailed engagement with the Environment Agency, two additional phases of ground investigation have been completed to determine the presence of PFAS within the site. The emerging water has been found to contain very low concentrations of PFAS, with no demonstrable PFAS impact . A significant PFAS outlier has been identified in the TP422/TP423 area, which is not believed to be associated with the emerging water and is likely the result of historic construction activity. A localised area of elevated leachable PFAS was identified at TP405A at 2m depth which was not typical of concentrations of PFAS within the site generally. PFAS identified in perched water within the former railway carriage shed was similarly not typical of concentrations observed elsewhere within the site, suggesting a separate source to the emerging water.

Aside from these identified areas of PFAS impact, soils analysis, soil leachability and groundwater testing generally indicates the presence of very low, diffuse concentrations of PFAS with no pattern to their distribution or known on-site source.

Controlled waters risk assessment

Ground investigations identified a small number of primary contamination sources, including the emerging water, a former railway gas storage facility ('gas works'), carriage shed, infilled reservoirs and outliers of PFAS contamination. Existing made ground has also been considered as a potential source of contamination, where it may be excavated for re-use within the HIF Infrastructure Works.

The key groundwater receptors comprise shallow groundwater in alluvium and the deep principal aquifers, which are formed of the Collyhurst Sandstone Formation and the Chester Formation sandstone. The River Irk forms the south-eastern boundary of the site and is also a controlled waters receptor. Ground investigation data suggests that the river receives discharge from both the shallow and deep aquifers beneath the site. Other potential receptors exist within the site, such as humans and the built environment, but the risk assessments presented in this report consider the risks to controlled waters only.

Contaminants of concern were identified by comparing the data obtained by ground investigation against published water quality standards and background concentrations (WQS). Shallow groundwater analysis identified exceedances of nickel and zinc, ammoniacal nitrogen, TPH and PAH. Comparison of the results of deep groundwater analysis against published WQS has identified similar contaminants to those in shallow groundwater.

Assessment of PFAS in shallow and deep groundwater did not identify any exceedances of the drinking water standard (DWS), which is the relevant screening value for the principal aquifers. However, as groundwater discharges into the River Irk, the environmental quality standard (EQS) becomes the relevant WQS, which is exceeded in some samples of shallow and deep groundwater. Note the EQS relevant to PFAS is recognised as highly conservative and based on assumptions inappropriate to the site (including human consumption of fish from the watercourse) and is exceeded in the River Irk upstream of the site, nonetheless the EQS has been applied in this assessment.

The results of soil leachate analysis for PFAS (using PFOS and PFOA as marker compounds) have been compared against WQS to provide an indication of the potential risks to the River Irk. The concentrations of PFOS and PFOA in soil leachate from TP422/TP423 exceed the DWS and remediation of this outlier is recommended to protect groundwater quality. No other exceedances of the DWS were noted for PFAS. However, as groundwater is a potential pathway for PFAS to reach the River Irk, the relevant standard for assessing risk to the river is the EQS. The majority of soil leachate samples exceeded the EQS.

Water quality in the River Irk has been measured on several occasions as part of ground investigations. Some exceedances of the water quality standards are noted in the river upstream of the site, most notably for zinc, fluoranthene and PFAS. The concentrations of these contaminants do not vary greatly as the river passes the site, indicating that the site is not having a significant impact on river water quality.

Detailed Quantitative Risk Assessment (DQRA)

A detailed quantitative risk assessment (DQRA) has been carried out using the Environment Agency's Remedial Targets Methodology (RTM) for the contaminants of concern identified by the controlled waters risk assessment.

Remediation criteria have been generated using RTM for the gas works area, the TP422/TP423 and TP405A areas and the carriage shed, which have all been identified as sources of contamination within the made ground.

General re-use criteria have not been derived for materials excavated and re-used within Red Bank plateau, as there is no evidence to indicate that water quality within the River Irk is being adversely impacted by existing ground conditions at the site and therefore local re-distribution of existing materials will not introduce new contaminant linkages or increase risks to controlled waters. Re-use criteria have been derived for site-won soils derived elsewhere within the site which is placed within St. Catherine's Wood or Red Bank terrace, as these could create a new risk to controlled waters.

Following the proposed remediation of the identified soil sources of contamination, very low concentrations of residual PFAS will remain in soil leachate and shallow groundwater. A simple mass-balance model has been developed to provide an indication of the potential impact of this residual PFAS on the River Irk. The mass-balance model suggests that there will be no measurable impact on river water quality from the residual PFAS sources identified at the site.

Remediation options appraisal

A remediation options appraisal has concluded that the most viable solution for the remediation of the contamination sources identified at the gas works, TP422/TP423, Carriage Shed and TP405A is excavation and offsite disposal of contaminated material.

The remediation options appraisal for residual PFAS identified a number of potentially viable remedial measures. Two of these remedial options aimed to fully remove residual PFAS risk from the site, with budget costs of £50 million (excavation and removal from site) and £53 million (ex-situ stabilisation) identified. As contamination of the groundwater has already occurred and there is no discernible impact on river water quality either measured on site or through mass-balance modelling, the complete remediation of made ground and groundwater to pristine quality is not justified. A number of other remediation options were identified which constitute best endeavours to prevent new pollution of controlled waters from occurring, without the substantial interventions required to achieve complete remediation. The budget costs identified for these options ranged from an estimated £1.2 million (temporary low permeability cover) to £4.7 million (permeable reactive barrier). Given however, there is no discernible impact on river water quality, it is concluded that expenditure to address residual PFAS would be disproportionate in relation to its environmental benefit and it is concluded that no additional measures are required to address the risk from residual PFAS or other contaminants identified at the site.

Remediation strategy

A Remediation Strategy and Verification Plan is to be developed for the HIF Infrastructure works by BAM, informed by the outcome of this DQRA. The following actions need to be carried forward into that document:

- Gross hydrocarbon contamination will need to be removed from the site, where encountered, including within the former carriage shed area and the excavation verified. This is likely to include perched contaminated shallow groundwater (e.g. with floating NAPL) and NAPL-contaminated soils;
- Remediation is required within the former gas works and carriage shed areas, including excavation of subsurface structures, removal of contaminated perched groundwater and associated soil contamination. Remedial targets are proposed in this report for these areas;
- Remediation is required to remove the PFAS sources identified as TP422/TP423 and TP405A. Remedial targets are proposed in this report for these areas;
- Materials sourced from elsewhere within the site that are re-used within St. Catherine's Wood and Red Bank terrace should be tested to ensure they achieve the proposed materials re-use criteria proposed in this report;
- Implementation of a discovery strategy during remediation to ensure that any previously unforeseen areas of contamination are identified and dealt with and are not taken for re-use as fill elsewhere within the site. In addition, any historic water wells that are encountered during the discovery strategy should be sealed.

1 Introduction

1.1 Background

This report has been prepared by Ove Arup & Partners Ltd (Arup) on behalf of BAM Nuttall Ltd to present a detailed assessment of the risks associated with ground contamination at the Victoria North HIF Infrastructure site.

A planning application has been made by Avison Young on behalf of Manchester City Council to include remediation of the HIF Infrastructure site for future development including the following main elements:

- Earthworks and remediation to create suitable development platforms;
- The construction of new internal access roads;
- New utility and services connections; and
- Provision of green infrastructure including green links and the first phase of a new city river park.

Following several rounds of ground investigation, a series of reports have been produced for the site which present the investigation findings, proposed a conceptual site model and human health and controlled waters risk assessments for the identified contaminants of concern (CoC). In addition, proposed remediation works were outlined. These previous reports are detailed in **Section 1.4** and should be read in conjunction with this report to avoid repetition of content. There have been numerous meetings with the Environment Agency to discuss the implications and findings of these reports throughout late 2022 and 2023. This report takes account of the discussions that have taken place and the comments provided by the Environment Agency.

During the review of these reports for the discharge of planning conditions by the Environment Agency, works on site encountered an area of standing water with input from a pipe entering the site along the north-western boundary. This is referred to throughout this report as the 'emerging water' and has been found by sampling and analysis to contain PFAS, a group of man-made chemicals that have been used extensively since the mid-twentieth century. On-going global research has established that PFAS contamination is a widespread issue of significant concern due to the persistence of the chemicals in the environment.

1.2 Planning applications and conditions

Manchester City Council (MCC) and Far East Consortium International Ltd (FEC) have been granted planning permission (reference: 133143/VO/2022) for the proposed main HIF Infrastructure works within the site, to create development platforms and carry out remediation to allow delivery of a future residential-led development at Red Bank Neighbourhood. The planning condition relevant to this report is Condition 7a:

"Notwithstanding the Ground Investigation Interpretative Reports [1], [2]*… before the development hereby approved commences (excluding vegetation clearance and tree removal), the following information shall be submitted for approval in writing by the City Council, as Local Planning Authority:*

- *Submission of the further Site Investigation and Risk Assessment Reports*
- *Submission of a detailed Remediation Strategy"*

A variation to the planning permission 133143/VO/2022 was submitted to amend Condition 7 (Ground Conditions) in May 2023. Condition 7 was varied to include a requirement for the submission of a Remediation Implementation Plan and verification plan.

Also of relevance to this report, Condition 8 of the planning permission states *"No infiltration of surface water drainage into the ground where adversely elevate concentrations of contamination are known or suspected to be present is permitted".* Condition 9 requires that details of the method for piling, or any other foundation design using penetrative methods shall be submitted for approval in writing by the City Council prior to the commencement of development.

1.3 Purpose of this report

The purpose of this report is to:

- Assess whether PFAS is present at the site and if so, its distribution and associated risks to controlled waters.
- Address comments made by the Environment Agency (EA) relating to risks to controlled waters arising from previously identified contaminants of concern. Update existing controlled waters risk assessments to address all contaminants of concern, including PFAS.
- Present sufficient information to discharge the first part of Condition 7a of planning permission 133143/VO/2022, namely the submission of further site investigation and risk assessment.
- Inform an updated remediation strategy for the HIF Infrastructure application and generate appropriate reuse criteria for recovered soils.

1.4 Previous assessments and reports

A Preliminary Ground Investigation Report (GIR), [2] which included a generic controlled waters risk assessment, was prepared using the results of the 2019 and 2021 AEG ground investigations [3],[4]. This GIR provided the first stage of assessment of contamination as required by the planning process. The report used desk study information and ground investigation data to review the site history, uses of the site that might have caused ground contamination, the environmental sensitivity of the site and the risks that contaminants of concern might present to the development and to controlled waters.

A third phase of ground investigation was subsequently completed in 2022 at the site by BAM, which is reported in the BAM factual report [5]. The results from this investigation were used to prepare an updated version of the GIR [1], together with a detailed controlled waters risk assessment [6].

A draft conceptual site model was subsequently submitted which focused on the emerging water and associated implications for the proposed development of the site [7]. The conceptual site model has been the subject of detailed discussions with the Environment Agency and Manchester City Council Environmental Health Department and formed the basis for further ground investigations focused on PFAS.

1.5 Limitations

This report has been prepared by Arup for use by BAM Nuttall Ltd. It should not be relied upon by any third party except as provided for in Arup's appointment with BAM. Arup has based this report on the sources detailed within it and believes them to be reliable but cannot and does not guarantee the authenticity or reliability of third-party information.

Reasonable skill and care have been exercised in preparation of this report in accordance with the technical requirements of the brief. Notwithstanding the efforts made by the professional team in undertaking this contamination assessment, it is possible that ground conditions and contamination other than that potentially indicated by this report may exist at the site.

This report has been prepared based on current legislation, statutory requirements, planning policy and industry good practice at the time of writing. Any subsequent changes or new guidance may require the findings, conclusions and recommendations made in this report to be reassessed in the light of the circumstances. Should the proposed earthworks, layout or use of the site change, the assessments and conclusions presented in this report may need to be revised.

Given the current status of PFAS as emerging contaminants, in addition to potential for changes in legislation and guidance, the potential exists for changes in the way current regulations and guidance are interpretated and applied by the waste management industry. These changes may occur in the short-term and may impact the conclusions reached in this report. Arup can accept no liability for any subsequent changes in relevant costs or unit rates arising from changes in legislation, guidance or industry practice.

2 The Site

2.1 Site location and description

The Victoria North HIF Infrastructure site is located in the Red Bank area of Manchester, to the north of Manchester Victoria railway station. It is centred at approximate national grid reference SJ846996, see **Figure 1**.

Figure 1:Victoria North HIF Infrastructure site (red outline) and proposed development plots

This report discusses three main areas of the site (**Figure 2**). These are:

- Red Bank plateau (circa. 40mOD to 43mOD), which was constructed by filling during the late 1800s to create railway sidings. The majority of the plateau is proposed for residential development. There is a plot in the north-eastern corner (Plot RB05b) which is currently proposed for a primary school development.
- St. Catherine's Wood, which extends down from the Red Bank plateau, with wooded slopes extending to the banks of the River Irk at circa. 30mOD. Along the north-eastern site boundary, slopes extend down from the plateau towards the adjacent Packaging Products site beyond the site boundary.
- Red Bank terrace, which extends down from the Red Bank plateau in the southwest part of the site to a level at the base of circa 31mOD. The flat-lying areas extending from the base of the Red Bank terrace slopes are currently occupied by a variety of commercial operations and car parking. This area is also planned for residential development, with the slope area designated for public realm.

A series of ground investigations [3][4][5] have been completed to inform the redevelopment of the area by a joint venture between Manchester City Council (MCC) and the Far East Consortium International Ltd (FEC). A detailed review of the history of the site and the findings of the ground investigations are presented in the Arup GIR [1], which should be read in conjunction with this report.

2.2 Geology

2.2.1 Summary

The geology of the HIF Infrastructure site has been assessed as part of the GIR [1] and is described in detail in that report. The descriptions below are based on the assessment presented in the GIR and form the basis for the further assessment that follows below.

2.2.2 Made ground

Adjacent to the north-western site boundary, made ground is typically between 1m and 4m thick. Generally comprising sandy gravel with low cobble content. The thickness of made ground across the Red Bank plateau increases to approximately 16m at the crest of the plateau, overlooking the River Irk. The generally granular made ground is typically described as a loose granular ash fill with localised pockets of cohesive material.

2.2.3 Alluvium

The alluvium is variable in composition and described as medium dense slightly gravelly sand and soft sandy clay or clayey sand. Alluvium is limited in extent, being mostly encountered close to the River Irk and in buried river channels and is recorded as between 0.3m and 4.7m thick.

2.2.4 Glacial till

The glacial till is described as soft to firm, becoming stiff at depth, slightly sandy gravelly clay. Granular bands have been identified within the till, described as medium dense to very dense brown slightly clayey sandy gravel and gravelly sand. Glacial till is locally absent within Red Bank terrace and adjacent to the River Irk, but was encountered beneath the Red Bank plateau and St. Catherine's Wood. The thickness of this stratum was recorded as between 0.3m and 10.5m.

2.2.5 Bedrock

According to published British Geological Survey (BGS) mapping [8], the bedrock beneath the site is formed of three units: the Chester Formation in the southern part of the site, the Manchester Marls Formation through the centre and the Collyhurst Sandstone Formation in the north. The Collyhurst Sandstone is shown on mapping to dip 5 degrees in a south-westerly direction, beneath the Manchester Marl. There is a fault running through the centre of the site within the Manchester Marl, downthrown to the south-west. Approximate bedrock boundaries based on the ground investigation observations are shown in **Drawing 1**.

Ground investigation has found that the uppermost part of all bedrock units is weathered. The Chester Formation is described in the field as a red brown slightly clayey coarse-grained sandstone; the Manchester Marls as a thinly laminated clayey mudstone and the Collyhurst Sandstone as a fine to coarse grained sandstone with lenses of red marl.

2.3 Hydrogeology and hydrology

Groundwater conditions in the made ground have been characterised as discontinuous bodies of perched groundwater trapped within obstructions or perched on underlying cohesive material, with a relatively thin saturated zone at the base of the made ground [1].

Groundwater receptors in the site were identified in the Arup GIR [1] as follows:

- A secondary A aquifer in the alluvium associated with the River Irk;
- A secondary (undifferentiated) aquifer in the glacial till;
- A secondary B aquifer in the Manchester Marl;
- Principal aquifers in the Collyhurst Sandstone and Chester Formation.

A stretch of the River Irk forms the south-eastern boundary of the site, flowing in a northeast to south-westerly direction.

2.4 Proposed development

For the purposes of this report, the site area is taken to be the HIF Infrastructure Works planning boundary and this report refers only to the planning application site. The site boundary is outlined in red in **Figure 2** below.

Figure 2:Proposed development boundary and main site areas

For the purposes of site investigation and risk assessment, the planning application site has been divided into three areas as described in **Section 2.1**. The current HIF earthwork proposals, intended to deliver the proposed development can be summarised as follows (**Figure 3**):

- Earthworks area 1 – re-grading the area of Red Bank terrace to create pedestrian footpaths and cycleways between Red Bank plateau and the lower lying areas to the south-west.
- Earthworks area 2 - construction of a highway embankment to allow access to the site off Red Bank.
- Earthworks area 3 - lowering of ground levels in plots RB02 and RB03 to 38.0mOD.
- Earthworks area 4 - regrading of the existing steep slopes between plots RB02 and RB03 and the River Irk.
- Earthworks area 5 - regrading parts of St Catherine's Wood to provide recreation space and to allow pedestrian and cycle movement between Dantzic Street and Red Bank plateau.

In addition to the earthworks required to deliver a platform for subsequent development, the GIR [1] identified the requirement for remediation works as part of the HIF Infrastructure works. These remediation works focussed on the removal of relic structures, including the below-ground remains of a former carriage shed and a former gas works **(Drawing 2).** Contaminated soil and perched groundwater are anticipated during the excavation of these relic structures and these works required dewatering, remediation and validation.

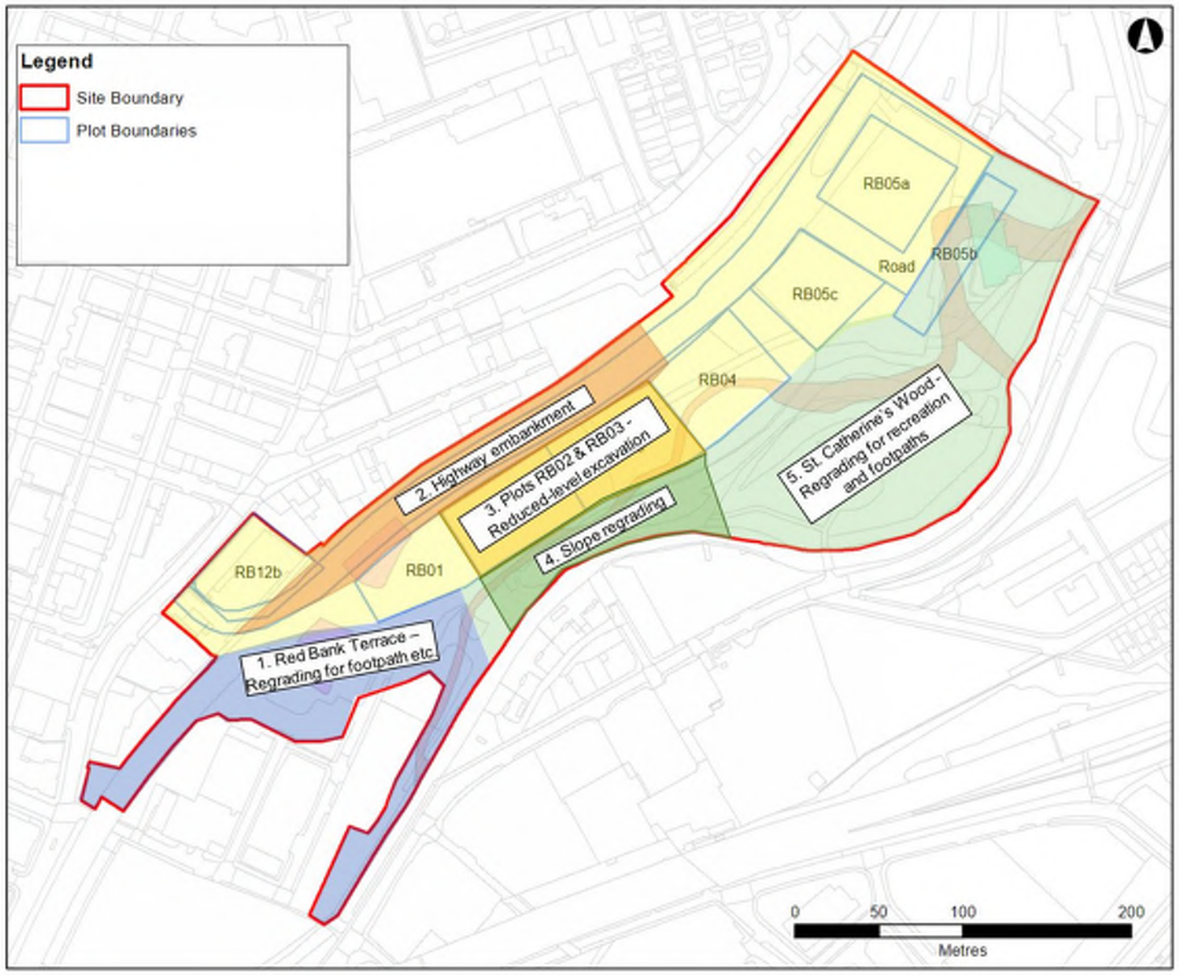


Figure 3: Summary of Victoria North earthworks areas.

3 Emerging Water

3.1 Background

During site clearance works undertaken by BAM in February 2022, in preparation for the proposed HIF Infrastructure works, emerging water was discovered in the north of the site. The emerging water was encountered in a confined area near to the boundary with the Honey Street retaining wall (**Drawing 2**) and as discussed in more detail in **Appendix A**, was found to be discharging from a buried 800mm diameter pipe that was not identified on available utility records. Investigations by BAM established that this pipe had originally been connected to a combined sewer however, historical damage had affected this connection, leading to water emerging at the surface of the site. Although the majority of the discharge was still finding its way to the combined sewer via a shallow surface channel and grate/catchpit (**Appendix A**), some of the emerging water had pooled on the surface of the site and may also have infiltrated through the largely granular made ground soils of the Red Bank plateau.

The emerging water was associated with a distinct orange precipitate, considered to be due to the presence of iron in the discharge. As the source of the discharge could not be traced, BAM recovered samples for analysis (**Appendix A**). These were found to contain elevated concentrations of ammoniacal nitrogen, dissolved methane and dissolved iron which potentially supported a link between the emerging water and a large area of former landfilling to the immediate north (Queens Road landfill). Concentrations of other contaminants tested were below the relevant screening criteria.

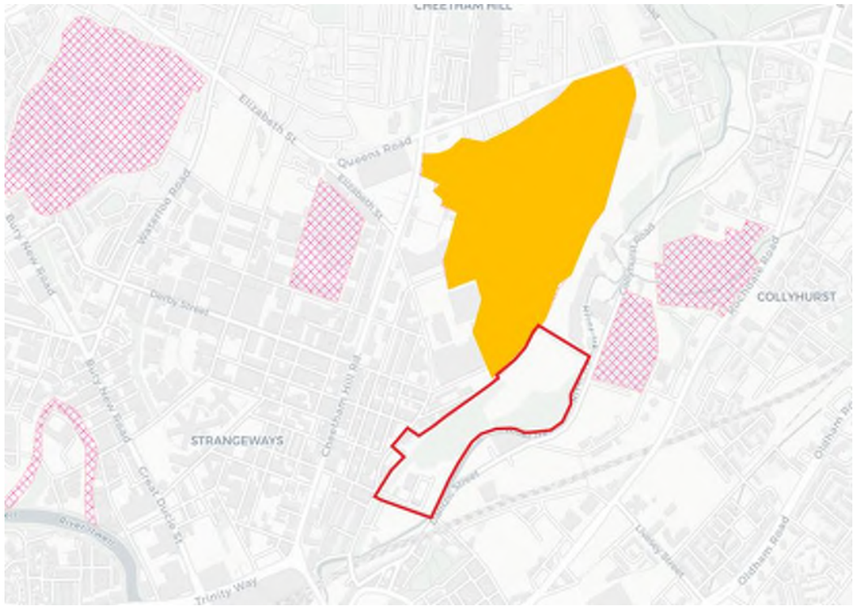


Figure 4: Queens Road landfill (shaded amber) and other nearby former landfills (red cross hatching)

Given the potential links between the emerging water and adjacent landfilling, in October 2022, after initial consultation with the Environment Agency (EA), BAM undertook additional sampling and analysis of the emerging water, which focused on PFAS, a group of man-made chemicals that are increasingly being identified with landfill sites and the environment more generally. The results of this initial PFAS analysis are presented in Appendix A **and summarised in Table 1: Emerging water PFAS analysis (January 2023 GI)**

. This data demonstrated the presence of PFAS, albeit at low concentrations in parts per trillion, in the emerging water.

Determinand	Units	SW04 Body of standing water	SW05 Outfall from800mm pipe
PFBA	ng/l	13.3	15.4
PFPA	ng/l	7.89	5.29
PFHxA	ng/l	3.33	4.16
PFBS	ng/l	7.5	8.61
PFHpA	ng/l	2.49	2.87
PFOA	ng/l	6.63	7.39
PFHxS	ng/l	2.7	2.99
PFNA	ng/l	<1	<1
PFHpS	ng/l	<1	<1
PFDA	ng/l	<1	<1
Linear PFOS	ng/l	3.29	2.84
Branched PFOS	ng/l	7.1	3.79
PFUnA	ng/l	<1	<1
PFDoA	ng/l	<1	<1
PFOSA	ng/l	<2	<2
6:2 FTS	ng/l	<1.6	<1.4
PFDS	ng/l	<1	<1
PFPeS	ng/l	<1	<1

Table 1: Emerging water PFAS analysis (January 2023 GI)

Given that the emerging water issue was only identified after the main ground investigations at the site had been completed, the Environment Agency expressed concerns that the risk assessments that had been undertaken for the site may not address risks associated with the presence of PFAS in the emerging water.

3.2 PFAS

3.2.1 PFAS in the environment

PFAS (Per- and polyfluoroalkyl substances) is the term used to describe a large group of several thousand synthetic chemical compounds that have been in production since the 1940s. PFAS compounds vary widely in their chemical and physical properties and as summarised in **Table 2** are classified principally by the number of carbon atoms within each molecule. This however, is only one of the factors that influences the properties and behaviour of the relevant compound in the environment. What distinguishes PFAS compounds is that the carbon atoms are paired with fluorine atoms. It is the strength and stability of these carbon-fluorine bonds that give PFAS compounds their inherent resilience and persistence both in the environment and within biological systems.

PFAS have been used, and are still used, in the manufacture of many domestic products, including cosmetics, floor polish, textile and fabric treatments, food packaging, baking equipment and firefighting foams [59]. From the late twentieth century, there has been increasing concern regarding the environmental persistence and potential toxicity of these compounds, resulting in restrictions to the manufacture and use of two compounds (PFOS and PFOA) through UK REACH.

Given their extensive use, PFAS have become widespread in the environment and are suspected to present health risks at very low concentrations. It is only recently however, that laboratory techniques with sufficient sensitivity have become widely available and these have only been for a limited number of PFAS compounds. As a result, the current understanding of PFAS and the risks they present is evolving and there is limited guidance on good practice when investigating, analysing or assessing the associated risk.

Compound		Carbon number	Classification
PFCAs			
PFBA		3	Short chain
PFPA		5	
PFHxA		5	
PFHpA		6	
PFOA		7	Long chain
PFNA		8	
PFDA		9	
PFUnA		11	
PFDoA		11	
PFSAs			
PFBS		4	Short chain
PFPeS		5	
PFHxS		6	Long chain
PFHpS		7	
PFOS		8	
PFDS		10	
OTHERS			
PFOSA	Sulfonamide	8	N/A
6:2-FTS	Fluorotelomer	8	

Table 2: Classification of PFAS compounds referred to during the current assessment

3.2.2 Presence of PFAS at Victoria North

Based on the desk study PFAS was not previously considered as a contaminant that could be present at Victoria North. The site has had a complex history of industrial use, but the majority of the uses pre-date the 1940s when PFAS started to be used in a wide range of products. The Red Bank plateau itself was placed using tipped materials in the late 1800s and early 1900s and therefore the made ground would not be expected to have been contaminated with PFAS at the time of placement, as they were not in widespread use at that time. The steep slopes of Red Bank plateau, Red Bank Terrace and St. Catherine's Wood have never been suitable for industrial use and are comprised of the same made ground tipped to create the plateau.

St. Catherine's Wood was historically used as a dye works and corn mill, becoming used as a church, school and residential area in the early 1900s. Following the demolition of the buildings it has been used as a public park. None of these uses are associated with PFAS contamination.

Railway land is not typically associated with PFAS contamination. A recent publication by CL:AIRE *"An overview of the uses of PFAS to assist with identification of sites of concern"* [9] only identifies that PFAS may be associated with rail yards where fuels may have been dispensed, where PFAS may have been used as part of a fire suppression system.

For these reasons, PFAS contamination was not considered likely to be present at Victoria North until the discovery of the emerging water. Only the Red Bank plateau area is considered to have the potential for PFAS contamination due to the past use as railway land, where refuelling facilities may have been provided historically, although no evidence of a fuel depot has been identified within the plateau.

3.3 Summary of emerging water

During site clearance by BAM in February 2022, emerging water was discovered in the north of the site. Some of this emerging water had pooled on the surface of the ground and may also have infiltrated through the largely granular made ground soils of the Red Bank plateau.

Laboratory testing of the emerging water identified the presence of Per- and polyfluoralkyl substances, also known as PFAS. This is a term used to describe a large group of synthetic chemical compounds that have been widely used, and are still used, in the manufacture of many domestic products and firefighting foams. PFAS have become widespread in the environment and may present health and environmental risks at low concentrations.

PFAS was not previously considered as a contaminant that could be present at Victoria North. Although the site has a long history of industrial uses, the majority of uses pre-date the widespread use of PFAS. The longest historical use of the site was as railway land. PFAS is not currently associated with railway land uses unless used as a fire suppressant where fuel is dispensed.

Only the Red Bank plateau area is considered to have the potential for PFAS contamination due to the past use as railway land, where refuelling may have been provided, although no evidence of a fuel depot has been found.

4 PFAS Ground Investigations

4.1 Introduction

In order to assess the potential risks associated with the presence of PFAS within the emerging water, two phases of additional ground investigation have been undertaken as follows:

- Initial PFAS ground investigation - January 2023
- Further PFAS ground investigation – March 2023 [62]

4.2 Initial PFAS ground investigation – January 2023

BAM's programme for the HIF Infrastructure Works identified the proposed excavation in earthworks area 3 and earthworks area 4 (**Figure 3**) as critical-path activities. Given their distance from the emerging water (in excess of 50m), these proposed earthworks were considered to be outside the area of emerging water impact, an assessment that was confirmed by site inspection, which identified no evidence for the emerging water in this area of the site. An initial phase of PFAS ground investigation was undertaken in January 2023 therefore, to validate this in anticipation of the proposed earthworks proceeding under a phased remediation and enabling strategy that was to be developed.

On 24th and 25th January 2023, five trial pits (TP401 to TP405) were excavated within earthworks area 3 with TP406 excavated in an area outside earthworks area 3, that had potentially been impacted by the emerging water. The trial pit locations are indicated on **Figure 5** and exploratory hole logs are given in **Appendix B**. The scope of this investigation was defined by Arup.

As reported previously [7], trial pits were excavated to depths of between 2.4m bgl (TP403) and 3.2m bgl (TP402 and TP404). As anticipated, and consistent with the prevailing Conceptual Site Model (CSM), no perched groundwater was encountered in the predominantly granular made ground encountered in the trial pits. Shallow, mid-depth and deep soil samples were recovered from the excavations and underwent analysis for a range of contaminants including metals, hydrocarbons and PFAS. Analysis of both solid phase and leachability samples was undertaken and the results of analysis are presented in **Appendix B**.

The results of analysis for metals and hydrocarbons were generally consistent with the findings of previous ground investigation. The results of PFAS analysis on soils identified no PFAS concentrations greater than the limit of detection (LOD). Post-Ox analysis (following TOP assay – see **Appendix B** for explanation) identified PFAS concentrations that were greater than the LOD in fourteen of the fifteen samples analysed. Leachability testing detected PFAS in 8 out of 15 samples. Of the 15 samples that underwent leachability analysis, PFOS concentrations were detected in the range of 1.77ng/l to 32ng/l.[1]

Given that the locations of TP401 to TP405 were in areas of the site which had not been impacted by the emerging water, and given that PFAS was not expected as a contaminant on the site, the presence of PFAS in the Post-Ox soils analysis and in the leachability analysis was not expected.

Research has identified the presence of PFAS in a range of environmental settings in areas that have no history of direct exposure to PFAS. A number of mechanisms have been proposed to explain the phenomenon of this background PFAS contamination, including transfer by dusts or via the rain-cycle (**Section 8.5**). It was concluded that the PFAS concentrations identified in TP401 to TP405 were not the result of historical or contemporary activities within the site and were not therefore, associated with the emerging water.

Despite careful measures being implemented to protect the integrity of the samples recovered during the January 2023 ground investigation (discussed in **Appendix B**), it was discovered during the interpretation of the data that glass vessels had been used to transfer sub-samples from the main laboratory to the specialist laboratory for PFAS analysis. All containers used for PFAS analysis should have been plastic (HDPE). Given that the impact of this chain of custody issue could not be quantified, it was considered that the findings of PFAS analysis from the January 2023 investigation could not be relied upon without verification.

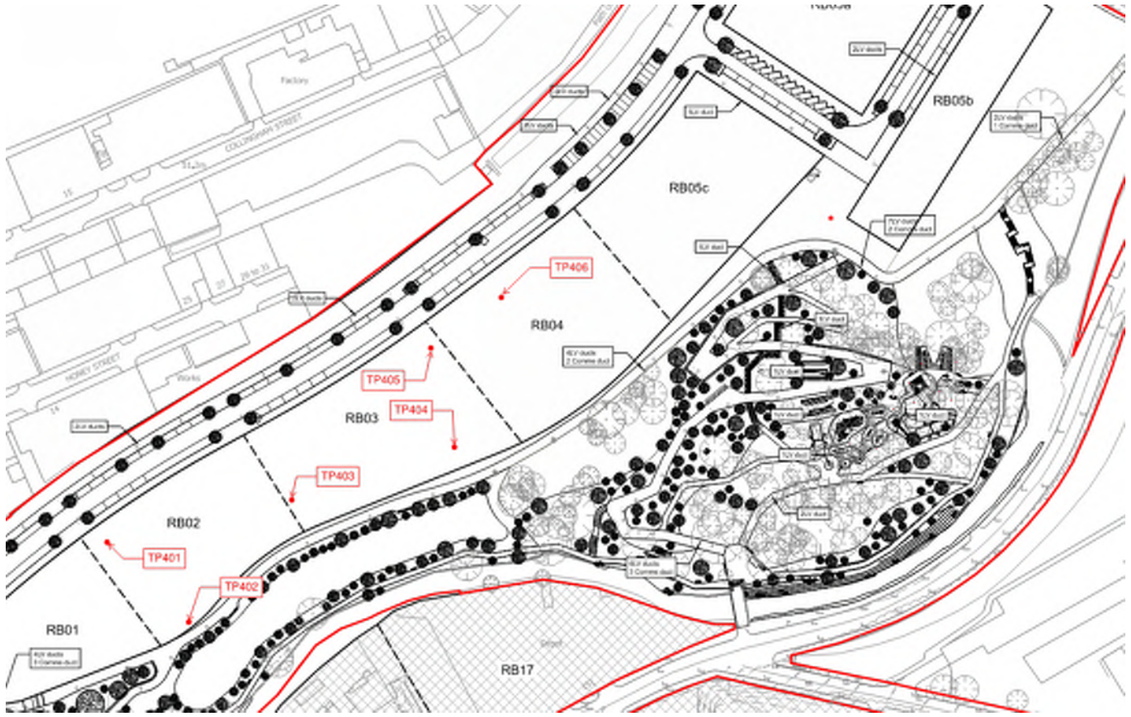


Figure 5: Initial PFAS ground investigation (January 2023) - trial pit locations

4.3 Further investigations – March 2023

A further round of PFAS investigation was undertaken in March 2023 by BAM under the direction of Arup. This further investigation had the following objectives:

- Sampling of the emerging water, to confirm previous analysis results and to assess a range of parameters for future water treatment prior to discharge to combined sewer.
- Sampling of surface water from the River Irk.
- Re-sampling of shallow soils at two locations within earthworks area 3, to validate the findings of the January 2023 analysis results (TP403A and TP405A).
- Further analysis of leachable PFAS concentrations from soils in TP403A and TP405A to provide additional validation of the findings of the January 2023 investigation and to assess the potential for oxidation of PFAS in soils that are proposed for excavation and re-use within the site.
- Widespread shallow sampling across the upper surface of the Red Bank plateau (outside earthworks area 3) to further assess potential background PFAS contamination (400-series trial pits).

[1] In the remaining leachability samples, analysis results for PFOS were less than the limit of detection

- Further investigation of the emerging waters area to establish the extent of PFAS impact (EW-series trial pits).
- Further investigation of the carriage shed area to establish the extent of PFAS impact (CS-series trial pits).

The scope of the March 2023 investigation was limited to the upper surface of the Red Bank plateau for the following reasons:

- The slopes flanking the plateau are steep and in many cases heavily vegetated. Ground investigation would not be possible without causing ecological damage.
- The lower-lying areas of Red Bank terrace have been formerly occupied by a range of industries. The main contaminative activities in this area however, predate the commercial availability of PFAS and therefore, no sources of PFAS can be identified in this area.
- In addition to generally being heavily vegetated, the lower-lying areas of St Catherines Wood are considered not to be at risk from PFAS impact associated with historical use. The area was formerly the site of a school, a church, a residential development and a mill. The industrial elements of this former development wholly pre-dates the commercial use of PFAS.

In preparation for these further investigations, additional steps were added to the soil sampling protocols applied previously. In addition to the steps outlined in **Appendix B**, the following measures were included during the further ground investigations:

- Use of a single analytical laboratory to avoid chain of custody issues during sub-sampling and leachate preparation.
- The use of HDPE containers at all stages of the laboratory preparation and analysis.

4.4 Results of further investigations

4.4.1 General

The findings of the March 2023 further PFAS investigation are presented in **Appendix C**. In addition to trial pit records and laboratory certificates, **Appendix C** contains the following:

- **Appendix C3** – summary of soil analysis data.
- **Appendix C4** – summary of analysis data from leachability and perched groundwater samples (liquid-phase).
- **Appendix C5** – screening of analysis of metals and hydrocarbons against relevant GACs (samples from carriage shed area only).
- **Appendix C6** – summary of residual PFAS concentrations in all sampled media.

Assessment of analytical data is presented below. Field records from the March 2023 ground investigation indicate rain was experienced on the 28th, 30th and 31st March and 11th April. Generally dry weather was experienced during the remainder of the ground investigation and sampling.

4.4.2 Characterisation of the PFAS identified within the made ground at the site

Before discussing the findings of the March 2023 ground investigation in detail, assessments have been undertaken to characterise the PFAS impact that has been identified within made ground at the site.

Soils data

In order to determine the most significant PFAS compounds in the soil samples recovered, a statistical assessment has been undertaken (**Table 3**). The limits of detection (LOD) in soil for individual PFAS compounds typically range between 1µg/kg and 3µg/kg. In order to perform statistical analysis of the data, where PFAS has not been detected in excess of the LOD, the LOD has been taken as the representative value. Available laboratory techniques did not allow concentrations less than 1µg/kg in soils to be reported for any of the individual PFAS compounds.

Given these considerations, a limit of detection of 3µg/kg has been used in this report for total PFAS in soils and other solid phase samples.

Compound	Units	No of results > LOD	Max concentration (with LOD)	Mean concentration (with LOD)
PFBA	µg/kg	0	3.00	3.00
PFPA	µg/kg	0	3.00	3.00
PFHxA	µg/kg	1	7.47	2.10
PFBS	µg/kg	0	1.00	1.00
PFHpA	µg/kg	2	13.80	1.27
6:2-FTS*	µg/kg	0	1.00	1.00
PFOA	µg/kg	3	29.80	1.62
PFHxS	µg/kg	0	1.00	1.00
PFNA	µg/kg	3	11.00	1.33
PFHpS	µg/kg	0	1.00	1.00
PFDA	µg/kg	3	22.50	1.49
PFOS	µg/kg	6	14.21	1.48
PFUnA*	µg/kg	3	21.00	1.53
PFDoA	µg/kg	2	2.74	1.03
PFOSA	µg/kg	0	1.00	1.00
PFDS	µg/kg	0	1.00	1.00
PFPeS	µg/kg	0	1.00	1.00

*- 51 sample results reported for these compounds.

Table 3: Statistical assessment of PFAS compounds (Soil samples, Pre-Ox. No. of samples = 53).

Out of a total of 53 soil samples that were recovered, PFOS was identified above the relevant limits of detection (LOD) in six samples (11%), with a number of other compounds identified above LOD in 3 samples (6% - PFOA, PFNA, PFDA and PFUnA).

The assessment of maximum concentrations suggests that PFOA is most conspicuous in the data, followed by PFDA and PFUnA.

In terms of the mean values, the most conspicuous compounds detected in soil are PFBA, PFPA and PFHxA however, these mean values are skewed by relatively high limits of detection for these compounds, with only a single marginal exceedance of the relevant limits of detection for PFHxA (which has a limit of detection in soils of 2µg/kg – **Appendix C3**). After removal of PFBA, PFPA and PFHxA from further consideration, PFOA, PFOS, PFDA and PFUnA had the highest mean concentrations.

Spatial analysis of the soil data shows that generally, PFOS occurs alongside other PFAS contaminants in soil, and if PFOS was to be treated or removed, the other PFAS contaminants would be treated/removed also. PFOS and PFOA have therefore been used in this report as marker compounds for general PFAS impact.

Liquid-phase data

The statistical assessment undertaken to determine the most significant PFAS compounds in leachability samples and samples of perched groundwater is summarised in **Table 4**.

Compound	Units	No of results > LOD	Max concentration (with LOD) ng/l	Mean concentration (with LOD) ng/l
PFBA	ng/l	9	130.00	31.56
PFPA	ng/l	13	1020.00	62.68
PFHxA	ng/l	16	4500.00	215.53
PFBS	ng/l	3	10.00	7.27
PFHpA	ng/l	14	1740.00	135.38
6:2-FTS	ng/l	4	98.70	11.26
PFOA	ng/l	20	3230.00	218.37
PFHxS	ng/l	1	49.80	8.22
PFNA	ng/l	5	438.00	29.11
PFHpS	ng/l	0	10.00	7.46
PFDA	ng/l	4	370.00	23.27
PFOS	ng/l	16	92.20	18.72
PFUnA	ng/l	0	20.00	8.23
PFDoA	ng/l	0	20.00	8.08
PFOSA	ng/l	0	20.00	13.38
PFDS	ng/l	0	20.00	8.19
PFPeS	ng/l	0	10.00	6.69

Table 4: Statistical assessment of PFAS compounds (Liquid-phase samples, Pre-Ox. No. of samples = 26).

Out of a total of 26 liquid-phase samples, PFOA was identified above the relevant limits of detection in 20 samples (77%), with PFOS and PFHxA identified above LOD in 16 samples (62%).

The assessment of maximum concentrations identifies that PFHxA is most conspicuous in the data, followed by PFOA and PFHpA. In terms of the mean for the data set, the most significant compounds are PFOA and PFHxA.

At the individual sample level, PFOS and/or PFOA in liquid are always detected when other PFAS are also present, meaning that these two compounds can be used as 'markers' for other PFAS.

Summary of PFAS characterisation

Overall, it is concluded that in both soil and liquid-phase samples, PFOA is the most conspicuous PFAS compound at the site. Although the concentrations of PFOS are lower than those identified for a number of other PFAS compounds, PFOS is detected in a greater number of samples than other PFAS compounds (excluding PFOA) and is therefore, more prevalent within the site. The statistical data for these two compounds is summarised in **Table 5** (soils) and **Table 6** (liquid-phase).

Compound	No > LOD	Max Concentration (µg/kg)	Mean concentration (µg/kg)
PFOS	6 of 53	14.2 (TP423, 0.5m)	<1.5
PFOA	3 of 53	29.8 (TP422, 0.5m)	<1.62

Table 5: Characterisation of the most significant PFAS compounds at the site (soil samples)

Given the findings of this characterisation exercise, the assessments of PFAS impact of soil, leachability samples and perched groundwater that follow will focus on PFOS and PFOA as marker compounds for PFAS. This approach is consistent with current UK and World Health Organisation (WHO) guidance, as these are the PFAS compounds that are currently provided with threshold concentrations in water. This is discussed further in **Section 6.1.1**.

Compound	No > LOD	Max Concentration (ng/l)	Mean concentration (ng/l)
PFOS	16 of 26	92.2 (TP405A, 2m)	<18.7
PFOA	20 of 26	3230.0 (TP422, 0.5m)	<218.4

Table 6: Characterisation of the most significant PFAS compounds at the site (liquid-phase samples)

4.4.3 Source of emerging water

Following the January 2023 PFAS ground investigation, a number of modifications were made to the emerging water area in preparation for treatment and discharge to combined sewer. As a result of these works, the sampling locations identified in **Table 1** were no longer available and alternative sampling locations were identified (**Photograph 1**).

The detailed results of the emerging water analysis are presented in **Appendix C**, with PFOS and PFOA concentrations summarised on **Table 7**.

When compared with the relevant regulated thresholds, the available analytical data indicates the following:

- The average emerging water concentrations for PFOS and PFOA are 12.6ng/l and 11.5ng/l respectively.
- PFOS and PFOA concentrations are all well below the drinking water wholesomeness threshold of 100ng/l.
- PFOS concentrations are all greater than the EQS of 0.65ng/l.

An assessment of the potential for PFAS oxidation is presented in **Appendix B** and demonstrated that the PFAS in the emerging water has very little potential to oxidise further in the environment.

Discussions with United Utilities (UU) have established that the concentrations of PFAS detected are acceptable to be discharged to the combined sewer on site without treatment. However, the concentrations of dissolved methane in the emerging water are not acceptable to be discharged to sewer. BAM has established a temporary treatment plant on the site to remove methane from the emerging water and a temporary discharge consent is in place to allow discharge of the treated water to sewer. MCC intends to install a permanent treatment facility for the emerging water, which will remove methane before discharge to sewer in the long term.

Photograph 1: Location of emerging water sampling points (March 2023 onwards - Table 7)

Key:

1. Viaduct pipe (discharges from under the viaduct)
2. SW08UP – upstream end of the standing water
3. SW08DOWN – downstream end of the standing water (behind operative and clay stank)
4. Showmen's Guild pipe – under concrete kerb race.

Date	Parameter	Body of standing water		Showmens' Guild pipe (ng/l)	Viaduct Pipe (ng/l)
		SW08 Down (ng/l)	SW08 Up (ng/l)		
28/03/2023	Total PFOS	9.0	18.0	16.0	-
	Total PFOA	10.0	11.0	12.0	-
29/04/2023	Total PFOS	-	-	-	15.0
	Total PFOA	-	-	-	16.0
31/05/2023	Total PFOS	-	-	4.0	-
	Total PFOA	-	-	7.0	-
07/06/2023	Total PFOS	-	-	<6.0	-
	Total PFOA	-	-	3.0	-
13/06/2023	Total PFOS	-	-	8.0	-
	Total PFOA	-	-	10.0	-
21/06/2023	Total PFOS	-	-	14.0	-
	Total PFOA	-	-	13.0	-
27/06/2023	Total PFOS	-	-	9.0	-
	Total PFOA	-	-	9.0	-
06/07/2023	Total PFOS	-	-	10.0	-
	Total PFOA	-	-	9.0	-
17/07/2023	Total PFOS	-	-	3.0	-
	Total PFOA	-	-	9.0	-
27/07/2023	Total PFOS	-	-	4.0	-
	Total PFOA	-	-	8.0	-
Sample point average	Total PFOS	9.0	18.0	8.2	15.0
	Total PFOA	10.0	11.0	8.9	16.0
Whole data average	Total PFOS	12.6			
	Total PFOA	11.5			

Table 7: Summary of surface water data for the emerging water area (PFOS and PFOA – Pre-Ox)

4.4.4 Surface water sampling from the River Irk

A number of sets of surface water samples were recovered from the River Irk (**Drawing 3**). The detailed results of this analysis are presented in **Appendix C**, and the data are summarised in **Table 8**.

Date	Compound	Location	Upstream SWS03 Pre-Ox (ng/l)	Upper midstream SWS02 Pre-Ox (ng/l)	Lower midstream SWS A Pre-Ox (ng/l)	Downstream SWS01 Pre-Ox (ng/l)
13/04/2023	PFOS	-	9.0	12.0	-	11.0
	PFOA	-	7.0	7.0	-	7.0
29/04/2023	PFOS	Left bank	7.0	6.0	-	7.0
	PFOA		8.0	7.0	-	8.0
	PFOS	Right bank	5.0	5.0	-	8.0
	PFOA		7.0	6.0	-	8.0
21/06/2023	PFOS	-	-	-	5.0	-
	PFOA	-	-	-	8.0	-
Sample point average	PFOS	-	7.0	7.7	5.0	8.7
	PFOA	-	7.3	6.7	8.0	7.7

Table 8: Summary surface water data for the River Irk (PFOS and PFOA – Pre-Ox)

The available analytical data indicates the following:

- The data from SWS03 indicates that the stretch of the River Irk upstream of the site contains average PFOS and PFOA concentrations of 7.0ng/l and 7.3ng/l respectively, which are greater than the relevant EQS of 0.65ng/l[2].
- The downstream concentrations (SWS01) are comparable with those from upstream (SWS03), with average concentration for PFOS and PFOA of 8.7ng/l and 7.7ng/l, recorded at the downstream sampling point.
- The data from SWS02 and SWS A indicate variable conditions along the relevant stretch of the river as it passes the site. The variations in concentration measured on opposite banks of the river at the same location are generally consistent with the findings of the repeatability assessment (**Appendix B**).

The results of TOP assay analysis show that there is no potential for future oxidation of releasing PFAS in the river water samples tested (see **Appendix B** for further details).

4.4.5 Validation of the January 2023 investigation in earthworks area 3

As discussed in **Section 4.2**, chain of custody issues potentially affected the outcome of the January 2023 ground investigation of earthworks area 3. In order to validate the findings of the earlier assessment, TP403 and TP405 were repeated (as TP403A and TP405A) as part of the March 2023 investigation.

Trial pit locations are shown on **Drawing 4** and exploratory hole logs together with the results of analysis are presented in **Appendix C**. The results of this validation assessment of soil samples are summarised for PFOS and PFOA in **Table 9**.

[2] The Environment Agency has confirmed that the relevant standard for PFOS in the River Irk is the Annual Average Environmental Quality Standard (EQS) of 0.65ng/l. As discussed previously in this **Section**, in the absence of any other PFAS standards for surface waters, this EQS has been applied to both PFOS and PFOA

Compound	Jan 23 GI - TP403, 0.65m Soil (µg/kg)		March 23 GI - TP403A, 0.6m Soil (µg/kg)	
	Pre-Ox	Post-Ox	Pre-Ox	Post-Ox
PFOS	<LOD	<LOD	<LOD	<LOD
PFOA	<LOD	2.9	<LOD	<LOD

Compound	Jan 23 GI - TP405, 0.6m Soil (µg/kg)		Mar 23 GI - TP405A, 0.55m Soil (µg/kg)	
	Pre-Ox	Post-Ox	Pre-Ox	Post-Ox
PFOS	<LOD	<LOD	<LOD	<LOD
PFOA	<LOD	2.72	<LOD	<LOD

Table 9: Comparison of January 2023 and March 2023 data for TP403/TP403A and TP405/TP405A

This summary confirms the findings of the January 2023 investigation for Pre-Ox PFOS and PFOA concentrations in soil, which have all been shown to be less than the limit of detection. Unlike the data obtained in January 2023 however, the findings of the March 2023 validation have identified no Post-Ox concentrations greater than the LOD in the relevant soil samples, but given the extremely low concentrations of PFAS being detected in the soil (the data is in the order of parts per trillion), it is likely that this difference in detection of post-ox concentrations is due to normal variance in the soil or testing methods.

The available data has not identified the presence of PFAS (PFOS and PFOA or other compounds) in the soil in earthworks area 3 at concentrations that exceed the relevant limits of detection. This supports the observations made on site that the emerging water had not caused contamination of the shallow soils in this area.

An assessment of the TOP Assay data has been carried out for soils in earthworks area 3 (**Appendix B**). There was an elevated concentration of leachable PFOS in TP405A at 2m bgl, which was not characteristic of the site and will be considered further in this report. The remaining data suggests that there is no significant potential for future oxidation of the made ground in this area of the site. As the soils in earthworks area 3 are proposed to be excavated and re-used elsewhere within Red Bank plateau, it is concluded that this will not lead to an increased risk from PFAS in made ground.

4.4.6 Shallow sampling across Redbank plateau (400-series trial pits)

To supplement the validated findings of the January 2023 ground investigation (**Section 4.4.5**), the March 2023 ground investigation included a series of additional shallow trial pits across the Red Bank plateau. The objective of these trial pits was to allow further assessments of the presence and/or distribution of PFAS in areas of the site that visual assessment suggested were not impacted by the emerging water. The 400-series trial pit locations are shown on **Drawing 4**. Exploratory hole logs together with the results of analysis are presented in **Appendix C**. No perched water was encountered in these excavations.

Soil samples

The results of analysis of soil samples (Pre-Ox) for PFOS and PFOA are summarised in **Table 10, Drawing 5** and **Drawing 6**. PFOS and PFOA concentrations above the relevant limits of detection were identified in TP422 and to a lesser extent TP423. As shown in **Table 11**, there were also a small number of other detectable PFAS compounds identified in TP422 and TP423.

Outside the TP422/TP423 area, the only other exceedances of the relevant limits of detection was a marginal exceedance of PFOS in TP411 (**Table 10**) and a marginal exceedance for PFDoA in TP421 (1.03µg/kg compared with the LOD of 1µg/kg - not shown in **Table 10**).

Compound	TP410, 0.4m Soil (µg/kg)	TP411, 0.4m Soil (µg/kg)	TP412, 1.0m Soil (µg/kg)	TP413, 0.5m Soil (µg/kg)	TP414, 0.45m Soil (µg/kg)	TP415, 0.5m Soil (µg/kg)	TP416, 1.1m Soil (µg/kg)
PFOS	<LOD	2.13	<LOD	<LOD	<LOD	<LOD	<LOD
PFOA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

Compound	TP417, 1.0m Soil (µg/kg)	TP418, 0.45m Soil (µg/kg)	TP420, 0.75m Soil (µg/kg)	TP421, 0.4m Soil (µg/kg)	TP422, 0.5m Soil (µg/kg)	TP422, 1.0m Soil (µg/kg)	TP422, 2.0m Soil (µg/kg)
PFOS	<LOD	<LOD	<LOD	<LOD	7.39	<LOD	<LOD
PFOA	<LOD	<LOD	<LOD	<LOD	29.8	4.89	1.24

Compound	TP423, 0.5m Soil (µg/kg)	TP423, 1m Soil (µg/kg)	TP423, 2m Soil (µg/kg)	TP424, 0.5m Soil (µg/kg)	TP424, 1.0m Soil (µg/kg)
PFOS	14.2	<LOD	<LOD	<LOD	<LOD
PFOA	<LOD	<LOD	<LOD	<LOD	<LOD

Table 10: Summary of 400-series trial pit assessment (PFOS and PFOA in soils – Pre-Ox)

Compound	Units	TP422 0.50-	TP422 1.00-	TP422 2.00-	TP423 0.50-0.50	TP423 1	TP423 2.00-
PFHxA	µg/kg	7.5	<LOD	<LOD	<LOD	<LOD	<LOD
PFHpA	µg/kg	138	<LOD	<LOD	<LOD	<LOD	<LOD
PFOA	µg/kg	29.8	4.9	1.2	<LOD	<LOD	<LOD
PFNA	µg/kg	8.6	11.0	1.1	<LOD	<LOD	<LOD
PFDA	µg/kg	22.5	5.5	1.1	<LOD	<LOD	<LOD
PFOS	µg/kg	7.4	<LOD	<LOD	14.2	<LOD	<LOD
PFUnA	µg/kg	3.0	21.0	2.8	<LOD	<LOD	<LOD
PFDoA	µg/kg	2.7	<LOD	<LOD	<LOD	<LOD	<LOD

Table 11: Summary of PFAS in soils in TP422 and TP423

Leachability samples

Leachability analysis was scheduled on soil taken from a selection of the 400-series soil samples, as summarised on **Table 12**, **Drawing 7** (total PFOS) and **Drawing 8** (PFOA).

Compound	TP410, 0.4m Leachability (ng/l)	TP414, 0.45m Leachability (ng/l)	TP419,1m Leachability (ng/l)	TP422, 0.5m Leachability (ng/l)	TP422, 1.0m Leachability (ng/l)
PFOS	3.0	4.0	<LOD	51.9	<LOD
PFOA	26.0	20.0	<LOD	3230.0	1930.0

Compound	TP422, 2.0m Leachability (ng/l)	TP423, 0.5m Leachability (ng/l)	TP423, 1m Leachability (ng/l)	TP423, 2m Leachability (ng/l)
PFOS	<LOD	75.8	<LOD	<LOD
PFOA	118.0	20.9	13.3	10.2

Table 12: Summary of 400-series trial pit assessment (leachability – Pre-Ox)

The results of **Table 12** can be summarised as follows:

- In the TP422 and TP423 area:
    - Leachable PFOS is in the range <LOD to 75.8ng/l.
    - Leachable PFOA is in the range <LOD to 3,230.0ng/l.
- Outside TP422/TP423:
    - Leachable PFOS is in the range <LOD to 4ng/l.
    - Leachable PFOA is in the range <LOD to 26ng/l.

The concentrations identified in both soil and soil leachate on samples from TP422 and TP423 are substantially higher than elsewhere across the site (**Table 10** and **Table 12**). In addition, the composition of the PFAS in the most impacted trial pit (TP422) differs from that encountered elsewhere. As shown in **Table 7**, in some emerging water samples, PFOS is the only compound identified above the relevant limit of detection. The deeper samples from TP422 however (which include a number of PFAS compounds), contain no PFOS (**Table 10,** TP422 and TP423, 1m and 2m depth). Given these observations, the PFAS identified in TP422 and TP423 is considered to be an outlier and the result of an additional small PFAS source at the site, distinct from the emerging water source. This outlier is discussed in further detail below.

TP422/TP423 PFAS outlier

Historical photographs from Google Earth indicate that in June 2009 at the location of TP422, a pair of upright cylindrical tanks were present within a temporary construction compound (

Figure 6). Adjacent to the tanks is an area of disturbed or recently placed soil. A number of products and cement additives which include PFAS are known to have been used in the construction industry [21] and it is considered that the elevated PFAS identified in TP422 and TP423 may be the result of a spillage from these tanks. On this basis, the PFAS identified in the TP422/TP423 area will be treated as a separate source.

The results of TOP assay analysis on the soil from TP422/PT423 is discussed in **Appendix B** concluded that the PFAS detected in soil and soil leachate has the potential for hidden precursors that could transform through environmental processes to detectable PFAS in future. The soils in this area of the site require further assessment of their PFAS risk, which is discussed later in this report.

Figure 6: Google Earth image from June 2009, showing tanks in a temporary construction compound.

4.4.7 Emerging waters investigations (EW-series trial pits)

As shown on **Drawing 4**, a series of trial pits were excavated as part of the March 2023 investigation within the area where shallow soil was known to have had contact with the emerging water, either at the lagoon where water was first noted to be ponding, or along the line of the broken pipe. Soil samples were recovered from a range of depths from the emerging water excavations, together with samples of perched groundwater, where encountered. Exploratory hole logs together with the results of analysis are presented in **Appendix C**.

Soil samples

The results of PFOS and PFOA analysis of soil samples from the emerging water area are summarised in **Table 13** and on **Drawing 5** and **Drawing 6**.

Compound	EW01, 1.5m Soil (µg/kg)	EW03, 0.5m Soil (µg/kg)	EW04, 2.0m Soil (µg/kg)	EW05, 0.5m Soil (µg/kg)	EW06, 0.75m Soil (µg/kg)
PFOS	<LOD	<LOD	<LOD	<LOD	<LOD
PFOA	<LOD	<LOD	<LOD	<LOD	<LOD

Compound	EW07, 0.5m Soil (µg/kg)	EW08, 0.5m Soil (µg/kg)	EW09, 1.5m Soil (µg/kg)	EW10, 3.0m Soil (µg/kg)	EW11, 0.9m Soil (µg/kg)
PFOS	<LOD	<LOD	<LOD	<LOD	<LOD
PFOA	<LOD	<LOD	<LOD	<LOD	<LOD

Table 13: Summary of EW series trial pit data (soils - Pre-Ox)

None of the soils sampled from the emerging water area were found to contain PFOS or PFOA concentrations greater than the limit of detection. No other PFAS compounds were encountered in the emerging water trial pits at concentrations greater than the relevant limits of detection. This is consistent with the concentrations of PFOS and PFOA detected in the emerging water itself, which were in the order of parts per trillion, and therefore lower than the limit of detection possible in the soil analysis.

Soil leachate samples

The results of soil leachate testing on samples recovered for the emerging water area are summarised in **Table 14**, **Drawing 7** (total PFOS) and **Drawing 8** (PFOA).

Compound	EW02, 1.5m Leachability (ng/l)	EW03, 0.5m Leachability (ng/l)	EW07, 0.5m Leachability (ng/l)
	Pre-Ox	Pre-Ox	Pre-Ox
PFOS	<LOD	2.0	2.6
PFOA	<LOD	2.3	4.6

Table 14: Summary of EW-series trial pit data (leachability – Pre-Ox)

From the soil leachate samples, PFOS and PFOA concentrations are generally low, less than 5.0ng/l. Comparing these concentrations with the PFOS and PFOA detected in the emerging water (see **Table 7,** 12.6ng/l and 11.5ng/l respectively) confirms that the PFOA concentrations in soil leachate are lower than those observed in the emerging water.

The results of TOP Assay analysis on soil leachate samples from the emerging water area (**Appendix B**) show that the PFAS has little or no potential for future oxidation, which is consistent with the findings of the oxidation assessment undertaken on the emerging water.

4.4.8 Analysis of brick masonry

TP EW11 exposed the outside face of the carriage shed sub-structure (**Section 4.4.9**), which was in contact with perched groundwater suspected to be associated with the emerging water source. A sample of crushed brick underwent analysis, with total PFAS less than LOD. This suggests that excavated masonry from the carriage shed may be suitable for re-use as part of the HIF Infrastructure Works.

4.4.9 Carriage shed investigation (CS-series trial pits).

Previous investigation of the carriage shed substructure had been limited by the ground conditions encountered. Despite several attempts, TP202 (29th March 2021,[4]) encountered brick masonry with groundwater trapped within the masonry. This groundwater inundated the trial pit leading to its abandonment after four attempts.

On the basis of the limited ground investigation information available, it had been concluded that the remains of the carriage shed consisted of a brick substructure which acts as a sump into which local surface water and shallow groundwater has collected. Given the proximity of the carriage shed to the emerging water, there was a potential that the perched groundwater in the carriage shed substructure was impacted with PFAS.

As shown on **Drawing 4,** a series of trial pits and trial trenches were excavated as part of the March 2023 investigation within the carriage shed footprint to investigate substructure conditions in more detail. Exploratory hole logs together with the results of analysis are presented in **Appendix C**.

A significant proportion of the carriage shed footprint was found to be generally dry with only limited perched water encountered (**Photograph 2**).

Photograph 2: – CS3 exposing carriage shed foundations with perched water inside the structure

The sub-structure of the carriage shed was found to consist of a perimeter of brick-masonry footings. Within the sub-structure, additional localised sections of masonry were encountered, with areas of brick paving (**Photograph 3**). These are thought to have been areas used for the servicing and maintenance of rail rolling stock. The brick paved areas were found to have associated areas of visual and olfactory hydrocarbon contamination. In addition to sampling for PFAS therefore, selected samples underwent testing for phenols, hydrocarbons and VOC/SVOC, together with asbestos and metals. The results of this analysis are presented in **Appendix C** and in **Appendix C5**, have been screened against the relevant generic assessment criteria for domestic development without plant uptake (6% SOM).

Photograph 3: CS6. Brick paved area with brick removed to allow sampling of areas of visual and olfactory contamination.

The results of this screening can be summarised as follows:

- Slightly elevated beryllium (TP CS3A, 1.2m) and lead (TP CS4, 1.6m) were encountered, similar to concentrations identified in previous phases of ground investigation[3].
- No asbestos was detected.
- No phenols, TPH, BTEX, VOCs or SVOCS were present at concentrations above the relevant generic assessment criteria for the proposed development.

PFAS in soil in the carriage shed area

The results of analysis of soil samples from the carriage shed investigation for PFOS and PFOA are summarised in **Table 15** and summarised on **Drawing 5** and **Drawing 6**. Generally, soil concentrations were less than the limit of detection, with only marginally elevated soil concentrations recorded in TP CS2 (0.4m), TPCS4A (0.5m), TP CS6 (0.5m) and TP CS8 (0.5m - Post-Ox only).

Compound	TP CS2, 0.4m Soil (µg/kg)	TP CS2, 1m Soil (µg/kg)	TP CS3, 1.5m Soil (µg/kg)	TP CS4A, 0.5m Soil (µg/kg)	TP CS4A, 1.5m Soil (µg/kg)	TP CS4A, 2.0m Soil (µg/kg)
PFOS	2.6	<LOD	<LOD	3.0	<LOD	<LOD
PFOA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

Compound	TP CS4, 1.6m Soil (µg/kg)	TP CS4, 1.8m Soil (µg/kg)	TP CS6, 0.5m Soil (µg/kg)	TP CS6, 1.1m Soil (µg/kg)	TP CS6A, 0.45m Soil (µg/kg)	TP CS6A, 2.4m Soil (µg/kg)
PFOS	<LOD	<LOD	1.9	<LOD	<LOD	<LOD
PFOA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

Compound	TP CS7, 0.5m Soil (µg/kg)	TP CS8, 0.5m Soil (µg/kg)	TP CS8, 1.5m Soil (µg/kg)	TP CS8, 2m Soil (µg/kg)	TP CS9, 0.5m Soil (µg/kg)
PFOS	<LOD	1.5*	<LOD	<LOD	<LOD
PFOA	<LOD	<LOD	<LOD	<LOD	<LOD

Compound	TP CS9, 3.5m Soil (µg/kg)	TP CS9A, 0.45 - 0.75m Soil (µg/kg)	TP CS9A, 2.5m Soil (µg/kg)
PFOS	<LOD	<LOD	<LOD
PFOA	<LOD	<LOD	<LOD

Notes:

*- - <LOD in Pre-Ox analysis. Concentration given is from Post-Ox assessment.

Table 15:Summary of CS-series trial pit assessment (soils)

4.4.10 PFAS in groundwater and perched water

A number of groundwater and perched water samples were recovered as part of the 2023 investigations in order to determine the presence of PFAS. As PFOS and PFOA have been selected as indicator PFAS compounds, discussion of groundwater quality in this section focuses on these compounds. The results of all analysis on these samples are presented in **Appendix C** and discussion of the potential for the PFAS in water to oxidise (determined by TOP Assay) is discussed in **Appendix B**.

Made ground groundwater

Three samples of groundwater were recovered from monitoring wells in made ground (BH102, BH207 and BH103). The response zone of BH103 is within the footprint of the former carriage shed, which was observed to contain perched groundwater, as discussed in **Section 4.4.9**.

Groundwater samples were taken from wells that were considered to be downgradient of the emerging water source (see **Drawing 9**). Groundwater sampling was also attempted from two other wells with response zones in the made ground (BH208 and WS207), however, these installations were dry. This is consistent with observations from previous groundwater monitoring as reported in Arup's GIR [1], where the made ground was typically found to be unsaturated at shallow depths.

The results of PFAS analysis of made ground groundwater recovered from trial pits or trenches excavated in the area of emerging water are also presented below. Although the sampling of groundwater in this manner is not best

[3] The GIR [1] reported beryllium in made ground on the Red Bank plateau at concentrations in the range <0.2 to 3.9mg/kg and lead in the range 6.4 to 1400mg/kg

practice, in this case it was considered an appropriate means to gather data to indicate of shallow groundwater quality.

Compound	BH102 (ng/l)	BH207 (ng/l)	EW05 (ng/l)	EW08 (ng/l)	EW11 (ng/l)
PFOS	4	<LOD	5	5	1
PFOA	7	9	5	11	11

Table 16: Total PFOS and PFOA concentrations in made ground groundwater

The results of the analysis of groundwater in the made ground are presented in **Table 16**, which demonstrate that very low concentrations of both PFOS and PFOA are typically present, in the range 1 to 5ng/l for PFOS and 5-11ng/l for PFOA. The concentration of PFOS in the groundwater is around half of the concentrations of PFOA, which is taken to reflect the lower mobility of PFOS compared to PFOA[4].

Perched groundwater samples in the carriage shed area

Given that a number of bodies of perched groundwater could be sampled, no leachability analysis of soil samples was required during the carriage shed investigations. The results of PFAS analysis of perched groundwater samples are summarised in **Table 17, Drawing 7** (PFOS) and **Drawing 8** (PFOA).

Compound	BH103 ng/l	TP CS3, 1.7m Groundwater (ng/l)	TP CS4, 1.7m Groundwater (ng/l)	TP CS7, 2m Groundwater (ng/l)	TP CS8, 1.5m Groundwater (ng/l)	TP CS9, 3.1m Groundwater (ng/l)
PFOS	25	50.0	33.0	19.0	43.0	22.0
PFOA	26	41.0	50.0	35.0	50.0	29.0

Table 17: Summary of CS-series trial pit assessment (perched groundwater)

Elevated total PFOS and PFOA concentrations are evident in the perched groundwater encountered within the carriage shed (up to 50ng/l for both compounds), when compared to the concentration of these compounds in the made ground groundwater generally.

Consideration of the TOP assay analysis results for this perched water shows that there is potential for future oxidation of the PFAS within the perched water in the carriage shed (**Appendix B**). As with the TP422/TP423 soil outlier, this suggests that the PFAS trapped within the carriage shed is of more recent origin as it has not yet oxidised in the environment. This points to a distinct source of PFAS within the carriage shed that will be assessed further later in this report.

Alluvium groundwater

Two samples of groundwater were taken from wells with response zones in the alluvium. Sampling was also attempted from BH322, however the installation was dry. The installation in BH306 is located within Red Bank terrace, whilst BH315 is located within Red Bank plateau, in the area of the former river meander:

As alluvium is not widespread across the site, there were few places where it could be sampled, and the results of analysis for PFAS are quite varied in the two locations where sampling was possible. No PFAS was detected in the sample taken from BH315 within the former river meander beneath Red Bank plateau. This monitoring well is located upgradient of the TP422/TP423 outlier and was not anticipated to be impacted by that source, and the results of testing indicate that this is the case.

[4] K_{oc} is a soil organic carbon-normalised sorption coefficient, and may be a useful parameter for evaluating transport potential. PFOS has a Log K_{oc} value of between 2.4 and 3.7, whilst PFOA has a Log K_{oc} of between 1.89 and 2.63 [35]. PFOS is therefore likely to sorb more strongly to the soil than PFOA.

Compound	BH306 (ng/l)	BH315 (ng/l)
Total PFOS	<LOD	<LOD
PFOA	28	<LOD

Table 18: Total PFOS and PFOA concentrations in alluvial groundwater

BH306 is not located in the Red Bank plateau area and is positioned in the south-west of the site, in a low-lying section of the Red Bank terrace (**Section 2.1**). No known historical uses of PFAS were identified within this area of the site as discussed previously in this section, but the presence of PFAS in the shallow groundwater suggests that there could be localised contamination of the made ground. Further consideration of the data from BH306is presented in **Section 8**.

Glacial till groundwater

Two samples of groundwater were recovered from the glacial till and the results are summarised in **Table 19**. BH311 is located upgradient of the emerging water source and the main Red Bank plateau area and was included to determine the presence of PFAS in background groundwater quality entering the site. The installation in BH204 straddles the made ground/glacial till boundary and is located downgradient of the TP422/TP423 outlier:

Compound	BH204 (ng/l)	BH311 (ng/l)
Total PFOS	<LOD	8
PFOA	48	9

Table 19: Total PFOS and PFOA concentrations in glacial till groundwater

The testing shows that PFAS is present in the glacial till as it enters the site at concentrations of a similar order of magnitude to those observed in the made ground (see **Table 16)**.

PFOA is present in the sample taken from BH204 at higher concentrations. BH204 is located close to the TP422/TP423 area where a PFAS outlier was observed to be present in the soil, which was discussed earlier in this section and is to be considered further in this report.

Bedrock groundwater

Three samples of groundwater were recovered from monitoring wells installed within the sandstone principal aquifers. None of the wells were suspected of being within the zone of influence of the emerging water. BH309 is located on the opposite bank of the River Irk outside the site boundary, and was included to determine the presence of PFAS in background groundwater quality:

Compound	BH210 (ng/l) Chester Formation	BH309 (ng/l) Collyhurst Sandstone (off-site)	BH310 (ng/l) Collyhurst Sandstone (on-site)
Total PFOS	<LOD	2	<LOD
PFOA	8	<LOD	<LOD

Table 20: Total PFOS and PFOA concentrations in bedrock groundwater

The results of bedrock groundwater analysis confirm that very low concentrations of PFAS are present in both the Chester Formation and Collyhurst Sandstone principal aquifers.

In the Collyhurst Sandstone, BH301 is upgradient of the identified PFAS sources already identified (the emerging water, TP422/TP423 outlier and the carriage shed) and is taken to reflect the quality of water coming onto the site

from the north-east. BH309 is not located within the site boundary and is also taken to reflect water quality within the Collyhurst Sandstone.

BH210 was the only monitoring well within the Chester Formation that could be sampled, as BH209 was dry. Concentrations of PFOS were below the limit of detection, and PFOA was less than 10ng/l.

4.5 Summary of PFAS ground investigations

The data from analysis of soils, leachability and perched groundwater samples presented above has been used to assess the presence and distribution of PFOS and PFOA at the site. As shown on **Drawing 5** and **Drawing 6** for soils and **Drawing 7** and **Drawing 8** for the liquid-phase analysis, comprehensive coverage has been provided across the surface of Red Bank plateau.

A significant PFAS outlier has been identified in the TP422/TP423 area, which can be identified in both the soils and leachability analysis data (**Drawing 5** to **Drawing 8**). An influence is also observed in shallow groundwater at BH204. This outlier is well-defined, being bounded to the east by the former gas works area and to the north, west and south by other 400-series trial pits that did not encounter marked PFAS impact. This outlier is considered to be the result of historical construction activity and is not associated with the emerging water (**Figure 6**). This outlier will need to be dealt with during the proposed HIF Infrastructure works.

From visual observations made on site during the ground investigations, it is known that the emerging water has been in contact with shallow soils in the area of ponding and along the line of the broken drainage pipe. Testing has identified concentrations of PFAS in perched groundwater and soil leachate in this area which are consistent with the emerging water. PFAS concentrations in soil are too low to be detected. On the basis of the available solid-phase data therefore, the emerging water has had no demonstrable impact on soil PFAS concentrations at the site.

The perched water sampled from within the footprint of the former carriage shed contains PFAS concentrations that are not typical of the rest of the site. This will need to be dealt with during the proposed HIF Infrastructure works.

Outside of the TP422/TP423 outlier and the carriage shed area, soils were generally found to contain PFAS concentrations that were less than the limit of detection (**Drawing 5** and **Drawing 6**). Only two soil samples were found with concentrations greater than the LOD however, these were marginal exceedances. Notably, none of the marginal PFAS exceedances were from the emerging water area. Furthermore, no evidence had been identified for PFAS impact of brickwork associated with the carriage shed sub-structure to the south and east of the emerging water area.

Outside the TP422/TP423 outlier and outside the carriage shed, leachability analysis on soils generally indicates the presence of low concentrations of PFOS and PFOA (**Drawing 5** to **Drawing 8**), together with a number of other PFAS compounds. An assessment has been undertaken to establish which individual PFAS compounds have been identified in the leachability analysis and whether there are any patterns in their distribution. The results of this assessment are presented in **Figure 7** and **Table 21**, and while a number of compounds are present, there is no overall pattern that can be identified in this data. The elevated PFOS and PFHxS concentrations identified in TP405A at 2m depth (**Table 21**) are not typical of the site. The laboratory was asked to check the validity of this data however, they could not identify a specific anomaly in their analysis results. This occurrence will require further assessment during the HIF works (**Section 8.1**).

Compound	Units	TP403A 0.50m Leach	TP403A 2m Leach	TP405A 0.5m Leach	TP405A 2m Leach	TP410 0.4m Leach	TP414 0.45m Leach	TPEW03 0.5m Leach	TPEW07 0.5m Leach
PFBA	ng/l	-	-	-	-	-	-	-	-
PFPA	ng/l	-	-	-	-	3	5	-	1.23
PFHxA	ng/l	-	-	-	-	6	8	1.69	2.19
PFBS	ng/l	-	-	-	-	-	-	-	-
PFHpA	ng/l	-	-	-	-	5	-	-	2.18
6:2-FTS	ng/l	-	11.4	-	-	-	-	-	-
PFOA	ng/l	15.6	-	15.8	-	26	20	2.29	4.57
PFHxS	ng/l	-	-	-	49.8	-	-	-	-
PFNA	ng/l	-	-	-	-	-	-	-	1.74
PFDA	ng/l	-	-	-	-	-	-	-	1.03
PFOS	ng/l	-	-	11.2	92.2	4	4	2.02	2.6

Table 21: Summary of PFAS concentrations exceeding LOD in the areas of the site outside the TP422/TP423 outlier and outside the carriage shed (leachability analysis).

PFAS has been detected at very low concentrations in both the shallow and deep groundwater within and outside the site boundary. The concentrations of PFOS and PFOA detected in or close to identified sources such as the carriage shed and TP422/TP423 outlier are higher and not typical of groundwater quality generally, indicating that further assessment or remediation is required.

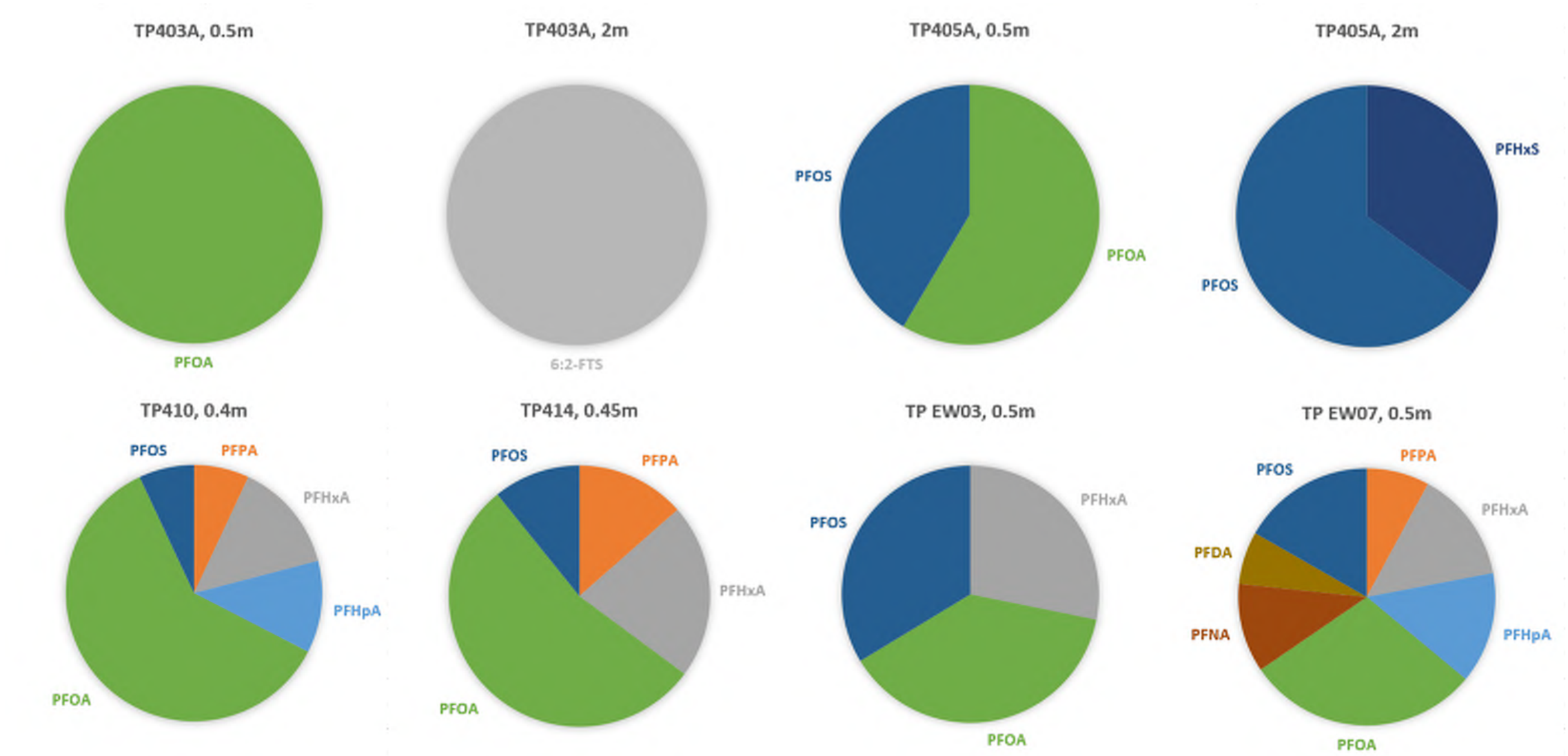


Figure 7: Residual PFAS compounds identified in leachability analysis

5 Conceptual Site Model

5.1 Sources

5.1.1 Overview

The Arup GIR [1] provides a list of on-site primary contamination sources identified across the HIF Infrastructure site. These include a former railway gas storage facility (marked on maps as a 'gas works'), railway infrastructure including a carriage shed and dye and other chemical works associated with the textile industry. In addition, the emerging water discussed in **Section 3** was identified as a source of contaminants, notably low concentrations of PFAS.

Made ground is extensive across the site and was used to infill a former meander of the River Irk in the northern part of the site and a historical mill race that extends the length of the site. Significant quantities of made ground were imported in the late 1800s in order to create what is now referred to as Red Bank plateau.

Ground investigations completed by AEG in 2019 [3] and 2021 [4], and by BAM in 2022 [5] confirmed that various contaminants are present in the soil and groundwater across the site. Although some defined contamination sources have been identified from desk-based information, it is likely that contamination is also present as a result of the imported made ground used to create Red Bank plateau.

A detailed evaluation of the data was undertaken to identify potential contaminants of concern in soil and groundwater, which is reported in the Arup GIR [1]. This presented generic quantitative assessments of soil and leachate data that identify various contaminants across the site at concentrations in excess of generic standards. In addition, a detailed evaluation of the data from PFAS investigations carried out in 2023 is presented in **Section 4**.

The following source areas of particular focus have been identified:

Emerging water

The emerging water (discussed in **Section 3**) has been identified as a source of very low concentrations of PFAS. Soil concentrations of PFAS in the vicinity of the emerging water are below the laboratory limit of detection, whereas soil leachate samples confirm that, whilst concentrations of the target analytes PFOS and PFOA are lower than those in the emerging water itself, they are still detectable in the soil leachate and in shallow groundwater within the made ground in the vicinity of the emerging water source.

Gas works

A historical railway gas storage facility (marked on maps as a 'gas works'), was shown on historical mapping published between 1906 and 1964 in the northeast of the site on Red Bank plateau. It should be noted that no evidence has been identified that this was a coal gas manufacturing plant, it is believed that it was a local storage facility for gas produced elsewhere, most likely the large gas works at Gould Street nearby [1]. Ground investigations in this area in 2021 encountered perched groundwater with an oily sheen, hydrocarbon contaminated soils and a 'metallic blue sand'. The 'metallic' description is thought to refer to the fact that there was a sheen on the soil, which may be related to the hydrocarbon contamination that was present rather than metals, which were not present at significant concentrations in this location. Contaminants identified in the ground and groundwater in excess of screening values in this area include petroleum hydrocarbons (TPH) and polyaromatic hydrocarbons (PAH), cyanide and ammoniacal nitrogen which are typical coal gas contaminants.

The gas works area was investigated further by BAM in 2022 using trenching methods, to determine the extent of relic foundations, and borehole drilling, to look at deeper ground conditions and install monitoring wells. Further observations of oily contamination were made in the subsurface of the gas works area, which have been cross-referenced with historical plans showing the gas works buildings. A sample of perched groundwater recovered from one of the trenches (TT301) was analysed and confirmed the presence of complex cyanide, ammoniacal nitrogen and the PAH compounds fluoranthene, anthracene and benzo(a)pyrene in excess of water quality standards. The outline of the gas works buildings is shown in **Drawing 2** and correlates well with the observations of surface contamination made during the ground investigations.

Groundwater contaminated with hydrocarbons has been detected downgradient of the gas works, suggesting that mobile contamination is migrating from the gas works source towards the River Irk. Outside of the gas works footprint area, hydrocarbon contamination has also been noted in some exploratory holes within the St. Catherine's Wood area (namely BH320, BH321 and BH322), however, the hydrocarbon contamination noted in these boreholes is not associated with the former gas works for the reasons set out below:

- BH320: Hydrocarbon odours were noted in the made ground during drilling from 0.3m bgl, becoming stronger from 3m bgl to the base of the made ground at 6.7m bgl. Groundwater was struck in this borehole at 4.6m. A monitoring well was installed in this hole with a response zone in the made ground was dry on subsequent monitoring visits. It is not considered that the hydrocarbon contamination originated in the groundwater and spread via a 'smear zone' in the made ground, as contamination was noted from a very shallow depth and is more likely to be associated with contaminated made ground placed in this part of the site. The description of the made ground in this area includes ask, timber, coal, mortar, concrete and slag, suggesting an industrial origin to the fill materials.
- BH321 – a strong hydrocarbon odour was noted from 4.4 to 4.85m bgl, but no groundwater was struck during drilling. The made ground in the area of the contamination was described as containing wire insulation, woody fragments, brick and coal, suggesting that the origin of the contamination is associated with the made ground rather than migration from the gas works.
- BH322 – a strong hydrocarbon odour was noted in the made ground from 0.9m to 3.25m. Alluvium reported to be present beneath made ground, where groundwater was struck during drilling. Groundwater was struck during drilling in the alluvium at 5.4m, rising to 4m after 20 minutes. No hydrocarbon odour was noted in the alluvium during drilling. The made ground where the hydrocarbon odour was noted included fragments of glass and slag, coal, burnt shale, brick and hard plastic, suggesting that the made ground is the likely source of contamination. Subsequent testing of the groundwater in BH322 identified concentrations of aromatic hydrocarbons in the range C12-C16 and fluoranthene in excess of the screening value. This borehole is located some distance away from the former gas works and is not located within the former river channel or mill race.

Whilst these areas are not believed to be linked to the gas works, the gas works is still considered to be a potential source of hydrocarbon contamination that poses a potential risk to controlled waters and requires consideration in risk assessment.

TP422/TP423

The ground investigations completed by BAM in 2023 also identified an area of PFAS contamination in soil at TP422/TP423 on the edge of the former gas works, thought to be associated with the use of this area as a temporary construction compound in 2009 (see **Section 4**). Elevated concentrations of PFAS have been detected in the shallow groundwater in the vicinity of this former compound area, which are believed to be associated with this source.

Carriage shed

A former railway carriage shed was located on Red Bank plateau in the north of the site. Hydrocarbon contamination, including NAPL, TPH and PAH was noted in groundwater perched in relic foundations. Observations of shallow hydrocarbon contamination in soil and perched groundwater correlated with the former footprint of the carriage shed, which is shown in **Drawing 2.**

The ground investigations completed by BAM in 2023 identified elevated PFAS concentrations within the perched groundwater contained within the relic foundations of the carriage shed (**Section 4**).

TP405A

An elevated concentration of leachable PFAS was identified in soil at TP405A (2m bgl) during the March 2023 ground investigation by BAM (**Section 4**). The concentrations of PFAS in this area were not typical of the made ground generally.

Infilled reservoirs

Historical mapping identified two former reservoirs or water features that were shown on maps dating from 1848 to 1906 in the south-western part of the site, which as the 1922 maps indicated were infilled by a significant thickness of made ground when Red Bank Plateau was formed; the features are now between 4 and 10m below current ground level.

Strong hydrocarbon odours were noted in material believed to be within the base of one of the former reservoirs (the southern feature in **Drawing 2**), where two boreholes have been drilled: BH314 and BH211A. Both encountered a strong hydrocarbon odour in made ground, but these did not extend into the underlying glacial till, which was approximately 0.8m thick beneath the reservoir over the Chester Formation sandstone.

Groundwater monitoring wells installed in the southern reservoir detected the presence of hydrocarbons (TPH and PAH) in the groundwater in BH211A, but not in BH314. Where detected, concentrations of TPH were not in excess of water quality standards. Fluoranthene and Benzo(a)pyrene were present in groundwater in BH211A at concentrations which exceed WQS, but exceedances of the WQS for these PAH compounds are present in shallow groundwater across the site.

The northern reservoir was investigated by BH210. No evidence of hydrocarbon contamination was noted in this reservoir and no contamination was noted in BH105, which was drilled slightly to the north. Groundwater quality was tested within the Chester Formation bedrock immediately beneath this reservoir and was found to be of good quality and likely to reflect the quality of upgradient groundwater entering the site.

Reused made ground as a source of contamination

As discussed in **Section 2.4**, material is to be recovered for re-use as fill within Red Bank plateau, and locally redistributed during regrading operations. There is no evidence to indicate that water quality within the primary receptor (the River Irk) is being adversely impacted by existing ground conditions at the site and therefore local re-distribution of existing materials (excluding the identified sources above) will not introduce new contaminant linkages or increase risks to controlled waters. Therefore, no general re-use criteria for re-used materials have been developed in this DQRA.

Where material is to be relocated from one area of the site to another (e.g. from Red Bank plateau to St. Catherine's Wood), there is the potential for new contamination risks to be introduced and for re-used material to act as a potential source of contamination. The risk posed by relocated materials will be assessed.

Emerging water as a source of PFAS contamination

As described in **Section 3**, during vegetation clearance on Red Bank plateau, BAM encountered a body of emerging water in an area of the site near to the boundary with the Honey Street retaining wall. BAM subsequently carried out extensive investigations of this emerging water to determine its impact on soil and groundwater contamination, the results of which are presented in **Section 4**.

The emerging water was found to contain very low concentrations of PFAS. The emerging water also contains dissolved methane that prevent it from being discharged to sewer without treatment. Temporary treatment is now in place to reduce methane concentrations and the emerging water is being discharged to sewer and is no longer discharging to ground within the site.

5.2 Receptors

5.2.1 Groundwater

The hydrogeology of the HIF Infrastructure site has been assessed based on the ground investigation data. Two aquifers have been identified at the site, which are termed the shallow aquifer and the deep aquifer in this report. These units are separated by glacial till (where present).

Shallow aquifer

The shallow aquifer is formed of made ground and alluvium. The made ground is continuous and extends across the entire site area. The made ground is described as variable, comprising largely granular materials. There is some near-surface perched groundwater within the made ground associated with relic structures (for example, the former carriage shed foundations) and cohesive materials, but this is not a continuous groundwater body. Groundwater is present at the base of the made ground, perched above the lower permeability glacial till, or in continuity with the alluvium where made ground rests directly over the alluvium.

The alluvium is present only in the area immediately adjacent to the River Irk, and is not continuous, having been disturbed or removed by historical development of the river valley. The alluvium includes a historical course of the River Irk which has been overtipped by made ground, see Drawing 2. It is defined as a Secondary A aquifer by the EA, likely because it provides some base flow to the River Irk, however it is of very limited extent.

An inferred piezometric surface for the shallow aquifer is presented in **Drawing 10** and suggests groundwater flow reflects the surface topography and flows towards the River Irk to the south-east. Groundwater monitoring within wells on the HIF Infrastructure site show shallow groundwater levels range across the study area from around 40mOD at the top of Red Bank plateau to 28mOD in St. Catherine's Wood and 27mOD at Red Bank terrace.

In situ hydraulic testing has been carried out within the strata that form this aquifer. The testing is described in the Contractor's Factual Report on the GI [3] and is summarised in Section 5 of the GIR [1]. The permeability of the alluvium in isolation was only measured in one well, at 7.53E-09m/s (0.0007m/day), where the alluvium was described as a dense sand. The made ground is generally more permeable, ranging from 5.68E-08m/s to 3.26E-05m/s with an average permeability of 0.6m/day.

The made ground and alluvium groundwater quality is affected by contamination, which is likely to be the result of historical industrial uses within the site and surrounding area. The shallow aquifer has not been considered as a receptor for the purposes of DQRA primarily as the alluvium is very limited in extent and predominantly cohesive.

Aquitard (glacial till)

The glacial till deposits, present across the majority of the HIF Infrastructure site, act as an aquitard separating the shallow aquifer from the deep groundwater in the bedrock below. The glacial deposits are described as sandy gravelly clay becoming stiff with depth. A number of granular bands have been recorded within the glacial till, which are described as medium dense to very dense slightly clayey sandy gravel/gravelly sand with a low to moderate cobble content. Groundwater has been encountered within the granular bands of the glacial till.

Within the HIF Infrastructure site, the thickness of the glacial till is proven to be between 1.1m and 6m. The glacial till deposits are absent within the river valley (St. Catherine's Wood area of the site) where they have been scoured by the River Irk and replaced by alluvium, or locally where no till is present made ground directly overlies the bedrock.

Where present, this aquitard is considered to provide a significant barrier preventing recharge of units below, but where absent (along the River Irk valley), the shallow and deep aquifers may be in continuity.

The glacial till has not been considered as a receptor for the purposes of DQRA due to its predominantly low permeability, aquitard characteristics.

Deep aquifer

Three distinct bedrock types are present within the site boundary: the Collyhurst Sandstone, which outcrops along the northern edge of the site; the Manchester Marls in the northern part of the site, and the Chester Formation in the southern part of the site (see **Drawing 1**). The Manchester Marl formation thickness is given by the BGS as between 15 and 45m, the Collyhurst Sandstone formation thickness is quoted as ranging from 0 to 300m and the Chester Formation thickness up to 420m [7].

The BGS Aquifer Properties Manual [7] describes the Collyhurst Sandstone Formation as a dune-bedded aeolian sandstone. The geological map [6] shows the Collyhurst Sandstone dipping gently (5 degrees) to the south-west, beneath the Manchester Marl. The Manchester Marl Formation is a mudstone that represents a marine incursion from the north. The Chester Formation overlies the Manchester Marl and is part of the younger Sherwood Sandstone Group, the major aquifer within this region. The Sherwood Sandstone Group is described as generally poorly cemented with high porosities.

The BGS hydrogeological map of the Cheshire Basin shows the regional groundwater flow direction in the Sherwood Sandstone is towards the southwest [8] and groundwater levels in the Chester Formation in the vicinity of the site are around +30mOD. This matches site observations of the groundwater levels in the deep aquifer in the Chester Formation, shown in **Drawing 11**, which show groundwater levels between 32 and 27mOD.

The Collyhurst Sandstone Formation only outcrops in a very small part of the HIF Infrastructure site. Two monitoring wells with response zones in the Collyhurst Sandstone within the site boundary had piezometric levels of 29.7 and 28.4mOD. A monitoring well within the Collyhurst Sandstone on the opposite bank of the River Irk had a water level of 27.7mOD. Piezometric heads within the Collyhurst indicate that groundwater within the deep aquifer flows towards and discharges to the River Irk, possibly influenced by the geological boundary marking the transition to the Manchester Marl.

Both the Collyhurst Sandstone and Chester Formation are classified as Principal aquifers by the EA and are a groundwater resource locally. Groundwater is abstracted from the Collyhurst Sandstone approximately 270m north-east of the site (hydraulically upgradient) by Packaging Products Ltd for general cooling. Groundwater is abstracted from the Chester Formation approximately 400m north-west of the site (upgradient) by Derby Brewery for cooling and process water. These sandstone groundwater bodies are considered to be receptors for the purposes of DQRA.

The Manchester Marl Formation is considered by the BGS to be an aquiclude [9], preventing the mixing of groundwater between the two sandstone units. The Manchester Marl is classified by the Environment Agency as a Secondary B aquifer however in the vicinity of the site it is an aquiclude with no resource potential and is not considered likely to be providing significant baseflow to the River Irk. It is not considered to be a receptor for the purposes of this DQRA.

5.2.2 Surface water

There is one surface watercourse close to the study area: the River Irk. This is located along the south-eastern boundary of the HIF Infrastructure site. The river course has been historically straightened where it passes the site, as historical mapping shows an old meander bend and mill race that are now buried beneath the plateau area (see **Drawing 2**). The River Irk flows from north-east to south-west past the site, entering a culvert beneath the active Network Rail viaduct (outside the HIF Infrastructure site boundary), before emerging for a short distance, passing over Scotland Weir and then entering Victoria culvert beneath the railway station. The confluence with the River Irwell is approximately 500m downstream of the HIF Infrastructure site.

The ground investigation data suggests that the river is in hydraulic continuity with both the alluvium and the sandstone aquifers. There is a visible outcrop of the Chester Formation sandstone to the south of the Victoria North HIF Infrastructure site within the channel of the River Irk.

There is no current surface water drainage system operating within the site boundary, therefore surface water currently infiltrates through the ground or runs off into the River Irk. The edges of the Red Bank plateau are formed of very steep slopes, which are likely to be encouraging runoff in these areas of the site.

The River Irk was considered to be the primary receptor in the initial screening of groundwater data as it may receive discharge from the adjacent groundwater bodies.

5.2.3 Other receptors

Other receptors identified in the Arup GIR [1] include future site residents, users, on site buildings, materials and services and soft landscaping. Risks to these receptors are not considered further in this controlled waters DQRA report but assessment of the risks to other receptors are detailed in the GIR and necessary mitigation will be detailed in the Remediation Strategy.

5.3 Pathways

5.3.1 Controlled waters pathways

The potential pathways linking contamination to controlled waters are as follows:

- Direct entry of emerging water to ground;
- Vertical migration of dissolved phase contamination;
- Lateral migration of contamination in groundwater (shallow and deep);
- Lateral and vertical migration of NAPL.

As discussed elsewhere in this report, the direct entry of emerging water to ground has ended, following the installation of a temporary treatment facility and discharge of the treated water to sewer. Therefore, this DQRA for controlled waters focuses on the evaluation of the soil leaching pathway and the lateral migration of existing dissolved phase contamination to the River Irk. It does not include any detailed modelling of risks associated with runoff, or the lateral and vertical migration of NAPL (as potentially mobile NAPL has not been identified by ground investigation). Further consideration will be given to these potential pathways within the Remediation Strategy by implementation of appropriate construction site management practices, including a rigorous discovery strategy during ground works.

5.3.2 Soil leaching pathway

The potential for contaminants to leach from soil will depend on both the presence of a leachable source in soil and a vertical flow of infiltrating water between the source and underlying groundwater. A potentially leachable source of PFAS has been identified in the existing made ground at the site, as discussed in **Section 4**.

The HIF Infrastructure Works are intended to prepare the site for future development, detailed in planning consent 133143/VO/2022 and **Section 2.4**, which will be brought forward in phases. There is a possibility that the development of Red Bank plateau may take many years to be complete, during which time the site will be left in an interim condition where a higher rate of leaching may be possible compared to the site in its fully developed condition.

The risk assessments presented in this report are designed to be protective of surface waters given the future proposed development. It is intended that the HIF Infrastructure Works will reduce the quantum of risk posed by the identified contaminants at the site, until the site becomes fully developed, at which point, the risk will be reduced further as the permeability of the surface and sub-surface materials reduces (through the construction of buildings and hardstanding). Any changes to the nature of the development will necessitate additional risk assessment by the future developers of the site.

A separate evaluation has been completed of potential leaching from materials that are proposed for reuse as part of the proposed cut and fill activities summarised on **Figure 3.**

5.3.3 Lateral migration of dissolved phase contamination

The potential for existing sources of dissolved phase contamination within the shallow and deep groundwater to migrate and cause significant impact at chosen compliance points has been assessed in this DQRA.

5.3.4 Vertical migration of dissolved phase contamination

The DQRA focuses on an evaluation of lateral migration within the aquifers, based on the site's hydrogeological setting, as this is expected to be more significant than the potential for vertical migration.

As discussed in **Section 5.2.1**, the glacial till is acting as an aquitard to prevent significant downwards migration of contamination from the shallow groundwater into the underlying bedrock. The review of groundwater data within the site confirms that the quality of groundwater within the bedrock under the Red Bank plateau, where glacial till is present, is better than that within the lower-lying areas of the site where the covering of glacial till is absent. Furthermore, the conceptual site model defines the River Irk as the receptor for discharge of groundwater from the bedrock strata.

5.3.5 Preferential pathways

Preferential pathways are physical features that serve to provide a route by which contaminants have the potential to migrate more rapidly through the subsurface, often by-passing normal physical barriers and reducing potential attenuation.

Potential preferential pathways within the HIF Infrastructure site are the former meander of the River Irk beneath the gas works site and a former mill race that extends the length of the site beneath the Red Bank plateau (see **Drawing 2**). When operational, the meander bend and mill race were connected. The former meander may be having an impact on groundwater movement local to the gas works, although the groundwater level monitoring was inconclusive. There is no evidence that these features were infilled with a higher-permeability material compared to the remainder of the made ground, therefore it is unlikely that they are acting as preferential pathways for contaminant migration.

As requested by the EA, a search for records of historical water wells was carried out within the current HIF Infrastructure site boundary, by reviewing of BGS water well records and borehole logs, the BGS hydrogeological map and historical mapping [1],[39]. No records of wells were identified, but the former mill race and River Irk is likely to have provided the former industries in the St. Catherine's Wood area with water. The HIF Infrastructure ground works will include extensive site turnover and will therefore identify any historical water wells that may be present. The Remediation Strategy will include a discovery strategy that ensures any historical water wells encountered are appropriately sealed to prevent them acting as a preferential pathway.

The Arup GIR [1] considered that preferential pathways may be created by future piled foundations when the site is developed. There will need to be a Foundation Works Risk Assessment (FWRA) completed prior to any future piling works within the site, which will be addressed to discharge planning conditions associated with the future detailed planning application for development of the site.

5.4 Potential pollutant linkages

Based on the review of ground investigation information, potential contaminant linkages have been reviewed for the following sources, with a view to determining the need for DQRA.

5.4.1 Emerging water

The direct entry of emerging water to ground has ended, following the installation of a temporary treatment facility and discharge of the treated water to sewer. However, the emerging water is suspected to have been discharging to ground within the site for several years and a pollutant linkage therefore exists between the emerging water source, shallow and deep groundwater.

5.4.2 Gas works

The gas works area directly overlies the former river channel of the River Irk, the alluvium and Collyhurst Sandstone, meaning there is a direct linkage connecting this source to the Principal Aquifer and River Irk. The glacial till is absent in this area and is therefore not protecting the aquifer beneath. Contamination consistent with coal gas waste has been detected in groundwater in this area and the PFAS outlier at TP422/TP423 is located adjacent to the gas works. There is a need to address the contamination in the former gas works for the protection of controlled waters, therefore this linkage will be assessed in the DQRA.

5.4.3 Carriage shed

A former railway carriage shed is located on made ground which directly overlies the Manchester Marl. In addition to the glacial till in this area, the upper part of Manchester Marl has weathered to a clay which will also prevent significant vertical migration of contamination. The Manchester Marl is not considered to be a receptor for the purposes of this DQRA. Hydrocarbon and PFAS contamination are present as perched groundwater within relic foundations and contaminated soils within the footprint of the former carriage shed. A pathway for contamination to reach the Principal Aquifers is not considered to be present. However, DQRA has been completed in order to generate verification targets for the remediation of the carriage shed, assuming the river as the receptor.

5.4.4 Infilled reservoirs

A review of the ground investigation information has concluded that the northern reservoir is not contaminated and the southern reservoir, whilst hydrocarbons are present in the basal deposits, is not causing significant groundwater contamination with hydrocarbons. The infilled reservoirs are at depth and are not proposed to be disturbed by future development; they are located at depth beneath an area that is proposed for public open space. The cross-section in **Drawing 12** shows that the southern reservoir is partially overlain by cohesive, lower permeability made ground which may be helping to isolate the basal material from the surrounding groundwater. No remediation is proposed in relation to these features and therefore DQRA has not been carried out for this source.

5.4.5 Made ground to be re-used

Despite the long-standing industrial nature of the site, the many phases of ground investigation that have been undertaken have not identified widespread significantly elevated concentrations of contaminants in made ground. A discussion of leachable PFAS in soil is considered separately in **Section 8**. Areas of the site which have been identified as potentially high risk, such as the former gas works and carriage shed, have been the subject of repeated and targeted assessment to verify the findings of previous phases of ground investigation. The general absence of identifiable contaminant 'hotspots' within the wider site is considered to be consistent with the site's history, in which the made ground material has been present over timescales in the order of 150 years.

Ground investigation has established that the groundwater quality across the site is impacted, which is likely to be the result of historical industrial activities within the site and the immediate surrounding area, together with the placement of imported made ground to form Red Bank plateau. The intrusive investigations have identified that the shallow and deep groundwater bodies are likely to discharge into the River Irk. Despite this however, repeated rounds of surface water quality monitoring have consistently demonstrated that there is no detectable evidence of water quality in the River Irk being impacted by existing ground contamination as it flows through the site (**Section 0)**.

The future development proposals on Red Bank plateau are for high-rise residential blocks, a primary school, new roads and predominantly hardstanding. The development will not have infiltration drainage and surface water is proposed to discharge into the River Irk. This proposed hardstanding is much more extensive than has been the case historically and therefore, once the site is developed, infiltration will be substantially reduced across the Red Bank plateau area. It is intended that the remediation carried out as part of the HIF Infrastructure Works will reduce the quantum of risk posed by the identified contaminants at the site, until the site becomes fully developed, at which point, the potential for continued mobilisation of residual contaminants in the made ground will be significantly reduced. These concepts are assessed further in **Section 8.6** of this report.

Within the St. Catherine's Wood and Red Bank terrace areas of the site, the proposals are for the creation of public open space and a river park (with the exception of Plot RB05b in St. Catherine's Wood, which is proposed for a primary school end use). These areas of the site have dense existing tree coverage and although some tree removal is required in order to deliver the HIF works, tree removal is to be limited to preserve the existing ecological conditions (the slopes adjacent to Plots RB02 and RB03 have limited existing tree cover). These proposals are considered not to introduce any significant change to the source-pathway-receptor linkages that have been identified for these areas of the site, and therefore, there is no potential for additional mobilisation of residual contaminants from within the made ground.

Given the sensitivity of surface watercourses, notably the River Irk, it is considered appropriate however, to safeguard controlled waters from potentially mobile contaminants that may be associated with new fill materials emplaced close to the river. Soils that are excavated from one area of the site and used as fill within St. Catherine's Wood or Red Bank terrace, will therefore, be screened against the re-use criteria presented in this DQRA. Two sets of re-use criteria have been generated depending on the distance from the river in which the soils are to be placed (**Drawing 14**).

5.5 Summary of plausible contaminant linkages

Table 22 below summarises the plausible contaminant linkages (PCL) that are to be considered with respect to their potential impact on controlled waters:

Possible Source		Pathway		Receptor	Plausible Contaminant Linkage
PFAS contaminated emerging water	→	Direct entry into ground and infiltration	→	Shallow aquifer	PCL1
			→	Deep aquifer (principal aquifers)	PCL2
			→	River Irk	PCL3
Contaminated made ground: Gas works Carriage shed Infilled reservoirs TP422/TP423 TP405A Made ground to be re-used	→	Leaching and infiltration Vertical migration	→	Shallow aquifer	PCL4
			→	Deep aquifer (principal aquifers)	PCL5
			→	River Irk	PCL6
		Pushing of contaminated soils during piling	→	Deep aquifer (principal aquifers)	PCL7
			→	River Irk	PCL8
NAPL PFAS sorbed to/ dissolved in NAPL	→	Lateral and vertical migration	→	Shallow aquifer	PCL9
			→	Deep aquifer (principal aquifers)	PCL10
			→	River Irk	PCL11
Contaminated shallow groundwater	→	Lateral migration in groundwater	→	River Irk	PCL12
		Vertical flow where glacial till absent	→	Deep aquifer (principal aquifers)	PCL13
		Vertical flow via building piles	→	Deep aquifer (principal aquifers)	PCL14

Table 22: Summary of pollutant linkages to be considered in DQRA

5.6 PFAS risk to health and ecology

5.6.1 Human health

A site-specific human health risk assessment has been produced to address the risks from the identified PFAS contamination to future users of the site, which is reported separately in VNIF-ARP-ZZ-YYY-RP-CG-0014 [10].

As PFAS are a contaminant of emerging interest there were relatively limited data reported in literature for parameters used in the modelling. For some parameters no literature values are available. PFOS and PFOA are the most well studied and it has therefore been possible to develop risk-based criteria for the sum of PFSAs using PFOS as a surrogate, and the sum of PFCAs, using PFOA as a surrogate, with sufficient confidence.

The site-specific assessment criteria (SSACs) developed are intended to be used for comparison to soil concentrations obtained during remediation verification testing and should be carried forward into the remediation strategy for the scheme.

Compound	Residential without homegrown produce scenario (µg/kg)	Public open space (on residential development) scenario (µg/kg)	Public open space (park) (µg/kg)
Total PFSAs	40.4	79.1	161.2
Total PFCAs	21.1	79	152.8

Table 23:Site Specific Assessment Criteria (SSAC) for PFAS in soil

Comparison of the results from soil testing against these criteria identified that samples from TP422 at 0.5m and 1m contain PFCAs marginally in excess of the human health soil criteria in residential developments, but the made ground on site will not be exposed due to the provision of clean cover or buildings and hardstandings.

The PFAS detected in TP422 and TP423 is not typical of the PFAS concentrations detected elsewhere within the site. An assessment of the potential risk to controlled waters is discussed in **Section 6**.

All other PFAS results in soil were below the human health soil criteria generated. Therefore, it was concluded that the soils tested do not pose a significant risk to human health from PFAS and will be suitable for re-use on the site.

5.6.2 Ecological risk

Soil screening values (SSVs) for assessing ecological risk were published by the Environment Agency for PFOS and PFOA in 2022 [63]. The report quotes concentrations for these potential contaminants for use in the risk assessment of waste recovery to land, which includes activities such as landspreading. The SSVs are levels of chemicals in soil below which there is unlikely to be any risk to its [soil] health and functions. These values are summarised in **Table 24** below, converted to µg/kg to allow for comparison against the human health criteria.

Compound	SSV for direct toxicity to organisms (µg/kg)	SSV for waste recovery to land (µg/kg)
PFOS	352	13
PFOA	320	19

Table 24: Ecological risk criteria for PFAS in soil

Apart from the identified outliers which will be targeted for remediation, the soil concentrations measured at Victoria North are well below these levels. No specific soil remediation is considered to be necessary to control risks to ecological receptors from PFAS within the site.

5.7 Summary

Ground investigations completed within the site have identified a small number of primary contamination sources, including the emerging water, a former railway gas storage facility (‘gas works’), carriage shed, infilled reservoirs and outliers of PFAS contamination. Existing made ground has also been considered as a potential source of contamination, where it may be excavated for re-use within the HIF Infrastructure Works.

The key controlled water receptors comprise the shallow aquifer, which is formed of made ground and alluvium; the deep principal aquifers, which are formed of the Collyhurst Sandstone Formation and the Chester Formation sandstone. These two sandstone units are separated by the Manchester Marl, which is an aquiclude with no resource potential. The River Irk forms the south-eastern boundary of the site and is also a controlled waters receptor. The river is a heavily modified river in an urban environment. Ground investigation data suggests that the river receives discharge from both the shallow and deep aquifers beneath the site.

A number of plausible contaminant linkages have been identified by which contamination may reach the controlled waters receptors: direct discharge of the emerging water to ground; the leaching of mobile soil contamination into shallow and deep groundwater; vertical migration of contamination into groundwater and lateral migration of contamination into the River Irk. The Red Bank plateau is underlain by an infilled meander of the River Irk and a former mill race, although no evidence has been found that these features were infilled with a higher-permeability material compared to the remainder of the made ground, therefore it is unlikely that they are acting as preferential pathways for contaminant migration. Preferential pathways may be created by future piled foundations when the site is developed and Foundation Works Risk Assessment (FWRA) will be completed.

These plausible contaminant linkages have been assessed in the controlled waters risk assessment.

6 Controlled Waters Risk Assessment

An assessment has been carried out to determine if existing sources of contamination present a significant risk to controlled waters and if so, to determine remedial targets for the site.

6.1 Selection of contaminants of concern and assessment criteria

6.1.1 Approach

There are no Generic Assessment Criteria (GAC) available for the direct assessment of contaminants in soil applicable to controlled waters. Therefore, evaluation of groundwater and soil leachate data has been completed to identify contaminants of concern and possible sources of soil contamination that present a risk of impacts to the underlying Principal Aquifers and River Irk.

The approach to assessing risks posed by contamination is outlined in the Environment Agency's land contamination guidance [41]. Assessment of risks to water resources is completed in general accordance with the Environment Agency Groundwater Protection guidance [42] for England and Wales.

The Environment Agency has developed specific guidance known as the Remedial Targets Methodology (RTM) [43] for the tiered assessment of risks to controlled waters. The first stage of quantitative risk assessment is undertaken by an initial screening of reported leachate and/or groundwater/surface water concentrations against selected published water quality standards (WQS) for potential contaminants of concern to identify those contaminants which warrant further detailed assessment.

The WQS are selected to assess potential risks to the controlled water receptors identified in the preliminary conceptual site model. The WQS can be derived in several ways with consideration to:

- whether the substance is classified as hazardous or non-hazardous under the Water Framework Directive (2000/60/EC) and Groundwater Daughter Directive (2006/118/EC) (included in **Appendix D**);
- background concentrations in the aquifer; and
- published guidance such as Environmental Quality Standards (EQS) that are protective of surface waters or the Water Supply (Water Quality) Regulations 2016 that are protective of drinking water.

Where groundwater contamination has been identified, the general approach is to use a published environmental standard which is relevant to the current or intended use of the aquifer. The following regulations and guidance have been referenced to select appropriate WQS for controlled waters:

- Environmental Quality Standards (EQS) for fresh water listed in the Water Framework Directive (WFD) 2015 [44]
- Other values not listed in WFD and taken from EA operational EQS [45]
- UK Drinking Water Standards (UK DWS) [46]
- EU Drinking Water Standards (EU DWS) [47]
- World Health Organisation (WHO) drinking water standards [48], [49]
- United States Environmental Protection Agency (USEPA) 2018 drinking water standards [50] and national aquatic life criteria [51]

Drinking Water Standards for PFAS

Regulations have been published to specifically address the risks from PFOS and PFOA in UK drinking water [11]. These regulations specify a 'wholesomeness' threshold of 0.1µg/l (100ng/l) for PFOS and 0.1µg/l (100ng/l) for PFOA.

In July 2022, additional good practice guidance was issued to water companies in England and Wales [12]. Rather than focusing on PFOS and PFOA, this good practice applies the wholesomeness threshold of 0.1µg/l to any individual PFAS compound.

In 2022, the World Health Organisation (WHO) published a background document for the development of guideline standards PFOS and PFOA in drinking water of 0.1µg/l (100ng/l). WHO also recommend a guideline standard for total PFAS of 0.5µg/l (500ng/l). These values are being reviewed by UK stakeholders [34], but it should be noted that the guideline standards for PFOS and PFOA match the wholesomeness thresholds currently used for drinking water in the UK.

The UK DWS is used in this assessment as the appropriate standard to assess the risks of PFAS to groundwater as a receptor.

Environmental Quality Standard

In the Priority Substances Directive (2013/39/EU), PFOS is classed as a Water Framework Directive priority hazardous substance and as a ubiquitous persistent, bioaccumulative and toxic substance. For inland surface waters, the Priority Substances Directive specifies a water column based annual average (AA) EQS of 0.65ng/l [14], a value based on the potential for secondary poisoning in humans due to fish consumption. No other EQS for PFAS have been published currently.

Currently only PFOS is considered as a hazardous substance by the Environment Agency under the Water Framework Directive (2000/60/EC) and Groundwater Daughter Directive (2006/118/EC).

The AA-EQS for PFOS is widely regarded as extremely challenging, considering the current PFOS levels recorded in European surface waters. It is also considerably lower than current drinking water standards, there being a difference of nearly three orders of magnitude between the AA-EQS and the current UK Drinking Water Standard (DWS) for PFOS.

The low level of the AA-EQS is driven by the assumptions relating to fish consumption. These are based on the Water Framework Directive (WFD) standard assumption that citizens eat 115g/day of fish and it aims to protect all situations including locations where local fishermen consume self-caught fish on a daily basis. However, a review of this 115g/day figure for fish consumption carried out by RIVM concluded that "It is obvious that the current European default for fish consumption is inadequately documented and probably outdated" [60]. This conclusion was based on a review of European fish consumption data, which found a wide variation in the amount of fish eaten by country.

Using UK National Diet and Nutrition Survey (NDNS) data from 2018/19 for fish consumption [61] quotes the mean fish consumption in UK adults in the range 21 to 24g/day, which is significantly less than the WFD assumption of 115g/day. The 97.5th percentile UK consumption rates are also lower than the WFD assumption. Also, it should be noted that the fish consumption recorded by the NDNS includes fish from all sources, not just self-caught fish and shellfish. Self-caught fish is expected to comprise a negligible amount of total fish consumption in the Manchester area, with the majority of fish consumption being from shop-bought fresh or canned fish, or processed fish products. Therefore, the assumptions inherent in the EQS derivation are overly conservative in the context of the Victoria North site.

The EQS for PFOS is therefore considered to be a highly conservative value for the assessment of risks from PFOS at Victoria North. The EA has confirmed that, in the absence of any other appropriate screening values, it should be used in this risk assessment to assess the risks posed by individual PFAS compounds in groundwater to the River Irk. As described in **Section 4.4.2**, the EQS has been applied to both PFOS and PFOA, which comprise the majority constituents of PFAS detected in soil leachate and groundwater at the site.

6.2 Groundwater quality

The groundwater quality within the site was monitored as part of the two previous ground investigations, by AEG in 2021 [4] and BAM in 2022 [5] and PFAS analysis of groundwater was carried out by BAM in 2023 [62]. The results of testing are summarised in **Appendix C** (PFAS investigation) **and Appendix D** (previous investigations). Groundwater data has been split into two sets, for the deep and shallow aquifers, as discussed below.

The groundwater data has been collected from standpipes with response zones within the various strata beneath the site. In determining contaminants of potential concern, the maximum concentration of each contaminant has been calculated. Where the maximum concentration of a contaminant is less than the WQS, that contaminant is not considered further in this risk assessment. Contaminants where the maximum concentration exceeds the WQS are highlighted in the tables below.

6.2.1 Shallow groundwater

Shallow groundwater data is based on testing of water from the made ground and alluvium, which are in continuity along the River Irk edge of the site where glacial till is absent. Fewer samples were taken of alluvium compared to made ground, because this stratum is not present across the entire site area and is confined to the area close to the River Irk.

Testing of groundwater from the made ground as summarised in **Table 25** identified that exceedances of cadmium, manganese, nickel, zinc, ammoniacal nitrogen, PAH are widespread across the site. Other less frequent exceedances were noted for antimony, arsenic, beryllium, chromium, copper, iron, lead, selenium, vanadium, cyanide and TPH.

Cyanide analysis was typically carried out for total cyanide, but given the historical land uses on the site, speciated analysis was undertaken for complex cyanide, free cyanide and thiocyanate on selected samples. The WQS used for cyanide is based on hydrogen cyanide (HCN) which exists in a free state and therefore the WQS is appropriate for free cyanide. Free cyanide was only detected occasionally in groundwater above the limit of detection. The same WQS was also used to assess total cyanide but not complex cyanide. The cyanide speciation, where undertaken, shows that the total cyanide is mostly formed of cyanide complexes.

Although thiocyanate can occur as an environmental contaminant in its own right (e.g. from mining and electroplating) more often it occurs in conjunction with cyanide sources. In the presence of sulphur, complex forms of cyanide can breakdown to produce less toxic thiocyanate. In acidic media, thiocyanate can breakdown to form hydrogen cyanide, however this is not expected to occur at the Victoria North HIF Infrastructure site where the prevalent conditions are neutral to slightly alkaline. Because of its lower environmental toxicity and the absence of relevant water quality standards, thiocyanate it is not considered to require separate fate and transport modelling. Cyanide has therefore been discounted from further assessment on the basis that free cyanide is not typically detected in groundwater beneath the site and the cyanide that is present is in complex form, which is likely to break down into less toxic thiocyanate.

TPH was detected in shallow groundwater in various locations across the site, but the highest concentrations were in BH102 (in the centre of Red Bank plateau, hydraulically downgradient from the carriage shed and gas works), BH204 (gas works), BH211A (infilled reservoir) and BH315 (gas works). Very light hydrocarbons in the range C5-C8 were generally not detected in shallow groundwater, except in BH315 in the gas works area, where low concentrations of benzene were present. Xylenes were detected in shallow groundwater in BH102. No visible evidence of hydrocarbons was noted in BH102 and BH315 during drilling in the superficial deposits or groundwater, although subsequent groundwater sampling noted a slight sheen on the groundwater at BH102. PAH compounds are also present in groundwater in these locations. Because hydrocarbon contamination was not noted in the overlying superficial deposits, it is conjectured that contamination is migrating in groundwater from an upgradient source, likely to be the former gas works or carriage shed.

The exceedances noted for antimony, arsenic, beryllium, copper, iron, lead, selenium and vanadium were based on only one or two locations and these contaminants are not typically elevated within shallow groundwater. They are therefore discounted from further assessment.

Contaminant	WQS value (mg/l)	No. of Samples	No. > WQS	Average	Maximum
Antimony	0.005	27	1	0.0015	0.01
Arsenic	0.05	27	2	0.019	0.192
Beryllium	0.004	27	1	0.00009	0.006
Cadmium	0.00015	27	12	0.001	0.0115
Chromium	0.0047	27	4	0.029	0.74
Copper	0.03375	27	2	0.038	0.84
Iron	1	5	1	4.28	19.7
Lead	0.00958	27	3	0.14	3.61
Manganese	0.226	27	21	3.66	15
Nickel	0.01607	27	9	0.17	0.098
Selenium	0.01	27	3	0.004	0.037
Vanadium	0.02	27	2	0.013	0.217
Zinc	0.03728	27	14	0.15	1.61
Free cyanide	0.001	12	3	0.01	0.007
Ammoniacal nitrogen as N	0.6	27	18	4.51	22
Aliphatic C8-10	0.3	23	2	0.99	21.4
Aliphatic C10-12	0.3	23	2	1.77	38
Aliphatic C12-16	0.3	23	3	3.94	81.8
Aromatic C8-10	0.3	23	1	0.43	9
Aromatic C10-12	0.09	23	3	1.02	21.3
Aromatic C12-16	0.09	23	6	2.43	48.1
Aromatic C16-21	0.09	23	3	1.52	29
Aromatic C21-35	0.09	23	3	0.64	12.4
Fluoranthene	0.0000063	23	20	0.003	0.027
Naphthalene	0.002	23	1	0.0009	0.013
Anthracene	0.0001	23	8	0.0008	0.0044
Benzo(a)pyrene	1.7E-07	23	14	0.0035	0.049
PFOS	0.0001 (DWS)/6.5E-07 (EQS)	15	11	1.43E-05	5.0E-05
PFOA	0.0001 (DWS)/6.5E-07 (EQS)	15	11	2.39E-05	5.0E-05

Table 25: Summary of contaminants in excess of WQS in the shallow groundwater

Assessment of PFAS (using PFOS and PFOA as marker compounds) in groundwater does not identify any exceedances of the DWS. However, the shallow groundwater discharges into the River Irk where the EQS is the relevant water quality standard, and the concentrations measured in shallow groundwater exceed this standard. Contaminants of concern in shallow groundwater identified from the screen against published WQS are as follows:

- Metals (cadmium, chromium, manganese, nickel, zinc)
- Ammoniacal nitrogen as N
- TPH (Aliphatic fractions C8-C16, aromatic fractions C8-C35)
- PAH (fluoranthene, anthracene, benzo(a)pyrene)
- PFAS (using PFOS and PFOA as marker compounds)

6.2.2 Deep groundwater quality

A summary of the groundwater quality within the two sandstone aquifers beneath the site is summarised in **Table 26** (Collyhurst Sandstone) and **Table 27** (Chester Formation). Because these two aquifers are separated by the Manchester Marl and are not anticipated to be in contact with each other, the results have been separated. This screening has identified exceedances of:

- Metals (antimony, cadmium, chromium, copper, iron, lead, manganese, nickel, vanadium, zinc)
- Ammoniacal nitrogen
- TPH Aliphatic C12-C16
- TPH Aromatic C12-C16
- PAH (fluoranthene, benzo(a)pyrene)
- bis(2-ethylhexyl)phthalate, and
- PFAS (using PFOS and PFOA as marker compounds)

These contaminants are very similar to those present in the shallow groundwater, suggesting that the two groundwater bodies (shallow and deep) are in continuity with each other where glacial till is absent close to the River Irk.

The TPH exceedances were only noted in the Collyhurst Sandstone, which is present beneath the former gas works area in the north-eastern part of the site. No exceedances of the WQS for TPH were noted in the Chester Formation, even though hydrocarbons had been identified in the former reservoirs. As glacial till is present beneath the reservoirs, it appears that it has prevented significant quantities of hydrocarbon from entering the Chester Formation groundwater. Both groundwater bodies are impacted by PAH contamination at similar concentrations, although only isolated exceedances of naphthalene and anthracene were noted in both aquifers.

One exceedance of the WQS for Bis(2-ethylhexyl)phthalate was noted in the Collyhurst Sandstone groundwater in the area of the former gas works. The source of this contamination is not known, but it was not detected in any other samples selected for semi-volatile organic compound (SVOC) testing in excess of the WQS and therefore its presence is not considered to be widespread across the site, therefore it is discounted from further assessment.

Two exceedances were noted for iron in the Chester Formation. Iron is naturally present in the Chester Formation and is not considered to be a contaminant of concern. A single exceedance of antimony was noted which is not considered to indicate widespread contamination in the deep groundwater and has not been assessed further.

As for the shallow groundwater, assessment of PFAS (using PFOS and PFOA as marker compounds) in deep groundwater was made against the UK Drinking Water Standard. No exceedances of the DWS were identified in the deep groundwater. However, the deep groundwater discharges into the River Irk where the EQS is the relevant water quality standard. An exceedance of the EQS was noted for PFOS in the Collyhurst Sandstone and of PFOA in the Chester Formation.

Contaminants	WQS (mg/l)	No. of samples	No. > WQS	Average	Maximum
Copper	0.03375	5	1 (BH203)	0.014	0.043
Lead	0.00958	5	2 (BH310, BH203)	0.025	0.088
Manganese	0.226	5	5 (BH310, BH203)	1.08	1.92
Cadmium	0.00015	5	1 (BH203)	0.0002	0.0003
Nickel	0.01607	5	1 (BH203)	0.006	0.02
Zinc	0.03728	5	3 (BH310, BH203)	0.05	0.14
Ammoniacal nitrogen as N	0.6	5	5 (BH310, BH203)	2.63	4.04
Aliphatic C12-16	0.3	5	2 (BH310)	0.9	3.32
Aromatic C10-12	0.09	5	1 (BH310)	0.03	0.11
Aromatic C12-16	0.09	5	2 (BH310)	0.36	1.35
Fluoranthene	0.0000063	5	4 (BH310, BH203)	0.0002	0.0003
Naphthalene	0.002	5	1 (BH203)	0.00001	0.0085
Anthracene	0.0001	5	1 (BH203)	0.00004	0.00012
Benzo(a)pyrene	1.7E-07	5	2 (BH310, BH203)	0.00014	0.0003
Bis(2-ethylhexyl)phthalate	0.0013	5	1 (BH203)	0.009	0.0052
PFOS	0.0001 (DWS) 6.5E-07 (EQS)	2	1 (BH309)	N/A	2E-06

Table 26: Summary statistics for contaminants in excess of WQS in the Collyhurst Sandstone

Contaminants	WQS (mg/l)	No. of samples	No. > WQS	Average	Maximum
Antimony	0.005	6	1 (BH212)	0.003	0.006
Cadmium	0.00015	6	2 (BH212)	0.0007	0.0038
Chromium	0.0047	6	1 (BH212)	0.008	0.045
Copper	0.03375	6	1 (BH212)	0.017	0.078
Iron	1	3	2 (BH210, RE15)	0.99	1.65
Lead	0.00958	6	2 (BH212, RE15)	0.16	0.87
Manganese	0.226	6	5 (BH210. BH212, RE15)	0.72	1.01
Nickel	0.01607	6	1 (BH212)	0.007	0.024
Vanadium	0.02	6	1 (BH212)	0.006	0.03
Zinc	0.03728	6	1 (BH212)	0.16	0.92
Free cyanide	0.001	3	3 (BH212, RE15)	0.14	0.26
Ammoniacal nitrogen as N	0.6	6	2 (BH210)	1.36	7.4
Fluoranthene	0.0000063	5	4 (BH212, BH210, RE15)	0.0002	0.00013
Benzo(a)pyrene	1.7E-07	5	2 (BH212, RE15)	0.00014	0.00006
PFOA	0.0001 (DWS) 6.5E-07 (EQS)	1	1	N/A	8E-06

Table 27: Summary statistics for contaminants in excess of WQS in the Chester Formation Sandstone

6.2.3 Soil leachate quality

The results of total PFOS and PFOA analysis on soil leachate are discussed in detail in **Section 4** and summarised on **Drawing 7** and **Drawing 8**. These data have been compared with the available PFAS water quality standards to provide an initial indication of potential risks to controlled waters.

The concentrations of PFOS and PFOA in soil leachate from the TP422/TP423 outlier exceed the current UK drinking water standard (100ng/l), and remediation of this outlier is recommended in order to protect groundwater and surface water quality.

All other liquid-phase data was found to contain total PFOS and PFOA concentrations that were below the 100ng/l wholesomeness threshold (maximum concentration = 92.2ng/l PFOS and 50ng/l PFOA, both in soil leachate in the same trial pit – TP405A, which will require further assessment as part of the HIF Infrastructure Works). PFOS and PFOA concentrations in soil leachate are typically much less than 100ng/l and pose no risk to the quality of the sandstone Principal Aquifers. Again, excluding the TP422/TP423 outlier, the total PFAS concentrations recorded in the liquid-phase samples are also all below the 500ng/l advisory limit recently set by WHO.

As no exceedances of the 100ng/l drinking water threshold have been observed for individual PFAS compounds, no remedial action is necessary to protect groundwater as a resource. However, although the groundwater is not a receptor for PFAS contamination, it is considered to be acting as a pathway for PFAS to reach the River Irk, where the relevant standard for PFOS and PFOA is taken as the EQS of 0.65ng/l. In a small number of cases, liquid-phase concentrations of PFOS were less than the limit of detection. For the majority of samples however, soil leachate concentrations exceed the EQS for PFOS of 0.65ng/l. For context, applying this same EQS value to the concentrations of PFOA that have been identified, also indicates that the majority of liquid-phase samples exceed the EQS. As discussed earlier in this section, the EQS for PFOS is considered to be a highly conservative value for the assessment of risks from PFOS at Victoria North, therefore further risk assessment has been completed to determine the potential risk posed by PFAS in soil to the quality of the River Irk. This is discussed further in **Section 8**.

6.2.4 Background water quality

The use of published conservative WQS enables an initial assessment of results. Results that are above the WQS do not necessarily represent a risk to controlled waters and alternative lines of evidence can be considered, such as comparison against background or upgradient groundwater and surface water concentrations or regional water quality, discussed below.

The site is located in an industrial area of central Manchester and numerous historical industrial activities present potential contamination sources in the vicinity of the site. Groundwater in the region has been affected by anthropogenic contamination, discussed below.

Background/upgradient groundwater quality

Baseline hydrochemistry for the Permo-Triassic sandstones in the region have been published by the BGS for some of the contaminants of concern identified in this screening exercise [40]. However, there are no BGS-reported baseline concentrations for many of the contaminants present in groundwater beneath on the site. Therefore, to determine background groundwater quality, upgradient boreholes have been identified within the site boundary:

- Collyhurst Sandstone: no upgradient boreholes are available, as this stratum outcrops in the northern end of the site where groundwater quality is already affected by hydrocarbon contamination, likely due to the presence of a former gas storage site (labelled as a gas works on plans) in this location;
- Chester Formation: borehole BH210 is present on the Red Bank plateau area, which is located in an upgradient area of the site.

These baseline concentrations are quoted in **Table 28**.

The baseline concentrations for iron and manganese regionally are higher than the EQS values used for the initial screen. The BGS reports [38] that the glacial till overlying the bedrock has resulted in reducing conditions. As the presence of iron and manganese in groundwater is the result of natural processes acting on the geology, rather than anthropogenic contamination, these contaminants have been discounted from further assessment.

The quality of groundwater within the Chester Formation is generally good, and concentrations of some contaminants are lower than the published regional baseline. The exception to this is for ammoniacal nitrogen, where the background concentration in upgradient groundwater is 7.2mg/l compared to the reported baseline of 0.4mg/l. This suggests that there is an upgradient source of ammoniacal nitrogen in the Chester Formation that is affecting the quality of groundwater moving on to the site. There are landfill sites to the north-east (especially Queens Road landfill) which could be a source of ammoniacal nitrogen in groundwater entering the site. Also, the former gas works is present over the Collyhurst Sandstone; ammoniacal nitrogen can be associated with old gas works sites therefore it cannot be ruled out as a potential contaminant of concern associated with the known source on the site.

One sample of groundwater from the Chester Formation was analysed for PFAS. This identified PFOS and PFOA at concentrations less than the UK DWS but in excess of the EQS. Monitoring data from England (2014-2019) indicated PFAS are widely present in surface and groundwaters [34], although no published background data currently exists for PFAS in groundwaters.

Further risk assessment is required to determine the potential risk posed by the low concentrations of PFAS in groundwaters to the River Irk. This is discussed further in **Section 7** and **Section 8**.

River Irk water quality

Water quality in the River Irk was measured on four separate occasions as part of the ground investigations in May 2021, on three occasions in March 2022 at a point upstream of the site, in the centre of the site and downstream and on three occasions in 2023 where only PFAS was analysed. A summary of the concentrations of contaminants of concern in the River Irk are presented in **Table 29**.

Exceedances of the EQS in river water are only noted for zinc, fluoranthene and PFAS. The concentrations of these contaminants of concern do not vary greatly from upstream of the site to downstream, indicating that the site

is not having a significant impact on surface water quality, and these contaminants are already present in river water in excess of their EQS upstream of the site.

PFOS is notable in the river water as it is present at concentrations that are an order of magnitude greater than the EQS in all locations sampled. This reflects the findings of a river quality assessment conducted by the Environment Agency between 2016 and 2018, which indicated that the EQS for PFOS was exceeded in over 90% of the surface waterbodies sampled [34]. A recent study by Cousins et al [37] stated that levels of PFOS in rainwater in the northern hemisphere are equal to, or even exceed the EQS. The study concluded that "regardless of wastewater inputs into freshwater, the EQS for PFOS will likely always be approached in populated regions and often exceed, as a result of the widespread presence of PFOS in atmospheric deposition".

Contaminant	WQS (mg/l)	Background concentrations (mg/l)	
		BGS baselinequality 95th %ile	Upgradient groundwater quality in Chester Formation 95th %ile
Cadmium	0.00015	0.005	0.00003
Arsenic	0.05	0.059	0.03
Chromium	0.0047	0.0057	0.0003
Copper	0.03375	0.028	0.003
Iron	1	2.488	1.1
Lead	0.00958	0.0024	0.0002
Manganese	0.226	2.41	0.84
Nickel	0.01607	0.0153	0.002
Zinc	0.03728	0.1115	0.004
Ammoniacal nitrogen as N	0.6	0.4	7.2
Aliphatic C8-10	0.3	N/A	<0.0001
Aliphatic C10-12	0.3	N/A	<0.001
Aliphatic C12-16	0.3	N/A	<0.001
Aromatic C8-10	0.3	N/A	<0.0001
Aromatic C10-12	0.09	N/A	<0.001
Aromatic C12-16	0.09	N/A	<0.001
Aromatic C16-21	0.09	N/A	<0.001
Aromatic C21-35	0.09	N/A	<0.001
Fluoranthene	0.000006	N/A	0.00002
Anthracene	0.0001	N/A	<0.00001
Benzo(a)pyrene	1.7E-07	N/A	<0.00001
PFOS	0.0001 (DWS) 6.5E-07 (EQS)	N/A	<LOD
PFOA	0.0001 (DWS) 6.5E-07 (EQS)	N/A	8E-06

Table 28: BGS baseline concentrations/background quality in sandstone

Contaminant of Concern	WQS mg/l	River water quality		
		Upstream 95th %ile mg/l	Central 95th %ile mg/l	Downstream 95th %ile mg/l
Arsenic	0.01	0.003	0.003	0.003
Cadmium	0.00015	<0.0002	<0.0002	<0.0002
Chromium	0.0047	<0.001	<0.001	0.001
Copper	0.03375	0.00785	0.0069	0.0105
Iron	1	0.27	No data	0.3
Lead	0.00958	0.00285	0.0028	0.00895
Selenium	0.01	0.001	<0.001	0.001
Manganese	0.226	0.0946	0.0838	0.003
Nickel	0.01607	0.004	0.0039	0.004
Zinc	0.037	0.05	0.0542	0.079
Ammoniacal Nitrogen	0.6	0.36	0.168	0.284
Fluoranthene	0.000006	0.00002	0.00002	0.00002
Anthracene	0.0001	0.00002	<0.00001	0.00002
Benzo(a)Pyrene	0.000017	<0.00001	<0.00001	<0.00001
TPH – Aliphatic C8-C10	0.3	<0.05	<0.05	<0.05
TPH – Aliphatic C10-C12	0.3	<0.05	<0.05	<0.05
TPH – Aliphatic C12-C16	0.3	<0.05	<0.05	<0.05
TPH – Aromatic C8-C10	0.3	<0.05	<0.05	<0.05
TPH – Aromatic C10-C12	0.09	<0.05	<0.05	<0.05
TPH – Aromatic C12-C16	0.09	<0.05	<0.05	<0.05
TPH – Aromatic C16-C21	0.09	<0.05	<0.05	0.0458
TPH – Aromatic C21-C35	0.09	<0.1	<0.1	0.1
PFOS	6.5E-07	8.8E-06	5.9E-06	7.9E-06
PFOA	6.5E-07	7.9E-06	7.0E-06	8.0E-06

Table 29: Summary statistics for concentrations of contaminants of concern in the River Irk

6.2.5 Re-screening against normal background concentrations

Following comparison against published water quality standards (see **Appendix D**), the shallow groundwater data have been re-screened against normal background concentrations, where these are available, as contamination in the shallow groundwater within the site may be impacting on the quality of the deep groundwater and River Irk.

The results of shallow groundwater screening summarised in **Table 30** identify that the majority of samples tested do not exceed the revised water quality standards.

A small number of exceedances are noted for cadmium and chromium (2 out of 27 samples tested) in the shallow groundwater. No exceedances of the revised WQS are noted for these contaminants in the Collyhurst Sandstone and only one exceedance of chromium is noted in the Chester Formation. Also, no impact of these contaminants is noted on the quality of the River Irk as it passes the site, therefore they are not assessed further.

A larger number of exceedances are noted for nickel, zinc, ammonia and certain PAH and TPH fractions in the shallow groundwater. There are no published background concentrations for PFOS and PFOA in groundwater, and, whilst these do not exceed the DWS, they do exceed the EQS.

Contaminant	WQS value (mg/l)	No. of Samples	No. > WQS	Average	Maximum
Cadmium	0.005	27	2	0.001	0.0115
Chromium	0.0057	27	2	0.029	0.74
Nickel	0.01607	27	9	0.17	0.098
Zinc	0.1115	27	5	0.15	1.61
Ammoniacal nitrogen as N	0.6	27	18	4.51	22
Aliphatic C8-10	0.3	23	2	0.99	21.4
Aliphatic C10-12	0.3	23	2	1.77	38
Aliphatic C12-16	0.3	23	3	3.94	81.8
Aromatic C8-10	0.3	23	1	0.43	9
Aromatic C10-12	0.09	23	3	1.02	21.3
Aromatic C12-16	0.09	23	6	2.43	48.1
Aromatic C16-21	0.09	23	3	1.52	29
Aromatic C21-35	0.09	23	3	0.64	12.4
Fluoranthene	0.0000063	23	20	0.003	0.027
Naphthalene	0.002	23	1	0.0009	0.013
Anthracene	0.0001	23	8	0.0008	0.0044
Benzo(a)pyrene	1.7E-07	23	14	0.0035	0.049
PFOS	0.0001 (DWS) 6.5E-07 (EQS)	15	11 (EQS)	1.43E-05	5.0E-05
PFOA	0.0001 (DWS) 6.5E-07 (EQS)	15	11 (EQS)	2.39E-05	5.0E-05

Table 30: Summary of contaminants in excess of revised WQS in the shallow groundwater

Nickel exceeds the WQS in 9 out of 27 samples. The exceedances of nickel do not show a spatial pattern across the site and are not associated with any of the known soil sources. The identified exceedences are typically marginal and of the same order of magnitude as the EQS. Only one exceedance of nickel is noted in the deep groundwater and the River Irk does not contain nickel in excess of the EQS at any point (upstream, midstream and downstream) indicating that there is currently no impact from nickel on surface water quality.

Ammoniacal nitrogen is present in 18 of the 27 shallow groundwater samples tested at concentrations above the WQS. A source of ammonia is present within the site boundary at the former gas works site and therefore ammonia will be assessed as part of the gas works DQRA. The emerging water discussed in **Section 3** was also found to have elevated concentrations of ammonia. This emerging water appears to have been discharging to ground for several years, but has now been diverted to sewer and will not constitute an ongoing source of ammonia to groundwater within the site, therefore the emerging water as a source of ammonia has not been considered further.

Zinc was detected in 5 of 27 samples tested in excess of the WQS. Zinc was also detected at concentrations in excess of the WQS in the River Irk upstream of the site, indicating that zinc is already present in the river. The maximum concentration of zinc detected in the made ground (1.6mg/l at BH204) was not typical of the other elevated concentrations of zinc, which are an order of magnitude lower. BH204 is in the area of the former gas works and therefore zinc will be assessed as part of the gas works DQRA.

Fluoranthene was detected in 20 out of 23 samples tested in excess of the EQS, benzo(a)pyrene in 14 of 23 samples and anthracene in 8 out of 23 samples. Naphthalene was only detected in one sample in excess of the EQS. Many of the elevated PAH concentrations identified as associated with known soil sources of hydrocarbons, these being the gas works and carriage shed. These soil sources have been considered further in the DQRA in order to derive remedial targets that are protective of controlled waters. No impact from PAH is observed on the quality of the River Irk as it passes the site, therefore these contaminants are not considered to be having an impact on surface water quality currently. As infiltration through the made ground is anticipated to reduce significantly in the long term, the risk from PAH in the made ground generally is not considered to pose a significant risk to the River Irk in the long term, provided that remedial action is taken to remove the identified sources of the gas works and carriage shed, together with any other unidentified sources of hydrocarbons that are encountered during the HIF Infrastructure Works.

Up to six exceedances of the WQS for TPH have been identified in the shallow groundwater. Some impact from TPH is seen in the Collyhurst Sandstone and in the river water quality downstream of the site. As discussed previously, DQRA is presented in the next section which derives soil targets for the main sources of hydrocarbon contamination identified within the site boundary.

As discussed above, there is no detectable impact on surface water quality from the majority of the contaminants detected in shallow groundwater in excess of the WQS. Where made ground is to be re-used in a different location e.g. if material from Red Bank Plateau is re-used in St. Catherine's Wood, this may result in an increase in risk to the river which needs to be assessed by DQRA. The contaminants selected for this DQRA include nickel, zinc, selected TPH fractions and the PAHs benzo(a)pyrene, fluoranthene and anthracene as these contaminants were more frequently present in excess of the relevant WQS in shallow groundwater.

PFOS and PFOA have been detected in excess of the EQS (but not the DWS) in the shallow groundwater and in some samples of deep groundwater. The EQS for PFAS is exceeded in the river upstream of the site, in common with 90% of surface waters tested in England. The known soil sources of PFAS (the Carriage Shed, the outlier at TP422/TP423 and TP405A described in **Section 5.1.1** will be assessed by DQRA to derive soil remedial targets for PFAS in these areas.

6.3 Summary of controlled waters risk assessment

A controlled waters risk assessment has been carried out to determine if existing sources of soil contamination, identified by ground investigation, present a significant risk to controlled waters and to determine remedial targets.

Contaminants of concern have been identified by comparing the data obtained by ground investigation (soil, soil leachate, groundwater and surface water analysis) against published water quality standards (WQS) and then background water quality, to identify which contaminants warrant further detailed assessment.

Water quality in the River Irk has been measured on several occasions as part of ground investigations. Some exceedances of the water quality standards are noted in the river upstream of the site, most notably for zinc, fluoranthene and PFAS. The concentrations of these contaminants do not vary greatly as the river passes the site, indicating that the site is not having a significant impact on river water quality.

Identified sources of contamination had already been delineated by ground investigation at the former gas works, carriage shed, TP422/TP423 and TP504A. Comparison of the results of shallow groundwater analysis against published WQS has identified exceedances of zinc, ammoniacal nitrogen, TPH and PAH at the gas works which requires further assessment. The hydrocarbon and PFAS contamination at the former carriage shed also requires assessment and PFAS at TP422/TP423 and TP405A.

There does not appear to be an impact on water quality in the River Irk from other contaminants that are present in groundwater in excess of the WQS. Assuming that the source of contamination is made ground within the site boundary, where made ground is to be relocated from one part of the site to another e.g. from the Red Bank Plateau to St. Catherine's Wood, this may increase the risk to the river and it is considered that this potential impact needs to be assessed by DQRA.

Assessment of PFAS in shallow and deep groundwater did not identify any exceedances of the drinking water standard (DWS), which is the relevant screening value for the principal aquifers. However, as groundwater discharges into the River Irk, the environmental quality standard (EQS) becomes the relevant WQS and is exceeded by the majority of groundwater samples tested. Note the EQS relevant to PFAS is recognised as highly conservative and based on human consumption of fish from the watercourse and existing background concentrations of PFAS in surface waters.

The results of soil leachate analysis for PFAS (using PFOS and PFOA as marker compounds) have been compared against WQS to provide an indication of the potential risks to controlled waters. The concentrations of PFOS and PFOA in soil leachate from TP422/TP423 exceed the DWS and DQRA is required to derive remedial targets for this outlier. Remediation of TP405A is also recommended, as the PFAS concentrations are not typical of the made ground.

No other exceedances of the DWS were noted for PFAS. However, as groundwater is a potential pathway for PFAS to reach the River Irk, the relevant standard for assessing risk to the river is the EQS. The majority of soil leachate samples exceeded the EQS.

7 Detailed Quantitative Risk Assessment (DQRA)

7.1 Methodology

The screening assessment in **Section 6** has identified the following contaminants of concern for DQRA:

- Nickel and zinc
- Ammoniacal nitrogen as N
- TPH – Aliphatic fractions C8-C16, aromatic fractions C8-C35
- PAH (fluoranthene, anthracene, benzo(a)pyrene)
- PFOS and PFOA (as marker compounds for PFAS)

DQRA has been completed using the Environment Agency's remedial targets methodology (RTM) and supporting worksheet to evaluate the contaminants listed above. "Remedial Targets" are derived at each level; these become increasingly less conservative as subsequent levels of assessment introduce new and more complex calculations to predict attenuation of contaminants.

The three levels of assessment include the following:

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

The input parameters used in the RTM models are provided in **Appendix D.** As discussed previously, the modelled scenarios are described below.

7.1.1 Remediation criteria for gas works area

The gas works is located over the Collyhurst Sandstone Principal Aquifer. Hydrocarbons have been noted in the made ground during the ground investigation. The DQRA is to consider these soil sources to derive remedial targets that are protective of groundwater and the River Irk. Contaminants of concern that have been modelled for the gas works include zinc and selected TPH fractions, PAH and ammoniacal nitrogen as N, as these contaminants have been identified in the soil and groundwater at this location.

7.1.2 Remediation criteria for TP422/TP423

An area of PFAS contamination located at TP422/TP423 has been identified to the immediate north-west of the gas works. The DQRA is to consider this soil source to derive remedial targets that are protective of groundwater and the River Irk. PFAS has been modelled (represented using PFOS and PFAS as marker compounds), which was detected in soil and shallow groundwater local to this outlier.

It is recommended that the criteria derived for TP422/TP423 are also applied to the PFAS outlier at TP405A.

7.1.3 Remediation criteria for the carriage shed

Hydrocarbons and PFAS have been noted in perched groundwater within the former carriage shed structure during the ground investigation. Remediation will be required to remove saturated soil and perched water from the carriage shed footprint and remedial targets are required for this operation that are protective of groundwater and the River Irk. Contaminants of concern that have been selected for the carriage shed are: selected TPH fractions, PAH, PFOS and PFAS (represented using PFOS and PFAS as marker compounds).

The carriage shed is located over the Manchester Marl, which is not considered as a receptor in this assessment. Therefore, the remedial targets generated for the gas works will be used to verify remediation of the carriage shed footprint, which assume that contamination migrates via the Collyhurst Sandstone to the river.

7.1.4 Reuse criteria for site-won soils in St. Catherine's Wood and Red Bank terrace

Re-use criteria have been derived for site-won soils placed within St. Catherine's Wood or Red Bank terrace. As discussed in previous sections, this is because these areas are in close proximity to the river, and where soils are excavated from another part of the site (for example, Red Bank plateau) it is considered prudent to ensure that such materials will not increase the risk to the River Irk.

Two sets of re-use criteria (Zone 1 and Zone 2) have been generated for fill derived elsewhere within the HIF Infrastructure site that is placed within St. Catherine's Wood or Red Bank terrace, depending on the distance from the river in which the soils are to be re-used. The zones are shown in **Drawing 14**.

These re-use criteria are designed to be protective of controlled waters, assuming that contaminants of concern are nickel, zinc, TPH and PAH fractions, PFOS and PFOA as identified in the screening of the data.

Re-use criteria will not be derived for materials that are excavated within Red Bank plateau and recovered for re-use within the plateau area. In addition, re-use criteria will not be derived for material within St Catherine's Wood and Red Bank terrace that is to be locally redistributed during regrading works. However, if material from any source within the site is placed within Zone 1 shown on **Drawing 14**, it will be screened against the relevant set of re-use criteria.

7.2 DQRA outcome – gas works

7.2.1 RTM output

The calculated soil remedial targets for the gas works area are provided in **Appendix D**. These targets are also intended to be applied to the carriage shed. The remedial targets are summarised in **Table 31** below against the 95th %ile soil concentrations detected during the ground investigations within the gas works.

It should be noted that visible evidence of hydrocarbon contamination was identified on perched groundwater (a sheen) and in soil within the gas works area and on perched water within the carriage shed, and the values below do not account for NAPL within perched waters. Measures to remove NAPL from perched groundwater will be addressed in the Remediation Strategy.

Contaminant	RTM-calculated soil remediation target (mg/kg)	95th %ile of soil concentration on plateau (mg/kg)
Ammoniacal nitrogen	4.5	Not tested in soil
Zinc	487	500
Benzo(a)Pyrene	3.6	2.5
Fluoranthene	0.3	7
Anthracene	0.9	1.8
TPH – Aliphatic C8-C10	4860	9.9
TPH – Aliphatic C10-C12	37900	9.9
TPH – Aliphatic C12-C16	758000	17.9
TPH – Aromatic C8-C10	1340	7.9
TPH – Aromatic C10-C12	772	31.2
TPH – Aromatic C12-C16	3860	60.4
TPH – Aromatic C16-C21	1120	85
TPH – Aromatic C21-C35	8100	200
TPH – C8-C35		2500*#
* RTM-calculated remediation criteria for several of the TPH fractions are far in exceedance of any soil concentrations. Any soils exceeding these criteria would be visibly grossly contaminated. Therefore, it was considered appropriate to set a soil remediation target for TPH C8-C35. # If exceedances of this value is noted, the risk-derived criteria for individual carbon bands detailed in this table shall be applied.		

Table 31: Summary of remediation targets for gas works

7.2.2 Discussion of remediation criteria for gas works

The RTM guidance states that, once remedial targets have been derived, the user should evaluate whether the compliance point and remedial target are reasonable (in terms of protection of receptors), practical and affordable.

The RTM-calculated remediation target for zinc is not exceeded within the gas works area and therefore no specific remedial action is necessary with respect to zinc.

The RTM-calculated remediation criteria for several of the TPH fractions are extremely high and far in exceedance of any site soil concentrations recorded. Any soils exceeding these criteria would be visibly grossly contaminated and therefore require remediation in accordance with the discovery strategy. Therefore, a soil remediation target for TPH C8-C35 of 2500mg/kg has been set for soil within the gas works area. Within this, individual hydrocarbon fractions will still be screened, but the overall target of 2500mg/kg is considered appropriate to protect controlled waters, together with the implementation of a discovery strategy to ensure than no free phase hydrocarbons are missed.

The soil targets generated by the DQRA for the gas works are extremely low for some of the contaminants of concern, particularly the PAH compounds, and may not be achievable considering the typical soil concentrations observed during the ground investigations. The main reasons for these low RTM-calculated remedial targets is the very low water quality standards used in the modelling, and conservatism of the modelling e.g. the short travel distance to the receptor (see **Appendix D**).

The 95%ile concentration for the PAH compounds within the made ground on Red Bank Plateau is provided in **Table 31** to put the calculated soil targets into context. The RTM-calculated targets for the PAH compounds Fluoranthene and Anthracene are inappropriate as remediation criteria, as they would require the remediation objective to be to remediate the soil within the gas works area of the HIF Infrastructure site to levels lower than the remainder of the Plateau. This is clearly not a sustainable approach as it would involve the removal of substantial quantities of made ground.

The remediation of the gas works will remove the source of the gas works contamination, which may currently be affecting groundwater quality locally. Minimal infiltration is expected to occur post-development. It is therefore proposed that the soil remedial targets for PAH used for the gas works are adjusted to match the 95th %ile concentration of the Red Bank Plateau area for PAH.

7.3 DQRA outcome – carriage shed

7.3.1 RTM output

The calculated soil remedial targets for the carriage shed area are provided in **Appendix D** and are based on the gas works input parameters in order to be protective of the River Irk. The remedial targets are summarised in **Table 32** below against the 95th %ile soil concentrations on Red Bank plateau.

It should be noted that visible evidence of hydrocarbon contamination was identified on perched groundwater (a sheen) within the carriage shed, and the values below do not account for NAPL within perched waters. Measures to remove NAPL from perched groundwater will be addressed in the Remediation Strategy.

7.3.2 Discussion of remediation criteria for carriage shed

As for the gas works, the RTM-calculated remediation criteria for several of the TPH fractions are extremely high and far in exceedance of any site soil concentrations recorded. Any soils exceeding these criteria would be visibly grossly contaminated and therefore require remediation in accordance with the discovery strategy. Therefore, a soil remediation target for TPH C8-C35 of 2500mg/kg has been set for soil within the gas works and carriage shed areas. Within this, individual hydrocarbon fractions will still be screened, but the overall target of 2500mg/kg is considered appropriate to protect controlled waters, together with the implementation of a discovery strategy to ensure than no free phase hydrocarbons are missed.

The soil targets generated by the DQRA for the carriage shed are extremely low for some of the contaminants of concern, particularly the PAH compounds, and may not be achievable considering the typical soil concentrations observed during the ground investigations. The main reasons for these low RTM-calculated remedial targets are the very low water quality standards used in the modelling, and conservatism of the modelling e.g. the short travel distance to the receptor (see **Appendix D**).

The 95%ile concentration for the PAH compounds within the made ground on Red Bank plateau is provided **t**o put the calculated soil targets into context. The RTM-calculated targets for the PAH compounds Fluoranthene and Anthracene are inappropriate as remediation criteria, as they would require the remediation objective to be to remediate the soil within the gas works and carriage shed areas of the HIF Infrastructure site to levels lower than the remainder of the plateau. This is clearly not a sustainable approach as it would involve the removal of substantial quantities of made ground.

The 95th percentile values for the Red Bank plateau show that the 95th %ile soil concentrations for PAHs in the gas works are not typical of Red Bank plateau generally and remediation to reduce soil concentrations to these levels would remove contamination outliers and bring the soil quality into line with the remainder of the plateau.

The remediation of the carriage shed will remove the source of the contamination, which is affecting perched groundwater quality within the carriage shed footptint. Minimal infiltration is expected to occur post-development. It is therefore proposed that the soil remedial targets used for the carriage shed areas are adjusted to match the 95th %ile concentration of the Red Bank plateau area for PAHs.

The RTM calculated remedial targets for PFAS in soil are lower than the laboratory limits of detection, which are <2µg/kg for PFOS and <1µg/kg for PFOA. The typical soil concentrations within Red Bank plateau are less than detection for these PFAS and therefore, the limits of detection are proposed to be used as remedial targets for the carriage shed. Additional consideration is given to the benefits of remediation of very low concentrations of PFAS is presented in **Section 9**.

Contaminant	RTM-calculated soil remediation target (mg/kg)	95th %ile of soil concentration on plateau (mg/kg)
Benzo(a)Pyrene	3.6	2.5
Fluoranthene	0.3	7
Anthracene	0.9	1.8
TPH – Aliphatic C8-C10	4860	9.9
TPH – Aliphatic C10-C12	37900	9.9
TPH – Aliphatic C12-C16	758000	17.9
TPH – Aromatic C8-C10	1340	7.9
TPH – Aromatic C10-C12	772	31.2
TPH – Aromatic C12-C16	3860	60.4
TPH – Aromatic C16-C21	1120	85
TPH – Aromatic C21-C35	8100	200
TPH – C8-C35	2500*#	N/A
PFOS	0.19µg/kg	<2µg/kg
PFOA	0.03µg/kg	<1µg/kg

* RTM-calculated remediation criteria for several of the TPH fractions are far in exceedance of any soil concentrations. Any soils exceeding these criteria would be visibly grossly contaminated. Therefore, it was considered appropriate to set a soil remediation target for TPH C8-C35.

If exceedances of these values are noted, the risk-derived criteria for individual carbon bands detailed in this table shall be applied.

Table 32 Summary of remediation targets for carriage shed

7.4 DQRA outcome – TP422/TP423 PFAS outlier and TP405A

As shown on **Drawing 5** and **Drawing 6**, an outlier of PFAS contaminated soil was identified during the ground investigation in the area of TP422 and TP423. This area of contamination is suspected of impacting on groundwater quality locally and therefore remedial targets have been calculated for soil and soil leachate. The remedial targets are summarised in **Table 33** below.

Contaminant	RTM-calculated soil remediation target (µg/kg)	95th %ile of soil concentration within TP422/TP423 (µg/kg)	95th %ile of soil concentration on plateau (µg/kg)
PFOS	0.19	12	<2
PFOA	0.03	20	<1

Table 33: Summary of remedial targets for TP422/TP423 outlier

7.4.1 Discussion of remediation criteria for TP422/TP423 and TP405A

The RTM calculated remedial criteria for the TP422/TP423 hotspot area have been compared against the 95th %ile concentrations for soil and leachate for the hotspot. These are exceeded by the 95th%ile concentrations within the hotspot, indicating that remediation of the hotspot will be required in order to protect the River Irk. It should be noted that the remedial targets derived are extremely low, which is driven by the very low EQS value for the River Irk. As discussed previously, the EQS is considered to be very conservative in the context of this site and its urban setting.

An additional small hotspot of PFAS was identified as a result of liquid-phase testing within the site: TP405A It is proposed that the remedial targets presented in **Table 33** are applied to this hotspot also, in order to be protective of the River Irk.

The RTM calculated remedial targets for PFAS in soil are lower than the laboratory limits of detection, which are <2µg/kg for PFOS and <1µg/kg for PFOA. The typical soil concentrations within Red Bank plateau are less than detection for these PFAS and therefore, the limits of detection are proposed to be used as remedial targets. Additional consideration is given to the benefits of remediation of very low concentrations of PFAS is presented in **Section 9**.

7.5 DQRA outcome – re-use of fill materials within St. Catherine's Wood or Red Bank Terrace

Current earthworks proposals include for a relatively small quantity of material excavated from Red Bank plateau to be transferred to each of the areas of proposed earthworks in St Catherine's Wood and Red Bank terrace areas of the site. The materials transferred to these areas of the site will need to be screened against the criteria set out in **Table 34** and **Table 35**, depending on proximity of the placed material to the River Irk. The St. Catherine's Wood and Red Bank terrace areas have been divided into two zones for the purposes of generating re-use criteria, as shown in **Drawing 14.**

7.5.1 RTM output

The RTM-calculated remedial targets for the re-use of fill within St. Catherine's Wood and Red Bank terrace are provided in **Appendix D**. The target concentrations have been calculated for soil and soil leachate. The remedial targets for Zone 1 are summarised in **Table 34** and those for Zone 2 are in **Table 35**.

It should be noted that soil containing visible evidence of hydrocarbon contamination will not be suitable for re-use. This will need to be addressed in the Remediation Strategy.

7.5.2 Discussion of re-use criteria

It can be seen from comparison of the calculated soil targets for Zones 1 and 2 that there is not a great deal of difference between them; Zone 1 targets tend to be slightly lower than Zone 2, which is a function of the proximity to the River Irk used in the modelling. Because the targets are not significantly different, it is proposed to adopt the Zone 1 targets as the re-use criteria for materials used within both Zones 1 and 2, close to the River Irk.

RTM-calculated remediation criteria for TPH Aliphatic C10-C12 and Aliphatic C12-C16 are extremely high and far in exceedance of any site soil concentrations recorded. Any soils exceeding these criteria would be visibly grossly contaminated and therefore would not be suitable for re-use in accordance with the remediation strategy. Therefore, a soil remediation target for TPH C8-C35 of 2500mg/kg has been set. Within this, individual

hydrocarbon fractions will still be screened, but the overall target of 2500mg/kg is considered appropriate, together with the implementation of a discovery strategy to ensure than no free phase hydrocarbons are missed.

The RTM-calculated criteria for re-use of excavated materials are extremely low for some of the contaminants of concern, particularly the PAH compounds and may not be achievable based on the typical soil concentrations observed during the ground investigations. The main reasons for these low RTM-calculated remedial targets are the very low water quality standard used in the modelling and conservatism inherent in the modelling. The upper 95th %ile concentrations in soil from the Red Bank Plateau (the source of any re-used material) are also presented in **Table 34** and **Table 35** to provide some context to the soil targets generated in RTM.

An additional useful comparator is the published normal background concentration (NBC) [24] for benzo(a)pyrene in soil in urban areas of 3.6mg/kg, which is significantly higher than the calculated targets. It is proposed that the re-use criteria used in St. Catherine's Wood and Red Bank terrace are adjusted to match the normal background concentration to ensure that the remedial target is reasonable and achievable. In addition, the re-use criteria for Anthracene and Fluoranthene will be adjusted to match the 95%ile concentrations for the made ground within the Red Bank plateau. This will ensure that the risk of harm to controlled waters will not exceed the current situation.

The RTM calculated remedial targets for PFAS in soil are lower than the laboratory limits of detection, which are <2µg/kg for PFOS and <1µg/kg for PFOA. The typical soil concentrations within Red Bank plateau are less than detection for these PFAS and therefore, the limits of detection are proposed to be used as remedial targets. Additional consideration is given to the benefits of remediation of very low concentrations of PFAS is presented in **Section 9**.

Contaminant	RTM-calculated soil remediation target (mg/kg)	95th %ile of soil concentration within Red Bank Plateau(mg/kg)
Nickel	26.5	50
Zinc	191	500
Benzo(a)Pyrene	0.4	2.5
Fluoranthene	0.04	7
Anthracene	0.15	1.8
TPH – Aliphatic C8-C10	1910	9.9
TPH – Aliphatic C10-C12	14900	9.9
TPH – Aliphatic C12-C16	297000	17.9
TPH – Aromatic C8-C10	153	7.9
TPH – Aromatic C10-C12	76	31.2
TPH – Aromatic C12-C16	208	60.4
TPH – Aromatic C16-C21	323	85
TPH – Aromatic C21-C35	2453	200
TPH C8-C35	2500*#	
PFOS	8.17E-05	<0.002
PFOA	1.24E-05	<0.001
* RTM-calculated remediation criteria for several of the TPH fractions are far in exceedance of any soil concentrations. Any soils exceeding these criteria would be visibly grossly contaminated. Therefore, it was considered appropriate to set a soil remediation target for TPH C8-C35. # If exceedances of these values are noted, the risk-derived criteria for individual carbon bands detailed in this table shall be applied.		

Table 34: Calculated re-use criteria for site-won soils placed within Zone 1

Contaminant	RTM-calculated soil remediation target (mg/kg)	95th %ile of soil concentration within Red Bank Plateau (mg/kg)
Nickel	28	50
Zinc	191	500
Benzo(a)Pyrene	0.7	2.5
Fluoranthene	0.06	7
Anthracene	0.21	1.8
TPH – Aliphatic C8-C10	1910	9.9
TPH – Aliphatic C10-C12	14800	9.9
TPH – Aliphatic C12-C16	297000	17.9
TPH – Aromatic C8-C10	236	7.9
TPH – Aromatic C10-C12	124	31.2
TPH – Aromatic C12-C16	429	60.4
TPH – Aromatic C16-C21	359	85
TPH – Aromatic C21-C35	2740	200
TPH – C8-C35	2500*#	
PFOS	7.92E-05	<0.002
PFOA	1.24E-05	<0.001
* RTM-calculated remediation criteria for several of the TPH fractions are far in exceedance of any soil concentrations. Any soils exceeding these criteria would be visibly grossly contaminated. Therefore, it was considered appropriate to set a soil remediation target for TPH C8-C35. # If exceedances of these values are noted, the risk-derived criteria for individual carbon bands detailed in this table shall be applied.		

Table 35: Calculated re-use criteria for site-won soils placed within Zone 2

7.6 DQRA summary

A detailed quantitative risk assessment (DQRA) has been carried out for the contaminants of concern identified by the controlled waters assessment, which comprised nickel and zinc, ammoniacal nitrogen, selected TPH fractions, selected PAH and PFAS (represented by PFOS and PFOA). The DQRA was completed using the Environment Agency's Remedial Targets Methodology (RTM) and supporting worksheet.

Remediation criteria were generated for the gas works area and TP422/TP423 and the carriage shed, which have been identified as the main primary sources of contamination within the site. Another small occurrence of PFAS soil contamination was identified as a result of ground investigation at TP405A. It is proposed that the remedial targets derived for TP422/TP423 are applied to this area, to be protective of controlled waters.

Re-use criteria were also derived for site-won soils to be placed within St. Catherine's Wood or Red Bank terrace. Two sets of re-use criteria, termed "Zone 1" and "Zone 2" have been generated for fill derived elsewhere within the site which is placed within St. Catherine's Wood or Red Bank terrace, depending on the distance from the river in which soils are to be re-used. General re-use criteria have not been derived for materials excavated and re-used within Red Bank plateau, there being no evidence of current significant impact on water quality within the River Irk.

Some of the RTM-calculated remedial targets are extremely low, which is largely driven by the very low water quality standards used and the conservatism inherent in the modelling. Such targets would require the remediation of known sources to achieve concentrations lower than present across the remainder of the Plateau. The RTM guidance states that, once remedial targets have been derived, the user should evaluate whether the remedial targets are reasonable, practical and affordable. Adoption of the RTM-calculated values is not a sustainable approach, which is discussed further in **Section 10**. Remediation to the RTM-calculated values is also not

reasonable when considered in the context of the lack of impact currently being observed on the River Irk. An alternative approach where RTM-calculated remedial targets are extremely low, is to remediate to achieve either normal background concentrations for urban environments, or the upper 95th percentile of the mean value for the contaminant in the soil where no normal background concentration has been published.

The RTM risk assessment has considered the risks associated with known soil sources to the quality of the River Irk. Whilst specific remedial action is proposed for the identified PFAS sources, after the completion of the HIF Infrastructure Works, there will remain a residual very low concentration of PFAS that is potentially leachable from made ground and which is already present in shallow groundwater. The potential impact of this residual PFAS has also been considered using a mass-balance approach, which is presented in **Section 8**.

8 Supplementary PFAS Risk Assessment

8.1 Purpose and drivers of supplementary risk assessment

The 2023 PFAS ground investigations identified that, whilst soil concentrations of PFAS are typically not detectable, soil leachate prepared in the laboratory and shallow groundwater contains very low concentrations of PFAS. Whilst the identified soil PFAS 'hotspots' have been assessed using RTM to generate remedial targets as discussed in **Section 7**, it was not considered feasible to carry out a numerical risk assessment using RTM to assess the entirety of the made ground within the Red Bank plateau area, which is approximately 300,000m^3 of material. Therefore, the residual PFAS in soil and shallow groundwater has been subject to a separate assessment of risk, which is described in this section.

Several studies have pointed to PFAS' ubiquitous presence in the environment, including its presence in rainfall and surface waters in excess of the EQS [37], but there are currently no published data confirming background concentrations in soil or water in the UK, making it difficult to assess the risk posed by the leachable PFAS in the soil to the River Irk.

The Water Framework Directive (WFD) 2000/60/EC aims to reduce pollution, prevent deterioration and improve the health of aquatic ecosystems. It sets the objectives that:

- measures are implemented to prevent or limit inputs of pollutants into groundwater;
- measures are implemented to reverse any significant and sustained upward trends;
- groundwater bodies should be protected such that their quality does not deteriorate to the point where additional treatment is required for drinking water supplies.

In the case of PFAS in the emerging water at the site, measures have already been implemented to prevent further inputs of pollution into the ground. As discussed previously in this report, BAM has secured a temporary discharge licence to discharge the emerging water to sewer on site, following treatment to reduce dissolved methane. A permanent treatment plant will be constructed to deal with the emerging water in the long term. Therefore, the ongoing impact of PFAS from the emerging water is already being reduced and the source term declining.

Regarding the protection of groundwater bodies to safeguard their use as future drinking water supplies, the concentrations of PFAS detected in groundwater or the emerging water do not exceed current drinking water guidelines (the 'wholesomeness threshold' discussed in **Section 6.1.1**). Therefore, the presence of very low concentrations of PFAS in groundwater do not currently require treatment if the principal aquifers were to be used for drinking water supply.

Where pollutants have already entered groundwater, as is the case at Victoria North, the priority under the WFD is to take all necessary and reasonable measures to:

- Minimise further entry of contaminants where there is a defined source;
- Limit the pollution of groundwater or any effect on the status of the groundwater body.

This risk assessment will therefore consider the significance of any further entry of PFAS into the water environment.

8.2 Summary of PFAS source terms

With the future discharge of emerging water to ground now dealt with, the assessment of data presented in **Section 4** indicates the following potential PFAS sources at the site:

- An outlier associated with TP422/TP423. This area is adjacent to the former gas works (**Drawing 2**), an area of the site that previously has been identified for remediation by excavation, removal of the arisings off site for disposal/treatment and backfilling. Subject to further considerations (**Section 10.2.2**), it is proposed that the remediation of the adjacent former gas works area is extended to include the area of the identified PFAS outlier. Remedial targets protective of controlled waters have been calculated for this outlier (see **Section 7**). In addition, this proposed remediation will address the human health risks discussed separately (**Section 5.6.1**).
- PFAS within perched water in the carriage shed foundations. Prior to the discovery of potential PFAS issues at the site, a requirement for remediation of the carriage shed had been noted, principally to address oil contamination in the perched groundwater and to remove the obstructions to development that were associated with the relic substructure. The additional findings of the PFAS ground investigation confirm that previous proposals for dewatering, excavation/breaking out and backfilling of the carriage shed remain appropriate. Remedial targets protective of controlled waters have been calculated for this area (see **Section 7**). Subject to further considerations (**Section 10.2.3**), the remediation of the carriage shed should adopt additional measures to address the identified PFAS impact of perched groundwater.
- Elevated leachable PFOS concentration of 92.2ng/l and leachable PFHxS concentrations of 49.8ng/l were recorded in TP405A at 2m bgl (c. 39.5mOD – **Appendix C2**). This area of the site is within earthworks area 3 (**Figure 3**) in which reduced-level excavation to 38.0mOD is proposed as part of the HIF Infrastructure works. Given the data from TP405A, PFAS-impacted soils may be encountered during the proposed excavation works. Remedial targets protective of controlled waters have been calculated for this area (see **Section 7**). Materials management measures will need to be adopted in this area of the site (**Section 10.2.4**), to delineate impacted soils and any areas of localised impact below the reduced-level excavation will need to be remediated and validated before reinstatement with suitable fill.

It is evident that once the proposed remedial works identified above have been completed, there will remain residual PFAS concentrations in the ground and shallow groundwater across the Red Bank plateau. In general, this residual PFAS cannot be measured in made ground soils across the site, however it *is* evident in leachability analysis data and in data obtained from the analysis of shallow groundwater.

A summary of the laboratory data relevant to residual PFAS (soil, leachability and perched groundwater data) is presented as **Appendix C6** and the distribution of residual PFAS in the liquid-phase samples (including shallow groundwater), is shown on **Drawing 15** (PFOS) and **Drawing 16** (PFOA)**.**

8.3 Residual PFAS terminology

When considering the issue of residual PFAS impact, the following terms have been used:

- **Background** – the term 'background' has only been used in this report when referring to studies undertaken by third parties, which measure the presence of PFAS in the environment, including its presence in rainfall and surface waters.
- **Residual** – the term 'residual' has been used in this report to refer to PFAS concentrations that will remain at the HIF Infrastructure site after the remediation activities described in **Section 8.1** have been completed. Given the established history of the site, residual PFAS impact is considered to have two components, as discussed below.
- **The emerging water source** – one component of the residual PFAS impact, associated with the previous discharge to ground of the emerging water (**Section 3**).
- **Diffuse PFAS impact** – the second component of residual PFAS impact identified at Red Bank plateau. Diffuse PFAS impact is not the result of historical or contemporary activities within the site and may therefore be of extraneous origin.

8.4 Residual PFAS characterisation

In order to characterise the residual PFAS compounds, the statistical assessment of soil leachate samples presented in **Section 4.4.2** has been revised to exclude the data from the TP422/TP423 outlier, the carriage shed and the data from TP405A (2m). Out of a total of 14 samples that represent the areas of residual impact, PFOA concentrations greater than the relevant limits of detection were recorded in nine samples and elevated PFOS was recorded in

eight samples. On the basis of the number of elevated occurrences therefore, PFOA and PFOS are the most prevalent residual PFAS compounds.

Compound	Units	No of results > LOD	Max concentration (with LOD) ng/l	Mean concentration (with LOD) ng/l
PFBA	ng/l	2	130.0	23.6
PFPA	ng/l	4	11.0	6.8
PFHxA	ng/l	7	10.0	7.4
PFBS	ng/l	3	10.0	7.1
PFHpA	ng/l	5	10.0	6.9
6:2-FTS	ng/l	1	11.4	6.1
PFOA	ng/l	9	26.0	10.3
PFNA	ng/l	1	10.0	6.1
PFDA	ng/l	1	10.0	6.4
PFOS	ng/l	8	13.0	8.0

Table 36: Statistical assessment of residual PFAS compounds (Liquid-phase samples, Pre-Ox. No. of samples = 14).

The assessment of maximum concentrations (**Table 36**) suggests that PFBA is most conspicuous in the residual PFAS data, followed by PFOA and PFOS. The maximum recorded value of PFBA however, is identified by the laboratory as less than the limit of detection (i.e. LOD reported for this sample as 130ng/l). On this basis, the data for PFBA in TP-EW11 has been disregarded. In terms of the mean for the data set, the most significant compounds are PFBA, PFOA and PFOS. The issues with limits of detection associated above with PFBA also apply in this case and the data from the relevant exploratory hole has been disregarded.

It is concluded from the summary presented in **Table 36**, that PFOA is most significant residual PFAS compound at the site, followed by PFOS. The statistical data for the residual impact associated with these compounds is summarised in **Table 37**.

Compound	No > LOD	Max Concentration (ng/l)	Mean concentration (ng/l)
PFOA	9 of 15	26.0	<10.3
PFOS	8 of 15	13.0	<8.0

Table 37: Characterisation of the most significant **residual PFAS compounds at the site**

These maximum leachable concentrations have been compared against the shallow groundwater concentrations of PFOS and PFOA, of which the maximum PFOA is 64ng/l, although this was measured in only one location, downgradient of the outlier at TP422/TP423 which is to be remediated. If this concentration is removed from the dataset, as the outlier at TP422/TP423 is to be remediated, the maximum concentrations are 28ng/l PFOA and 5ng/l PFOS. These values are similar to the maximum residual concentrations identified in shallow groundwater, indicating that residual leachable concentrations in soil could be responsible for the PFAS that is being measured in shallow groundwater.

Given its presence across the majority of the Red Bank plateau, it is considered that the residual PFAS is not attributable solely to the emerging water. Any localised impact that may have arisen from the discharge of emerging water to ground in the immediate vicinity of the emerging water source, cannot be distinguished from the diffuse PFAS that has been identified across the site (**Drawing 15** and **Drawing 16**). Consideration has been given to whether the diffuse PFAS contamination might be cross-contamination associated with the TP422/TP423 outlier. Such cross-contamination may have occurred for example, following plant movements across the site either during preparatory works for the Victoria North HIF scheme, or by historical operations at the site. If plant movements were the cause of the residual PFAS contamination however, it would be anticipated that the distribution would be focussed on the TP422/TP423 outlier, with PFAS concentrations reducing with distance from the outlier. This anticipated distribution is not evident in the available data and on this basis, it is considered that the diffuse PFAS contamination is not associated with cross-contamination caused by plant movement.

The possibility that the diffuse PFAS impact is due to cross-contamination from the TP422/TP423 outlier is also unlikely given the composition of the different PFAS compounds in the soil at TP422/TP423, which differs from the composition of PFAS identified in the majority of other samples. Furthermore, as discussed in **Section 4.4.6**, the PFAS at TP422/TP423 does not appear to be fully oxidised compared to the diffuse PFAS impact that has been identified in the made ground generally.

Having eliminated the emerging water and cross-contamination associated with the TP422/TP423 outlier as likely sources, it is concluded that the diffuse PFAS contamination is not the result of historical or contemporary activities within the site.

8.5 Literature review

8.5.1 Classification of PFAS impacted sites

A review of published literature has identified that PFAS impacted sites can be separated into primary-source sites and secondary-source sites [15]. Primary source sites include those used for PFAS manufacturing and fire training areas. Secondary-source sites may be impacted by migration from adjacent primary-source sites. Alternatively, secondary source sites may be impacted by PFAS-contaminated media, resulting for example from the spreading of sewage sludge or by irrigation with PFAS-impacted water. The TP422/TP423 outlier is considered to be a secondary-source impact.

In addition, 'background sites' have also been identified in the published literature [15]. These are sites for which there is no evidence for activities that are directly associated with PFAS but nevertheless, the sites have been shown to be impacted. The diffuse PFAS impact that has been identified across the Red Bank plateau appears possibly to be associated with background sources.

In a study on background concentrations of PFAS in soils by Brusseau et al [64], PFAS were found to be present in soil at almost every site tested. Low but measurable concentrations were seen even in places which were far from potential sources of PFAS. A number of mechanisms have been proposed to explain the phenomenon of background PFAS contamination, including transfer by dusts or via the rain-cycle.

Cousins et al [37] report that the background soil contamination with PFAS is a "result of the environmental ubiquity of PFAAs in atmospheric deposition".

The findings of a worldwide review of available ground investigation soil data for PFOS and PFOA are summarised in
Table 38 and compared with a summary of the residual PFAS impact identified at Victoria North (after the remediation of the TP422/TP423 hotspot, the carriage shed and TP505A, in accordance with the preliminary recommendations of **Section 8.1**).

The data summarised on **Table 38** suggests that on the basis of PFOA and PFOS, PFAS concentrations identified in soils at Victoria North are much lower than those typically associated with either primary-source or secondary-source sites. The data also suggests that PFOA and PFOS conditions are generally lower that the background conditions identified in published literature. Overall therefore, after the proposed remediation identified in **Section 8.1**, there will be no demonstrable PFAS impact of soils at the site beyond that which could be expected as a result of background contamination.

Source	PFAS soil concentration (µg/kg)	
	PFOS	PFOA
Primary-source sites	8722*	83*
Secondary-source sites	680.5*	38*
Background sites	2.7*	2.7*
Victoria North (mean soil concentration)**	1.2	<1.0
Victoria North (maximum concentration)**	2.1	<1.0

* - median maximum value
** - calculated for all data points outside the TP422/TP423 outlier and the data from the carriage shed

Table 38: Comparison of residual Victoria North data with worldwide PFAS data [15]

8.5.2 Transport and fate of PFAS in soils.

The potential risk to controlled waters from the residual PFAS impact identified at the site will be mediated by the behaviour of PFAS in the subsurface.[16] As discussed below, research into PFAS fate and transport has identified a number of important factors that need to be considered for the assessment of risk from PFAS at Victoria North.

Conceptualising the extent of PFAS impact in soils

At higher concentrations, PFAS may be present as aggregates referred to as micelles or hemimicelles, in which hydrophobic portions of each PFAS molecule interact with one another. For PFOS, critical micelle concentrations (CMC) of 500 to 5,000 mg/l have been reported, with hemimicelles forming at concentrations as low as 0.5mg/l (500,000 ng/l) [17]. The PFOS concentrations identified in the liquid phase at Victoria North are several orders of magnitude lower than the concentrations at which hemimicelles can be expected to form. PFAS aggregates will not therefore, need to be considered in risk assessments undertaken for the site.

Degradation of PFAS

PFOS and PFOA are understood not to undergo significant biotransformation under normal environmental conditions [18]. A number of authors have noted that certain PFAS compounds (particularly the longer-chain molecules – **Table 2**) degrade by oxidation in aerobic environments [19]. Typically, these longer-chain PFAS compounds are understood to degrade to shorter-chain, more mobile compounds.
According to the HSE's analysis of appropriate regulatory management options for PFAS [34] "there are very few environmentally relevant degradation or transformation studies for precursor, intermediate or arrowhead substances analytes. Subsequently, there is ambiguity around the extent to which precursor transformation occurs on any scale, which environmental compartments represent the majority of transformation (e.g. soil or atmospheric) and what relevant conditions affect transformation processes, rates and pathways."

The issues associated with degradation of PFAS in the environment led in part to the development of the TOP-assay protocol. As discussed in **Appendix B**, although TOP assay allows the potential for degradation over a prolonged future timescale to be assessed, the harsh oxidising procedures adopted in the laboratory have led some to researchers to suggest that the results of TOP assay assessment should be considered as indicative only [20]. As presented in **Appendix B**, the available ground investigation data provides little evidence that oxidation is a significant risk associated with the residual PFAS impact identified at Victoria North.

Factors affecting mobility of PFAS in the environment

PFAS are soluble in groundwater and are capable of forming long groundwater plumes [35]. It has been recognised however, that in unsaturated conditions, adsorption of PFAS molecules to soil is important when considering the mobility of PFAS [16][18]. It has been concluded that "The effect of PFAS sorption to sediments or soils during transport is to remove a portion of the PFAS from the aqueous phase, either permanently or temporarily" [18]. Initial research identified two mechanisms that control the degree of PFAS sorption to soils:

1. Hydrophobic sorption to naturally occurring solid organic particles; and
2. Surface sorption to charged mineral surfaces.

It has been confirmed that organic carbon in the solid phase is a highly significant factor in the retention of PFAS in the unsaturated zone [22]. Ferric oxides have also been identified as potentially important [18][23]. Data from the various phases of ground investigation that have been undertaken at Victoria North indicate total organic carbon (TOC) concentrations in the made ground of 27.3% (90th %ile) and iron concentrations of 59,000mg/kg (90th %ile).

Subsequent research however, has noted that sorption to soil is only one of a number of partitioning processes that have significant impact on PFAS attenuation [16]. This led to the development of the following multi-modal retardation model:

1. Adsorption to the solid phase.
2. Partitioning to the soil atmosphere.
3. Adsorption at air-water interfaces.
4. Partitioning to trapped organic liquids (NAPL).
5. Adsorption at NAPL-water interfaces.

Given the generally low volatility of PFAS compounds, partitioning to the soil atmosphere (point 2 above) is considered to be negligible [16].

PFAS molecules typically possess a hydrophobic/lipophobic tail together with a head that makes the molecule readily soluble [24]. This structure causes PFAS to concentrate at liquid/air interfaces and liquid/liquid interfaces. To further understand the implications of this behaviour for sorption modes 3 to 5 above, the behaviour of relevant PFAS-impacted systems has been investigated [16][25]. This research established that retardation of PFOA and PFOS was significantly greater under unsaturated conditions than was the case under saturated conditions, attributing the greater retardation largely to the adsorption of PFAS at air-water interfaces. It has been established that air-water interfacial adsorption contributes approximately 50% to 75% of total retention, depending on the degree of saturation. In unsaturated soils, air-water interfaces can be extensive, being present as films of moisture that are intimately associated with the soil particles (as shown to the upper left in **Figure 8**).

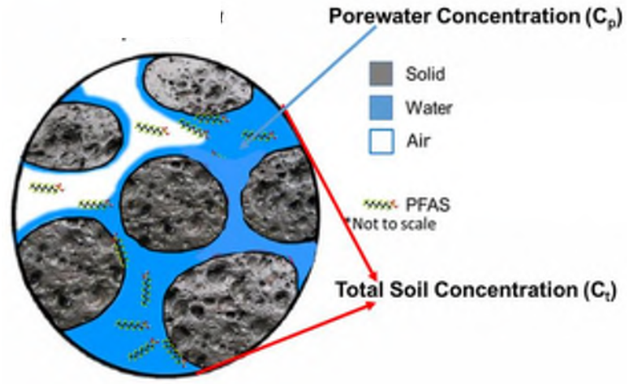


Figure 8: Idealised PFAS distribution model for unsaturated soils [26]

Ground investigation at Victoria North has established that the made ground used to form Red Bank plateau is predominantly granular, with perched water associated only with limited lenses of cohesive material (moisture content in the made ground is 26.7% - 90th %ile), or trapped within relic structures (i.e. the former carriage shed). It can be concluded therefore, that made ground is generally unsaturated and that adsorption at air-water interfaces will play a significant role in the transport and fate behaviour of PFAS at the site.

Further research has established that the presence of NAPL has the potential to alter both the sorbing characteristics and the access of PFAS to soil organic matter and provide potential new interfacial or absorptive capacity [27]. Separately, studies have established that the presence of residual NAPL measurably increased overall retardation for most PFAS [16]. This increased retention was attributed primarily to NAPL partitioning,

while the potential for adsorption to the NAPL-water interface was also noted. Ground investigation data indicates that of approximately 105 soil samples recovered from the Red Bank plateau, 25 samples (24%) contained hydrocarbon concentrations for one or more TPHCWG fractions that were greater than the relevant theoretical saturation limit. However, not all of these samples were saturated, and visual observations of NAPL during the ground investigations were fewer and confined to areas of perched groundwater.

In unsaturated conditions however, it has been demonstrated that PFAS compounds such as PFOS preferably partition to the air-water interfaces (mode 3 above), rather than water-oil interfaces (mode 5 above) [28], providing further evidence for the importance of air-water interfacial adsorption in unsaturated conditions, when assessing transport and fate behaviour of PFAS.

After consideration of the multi-modal model presented above, researchers have concluded that retardation of PFAS in the unsaturated zone may be significantly greater than will be estimated based on the assumption of solid-phase adsorption as the sole retention mechanism [16]. Air-water interface adsorption was identified as one of the principal modes of retention in the unsaturated zone. Where NAPL was present, the potential for NAPL-water partitioning and NAPL-water interfacial adsorption interactions were also found to be potentially significant. These conclusions have important implications for the estimation of the migration potential of PFAS in soil and the associated risks to controlled waters.

Time-related retention and release of PFAS from soils

Although the degree of retention varies between individual PFAS compounds, as a consequence of the various retention processes that have been identified, significant retention of PFAS will occur in the unsaturated zone over timeframes that extend for a number of decades [15]. Separate studies using data from ground investigation together with mathematical modelling, supported these conclusions, with retention attributed primarily to the adsorption of PFAS at the air-water interface as well as on soil grain surfaces. These studies concluded that "….transport of PFAS through soil is quite slow" [29].

Research has established that "Sorption and partitioning….may restrict leaching rates from the vadose zone and reduce the advection-driven transport velocity of PFAS in groundwater, depending on specific properties of the compounds. These processes may help limit plume development and discharge to surface water and may also provide time for transformation of PFAA precursors" [17]. Separate research has reached similar conclusions, noting cases in which desorption from soils had been on-going for more than 40 years [22]. Complex desorption processes together with variation in the degree of flushing (infiltration) have been identified as the principal factors influencing the dispersal of ground-borne PFAS contamination [22][30][31].

It has been concluded that downward leaching through the unsaturated zone during precipitation, will promote dissolution of the soil-bound contaminant mass [17][32][33] however, long-term retention has been noted even after extended percolation [17][30][22]. Simulations have been used to establish timeframes for migration of a number of PFAS compounds [26]. These simulations identified that PFPeA and PFOA migrated to the bottom of a 4m deep simulated unsaturated zone within 30 years of the simulated contamination event, whereas PFOS migrated to only 2.5m bgl in the same timeframe due to its greater retention associated with solid phase sorption and air-water interfacial adsorption,[26] illustrating that chain length is not the only, or the dominant, influence on behaviour in the vadose zone.

8.6 Theoretical model of residual PFAS at Victoria North

To prevent the continued discharge of emerging water to ground, the source of emerging water has recently been re-connected to the combined sewer, under a temporary discharge consent. Once the specific remediation tasks proposed in **Section 8.1** are completed and validated, residual PFAS will remain at the site. It has been assumed that the remediation activities identified in **Section 8.1**, will take two years to complete (2024 and 2025).

A theoretical model has been developed to provide an indicative assessment of the potential risk to the River Irk, associated with this residual PFAS. As discussed in **Section 8.1**, two components of the residual PFAS have been identified for the theoretical modelling exercise:

- Emerging water which is known to have contained PFAS (**Section 8.6.1**).
- Diffuse PFAS which is not the result of historical or contemporary activities within the site.

The literature review presented above indicates that the potential risk to the River Irk will be ameliorated by retardation of PFAS in the substantial unsaturated zone present at the site. Ground conditions include made ground with elevated soil organic matter content, potentially significant iron content. Given the very low concentrations that characterise the residual PFAS impact at Victoria North (**Table 38**), there is considered to be abundant sorptive capacity within the soil.

8.6.1 Emerging water - historical model

It has been recognised that prior to 2022 when the emerging water issue was first discovered, a proportion of the discharge from the 800mm diameter pipe reached the combined sewer (**Section 3.1**). The proportions of emerging water that reached the combined sewer and how these proportions may have varied over time, have been considered when developing the indicative PFAS model (**Appendix E1** - PFOS and **Appendix E2** - PFOA).

The emerging water that consequently discharged to ground is assumed to have undergone the following:

i. Infiltration through the unsaturated zone. PFAS in the infiltrating water will have either:
   a. Adsorbed to the soil matrix as a result of the various modes of retardation that have been identified (**Section 8.5.2**); or
   b. Passed directly through with infiltrating water (see 'Pass through' below).
ii. Retention in the unsaturated zone. Retention will have provided opportunities for oxidation of longer chain PFAS compounds to occur.
iii. Subsequent rainfall infiltration. Infiltration will have released a proportion of the adsorbed PFAS via leaching.

Pass-through

Prior to the recent re-connection of the 800mm diameter pipe to the combined sewer, a proportion of the infiltrating water is likely to have passed through the unsaturated zone until deeper superficial groundwater bodies were encountered. These deeper groundwater bodies include groundwater identified at the made ground/glacial till interface [7].

The available ground investigation data does not allow the proportion of historical pass-through to be determined. The theoretical model therefore, assumes that prior to the recent re-connection with the combined sewer, there will have been effectively no pass-through, with all PFAS in the infiltrating water having been adsorbed to the soil matrix. Although the implications of this assumption may be to underestimate the risk to the River Irk at any previous point in time, such historical risk cannot be managed retrospectively. The zero pass-through assumption however, results in larger estimates for the mass of residual PFAS retarded in the unsaturated zone, than would be the case if a proportion of historical pass-through had been allowed for. When current and future risk to the river is modelled therefore, the zero pass-through assumption allows a conservative, worst-case assessment of risk to be undertaken (**Section 8.8**).

Oxidation of PFAS in the emerging water area.

The potential for oxidation of PFAS in soils in the emerging water area has been addressed as part of the March 2023 ground investigation (**Appendix B**). The available data identified little or no potential for future oxidation of the residual PFAS impact, suggesting that the PFAS measured in the soil and emerging water has already transformed into shorter, more mobile compounds and the analysis reflects what can be considered as worst-case conditions.

Leachability

In most cases, the concentrations of PFAS in soil at Victoria North have been shown to be below the laboratory limit of detection. There is therefore, limited data available that can be used to determine the proportion of leachable residual PFAS at the Victoria North site. The only available samples which have yielded both elevated soil and leachable PFAS concentrations are from within the TP422/TP423 outlier.

Although the PFAS conditions in the TP422/TP423 outlier are not representative of the residual PFAS across the site, in the absence of other data, this has been used to provide indicative values for the leachable proportion of residual PFOS and PFOA. The values of leachable PFOS and PFOA taken forward into the model are given in the right-hand column in (**Table 39**).

Compound	Leachable proportion (Appendix D3) (range - %)	Leachable proportion (Appendix D3) (mean - %)	Leachable proportion used in the indicative model. (%)
PFOS	0.5 to 1.3	0.8	1.0
PFOA	2.1 to 39.5	15.5	20.0

Table 39: Summary of leachable proportion assessment.

Emerging water: estimate of timescales

The period of time during which the emerging water has been impacting the Victoria North site cannot be determined exactly. On the basis that the discharge passing through the 800mm pipe was originally contained within the combined sewer network (**Section 3.1**), emerging water has only been an issue from the point in time when damage to the combined sewer system occurred.

When Red Bank plateau was an active rail site, issues such as the emerging water will have presented potentially significant operational constraints and will therefore have been repaired relatively quickly. The ad-hoc measures taken to by-pass the blocked section of pipe and discharge the emerging water into a surface water grate/catchpit, suggests that the damage to the combined sewer system occurred towards the end of the operational life of the rail sidings, at a time when there were few operational or financial incentives for undertaking a more substantial repair. Rail operations at Red Bank plateau ended in 1989, possibly indicating a mid- to late-1980s date for the start of emerging water issues at the site. Recently the emerging water has been reconnected to the combined sewer, marking the end of the period in which emerging water discharged to ground. On this basis, the indicative PFAS model assumes that emerging water has been an issue at the site for approximately 40 years, between the mid-1980s and 2024[5].

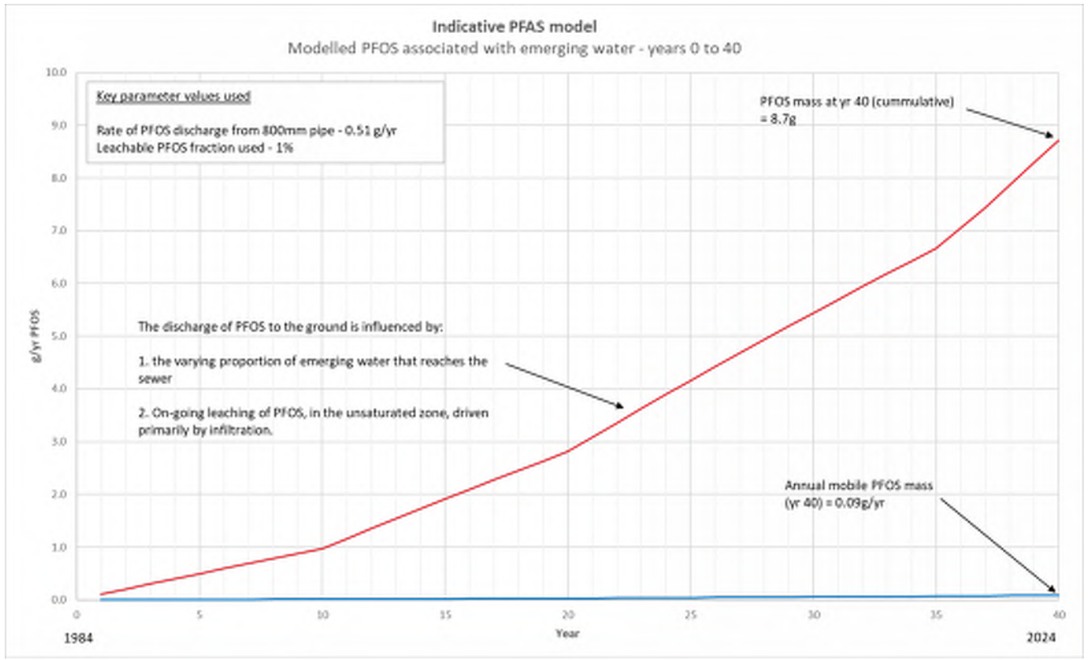
Emerging water: theoretical model output

In order to assess the historical implications of the emerging water, a simple mass-balance model has been developed. This model is based on assumptions regarding the rate of discharge from the source (the 800mm diameter pipe), the maximum concentrations of PFOS and PFOA in the emerging water **(Table 7**) and the proportion of the emerging water that historically has not reached the combined sewer and has therefore discharged to ground. Other assumptions used to model the historical implications of the emerging water are given in **Appendix E1** (PFOS) and E2 (PFOA).

As stated above, the conservative model assumes zero pass-through of the infiltrating water, with retardation having occurred as a result of adsorption to the solid phase and by partitioning at the complex air-water interface within the unsaturated zone. In areas where hydrocarbons are present, additional partitioning to NAPL and adsorption at NAPL-water interfaces may have been of further significance. The model further assumes that each year, a proportion of the accumulating mass of PFAS has been subject to leaching, as a result of rainfall infiltration (**Table 39**).

Figure 9 and **Figure 10** present the output from the indicative PFAS model for the period 1984 to 2024 (years 0 to 40). The red lines provide an indication of the manner in which historically, a cumulative mass containing PFOS (**Figure 9**) and PFOA (**Figure 10**) may have developed in the soils of the Red Bank plateau. The blue lines on these figures represent an indication of the mobile PFOS and PFOA that has been released each year as a result of rainfall infiltration and consequent leaching. It is the mobile PFAS fraction represented by these blue lines that historically (years 0 to year 40), has presented a risk to the River Irk.

Figure 9: Modelled PFOS associated with the emerging water (year 0 to year 40)



[5] Initially, a temporary discharge consent is in place. It is assumed for the indicative model that the permanent consent will be in place by 2024.

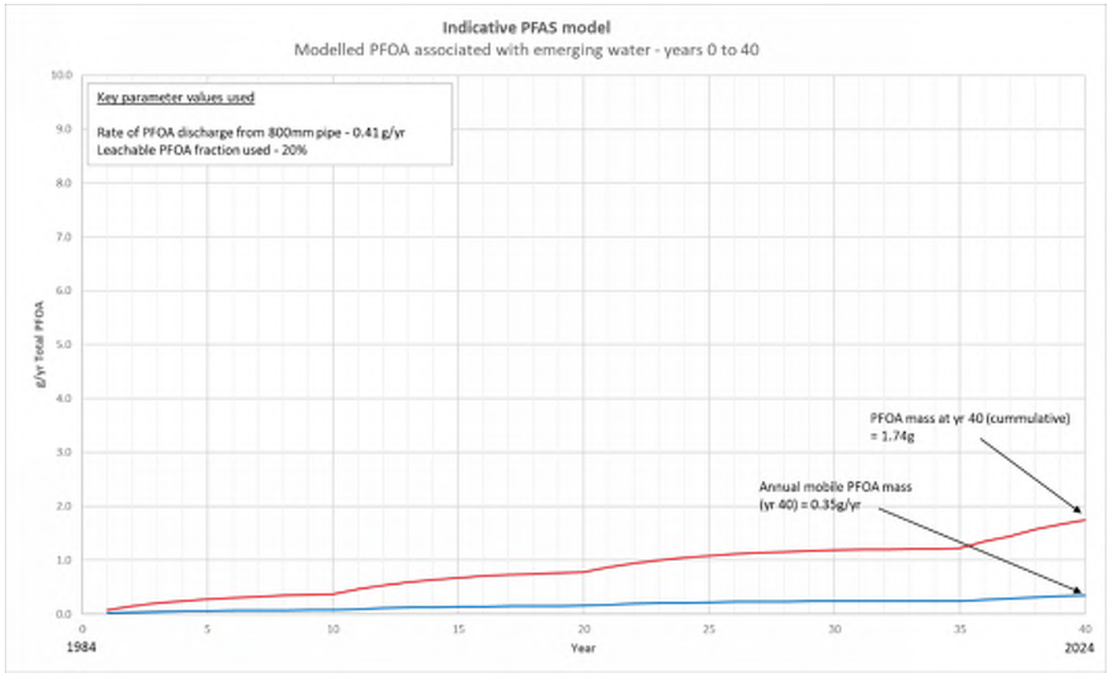


Figure 10: Modelled PFOA associated with the emerging water (year 0 to year 40)

Comparison of indicative model output with the findings of ground investigation

The indicative PFAS model presented as **Figure 9** and **Figure 10**, indicates that following a period of discharge of four decades (to 2024), up to 8.7g of PFOS and 1.7g of PFOA may have been retained in the unsaturated zone. As discussed above however, excluding the TP422/TP423 outlier, laboratory analysis has failed to identify soil impact in the emerging water area (**Table 13**). There are two possible explanations for this:

1. The model presented in **Figure 9** and **Figure 10**, does not include for any direct pass-through of infiltrating water and is therefore, a worst-case assessment. Actual concentrations at site will be lower than indicated by the model, depending on the degree of direct pass-through that has occurred historically.

2. The PFAS impact of soils associated with the emerging water is low and cannot be identified given the limitations of sensitivity associated with the current laboratory methods (**Appendix B**).

Assuming a density of 18kN/m^3 for the made ground soils, to exceed the laboratory limit of detection for both linear and branched PFOS in soil (2µg/kg), an estimated PFOS load of 8.7g would need to be confined within a volume of soil less than 2,400m^3 – an area less than 20m by 60m in plan and approximately 2m deep, for example. Except for TP EW06 in the north of the site, trial pit logs indicate made ground in this area of the site is greater than 3m deep (**Appendix C**) and as shown on **Drawing 17** the emerging water area covers an area of over 4,000m^2..

When the total mass of PFAS indicated by the model is distributed within the volume of made ground present in the emerging water area (**Drawing 17**), the resulting soil concentrations will be lower than the laboratory limit of detection.

8.6.2 Diffuse PFAS: historical model

As discussed in **Section 8.1**, diffuse very low concentrations of PFAS have been identified in soil leachate and shallow groundwater across Red Bank plateau which are not the result of historical or contemporary activities within the site. For the purposes of developing an indicative model of this diffuse impact, the findings of the March 2023 ground investigation have been taken to indicate that PFAS is present at concentrations at parts per trillion level in the majority of the shallow made ground soils across Red Bank plateau and that a proportion of this PFAS mass will be mobilised by leaching following rainfall infiltration (**Table 39**). It is assumed that diffuse PFAS has been a feature of the site for a significant period of time (at least over the period represented by the historical model – 1984 to 2024). Other assumptions used to assess the potential impact of diffuse PFAS are included in **Appendix E1** (PFOS) and **Appendix E2** (PFOA).

For the selected PFAS compounds, **Figure 11** (PFOS) and **Figure 12** (PFOA) compare the leachable diffuse PFAS mass indicated by the model (purple lines) with the leachable PFAS mass associated with the emerging water (blue lines). From these figures, it can be seen that year-on-year, the mobile PFAS impact associated with the emerging water has been less than the leachable mass associated with the diffuse PFAS across the site.

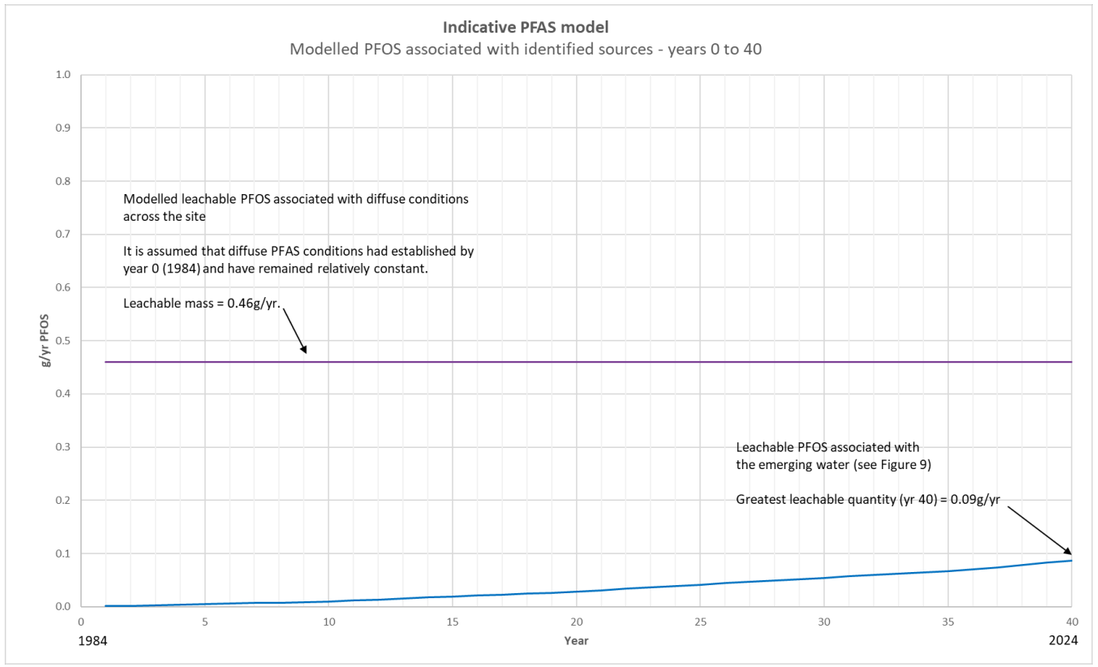


Figure 11: Modelled leachable PFOS from both sources – year 0 to year 40

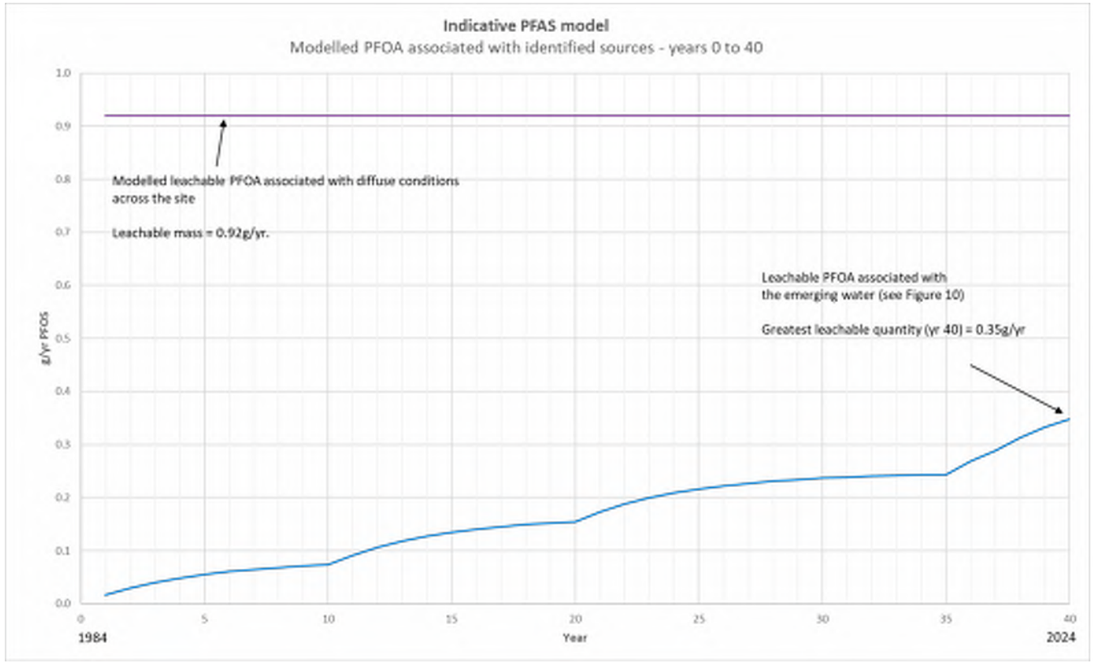


Figure 12: Modelled leachable PFOA from both sources – year 0 to year 40

8.6.3 Summary of historical PFAS model.

The historical mass-balance model indicates that by year 40 (2024) up to 8.7g of PFOS and 1.7g of PFOA may have discharged to the unsaturated zone as a result of the emerging water (**Figure 9** and **Figure 10**, red line). As a result of exposure to leaching however, a proportion of the adsorbed PFAS mass associated with the emerging water has been mobilised. In addition, the model assumes that infiltrating rainfall has mobilised a proportion of the diffuse PFAS mass that has been identified at the site (**Figure 11** and **Figure 12**).

Based on the simple mass-balance modelling that has been undertaken, the PFAS associated with both identified sources (emerging water and diffuse impact) at year 40 (2024), is summarised on **Table 40**.

Compound	Leachable mass released from emerging water area (g/yr - Fig 11 and 12, blue line)	Leachable mass released from the diffuse PFAS (g/yr – Fig 11 and 12, purple line)	Total for both sources (g/yr)
PFOS	0.09	0.46	0.55
PFOA	0.35	0.92	1.27

Table 40: Summary of potential leachable PFOS and PFOA associated with both sources at year 40 (2024).

This suggests that at year 40 (2024), the total leachable mass associated with both the emerging water and diffuse PFAS, is in the order of 0.55g/yr for PFOS and 1.27g/yr for PFOA. Further assessment is presented below to consider whether this PFAS may present a risk to the River Irk.

8.7 Indicative PFAS model – future risk to the River Irk

Following the completion of remediation at the site (**Section 8.1**) which is assumed to take two years (**Section 8.6**), there will remain a risk to controlled waters associated with residual PFAS. In order to investigate this potential future risk, the indicative PFAS model has been extended.

Given that the emerging water has recently been reconnected to combined sewer, the model no longer includes an on-going PFAS input associated with this source. The model does however, address the implications of the PFAS mass that has accumulated in the emerging water area by year 40 (**Figure 9** and **Figure 10**) and the potential implications of continued leaching from this mass. The model also assumes on-going leaching from the diffuse PFAS that has been identified across the site.

As **Figure 13** and **Figure 14** indicate, in the period prior to any significant development at the site (assumed as year 40 to year 44), the leachable PFOS and PFOA from the emerging water source (blue lines) reduces. This is because this source of PFAS is no longer being added to, and yet the emerging water area is subject to on-going leaching as a result of continued rainfall infiltration. For the same period (year 40 to year 44), the model assumes that the rate of leaching from the diffuse PFAS source (purple lines) will remain relatively constant.

The model also makes a number of assumptions regarding the impact of proposed development on future rainwater infiltration across the site and the consequences of this for the release of leachable PFAS from both sources beyond year 44. Other assumptions used to develop the model are included in **Appendix E1** (PFOS) and **Appendix E2** (PFOA). As **Figure 13** and **Figure 14** indicate therefore, after year 44, the reduced infiltration associated with proposed development has a marked impact on the generation of leachable PFAS (**Table 41**).

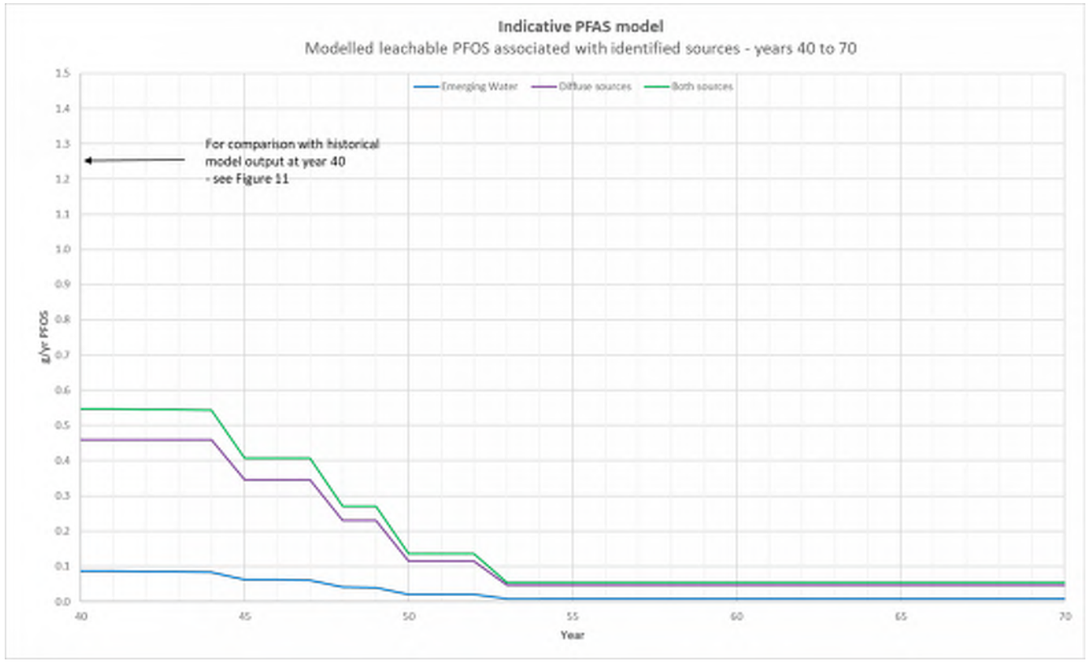


Figure 13: Modelled leachable PFOS from both sources – post year 40 with site development

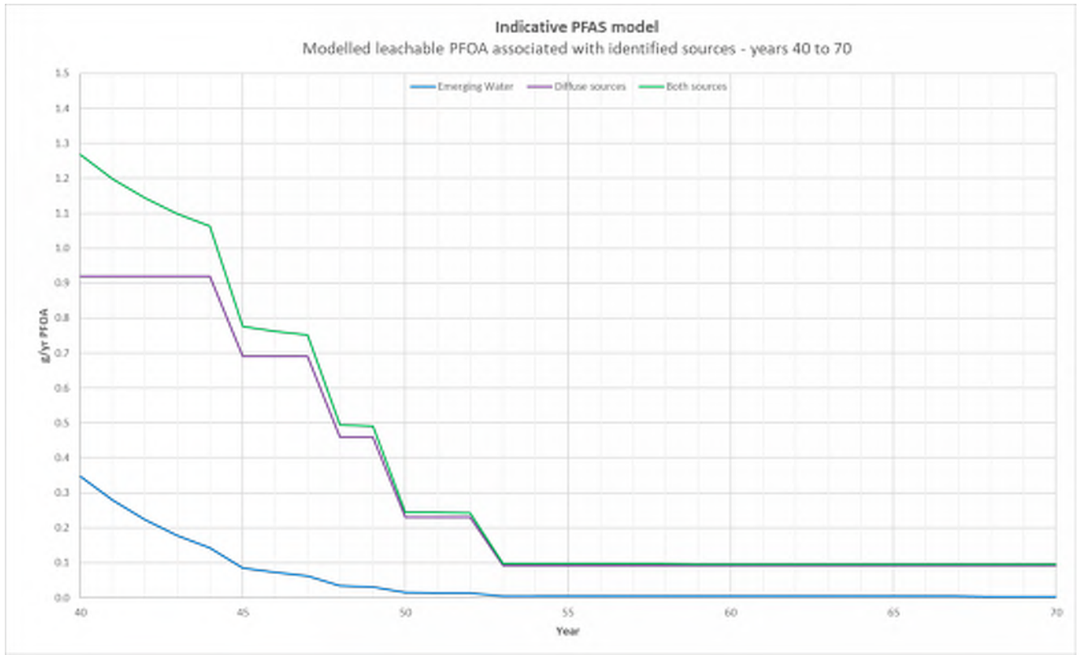


Figure 14: Modelled leachable PFOA from both sources – post year 40 with site development

Compound	Leachable mass associated with both sources at the start of development (yr 44) (g/yr – Fig 11 and 12, green line)	Leachable mass associated with both sources at the completion of development (yr 53) (g/yr – Fig 11 and 12, green line)
PFOS	0.54	0.05
PFOA	1.06	0.1

Table 41: Summary of modelled potential leachable PFOS and PFOA (beyond year 40).

The model suggests that the proposed development of the site greatly reduces the year-on-year risk to the River Irk by reducing rainfall infiltration.

8.8 Potential PFOS and PFOA risk to the River Irk

To allow comparison of the indicative model output for the years beyond year 40 (**Section 8.7**) with the EQS value for the River Irk, an additional assessment step has been made. It is acknowledged that dilution within the River Irk is not possible, as the concentration of PFOS in the river already significantly exceeds the EQS. Furthermore, the information presented here does not advocate the use of dilution in the river as a means to mitigate PFAS risk from the site, but is presented here to put the concentrations measured within the site into appropriate context.

Conservatively assuming no dilution or attenuation of the mobile PFOS or PFOA within the site, a preliminary assessment of the potential impact on the river has been undertaken (**Appendix E4**). These calculations assume that the remediation measures outlined in **Section 8.1** have been implemented and therefore, future PFAS risks are those associated only with the residual PFAS at the site.

As demonstrated in **Appendix E3**, these calculations indicate that in the period immediately following remediation (year 42 - **Section 8.1** and **Section 8.6**), the estimated impact of residual PFAS on the River Irk will be:

- 0.10ng/l for PFOS
- 0.21ng/l for PFOA

Both concentrations are less than the current laboratory limit of detection and less than the EQS of 0.65ng/l.

Following development of the site (year 53), with reduced infiltration associated with the proposed development, the modelled impact to the river is reduced to 0.01ng/l for PFOS and 0.02ng/l for PFOA, significantly less than the EQS.

For context, the mean PFOS concentration in the River Irk upstream of the site (monitoring point SWS03 – see **Drawing 3**) is 7.0ng/l (**Table 8**). Using the flow data at the gauging station at Collyhurst Weir, calculations suggest that currently (year 40), 378g of PFOS enters the relevant stretch of the river each year upstream of the site (**Appendix E4**), compared with a maximum of 0.55g/yr from both sources at Victoria North (**Figure 13**). Repeating the calculations for PFOA suggests that currently (year 40), 392g of PFOA enters the relevant stretch of the river each year (**Appendix E4**), compared with a maximum of 1.27g/yr from both sources at Victoria North (**Figure 14**).

Whilst a number of potential pathways have been identified which may give rise to such a plausible source-pathway-target linkage for PFAS to enter the river, as discussed in **Section 5.4.5**, repeated rounds of surface water quality monitoring have demonstrated that there is no detectable deterioration in water quality in the River Irk as it flows past the site. The calculations presented above provide support for the lack of observable impact on river quality.

8.9 Summary of indicative PFAS modelling

The findings of the simple mass-balance model presented above provide only an indication of the potential implications of the presence of PFAS that has been identified at the site.

The model is based on a number of assumptions as set out in the text and appendices to this report. Most significantly, it should be noted that no plausible linkage between PFAS in the site and the River Irk channel has been proven. Following the proposed remediation of the site (**Section 8.1**), which for the purpose of modelling, is assumed to require two years (**Section 8.6**), the findings of the indicative PFAS model suggest that if a source-pathway-receptor linkage is present, the concentrations of PFOS and PFOA at year 42 (2026) that may enter the river will be less than the current laboratory limits of detection. The ground investigation that has been undertaken and the indicative modelling that has been based on the findings of this ground investigation, suggest therefore, that there will be no measurable impact on river water quality from the residual PFAS sources identified at the site.

The output from the indicative PFAS model therefore, provides lines of evidence for the following:

1. The lack of observable impact on river quality from PFAS currently;
2. The potential benefit to groundwater and river water quality that can be realised by the proposed remedial works to be carried out as part of the HIF Infrastructure Works (**Section 8.1**);
3. The further potential benefit that can be realised by reducing infiltration at the site as a result of the proposed development.

The conclusion is that no specific remediation measures need to be taken to minimise further entry of residual PFAS into the water environment, as the identified defined sources are being removed and there is no discernible effect predicted or observed in the surface water body from the residual.

9 Updated conceptual site model

The following matrix summarises the contaminant linkages that have been identified and the lines of evidence that have been presented to confirm or discount the linkage:

Plausible Contaminant Linkage	Description	Lines of Evidence	Remediation/ mitigation
PLC1	Direct entry of PFAS contaminated emerging water into ground and infiltration into shallow groundwater	Emerging water has been diverted to sewer, source term is declining. PFAS concentrations in emerging water very low. Very low concentrations of PFAS in shallow groundwater in vicinity of emerging water. Soil concentrations of PFAS less than detection in area of emerging water.	Short term: Mitigation via temporary treatment and discharge to sewer. Long term: Permanent treatment system and discharge to sewer.
PCL2	Direct entry of PFAS contaminated emerging water into ground and infiltration into deep groundwater	PFAS concentrations generally very low in deep aquifer. Lower concentrations observed in deep aquifer compared to shallow groundwater, suggesting no/limited pathway. Concentrations of PFOS and PFOA in deep aquifer do not exceed the relevant water quality standard.	No remediation required to protect groundwater quality as water quality standard is not exceeded.
PCL3	Direct entry of PFAS contaminated emerging water into ground and migration via shallow/deep groundwater into the River Irk	No significant increase in PFAS in River Irk as it passes the site. Modelling shows impact of diffuse PFAS from emerging water over time will not have a significant impact on the quality of the River Irk.	Development will reduce infiltration through the ground in the long term, providing further mitigation.
PCL4	Leaching and infiltration through contaminated made ground sources into shallow groundwater	Shallow groundwater contains a number of contaminants present in excess of relevant water quality standards that may pose a risk to the River Irk: Nickel, zinc, ammonia, TPH fractions, PAH, PFOS, PFOA DQRA has been carried out to derive remedial targets for identified source areas to reduce the entry of contamination into shallow groundwater.	Removal of identified sources of contamination: Gas works, TP422/TP423, TP405A, Carriage Shed. Management of materials to be excavated and re-used as fill within the site. Reduction in infiltration through the made ground in the long term as a result of development.
PCL5	Leaching and infiltration through contaminated made ground sources into deep groundwater	Remediation of identified source areas is required to reduce the entry of contamination (hydrocarbons, metals, PFAS) into shallow groundwater, which will reduce entry of contamination into deep groundwater Concentrations of PFOS and PFOA in deep aquifer do not exceed the relevant water quality standard.	Removal of identified sources of contamination: Gas works, TP422/TP423, TP405A, Carriage Shed. Management of materials to be excavated and re-used as fill within the site. Reduction in infiltration through the made ground in the long term as a result of development.
PCL6	Leaching and infiltration through contaminated made ground sources and migration via shallow/deep groundwater into River Irk	Remediation of identified source areas is required to reduce the entry of contamination (hydrocarbons, metals, PFAS) into shallow groundwater. Modelling shows impact of residual leachable PFAS in soil will not have a significant impact on the quality of the River Irk. No significant deterioration in quality of River Irk as it passes the site.	Removal of identified sources of contamination: Gas works, TP422/TP423, TP405A, Carriage Shed. Management of materials to be excavated and re-used as fill within the site. Reduction in infiltration through the made ground in the long term as a result of development.
PCL7	Pushing of contaminated soils during piling into the deep aquifer	Piling not required as part of the HIF Infrastructure Works Will be required for future development within Victoria North.	Completion of Foundation Works Risk Assessment (FWRA) will be required once details of piled foundations for future development are known. Infilled reservoirs beneath Red Bank plateau should be avoided, or FWRA completed for piling in this area.
PCL8	Pushing of contaminated soils during piling into deep groundwater and migration into River Irk	Piling not required as part of the HIF Infrastructure Works Will be required for future development within Victoria North.	Remediation of identified source areas is required to reduce the entry of contamination (hydrocarbons, metals, PFAS) into shallow groundwater. Completion of FWRA will be required once details of piled foundations for future development are known. Infilled reservoirs beneath Red Bank plateau should be avoided, or FWRA completed for piling in this area.

Plausible Contaminant Linkage	Description	Lines of Evidence	Remediation/ mitigation
PCL9	Lateral and vertical migration of NAPL and PFAS sorbed to/dissolved in NAPL entering the shallow aquifer	Potentially mobile NAPL not identified by ground investigation. Identified sources of NAPL have been within water perched in relic structures (i.e. gas works, carriage shed) which are to be remediated. Retardation of PFAS by NAPL in the unsaturated zone likely to be significant. If NAPL removed, PFAS will also be removed.	Remediation of identified source areas is required to remove hydrocarbon contamination in the unsaturated zone and NAPL in perched water in relic structures. Where NAPL is encountered in unsaturated zone during earthworks, it will be remediated.
PCL10	Lateral and vertical migration of NAPL and PFAS sorbed to/dissolved in NAPL entering the deep aquifer	Potentially mobile NAPL not identified by ground investigation. Identified sources of NAPL have been within water perched in relic structures (i.e. gas works, carriage shed) which are to be remediated. No evidence of NAPL in deep aquifer.	Remediation of identified source areas is required to remove hydrocarbon contamination in the unsaturated zone and NAPL in perched water in relic structures. Where NAPL is encountered in unsaturated zone during earthworks, it will be remediated.
PCL11	Lateral and vertical migration of NAPL and PFAS sorbed to/dissolved in NAPL entering the River Irk via groundwater	Remediation of identified source areas is required to remove hydrocarbon contamination in the unsaturated zone and NAPL in perched water in relic structures. Where NAPL is encountered in unsaturated zone during earthworks, it will be remediated. No significant deterioration in quality of River Irk as it passes the site.	Remediation of identified source areas is required to remove hydrocarbon contamination in the unsaturated zone and NAPL in perched water in relic structures. Where NAPL is encountered in unsaturated zone during earthworks, it will be remediated.
PCL12	Lateral migration of contaminated shallow groundwater to the River Irk	Remediation of identified source areas is required to reduce the entry of contamination (hydrocarbons, metals, ammonia, PFAS) into shallow groundwater. Modelling shows impact of diffuse PFAS in shallow groundwater will not have a significant impact on the quality of the River Irk. No significant deterioration in quality of River Irk as it passes the site.	Removal of identified sources of contamination: Gas works, TP422/TP423, TP405A, Carriage Shed. Management of materials to be excavated and re-used as fill within the site. Reduction in infiltration through the made ground in the long term as a result of development.
PCL13	Vertical flow of contaminated shallow groundwater where glacial till is absent into deep aquifer	Remediation of identified source areas is required to reduce the entry of contamination (hydrocarbons, metals, PFAS) into shallow groundwater. Modelling shows impact of diffuse PFAS in shallow groundwater will not have a significant impact on the quality of the River Irk. No significant deterioration in quality of River Irk as it passes the site.	Removal of identified sources of contamination: Gas works, TP422/TP423, TP405A, Carriage Shed. Management of materials to be excavated and re-used as fill within the site. Reduction in infiltration through the made ground in the long term as a result of development.
PCL14	Vertical flow of contaminated shallow groundwater into deep aquifer via building piles	Piling not required as part of the HIF Infrastructure Works Will be required for future development within Victoria North.	Completion of Foundation Works Risk Assessment (FWRA) will be required once details of piled foundations for future development are known. Infilled reservoirs beneath Red Bank plateau should be avoided, or FWRA completed for piling in this area.

10 Remediation options appraisal

10.1 Summary of previous assessments

The objective of the proposed remediation scheme (part of the HIF Infrastructure works) is to facilitate the development of the Victoria North site for proposed residential and public open space end-use.

The GIR [1] included an outline remediation strategy however, the strategy was developed prior to the discovery of the emerging water. In summary, the earlier outline remediation proposals were as follows:

- Remediation was to be limited to mitigating identified risks to controlled waters only. Land contamination risk assessment and remediation associated with plot-specific development requirements were to be undertaken under subsequent application by developers.
- Removal of relic structures including the remains of a former carriage shed and a gas works. During these works, contaminated soil and perched groundwater were to undergo remediation and validation. The outline strategy focussed on excavation as the principal remedial approach.
- The proposed enabling and remedial works would lead to the generation of soil arisings that are potentially suitable for re-use as engineering fill within the site. Proposals for the assessment and management of these soil arisings were provided.

Following the discovery of PFAS in the emerging water, it has been necessary to revise the remediation proposals to address risks associated with all contaminants of concern, including PFAS.

10.2 Summary of relevant contaminant linkages

Based on the findings of the GIR [1], together with the results of the January 2023 and March 2023 investigations of PFAS impact across the site, a number of relevant source-pathway-target linkages have been identified.

10.2.1 Gas works

The gas works is located over the Collyhurst Sandstone Principal Aquifer. The contaminants of concern that have been identified in the gas works area include selected TPH fractions, PAH and ammoniacal nitrogen, which have all been detected in groundwater.

The DQRA considered the contaminant source in the gas works area and has derived remedial targets that are protective of groundwater. As discussed in **Section 7**, the remedial targets derived using RTM for PFOS and PFOA are inappropriate as remediation criteria, since they would require the remediation to achieve contaminant concentrations lower than 'residual' PFAS concentrations within the site. The remediation of 'residual' contamination is discussed in **Section 10.2.5** below.

10.2.2 TP422/TP423 PFAS outlier

An area of elevated PFAS concentrations has been identified in TP422 and to a lesser extent, in TP423, extending to a depth of c. 2.5m in TP422. A separate assessment of the potential risks to human health posed by PFAS [9] concluded that the contamination detected in TP422 and TP423 is not typical of the PFAS concentrations detected elsewhere within the site, and that the soil tested from TP422 contains PFCAs marginally in excess of the human health criteria for residential developments.

In addition, leachable concentrations of PFOA in excess of the Drinking Water Standards 'wholesomeness' threshold [11] have been recorded in TP422, with leachable concentrations of both PFOS and PFOA in excess of the EQS values [14] in TP422 and TP423. Vertical and lateral migration pathways through the made ground and alluvial soils at the site may provide viable pathways for these sources of contamination. Although no plausible linkage between the TP422/TP423 outlier and controlled waters has been conclusively demonstrated, the presence of elevated PFAS concentrations in the TP422/TP423 outlier are considered to present a potential risk to both groundwater and the River Irk.

Remediation criteria have been developed for this outlier which are protective of the River Irk, which were presented in **Section 7**.

10.2.3 The carriage shed

A risk from hydrocarbons associated with the relic carriage shed sub-structure was identified in the GIR and has been investigated further during the March 2023 PFAS investigations. Sources of both hydrocarbons and PFAS have been identified associated with perched water within the carriage shed remains. In addition, potential hydrocarbon impact of the relic carriage shed masonry has been identified.

Although no concentrations of PFOA or PFOS have been recorded in perched groundwater samples, that are greater than the Drinking Water Standards 'wholesomeness' threshold [11], the concentrations recorded are in excess of the EQS values [14].

Lateral migration pathways through the made ground at the site may provide viable pathways for these sources of contamination and therefore the presence of elevated hydrocarbon and PFAS concentrations associated with perched water encountered within the carriage shed sub-structure present a potential risk to controlled waters.

As discussed in **Section 7**, the remedial targets derived using RTM for PFOS and PFOA are inappropriate as remediation criteria, since they would require the remediation to achieve contaminant concentrations lower than 'residual' PFAS concentrations within the site. The remediation of 'residual' contamination is discussed in **Section 10.2.5** below.

10.2.4 TP405A

The March 2023 ground investigation identified an elevated leachable PFOS concentration of 92.2ng/l and leachable PFHxS concentrations of 49.8ng/l in TP405A at 2m bgl in an area of the site (earthworks area 3) that is proposed for reduced-level excavation as part of the HIF Infrastructure works. PFAS-impacted soils may be encountered during the proposed excavation works. Materials management will need to be adopted to delineate impacted soils and any areas of localised impact below the reduced-level excavation will need to be remediated and validated before reinstatement with suitable fill.

As discussed in **Section 7**, it is proposed that the remedial targets generated for the TP422/TP423 outlier are proposed for use in verifying the re-use of materials from TP405A.

10.2.5 Residual PFAS contamination of made ground

Following the completion of the remedial activities required to address the relevant source-pathway-receptor linkages discussed above, a very low residual PFAS concentration will remain within the made ground and shallow groundwater across the site (**Appendix C6**, **Drawing 15** and **Drawing 16**). This residual PFAS is generally associated with slightly elevated PFAS concentrations in the liquid phase (leachable PFAS and in limited perched groundwater), all of which are less than the Drinking Water Standards 'wholesomeness' threshold but in excess of the relevant EQS value for PFOS. The mass-balance calculations in **Section 9** conclude that this residual PFAS is not posing a significant risk to the River Irk. This options appraisal for Remedial task E considers whether there are any other reasonable measures that can be taken to prevent or minimise the further entry of PFAS into the water environment.

10.3 Relevant legislation and guidance

10.3.1 Waste management

In addition to general legislation on waste management and guidance, consideration has been given to additional guidance relating to the management of wastes containing persistent organic pollutants (POPs) [67]. The persistent organic pollutants addressed in the relevant guidance include PFOS and PFOS derivatives.

The guidance prohibits a number of activities when managing POPs waste, including:

- the repackaging and temporary storage of POPs waste (except for separation and destruction);
- recycling and re-use of waste that contains POPs.

The guidance also introduces the following hierarchy for the management of wastes which includes POPs:

- Removal of POPs from the waste (e.g. by physical separation);
- Destruction of POPs waste (e.g. by incineration);
- Applying to dispose of POPs waste by permanent storage.

Permanent storage includes disposal to hazardous waste landfills (no option is provided for disposal to other landfills), however disposal to hazardous waste landfill is only possible when the concentrations of PFOS and PFOS derivatives within the waste are less than 50mg/kg (50,000 µg/kg - the highest recorded residual PFOS concentration in soils at Victoria North is 2.13µg/kg).

In order to undertake disposal of POPs waste to hazardous waste landfill sites, a case-specific application needs to be made to the Environment Agency for their approval. We consider that the March 2023 PFAS ground investigation and the assessments presented in this report, represent the initial phases of the case-specific application for the Victoria North HIF Infrastructure works, referred to in the POPs guidance.

10.3.2 Remedial option appraisals

Selection of the most appropriate remediation approach requires an options appraisal exercise. The following guidance has been considered when addressing requirements for remediation at the Victoria North site:

10.3.3 HM Treasury (2018) The Green Book

The Green Book is guidance issued by HM Treasury on how to appraise policies, programmes and projects. It also provides guidance on the design and use of monitoring and evaluation before, during and after implementation. The guidance applies to all proposals that concern public spending, taxation, changes to regulations, and changes to the use of existing public assets and resources. It is therefore very broad in its applicability. However it does introduce the principles and terminology relevant to this assessment and used in other guidance, such as LC:RM [41] and SuRF UK [65], including:

- There should be a clear rationale for intervention, which is used to identify the objectives or desired outcomes.
- Identify and assess a long-list and subsequently a short-list of options.
- Identification of the preferred option through analysis of which option provides the best balance of costs, benefits, risks and unmonetisable factors.

10.3.4 LCRM

Land Contamination: Risk Management [41] is online guidance published by the Environment Agency. It includes specific relevant guidance relating to managing contamination on development sites. In relation to options appraisal, it is essentially consistent with previous (now withdrawn) CLR 11 guidance [68] and identifies three stages to the assessment: 1. Identify feasible remediation options; 2. Detailed evaluation of options; and 3. Select your final remediation options.

10.3.5 EA R&D on groundwater remediation cost benefit

Between 1999 and 2001 the EA commissioned a series of research studies with the intention of producing guidance on the assessment of costs and benefits associated with groundwater remediation to aid decision making, particularly related to Part 2A. The key outputs were a ‘research level’ framework for undertaking cost benefit assessment and an example of its application to a fabricated case study. The work was not progressed to an operational framework.

The reports identify many obstacles to effective groundwater cost-benefit assessment, such as the difficulty and expense associated with monetising site specific benefits and valuation of changes to risk based on the premise that the benefit of remediation is equal to the total value of the damages that would occur without remediation.

The documents focus on groundwater resource value and provide no guidance to surface water valuation and is therefore of limited direct applicability for Victoria North.

10.3.6 EA Remedial Targets Methodology

Of particular relevance to this options appraisal is the guidance in RTM **Section 9.2** [43] on assessment of environmental costs and benefits that should be undertaken if dilution in the receptor is to be considered when defining remedial targets.

RTM states ‘When evaluating whether to implement remediation measures where contamination has resulted from historical activities, the environmental benefit should be considered in relation to the cost of the scheme. The following should be taken into account:

- The cost of implementing the scheme and whether this is disproportionate in relation to environmental benefit;
- Whether remediation is technically feasible;
- The practicality of implementing the scheme;
- The improvement in water quality that would result from remediation;
- The degree of reduction in risk of future pollution;
- The wider environmental costs (such as waste generation).

These points have specifically been considered in the options appraisal.

Of relevance to Victoria North and the presence of residual PFAS contamination, RTM also states that, where the contamination of groundwater has already occurred, the complete remediation of groundwater (to pristine quality) is not always achievable or cost-beneficial, but should seek to prevent new pollution or to undertake best endeavours to do so.

10.3.7 SuRF UK

The SuRF UK (Sustainable Remediation Forum UK) framework [65] is a voluntary framework for assessing the sustainability of soil and groundwater remediation, and for incorporating sustainable development criteria in land contamination management strategies. It aims to help assessors to identify the optimum land and/or groundwater remediation strategy and/or technique.

The SuRF-UK framework recognises two main site management stages where sustainable remediation decision-making can be applied:

Stage A. The project/plan design stage; and

Stage B. The remediation options appraisal, selection and implementation.

The underlying principle of SuRF UK is that each element of sustainability (economic, environmental and social) is assessed on the basis of indicators, with sustainability being a function of all three elements.

This assessment fits into the Stage B scenario and incorporates a qualitative assessment that accords with the principles defined in the SuRF UK framework.

10.4 Remedial options appraisal approach

10.4.1 Approach

This remedial options appraisal is based largely on the Environment Agency/DEFRA publication 'Land contamination: risk management' (LCRM) and CLR 11: Model Procedures for the Management of Land Contamination [68]. The approach involves completion of the following steps:

- Undertake risk assessment – **Section 7** and **Section 8**.
- Define relevant pollutant linkages and unacceptable risks that require managing – **Section 10.2**.
- Define remediation objectives.
- Undertake a preliminary assessment of available remediation techniques to determine those which are most appropriate given the specific constraints and risks that have been identified at the site.
- Identify the most technically feasible options which address relevant pollutant linkages and meet remedial objectives.
- Selection of most suitable option or options to create a remediation strategy.

10.4.2 Remediation objectives

The remediation objectives should relate to the reduction or control of risks associated with the relevant pollutant linkages that have been identified and can be 'technical' or 'management' related.

Management objectives:

- To design and implement a remediation strategy that will achieve regulatory approval and be compliant with regulatory requirements;
- To ensure that the site is remediated to a state that will reduce the risks of future regulatory intervention;
- The successful remediation of the site must be carried out within a specified budget, therefore cost-effective remediation techniques are required;
- The successful remediation and handover of the site must be carried out within a specified time frame in order to satisfy requirements of funding bodies;
- Remediation techniques should be reliable and proven;
- An environmentally sustainable solution is sought that will limit environmental impacts;
- Unacceptable health and safety risks to site workers must be avoided.

Technical objectives:

- To address relevant pollutant linkages to ensure that no unacceptable acute or long-term risks are posed to the identified receptors;
- To prevent unacceptable impact on the River Irk;
- To prevent deterioration of groundwater quality beneath the site;
- Risk of damage to existing site infrastructure should be prevented.

10.5 Assumptions regarding remedial costs

The unit rates used to undertake the remedial options appraisal presented in **Appendix F** and summarised below have been determined after extensive consultation with BAM Nuttall Limited and their supply chain. In addition, appropriate unit rates from other relevant projects have been considered when undertaking the cost-benefit appraisal that is presented in this report. The unit rates and associated costs presented in this report are therefore, considered to be appropriately robust for the purpose of this cost-benefit assessment. These rates and costs should not however, be used for any other purpose.

As discussed in **Section 1.5**, given the current status of PFAS as emerging contaminants however, there is the potential for changes in legislation and guidance, together with changes in the way current regulations are interpretated and applied by the waste management industry. These changes may occur in the short-term and may impact the conclusions reached in this cost-benefit assessment (for example by impacting relevant unit rates and costs). Arup can accept no liability for any subsequent changes in relevant costs or unit rates arising from changes in legislation, guidance or industry practice.

10.6 Identification of feasible remediation options

In order to identify the feasible remedial solutions that are applicable to the Victoria North site, each of the relevant source-pathway-target linkages discussed in **Section 10.2** has been considered. Feasible remediation technologies are categorised as those which potentially address the source and those which address the pathway between a source and receptor. The base-case of no further action is also considered.

In the assessments that follow, items identified in green text are considered to be significant advantages of the relevant remedial technique, when applied to the site. Items in red text are considered to be significant disadvantages.

10.6.1 Remedial Task A: Gas works

Principal contaminants of concern have been identified as selected TPH fractions, PAH and ammoniacal nitrogen. These contaminants have been shown to be present in groundwater and are therefore, mobile. In some areas, contaminated groundwater will be confined by the relic gas works structure.

Remediation technique	Remediation achieved by…	Description	Do proposals fit with site development plans?	Relative Cost (£) and programme implications (T)	Potential advantages	Potential limitations	Comments
Excavation and disposal off site	Removing the source	Excavation of impacted soils. Excavation of relic gas works structures. Dewatering will be required during excavation, with treatment and/or off-site disposal of fluids. Off site disposal of excavated soils.	No – unless reduced ground levels across the site are to be adopted, excavation will need to be reinstated with site won or imported fill.	££££ TTT	Effective in permanently removing the risks from the site. Requires only conventional earthworks plant.	Transfers the problem elsewhere. Only likely to be cost-effective for the most heavily impacted soils. May require consideration of the waste management implications of the removal of PFAS impacted soils from site if remediation is combined with TP422/TP423 outlier removal.	A versatile approach that can respond to unforeseen ground conditions and can address a variety of constraints. It may be appropriate to combine the gas works remediation with the adjacent remediation of the TP422/TP423 outlier. If stabilisation is proposed for the remediation of the adjacent TP422/TP423 outlier, it may not be appropriate to mix treatment techniques.
Ex-situ stabilisation	Reducing contaminant mobility (limiting the pathway)	Impacted soils require excavation. Excavation of relic gas works structures. Dewatering will be required during excavation, with treatment and/or off-site disposal of fluids. On-site addition of stabilisers and reuse of stabilised material to reinstate excavation	Yes	£££ TTTT	Correctly dosed and with the selection of an appropriate stabilising medium, this approach may be effective in addressing the relevant risks. Requires only conventional earthworks plant.	A single stabilising agent may be unable to address the range of contaminants of concern that have been identified at the former gas works site. Will require consideration of waste management permitting to allow re-use of treated soils. Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require site trials to determine the details of the required stabilisation program. Control of pH may be required to avoid release of PFAS in alkaline conditions. If excavation and removal is proposed for the remediation of the adjacent TP422/TP423 outlier, it may not be appropriate to mix treatment techniques.
In-situ stabilisation	Reducing contaminant mobility (limiting the pathway)	In-situ mixing of stabilisers to reduce the availability of contaminants of concern.	Yes	£££ TTT	Correctly dosed and with the selection of an appropriate stabilising medium, this approach may be effective in addressing the relevant risks. Waste management permitting requirements may be less onerous than other techniques.	Not considered to be feasible due to the remains of relic structures that will inhibit the in-situ mixing process. A single stabilising agent may be unable to address the range of contaminants of concern that have been identified at the former gas works site. Requires specialist in-situ treatment plant. Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require site trials to determine the details of the required stabilisation program. Proof-of-concept may need to be demonstrated. Control of pH may be required to avoid release of PFAS in alkaline conditions. If excavation and removal is proposed for the remediation of the adjacent TP422/TP423 outlier, it may not be appropriate to mix treatment techniques.
Provide clean cover/ impermeable site finish	Breaking the pathway	Provision of a low permeability clean soil layer across the former gas works, using Geobinder or similar.	Yes	£ T	Will reduce infiltration leading to a reduction in contaminant leaching. Will protect users of the site.	Will not address in-ground obstructions (the gas works substructure). Localised provision of impermeable cover will not address risks arising from rainfall infiltration within the site and associated lateral migration pathways. Will require provision of surface water drainage– likely to require discharge to sewer and/or on-site treatment.	Clean cover systems offer protection to users of the site against a range of contaminants of concern. Combining this with a low permeability layer will reduce infiltration in the period prior to development.
No further action	-	No specific remedial actions taken	Yes	None	Has zero cost and programme implications	Offers no means to address the plausible source-pathway-receptor linkages that have been identified.	Contaminant risks are not addressed.

10.6.2 Remedial task B: TP422/TP423 Outlier

The principal contaminant of concern has been identified as PFAS, which has been shown to be present at elevated concentrations in soil and in the leachable fraction. No relic structures have been identified in this area and perched groundwater is unlikely to present a significant constraint.

Remediation technique	Remediation achieved by…	Description	Do proposals fit with site development plans?	Relative Cost (£) and programme implications (T)	Potential advantages	Potential limitations	Comments
Excavation and disposal off site	Removing the source	Excavation of impacted soils. Off site disposal of excavated soils.	No – unless reduced ground levels across the site are to be adopted, excavation will need to be reinstated with site won or imported fill	£££ TTT	Effective in permanently removing the risks from the site. Requires only conventional earthworks plant.	Transfers the problem elsewhere. Only likely to be cost-effective for the most heavily impacted soils. Will require consideration of the waste management implications of the removal of PFAS impacted soils from site.	A versatile approach that can respond to unforeseen ground conditions and can address a variety of constraints. It may be appropriate to combine the remediation of the TP422/TP423 outlier with the remediation of the adjacent gas works area. If stabilisation is proposed for the remediation of the adjacent gas works area, it may not be appropriate to mix treatment techniques.
Ex-situ stabilisation	Reducing contaminant mobility (limiting the pathway)	Impacted soils require excavation. On-site addition of stabilisers and reuse of stabilised material to reinstate excavation	Yes	£££ TTTT	Correctly dosed and with the selection of an appropriate stabilising medium, this approach may be effective in addressing the relevant risks. Requires only conventional earthworks plant.	Will require consideration of waste management permitting to allow re-use of treated soils. Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require site trials to determine the details of the required stabilisation program. Control of pH may be required to avoid release of PFS in alkaline conditions. If excavation and removal is proposed for the remediation of the adjacent gas works, it may not be appropriate to mix treatment techniques.
In-situ stabilisation	Reducing contaminant mobility (limiting the pathway)	In-situ mixing of stabilisers to reduce the availability of contaminants of concern.	Yes	£££ TTT	Correctly dosed and with the selection of an appropriate stabilising medium, this approach may be effective in addressing the relevant risks. Waste management permitting requirements may be less onerous than other techniques.	The effectiveness of this remediation technology is not fully established in the marketplace. Requires specialist in-situ treatment plant. Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require site trials to determine the details of the required stabilisation program. Proof-of-concept may need to be demonstrated. Control of pH may be required to avoid release of PFS in alkaline conditions.
Provide clean cover/ impermeable site finish	Breaking the pathway	Provision of a low permeability clean soil layer across the outlier using Geobinder or similar.	Yes	£ T	Will reduce infiltration leading to a reduction in contaminant leaching. Will protect users of the site.	Localised provision of impermeable cover will not address risks arising from rainfall infiltration within the site and associated lateral migration pathways. Will require provision of surface water drainage– likely to require discharge to sewer and/or on-site treatment.	Clean cover systems offer protection to users of the site against a range of contaminants of concern. Combining this with a low permeability layer will reduce infiltration in the period prior to development.
No further action	-	No specific remedial actions taken	Yes	None	Has zero cost and programme implications	Offers no means to address the plausible source-pathway-receptor linkages that have been identified.	Contaminant risks are not addressed.

10.6.3 Remedial task C: Carriage shed

The principal contaminants of concern have been identified as selected TPH fractions and PFAS. These contaminants have been shown to be present in perched groundwater which is constrained by the relic carriage shed sub-structure.

Remediation technique	Remediation achieved by…	Description	Do proposals fit with site development plans?	Relative Cost (£) and programme implications (T)	Potential advantages	Potential limitations	Comments
Excavation and disposal off site	Removing the source	Excavation of impacted soils. Excavation of relic carriage shed sub-structure. Dewatering will be required during excavation, with treatment and/or off-site disposal of fluids. Processing of suitable excavation arisings for recover and re-use where possible. Off site disposal of excavated soils.	No – unless reduced ground levels across the site are to be adopted, excavation will need to be reinstated with site won or imported fill	£££ TTT	Effective in permanently removing the risks from the site. Requires only conventional earthworks plant.	Transfers the problem elsewhere. Only likely to be cost-effective for the most heavily impacted soils. Will require consideration of the waste management implications of the removal of PFAS impacted soils from site and of recovery and re-use of suitable excavation arisings.	A versatile approach that can respond to unforeseen ground conditions and can address a variety of constraints.
Ex-situ stabilisation	Reducing contaminant mobility (limiting the pathway)	Impacted soils require excavation. Excavation of relic sub-structure. Dewatering will be required during excavation, with treatment and/or off-site disposal of fluids. On-site addition of stabilisers and reuse of stabilised material to reinstate excavation	Yes	£££ TTTT	Correctly dosed and with the selection of an appropriate stabilising medium, this approach may be effective in addressing the relevant risks. Requires only conventional earthworks plant.	A single stabilising agent may be unable to address the range of contaminants of concern that have been identified. Will require consideration of waste management permitting to allow re-use of treated soils. Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require site trials to determine the details of the required stabilisation program. Control of pH may be required to avoid release of PFS in alkaline conditions.
In-situ stabilisation	Reducing contaminant mobility (limiting the pathway)	In-situ mixing of stabilisers to reduce the availability of contaminants of concern.	Yes	£££ TTT	Correctly dosed and with the selection of an appropriate stabilising medium, this approach may be effective in addressing the relevant risks. Waste management permitting requirements may be less onerous than other techniques.	Not considered to be feasible due to the remains of relic structures that will inhibit the in-situ mixing process. Effectiveness of stabilisation may not be fully proven. A single stabilising agent may be unable to address the range of contaminants of concern that have been identified at the site. Requires specialist in-situ treatment plant. Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require site trials to determine the details of the required stabilisation program. Proof-of-concept may need to be demonstrated. Control of pH may be required to avoid release of PFS in alkaline conditions.
Provide clean cover/ impermeable site finish	Breaking the pathway	Provision of a low permeability clean soil layer across the carriage shed area, using Geobinder or similar.	Yes	£ T	Will reduce infiltration leading to a reduction in contaminant leaching. Will protect users of the site.	Will not address in-ground obstructions (the carriage shed substructure). Localised provision of impermeable cover will not address risks arising from rainfall infiltration within the site and associated lateral migration pathways. Will require provision of surface water drainage– likely to require discharge to sewer and/or on-site treatment.	Clean cover systems offer protection to users of the site against a range of contaminants of concern. Combining this with a low permeability layer will reduce infiltration in the period prior to development.
No further action	-	No specific remedial actions taken	Yes	None	Has zero cost and programme implications	Offers no means to address the plausible source-pathway-receptor linkages that have been identified.	Contaminant risks are not addressed.

10.6.4 Remedial Task D: TP405A

Elevated leachable PFAS concentrations have been identified in TP405A at 2m bgl in an area of the site proposed for reduced-level excavation (earthworks area 3). PFAS-impacted soils may be encountered during the proposed excavation works requiring the adoption of materials management measures. Areas of localised PFAS impact below the reduced-level excavation may require remediation, validation and reinstatement.

Remediation technique	Remediation achieved by…	Description	Do proposals fit with site development plans?	Relative Cost (£) and programme implications (T)	Potential advantages	Potential limitations	Comments
Excavation and disposal off site	Removing the source	Excavation of impacted soils. Off site disposal of excavated soils.	Largely yes, however any remediation required below the base of the reduced-level excavation will require reinstatement with site won or imported fill.	££££ TTT	Effective in permanently removing the risks from the site. Requires only conventional earthworks plant.	Transfers the problem elsewhere. Only likely to be cost-effective for the most heavily impacted soils. Will require consideration of the waste management implications of the removal of PFAS impacted soils from site.	A versatile approach that can respond to unforeseen ground conditions and can address a variety of constraints. Remediation by means of excavation and removal may be appropriate given that earthworks area 3 is a net-excavation area.
Ex-situ stabilisation	Reducing contaminant mobility (limiting the pathway)	Impacted soils require excavation. On-site addition of stabilisers and reuse of stabilised material to reinstate excavation	Yes	£££ TTTT	Correctly dosed and with the selection of an appropriate stabilising medium, this approach may be effective in addressing the relevant risks. Requires only conventional earthworks plant.	A single stabilising agent may be unable to address the range of contaminants of concern that have been identified. Will require consideration of waste management permitting to allow re-use of treated soils. Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require site trials to determine the details of the required stabilisation program. Control of pH may be required to avoid release of PFS in alkaline conditions.
In-situ stabilisation	Reducing contaminant mobility (limiting the pathway)	In-situ mixing of stabilisers to reduce the availability of contaminants of concern.	Yes	£££ TTT	Correctly dosed and with the selection of an appropriate stabilising medium, this approach may be effective in addressing the relevant risks. Waste management permitting requirements may be less onerous than other techniques.	The effectiveness of this remediation technology is not fully established in the marketplace. A single stabilising agent may be unable to address the range of contaminants of concern that have been identified at the site. Requires specialist in-situ treatment plant. Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require site trials to determine the details of the required stabilisation program. Proof-of-concept may need to be demonstrated. Control of pH may be required to avoid release of PFS in alkaline conditions.
Provide clean cover/ impermeable site finish	Breaking the pathway	Provision of a low permeability clean soil layer across the outlier, using Geobinder or similar.	Yes	£ T	Will reduce infiltration leading to a reduction in contaminant leaching. Will protect users of the site.	Localised provision of impermeable cover will not address risks arising from rainfall infiltration within the site and associated lateral migration pathways. Will require provision of surface water drainage– likely to require discharge to sewer and/or on-site treatment.	Clean cover systems offer protection to users of the site against a range of contaminants of concern. Combining this with a low permeability layer will reduce infiltration in the period prior to development.
No further action	-	No specific remedial actions taken	Yes	None	Has zero cost and programme implications	Offers no means to address the plausible source-pathway-receptor linkages that have been identified.	Contaminant risks are not addressed.

10.6.5 Remedial task E: Residual PFAS contamination of made ground

Generally, elevated PFAS concentrations in made ground have not been identified. Very low concentrations of residual PFAS have been identified in the leachable fraction and in shallow groundwater. Whilst a mass-balance approach has been taken to assess the potential risks to the River Irk from residual PFAS, which shows no significant impact, if the conclusions of the mass balance approach are not accepted, then remediation to address risks to controlled waters from residual PFAS across the site would be required and is considered below.

Remediation technique	Remediation achieved by…	Description	Do proposals fit with site development plans?	Relative Cost (£) and programme implications (T)	Potential advantages	Potential limitations	Comments
Excavation and disposal off site	Removing the source	Excavation of all made ground across Red Bank plateau. Off site disposal of excavated soils. Assume no reinstatement of original ground levels.	No – masterplanning and design of supporting infrastructure will need to be repeated to accommodate revised ground levels. Proposal has implications for existing boundary features, retaining walls etc.	£££££ TTTT	Effective in permanently removing the risks from the site. Requires only conventional earthworks plant.	The volume of the impacted made ground will be substantial, there may be insufficient landfill capacity available for this option. Significant traffic impact due to off-site haulage requirements. Transfers the problem elsewhere. Not considered cost-effective for marginal PFAS impact. Post-remediation access into the site from Red Bank will be difficult. Will require consideration of the waste management implications of the removal of PFAS impacted soils from site.	Reduced site levels will make access to the site more difficult imposing an additional constraint for development. Significant cost and programme implications
Ex-situ stabilisation	Reducing contaminant mobility (limiting the pathway)	Excavation of all made ground across Red Bank plateau. Treatment of all impacted soils. On-site addition of stabilisers and reuse of stabilised material to reinstate excavation	Yes	£££ TTT	Correctly dosed and with the selection of an appropriate stabilising medium, this approach may be effective in addressing the relevant risks. Requires only conventional earthworks plant.	The volume of treatment required will be substantial. Will require consideration of waste management permitting to allow re-use of treated soils. Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require site trials to determine the details of the required stabilisation program. Proposal has implications for existing boundary features, retaining walls etc. Significant cost and programme implications
In-situ stabilisation	Reducing contaminant mobility (limiting the pathway)	In-situ mixing of stabilisers to reduce the availability of contaminants of concern.	Yes	£££ TT	Correctly dosed and with the selection of an appropriate stabilising medium, this approach may be effective in addressing the relevant risks. Avoids requirement to excavate, treat and re-engineer made ground – treatment is undertaken in-situ. Waste management permitting requirements may be less onerous than other techniques.	The effectiveness of this remediation technology is not fully established in the marketplace. Maybe difficult to carry out in-situ treatment at depth. Requires specialist in-situ treatment plant Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require site trials to determine the details of the required stabilisation program. Proof-of-concept may need to be demonstrated. Control of pH may be required to avoid release of PFS in alkaline conditions. Significant cost and programme implications
Provide clean cover/ impermeable site finish	Breaking the pathway	Provision of a low permeability clean soil layer across the plateau, using Geobinder or similar.	Yes	£ T	Will reduce infiltration leading to a reduction in contaminant leaching. Will protect users of the site.	Will require provision of surface water drainage– likely to require discharge to sewer and/or on-site treatment.	Clean cover systems offer protection to users of the site against a range of contaminants of concern. Combining this with a low permeability layer will reduce infiltration in the period prior to development.

Remediation technique	Remediation achieved by…	Description	Do proposals fit with site development plans?	Relative Cost (£) and programme implications (T)	Potential advantages	Potential limitations	Comments
Permeable reactive barrier (PRB)	Interrupting the pathway	A series of closely spaced boreholes are drilled along the edge of the Red Bank plateau to intercept the made ground/alluvium/glacial till interface. Reactive media installed in boreholes (3m thick) to intercept groundwater at interface.	Largely, but may sterilise a strip of land along and behind the PRB.	££ TTT	Correctly dosed and with the selection of a suitable reactive medium, the approach is likely to address lateral migration of residual PFAS towards the River Irk. Use of boreholes will mitigate significant practical difficulties associated with the provision of a trench-based PRB.	Effectiveness of reactive media will need to be demonstrated. Operational life (before reactive media becomes saturated) will need to be demonstrated. Post-remediation monitoring and validation requirements will need to be agreed with the EA.	Will require trial programme to determine the details of the required PRB installation. May be possible to further refine the system and reduce costs by considering a 'funnel and gate' type approach, with a limited extent of PRB. This will require further groundwater modelling.
No further action	-	No remediation of residual PFAS Yes	Yes	None	Has zero cost and programme implications	Offers no means to address plausible source-pathway-receptor linkages that may be identified.	Indicative PFAS model indicates risk from residual PFAS contamination is acceptable.

10.7 Evaluation of remedial options

10.7.1 Assessment of remedial options short-list

In order to further inform the remedial options appraisal and to assist with the rationalisation of the information presented in **Section 10.6**, the following further consideration has been given to the identified remediation options:

- In-situ stabilisation. This technique has not been carried forward into the identification of preferred remediation options because the approach is currently not widely established in the UK remediation marketplace. Given that the proposed development of the site is for a residential end-use, the viability of the remediation technique is likely to be impacted by the need to undertake further development and proof-of concept work, in order to satisfy the requirements of organisations such as National House Building Council (NHBC). Although, in-situ stabilisation has a number of potential advantages over other approaches (see the green text in **Section 10.6**), the programme implications of demonstrating the viability and suitability of this remedial approach are considered to be too great to allow it to be considered further for this project.
- Impermeable cover. For remedial tasks A to D, localised provision of impermeable cover is not considered viable when applied only to specific outliers within the site. This is because rainfall infiltration in those areas of the site that have not been provided with impermeable cover, may lead to the development of lateral migration pathways which may in turn lead to leaching of contaminants from within the outliers and a consequent risk to controlled waters. The provision of a temporary impermeable cover is considered viable for remedial task E however, because in this case, the impermeable cover would be applied across the entire surface of Red Bank plateau and would therefore provide a more widespread barrier to rainfall infiltration.

10.7.2 Remedial tasks A to D

The objectives of Remedial tasks A to D are to address the primary areas of contaminant impact within the site for which unacceptable risks to human health and controlled waters have been demonstrated. The completion of remedial tasks A to D is considered to address the key ground contamination issues associated with the site.

Having further considered the viability of the remedial options that have been identified (**Section 10.7.1**), the remaining remedial options relevant to remedial tasks A to D are presented in **Table 42**, together with further considerations of viability and a summary of relevant budget remediation costs. The assessments used to develop these budget remediation costs are presented in **Appendix F**. Note these are indicative budget costs only and should only be used as part of this remedial options appraisal.

Remedial task	Remedial option 1a Excavation, disposal and reinstatement[1]	Remedial option 2 Ex-situ stabilisation[2]	Remedial option 3 No further action
A Gas works	£2,000,000	£1,100,000	Not viable risks to human health and controlled waters have been identified
B TP422/TP423	£1,500,000	£1,400,000	
C Carriage shed	£2,000,000	£2,200,000	
D TP405A	£60,000	£30,000	May be viable subject to further assessment during earthworks
Estimated total budget costs for tasks A to D	**£5,560,000**	**£4,730,000**	

Notes

See Appendix F for the derivation of costs used in this cost-benefit assessment.

1 Includes: dewatering if required, excavation, haulage and disposal, reinstatement and validation.

2 Includes: dewatering if required, excavation, stabilisation, reinstatement and validation.

Table 42: Remedial options viability/cost matrix – remedial tasks A to D

Table 42 indicates that to address remedial tasks A to D, two remedial options are potentially viable. These are:

- Remedial option 1a – excavation, removal off site and reinstatement with suitable soils, recovered from site.
- Remedial option 2 – excavation, ex-situ stabilisation of the arisings and reinstatement of the excavations using treated material.

There are a number of further important considerations that should be noted when assessing **Table 42**:

- When remedial option 1a is applied to the carriage shed, it has been assumed that up to 50% of the excavated material will be suitable for recovery by processing, with the recovered fill suitable for use as general fill within the development. The PFAS soil concentrations identified in the carriage shed (**Appendix C3**) are lower than the ecological risk criteria identified in **Table 24**, indicating that the recovery of excavated soils containing residual PFAS at Victoria North will not present an ecological risk.
- Further assessment will be required to establish whether remedial option 2 needs to be applied to all excavated soils removed from the carriage shed area. For this cost assessment, it has been assumed that all the material excavated from the footprint of the carriage shed will need to be stabilised prior to recovery for re-use.

We do not consider it appropriate or cost-effective to select different remedial options when addressing remedial tasks A to D and a commitment to either excavation and disposal (Option 1a) or to ex-situ stabilisation (Option 2) is required. Option 1a represents a remedial approach that is deliverable in the short term, without the need for remedial trials or other forms of proof of concept work. If remedial tasks A to D are addressed by excavation and removal from site, total budget costs for all four remedial tasks are estimated at £5.56M.

Rather than excavation and disposal, ex-situ stabilisation (Option 2) could be selected to address remediation tasks A to D. Budget costs of £4.73M have been identified for Option 2. Option 2 however, may have more significant programme implications as it is likely to require laboratory and/or field trials to demonstrate that the proposed remedial technique will achieve the required objectives for all contaminants of concern. In addition, there may be significant regulatory requirements during the post-remediation (validation) phase, required to demonstrate that the remediation objectives have been met in the long-term. These will add to the programme and potentially lead to additional costs that cannot be identified at this stage. The budget costs presented in **Table 42**, do not include for the potential costs that may be incurred as a result of programme delays that may be associated with field trials and any subsequent environmental permitting requirements.

10.7.3 Remedial task E

Once remedial tasks A to D have been completed, there will remain a potential risk to the River Irk from residual PFAS at the site. Remedial task E is intended to address this risk and as **Table 43** indicates, a number of viable remediation options have been identified which are each considered to address the requirements of this remedial task.

Remedial task	Remedial option 1b. Excavation and disposal[1]	Remedial option 2 Ex-situ stabilisation[2]	Remedial option 3 Impermeable cover	Remedial option 4 Permeable Reactive Barrier[3]	Option 5 No further action
E Residual PFAS	£50,000,000	£53,000,000	£1,200,000	£4,700,000	Viable based on findings of Arup indicative PFAS model

Notes

See Appendix F for the derivation of costs used in this cost-benefit assessment.

1 Includes: dewatering if required, excavation, haulage and disposal and validation. No cost allowance has been made for reinstating original ground levels, once made ground has been removed.

2 Includes: dewatering if required, excavation, stabilisation, reinstatement and validation. For remedial task E, the budgets costs have assumed that once stabilised, the treated material will be used to reinstate development levels.

3 Includes: closely-spaced CFA boreholes along 600m alignment, with 3m reactive zone in each.

Table 43: Remedial options viability/cost matrix – remedial task E

Table 43 indicates that there are a number of viable interventions that will address the potential risks to the River Irk associated with residual PFAS at the site. These interventions range in cost from the provision of a temporary impermeable cover layer across the site (£1.2M) to the ex-situ stabilisation of the made ground and reinstatement of ground levels (£53M).

There are a number of further important considerations that should be noted when assessing Table **43: Remedial options viability/cost matrix – remedial task E**

- Remedial option 1b – excavation and disposal. It has been assumed for this options appraisal, that all made ground will be removed from site, in order to fully remove potential PFAS risks to the River Irk. In addition to the substantial cost, this option will have significant programme implications and it may be difficult to identify sufficient hazardous waste landfill capacity in accordance with the requirements of the guidance on waste management of materials containing persistent organic pollutants (POPs – **Section 10.3**). The resulting reduced site levels will make access to the site more difficult, imposing an additional constraint for development. Reduction of site levels will also have significant implications for existing boundary features, retaining walls etc. and will require that masterplanning and the design of supporting infrastructure is revised to accommodate the lower ground levels that result from remediation. The costs of securing sufficient volumes of imported suitable fill to reinstate ground levels are considered to be further prohibitive and have not therefore, been allowed for in this assessment.
- Remedial option 2 – ex-situ stabilisation. Unlike remedial option 1b, this option includes for reinstating ground levels with stabilised material, which adds to the associated budget costs. Option 2 however, may have more significant programme implications as it is likely to require laboratory and/or field trials to demonstrate that the proposed remedial technique will achieve the required objectives for all contaminants of concern. In addition, there may be significant regulatory requirements during the post-remediation (validation) phase, required to demonstrate that the remediation objectives have been met in the long-term. These will add to the programme and potentially lead to additional costs that cannot be identified at this stage. The budget costs presented in **Table 43**, do not include for the potential costs that may be incurred as a result of programme delays associated with field trials and any subsequent environmental permitting requirements. During stabilisation works, site levels will be reduced temporarily, with associated temporary implications for existing boundary features, retaining walls etc. This option however, will not require that masterplanning and the design of supporting infrastructure is revised to accommodate a permanent reduction of ground levels.
- Remedial option 3 -Impermeable cover. Under this remedial option, existing made ground would remain in-situ and risks to the River Irk would be addressed by the provision of an impermeable cover across the entire site. This impermeable cover would be a temporary intervention, which will reduce rainfall infiltration and therefore reduce leaching, in the period leading up to development. In the long-term, the temporary impermeable layer would be progressively replaced by the ground-floor slabs of proposed buildings, proposed carriageways and other areas of hard standing, allowing the overall reduction in leaching to be maintained. The budget costs that have been presented include for a temporary surface water drainage system however, there will be issues relating to the point of discharge for this temporary drainage system and discussions with UU and/or the EA will be required to resolve these.
- Remedial option 4 – permeable reactive barrier. Under this option, risks to the River Irk are addressed by the construction of a permeable reactive barrier (PRB) system along the downgradient edge of the site before groundwater can reach the river. In this case it is assumed that this PRB would consist of a series of closely spaced boreholes, each of which would be provided with a 3m reactive zone at the made ground/glacial till interface, by injection of the permeable reactive agent. The provision of a PRB however, is likely to lead to a reduction of developable area on Red Bank plateau, as access to the full length of the permeable reactive barrier will be required for on-going monitoring and maintenance. In addition, remedial option 4, may have significant programme implications associated with the need for laboratory and/or field trials (to demonstrate that remedial objectives will be met) and to address post-remediation monitoring requirements.

As demonstrated in **Section 8.6** however the mass-balance model that has been developed for Victoria North, indicates that residual PFAS does not present a demonstrable or measurable risk to the river and on this basis, it is appropriate to consider a ‘no further action’ option (Option 5). Under this scenario, there would therefore be no additional remediation costs in addition to those indicated for remedial tasks A to D above.

10.8 Conclusions of options appraisal

The remediation options appraisal has concluded that the most viable solution for the remediation of the contamination sources identified at the gas works, TP422/TP423, Carriage Shed and TP405A (remedial tasks A to D) is excavation, disposal and reinstatement. This conclusion is based principally on the programme constraints that are understood to exist in relation to existing funding opportunities for the Victoria North HIF Infrastructure Works. As currently understood, these programme constraints are considered to largely preclude adoption of remedial option 2 to address remedial tasks A to D.

With regard to the remediation of residual PFAS (remedial task E), the remediation options appraisal has identified four viable remedial interventions, with estimated costs in the range £1.2 million (option 3 - temporary impermeable cover) to £53 million (option 2 - ex-situ stabilisation). However, the mass-balance modelling presented in **Section 8.6** has established that the residual PFAS impact at the site presents no demonstrable risk to the River Irk. On this basis, it is concluded that the cost of implementing remedial options 1b to 4 to address remedial task E would be disproportionate in relation to their environmental benefit and would not result in a discernible improvement in water quality within the river. Furthermore, the wider environmental costs associated with these potential remedial interventions, such as the waste generated by Option 1b (excavation and disposal) and the potential carbon emissions associated with transportation of the waste from site, or ex-situ stabilisation (Option 2) would be significant.

As contamination of the groundwater has already occurred and there is no discernible impact on river water quality currently, the complete remediation of made ground and groundwater to pristine quality is not justified. However, the other remediation actions proposed (remedial tasks A to D) are considered appropriate as they constitute best endeavours to prevent new pollution of controlled waters from occurring.

11 Discussion and conclusions

11.1 Conclusions and summary of risk assessment findings

The key controlled water receptors comprise shallow groundwater in alluvium; the deep principal aquifers (the Collyhurst Sandstone and the Chester Formation) and the River Irk, which forms the south-eastern boundary of the site. Ground investigation data suggests that the river receives discharge from both the shallow and deep aquifers.

Water quality in the River Irk has been measured on several occasions as part of ground investigations. Some exceedances of the water quality standards are noted in the river upstream of the site, most notably for zinc, fluoranthene and PFAS. The concentrations of these contaminants do not vary greatly as the river passes the site, indicating that the site is not having a significant impact on river water quality.

Emerging water that was identified in a small area in the north of the site has been found to contain very low concentrations of PFAS, with no demonstrable impact on soil concentrations. Outside the emerging water area, PFAS has generally not been identified in soil however, a significant PFAS outlier has been identified in the TP422/TP423 area, which is not believed to be associated with the emerging water and is likely the result of historic construction activity.

Assessment of soil leachability and shallow groundwater has identified the presence of elevated PFAS concentrations in shallow groundwater within the former railway carriage shed, which are not typical of concentrations observed elsewhere within the site, suggesting a separate source to the emerging water. In addition, a localised occurrence of leachable PFAS was identified at TP405A at 2m depth which was not typical of the site generally. Other contaminants of concern identified are metals, ammoniacal nitrogen, TPH and PAH, which are generally associated with the gas works and carriage shed areas.

The drinking water standard (DWS) is considered to be the relevant screening value for the principal aquifers. However, as groundwater discharges into the River Irk, the environmental quality standard (EQS) becomes the relevant water quality standard (WQS).

The results of soil leachate analysis for PFAS (using PFOS and PFOA as marker compounds) have been compared against WQS to provide an indication of the potential risks to controlled waters. The concentrations of PFOS and PFOA in soil leachate from TP422/TP423 exceed the DWS and remediation of this outlier is recommended to protect groundwater quality. No other exceedances of the DWS were noted for PFAS. However, the majority of soil leachate samples and shallow groundwater samples exceeded the EQS.

Detailed quantitative risk assessment (DQRA) has been carried out using RTM, with remediation criteria generated for the identified soil source areas. Re-use criteria have also been derived for site-won soils to be placed within St. Catherine's Wood or Red Bank terrace, where the soil has been derived elsewhere within the site. General re-use criteria have not been derived for materials excavated and re-used within Red Bank plateau, as there is no evidence to indicate that water quality within the River Irk is being adversely impacted by existing ground conditions at the site and therefore local re-distribution of existing materials will not introduce new contaminant linkages or increase risks to controlled waters.

On the basis of the controlled waters risk assessment that has been undertaken, the following requirements for targeted remediation have been identified in order to protect human health or controlled waters:

- Remedial task A – The former 'gas works' site.
- Remedial task B – The TP422/TP423 PFAS outlier.
- Remedial task C – The former carriage shed area.
- Remedial task D – TP405A at 2m bgl.

After remediation of the four areas identified above (remedial tasks A to D) there will remain very low residual leachable PFAS concentrations at the site, together with very low PFAS concentrations in shallow groundwater. A simple mass-balance model has been developed to provide further assessment of the risks to the River Irk from residual PFAS. Following the proposed remediation of the site (remedial tasks A to D), the mass-balance model suggests that there will be no measurable impact on river water quality from the residual PFAS sources that have been identified.

A remedial options appraisal including a cost benefit assessment has concluded that the most viable remedial option for tasks A to D is excavation and offsite disposal of contaminated material (remedial option 1a). An alternative intervention (ex-situ soil stabilisation – remedial option 2) has been considered however, the timescales that are considered necessary to undertake site trials and to develop the relevant remediation strategy, are considered to be protracted and may impact milestones associated with funding opportunities that have been secured for the site.

The remediation options appraisal for residual PFAS (remedial task E) identified a number of potentially viable remedial measures. Two of these remedial options aimed to fully remove residual PFAS risk from the site, however as contamination of the groundwater has already occurred and there is no discernible impact on river water quality either measured on site or through mass-balance modelling, the complete remediation of made ground and groundwater to pristine quality is not justified. A number of other remediation options were identified which constitute best endeavours to prevent new pollution of controlled waters from occurring, without the substantial interventions required to achieve complete remediation. Given however, there is no discernible impact on river water quality, it is concluded that expenditure to address residual PFAS would be disproportionate in relation to its environmental benefit and it is concluded that no additional measures are required to address the risk from residual PFAS or other contaminants identified at the site.

It is recommended therefore, that remediation is undertaken to address remedial tasks A to D and that excavation and removal from site is the most appropriate remedial option. Of the viable remedial options considered, it is concluded that no further action is required to address risks to the River Irk associated with residual PFAS identified at the site.

11.2 Recommendations for remediation strategy

A Remediation Strategy and Verification Plan is to be developed for the HIF Infrastructure works by BAM, informed by the outcome of this controlled waters risk assessment. Approval of the Remediation Strategy and Verification Plan is anticipated to be a pre-commencement planning condition. The following actions need to be carried forward into that document:

- Implementation of a discovery strategy during remediation to ensure that any previously unidentified areas of contamination are identified and dealt with and are not taken for re-use as fill elsewhere within the site. In addition, any existing monitoring wells or historic water wells that are encountered during the discovery strategy should be grouted to prevent them acting as a pathway in future;
- Gross hydrocarbon contamination should be removed where it is encountered during earthworks carried out as part of the HIF Infrastructure Works. Gross hydrocarbon contamination is defined as material saturated with free product, i.e. significant visible oil, solvents or tar within soil, or on/within groundwater;
- Remediation is required within the former 'gas works', including excavation of subsurface structures and associated contamination. The remedial targets to be met are set out in **Table 44** below. The Remediation Strategy should include frequency of testing and approach to data interpretation;
- Remediation is required within the former carriage shed, including excavation of subsurface structures, removal of perched groundwater and associated soil contamination. The remedial targets to be met are set out in **Table 45** below. The Remediation Strategy should include frequency of testing and approach to data interpretation;
- Remediation is required to the PFAS outlier at TP422/TP423 and TP405A, including excavation of the PFAS-contaminated soils. The remedial targets to be met are set out in **Table 46.** The Remediation Strategy should include frequency of testing and approach to data interpretation;
- Materials sourced from elsewhere within the site that the Materials Management Plan (MMP) identifies for re-use within St. Catherine's Wood and Red Bank Terrace should be tested to ensure they achieve the proposed re-use criteria, as set out in **Table 47** below, which have been determined on the basis of the distance from the banks of the River Irk in which fill is to be placed. The Remediation Strategy should include frequency of testing and approach to data interpretation.

Contaminant	Soil target (mg/kg)	Rationale for soil target
Ammoniacal nitrogen	4.5	RTM
Benzo(a)Pyrene	3.6	RTM
Fluoranthene	7	95%ile of Plateau made ground
Anthracene	1.8	95%ile of Plateau made ground
TPH – C8-C35	2500*#	Professional judgement
*Discovery strategy to be implemented to ensure no soil with visual or olfactory evidence of contamination is re-used # If exceedances of these values are noted, the risk-derived criteria for individual carbon bands detailed in this table shall be applied.		

Table 44 Proposed soil remedial targets for gas works

Contaminant	Soil target (mg/kg)	Rationale for soil target
Benzo(a)Pyrene	3.6	RTM
Fluoranthene	7	95%ile of Plateau made ground
Anthracene	1.8	95%ile of Plateau made ground
TPH – C8-C35	2500*#	Professional judgment
PFOS	<2µg/kg	Laboratory limit of detection and typical site concentration
PFOA	<1µg/kg	Laboratory limit of detection and typical site concentration
*Discovery strategy to be implemented to ensure no soil with visual or olfactory evidence of contamination is re-used # If exceedances of these values are noted, the risk-derived criteria for individual carbon bands detailed in this table shall be applied.		

Table 45 Proposed soil remedial targets for carriage shed

Contaminant	Soil target (mg/kg)	Rationale for soil target
PFOS	<2µg/kg	Laboratory limit of detection and typical site concentration
PFOA	<1µg/kg	Laboratory limit of detection and typical site concentration

Table 46: Proposed soil remedial targets for TP422/TP423 outlier and TP405A

Contaminant	Soil target (mg/kg)	Rationale for soil target
Nickel	27	RTM
Zinc	191	RTM
Benzo(a)Pyrene	3.6	NBC
Fluoranthene	7	95%ile of Plateau made ground
Anthracene	1.8	95%ile of Plateau made ground
TPH C8-C35	2500*#	Professional judgement
PFOS	<2µg/kg	Laboratory limit of detection and typical site concentration
PFOA	<1µg/kg	Laboratory limit of detection and typical site concentration
*Discovery strategy to be implemented to ensure no soil with visual or olfactory evidence of contamination is re-used # If exceedances of these values are noted, the risk-derived criteria for individual carbon bands detailed in this table shall be applied.		

Table 47 Proposed re-use criteria for site-won soils placed within Zones 1 and 2

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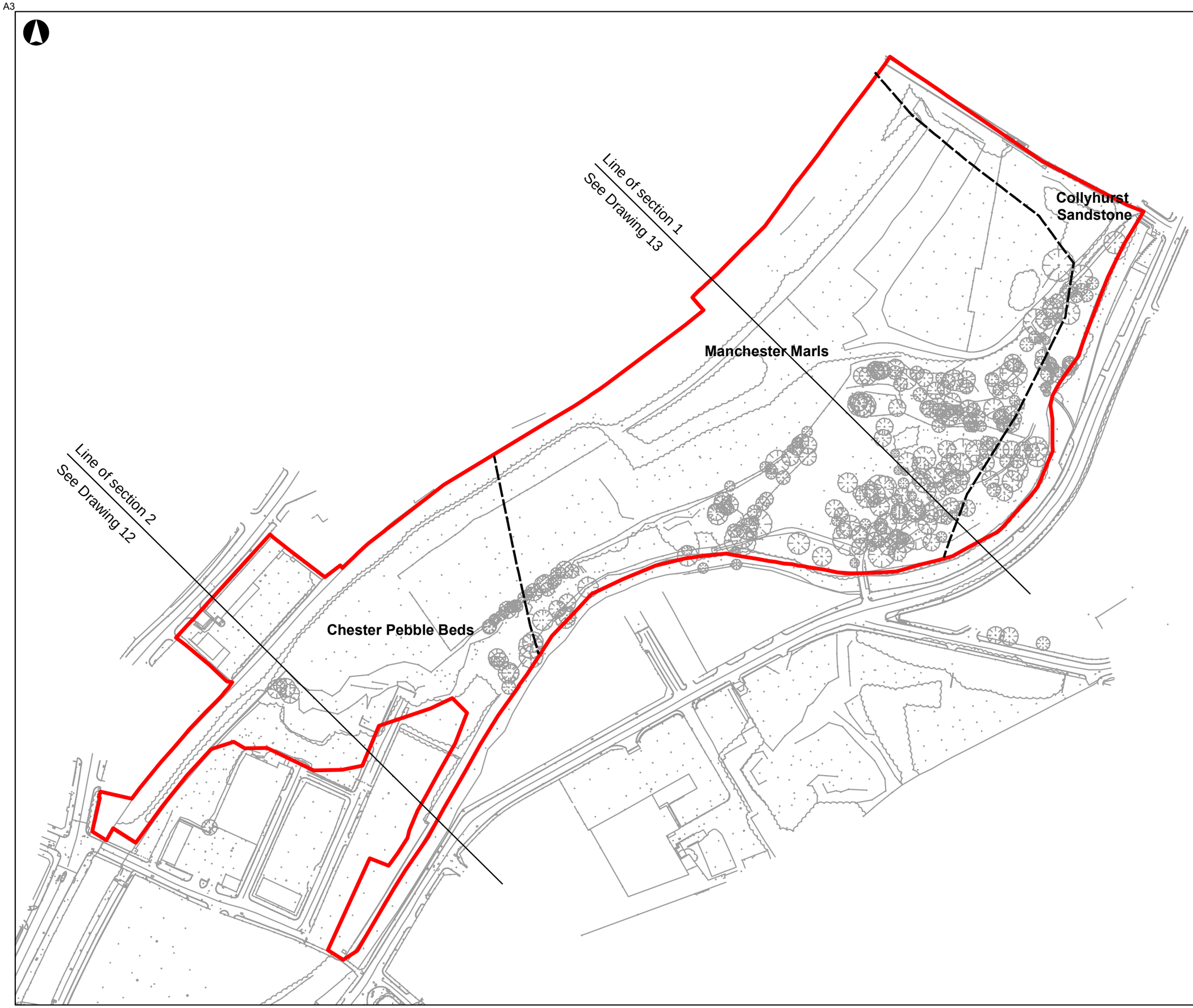
A3



Key

- Site boundary
- Inferred bedrock boundaries

Issue	Date	By	Chkd	Appd
P0	2022-07-11	LH	LH	LH

Metres
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BAM Nuttall Limited

Project Title
Victoria North, Controlled Waters Detailed Quantitative Risk Assessment

Drawing Title
Inferred bedrock types

Scale at A3
1:2,009

Arup Job No	Suitability
282022-00	**Preliminary**

Name	Rev
Drawing 1	**P0**

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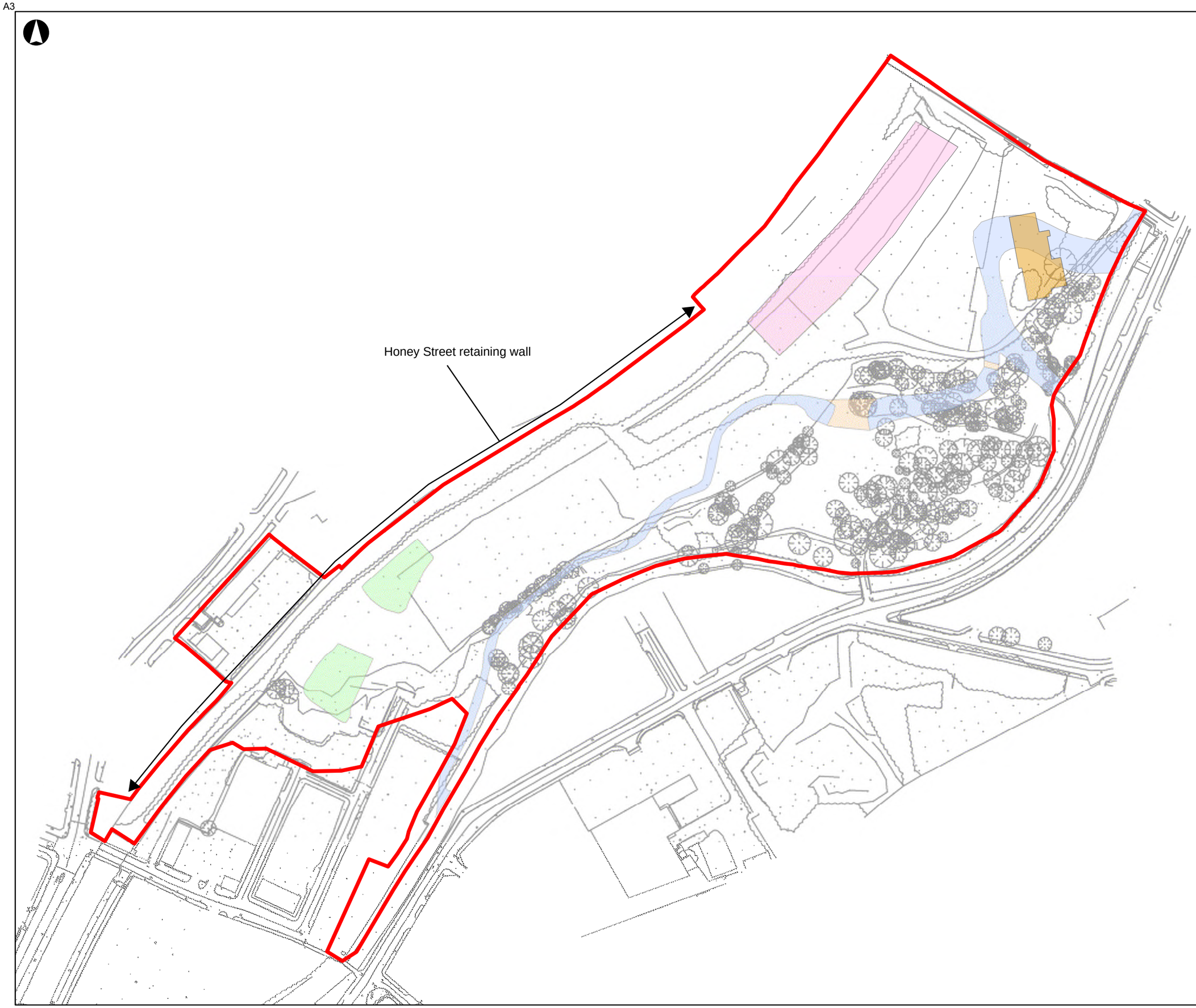
A3



Key

Site boundary

Historical site features

- Bridge
- Carriage Shed
- Infilled River Channel
- Infilled Reservoir
- Gasworks footprint

Issue	Date	By	Chkd	Appd
P0	2022-08-04	LH	DH	DH

Metres
0 25 50 100

ARUP

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Client
BAM Nuttall Limited

Project Title
**Victoria North,
Controlled Waters Detailed
Quantitative Risk Assessment**

Drawing Title
Historical site features

Scale at A3
1:2,000

Arup Job No
282022-00

Suitability
Preliminary

Name
Drawing 2

Rev
P0

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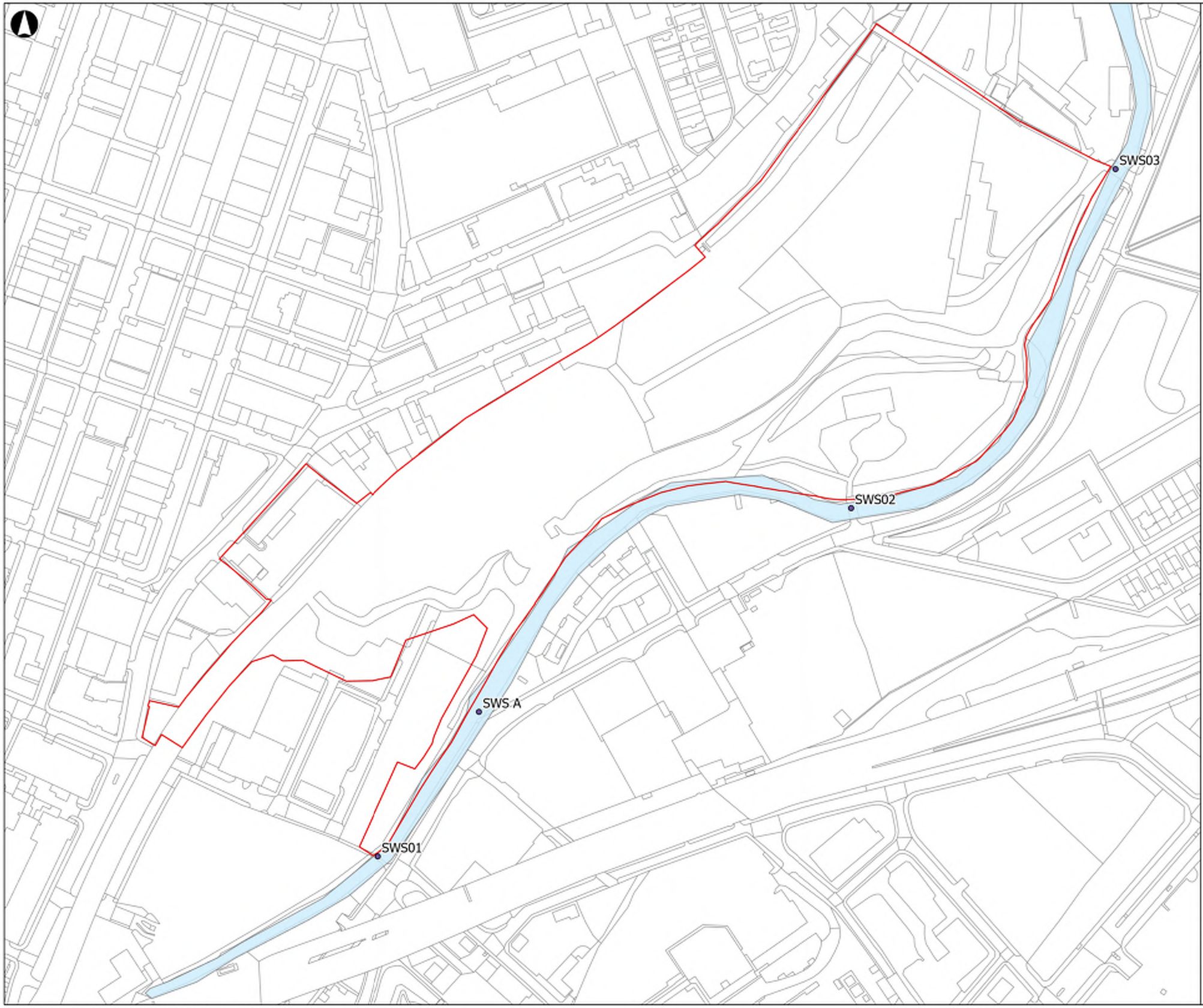

A3

Site Boundary
Surface Water Samples
River Irk

Coordinate System: British National Grid

--

Metres
0 30 60 120

Rev	Date	By	Chkd	Appd	Authd
--	13/07/23	KB	CR	--	--

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Client
BAM Nuttall Limited

Project Name
**Victoria North,
Controlled Waters Detailed
Quantitative Risk Assessment**

Drawing Title
Surface Water Sampling Locations

Scale at A3
1:2,300
Role
--
Suitability
--
Project Number
282022-00
Rev
01
Drawing Number
Drawing 3

B:\280000\282022-00 Vic North\Workspaces\GI Drawings\Drawing 3 - Surface Water Sampling Locations.aprx

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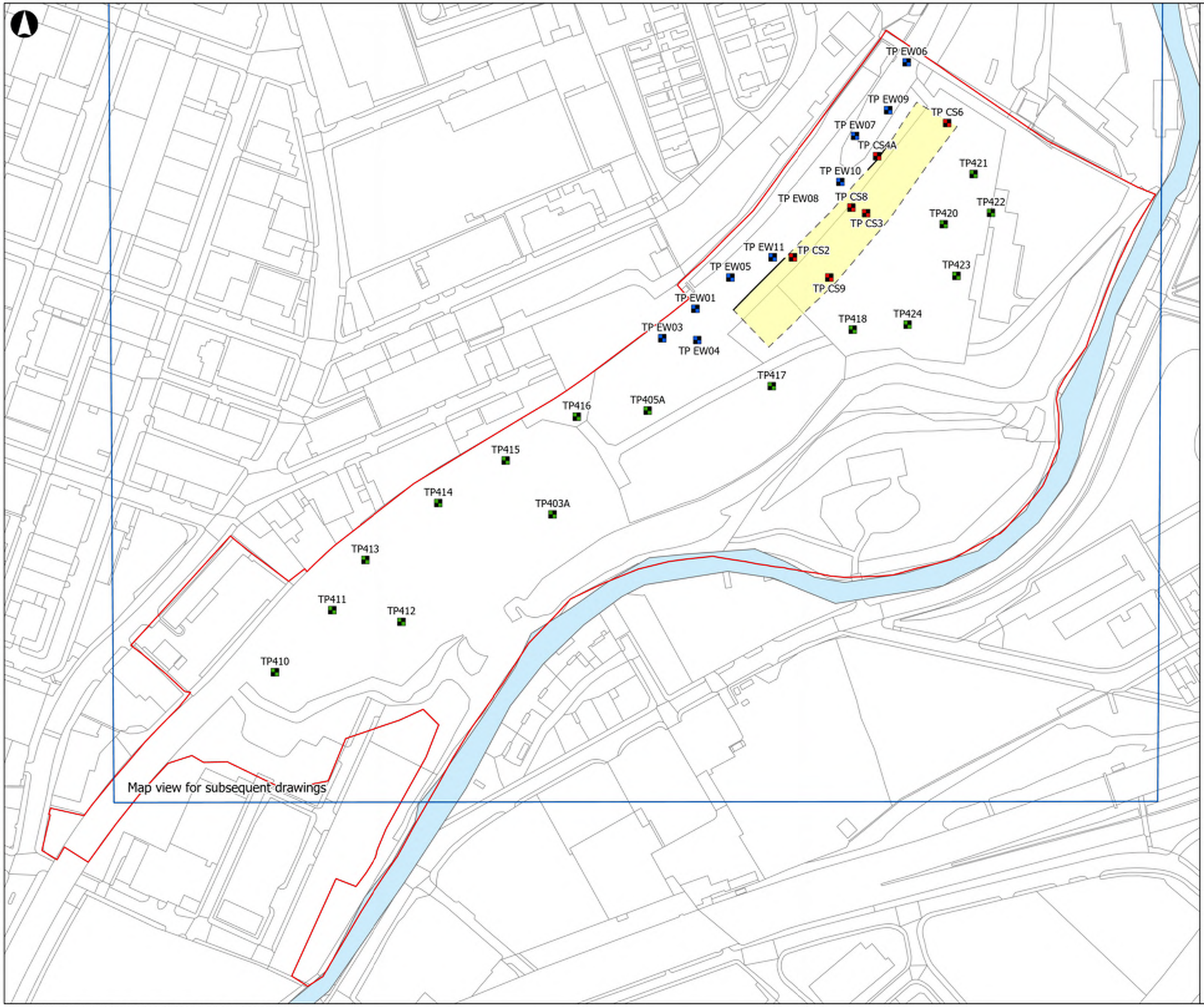

A3

Site Boundary

Trial Pit Locations

- TP40X - 400 Series Trial Pits
- TP EW0X - Emerging Water Trial Pits
- TP CS0X - Carriage Shed Trial Pits

Carriage Shed (Confirmed Boundary)

Carriage Shed (Indicative Boundary)

River Irk

Coordinate System: British National Grid

--

Metres

0 25 50 100

Rev	Date	By	Chkd	Appd	Authd
--	13/07/23	KB	CR	--	--

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Project Name
Victoria North,
Controlled Waters Detailed Quantitative Risk Assessment

Drawing Title
March 2023 PFAS ground investigation locations

Scale at A3
1:2,000

Role
--

Suitability
--

Project Number
282022-00

Rev
01

Drawing Number
Drawing 4

8/17/2023 10:47 AM

B:\280000\282022-00 Vic North\Workspaces\GI Drawings\Drawing 4 - Trial Pit Layout Soil Samples.aprx

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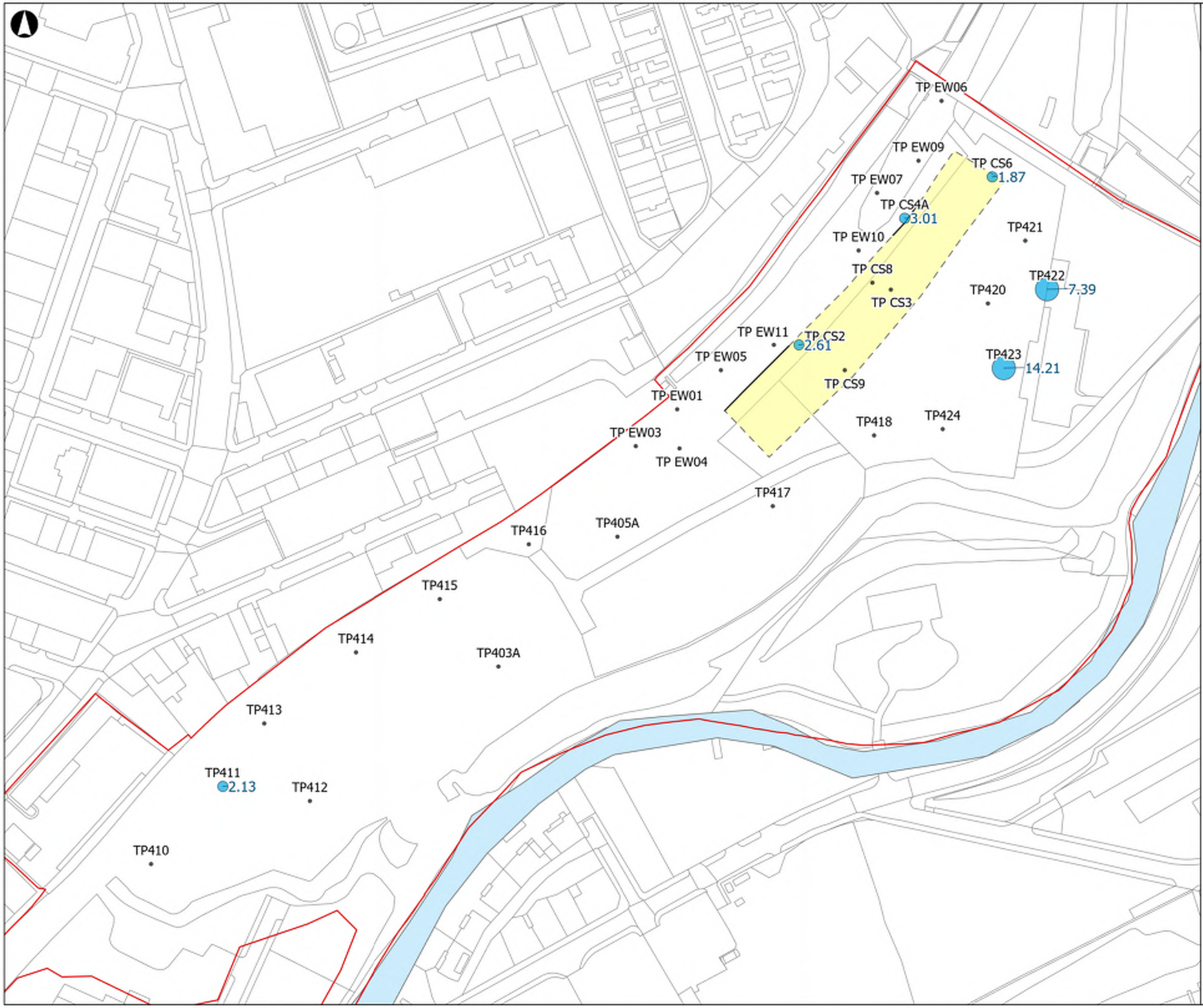

A3

Site Boundary

Trial Pit Locations - Total PFOS (Pre-Ox) (µg/kg)

- <LOD
- <LOD - 5.00
- 5.01 - 50.00

Carriage Shed (Confirmed Boundary)

Carriage Shed (Indicative Boundary)

River Irk

Coordinate System: British National Grid

--

Metres

0 20 40 80

Rev	Date	By	Chkd	Appd	Authd
--	17/08/23	KB	CR	--	--

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Project Name
**Victoria North,
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Quantitative Risk Assessment**

Drawing Title
Summary of Soil Analysis - Total PFOS (Pre-Ox)

Scale at A3
1:1,600

Role
--

Suitability
--

Project Number
282022-00

Rev
01

Drawing Number
Drawing 5

8/16/2023 9:30 AM

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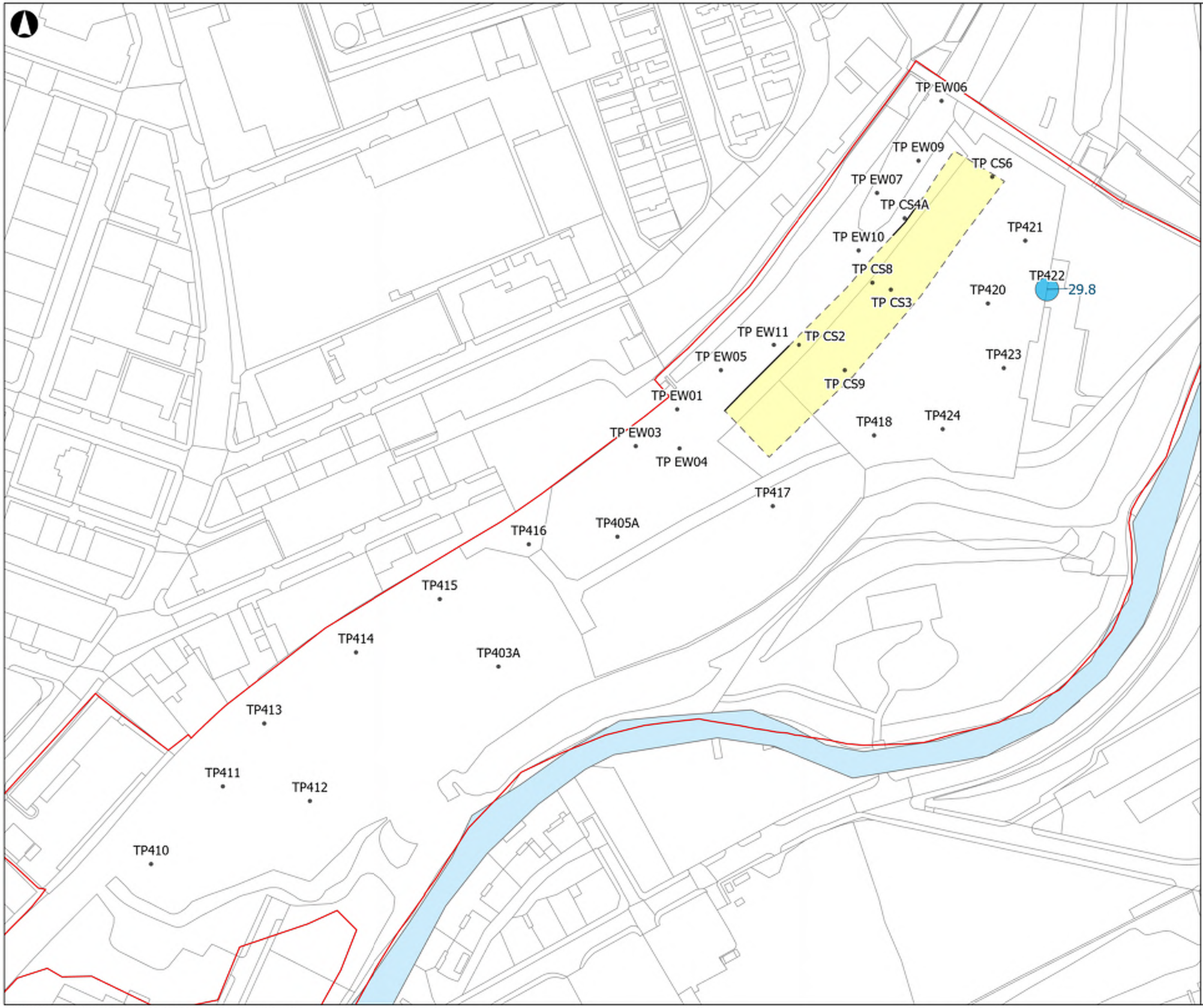

A3

Site Boundary

Trial Pit Locations - Total PFOA (Pre-Ox) (µg/kg)

- <LOD
- <LOD - 5.00
- 5.00 - 50.00

Carriage Shed (Confirmed Boundary)

Carriage Shed (Indicative Boundary)

River Irk

Coordinate System: British National Grid

Metres

0 20 40 80

Rev	Date	By	Chkd	Appd	Authd
--	13/07/23	KB	CR	--	--

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Project Name
**Victoria North,
Controlled Waters Detailed Quantitative Risk Assessment**

Drawing Title
Summary of Soil Analysis - Total PFOA (Pre-Ox)

Scale at A3
1:1,600

Role
--

Suitability
--

Project Number
282022-00

Rev
01

Drawing Number
Drawing 6

8/17/2023 11:33 AM

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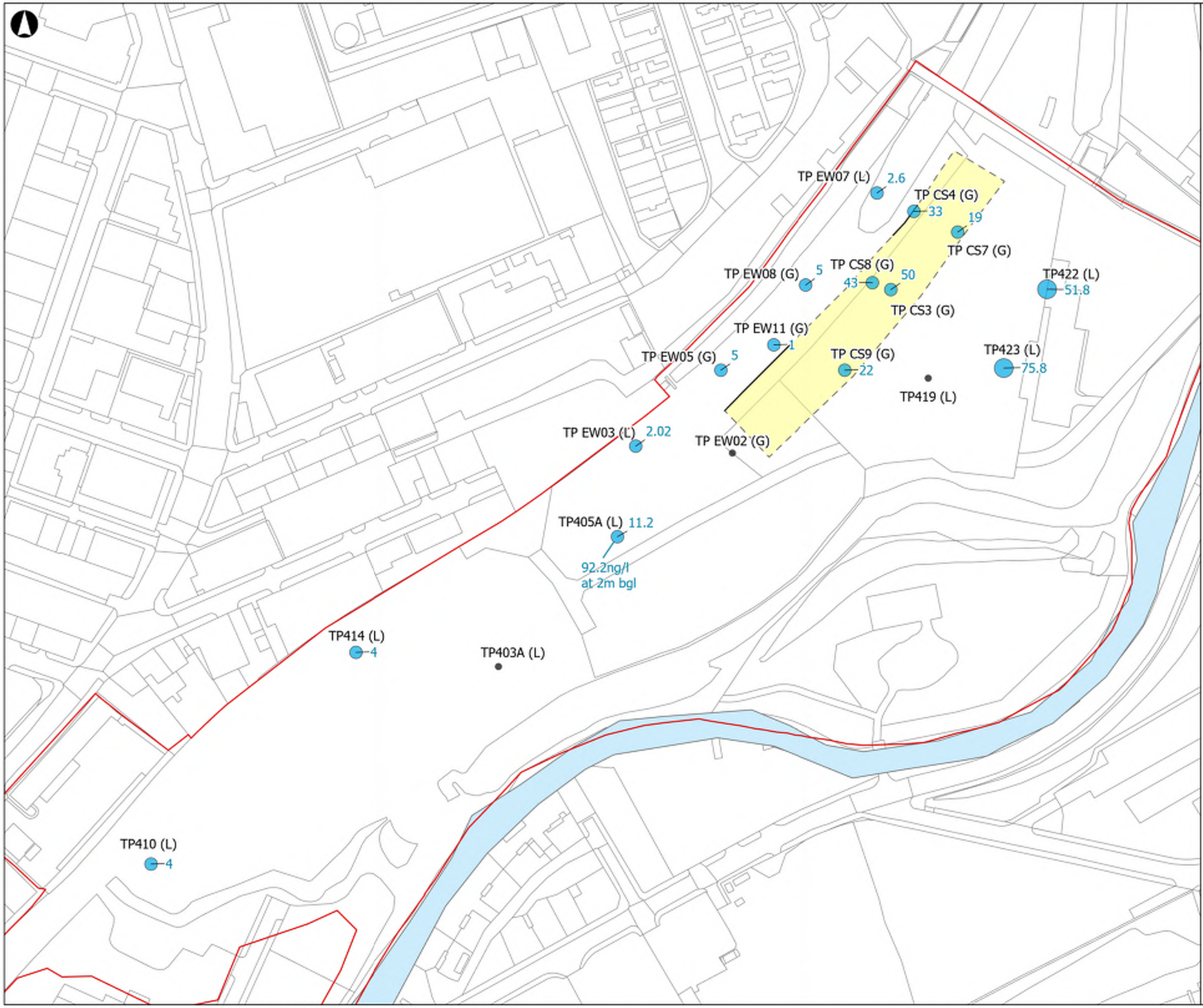

A3

Site Boundary

Trial Pit Locations - Total PFOS (Pre-Ox) (ng/l)

- <LOD
- 6.51 - 50.00
- 50.01 - 200.00
- 200.01 - 3300.00

Carriage Shed (Confirmed Boundary)

Carriage Shed (Indicative Boundary)

River Irk

G - Groundwater
L - Leachate

Coordinate System: British National Grid

--

Metres
0 20 40 80

Rev	Date	By	Chkd	Appd	Authd
--	13/07/23	KB	CR	--	--

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Project Name
Victoria North, Controlled Waters Detailed Quantitative Risk Assessment

Drawing Title
Summary of Leachability and Perched Groundwater Analysis - Total PFOS (Pre-Ox)

Scale at A3
1:1,600

Role
--

Suitability
--

Project Number
282022-00

Rev
01

Drawing Number
Drawing 7

8/17/2023 1:35 PM

B:\280000\282022-00 Vic North\Workspaces\GI Drawings\Drawing 7 - Summary of Liquid Analysis PFOS.aprx

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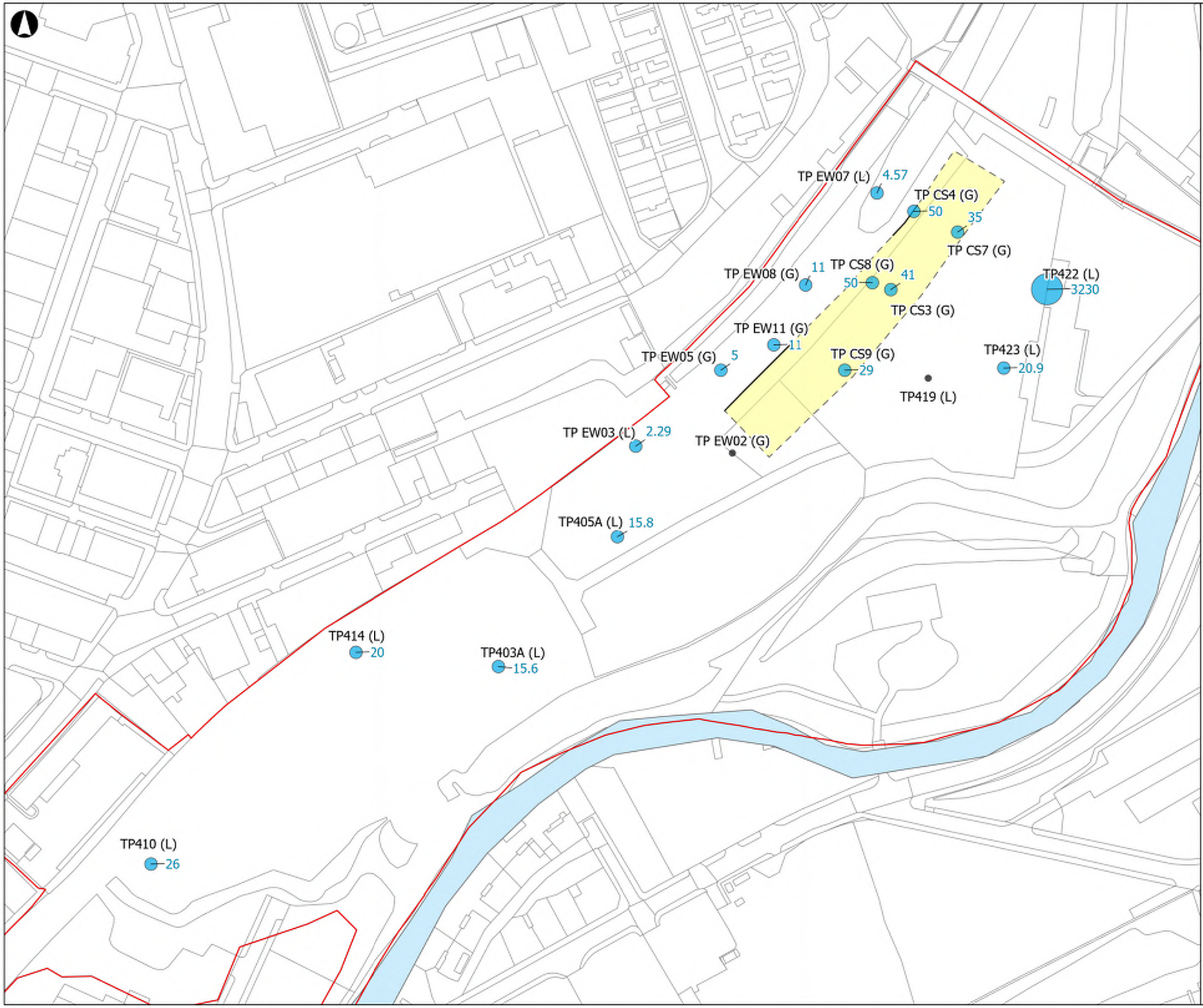

A3

Site Boundary

Trial Pit Locations - Total PFOA (ng/l)

- <LOD
- LOD - 50.00
- 50.01 - 200.00
- 200.01 - 3300.00

Carriage Shed (Confirmed Boundary)

Carriage Shed (Indicative Boundary)

River Irk

G - Groundwater
L - Leachate

Coordinate System: British National Grid

--

Metres
0 20 40 80

Rev	Date	By	Chkd	Appd	Authd
--	13/07/23	KB	CR	--	--

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BAM Nuttall Limited

Project Name
Victoria North Controlled Waters Detailed Risk Assessment

Drawing Title
Summary of Leachability and Perched Groundwater Analysis - Total PFOA (Pre-Ox)

Scale at A3
1:1,600

Role
--

Suitability
--

Project Number
282022-00

Rev
01

Drawing Number
Drawing 8

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A3

384400 384600 384800

399800 399600 399400

BH315
BH204
BH103
BH102
BH207
BH310
BH309
BH311
BH210
BH306

Legend

Site Area

- Red Bank Plateau
- Red Bank Terrace
- St Catherine's Wood

Monitoring Installations

Response strata

- Made ground
- Alluvium
- Glacial till
- Bedrock

Issue	Date	By	Chkd	Appd
P1	2022-08-01	LH	LH	LH

Metres
0 25 50 100

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Client
BAM Nuttall Limited

Project Title
**Victoria North,
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Quantitative Risk Assessment**

Drawing Title
Groundwater sampling locations

Scale at A3
1:1,900

Arup Job No
282022-00

Suitability
Issue

Name
Drawing 9

Rev
P1

\\globalgis\UK\280000\282022-00 Vic North\Workspaces\VN Phase 3 GIR - Drawing 02 onwards.mxd

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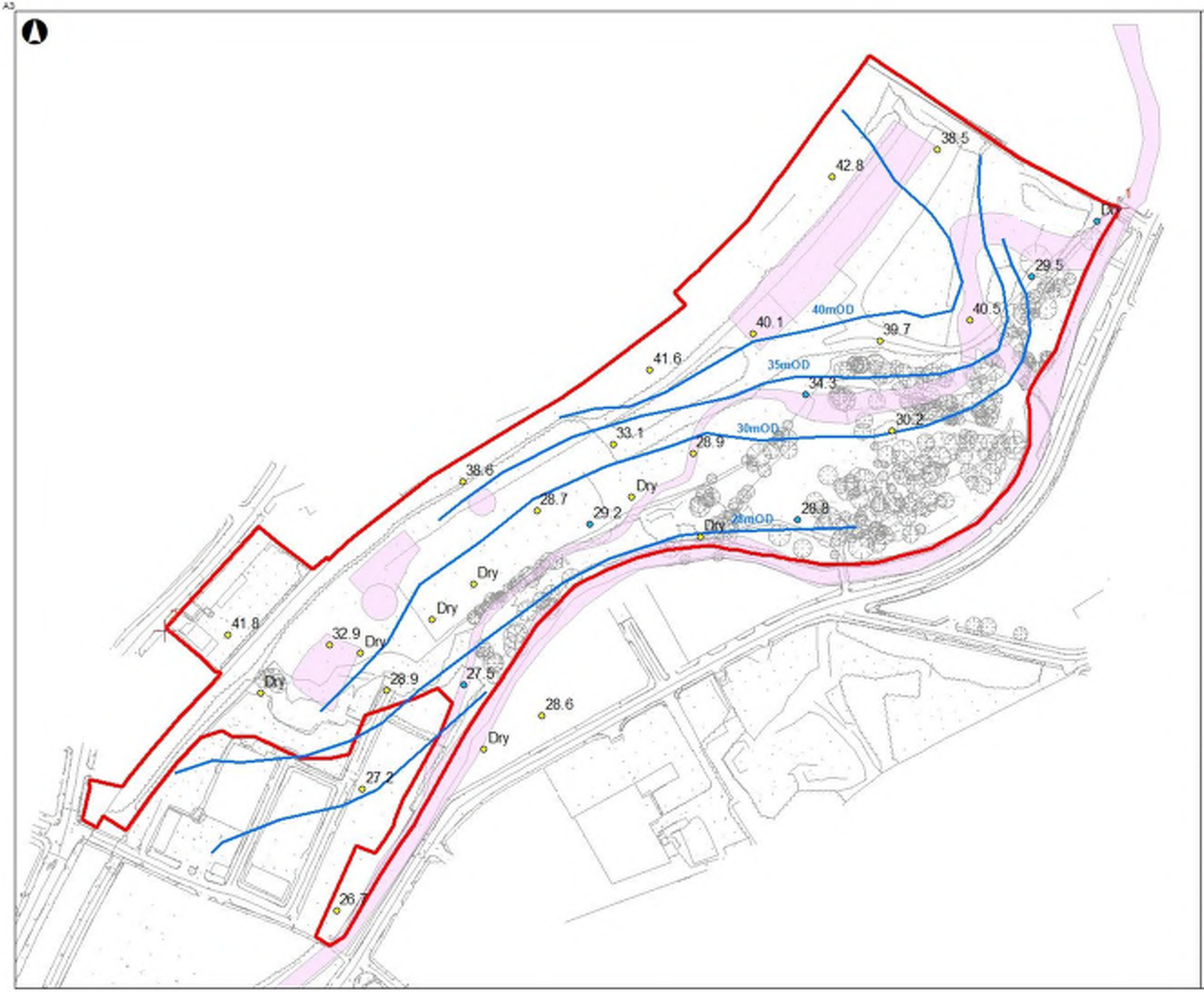
A3



Key

- Site boundary
- Inferred groundwater contour
- Groundwater levels in made ground (mOD)
- Groundwater levels in alluvium (mOD)

ARUP

Client
BAM Nuttall Limited

Project Title
Victoria North,
Controlled Waters Detailed Quantitative Risk Assessment

Drawing Title
Groundwater levels in shallow aquifer

Scale at A3
1:2,000

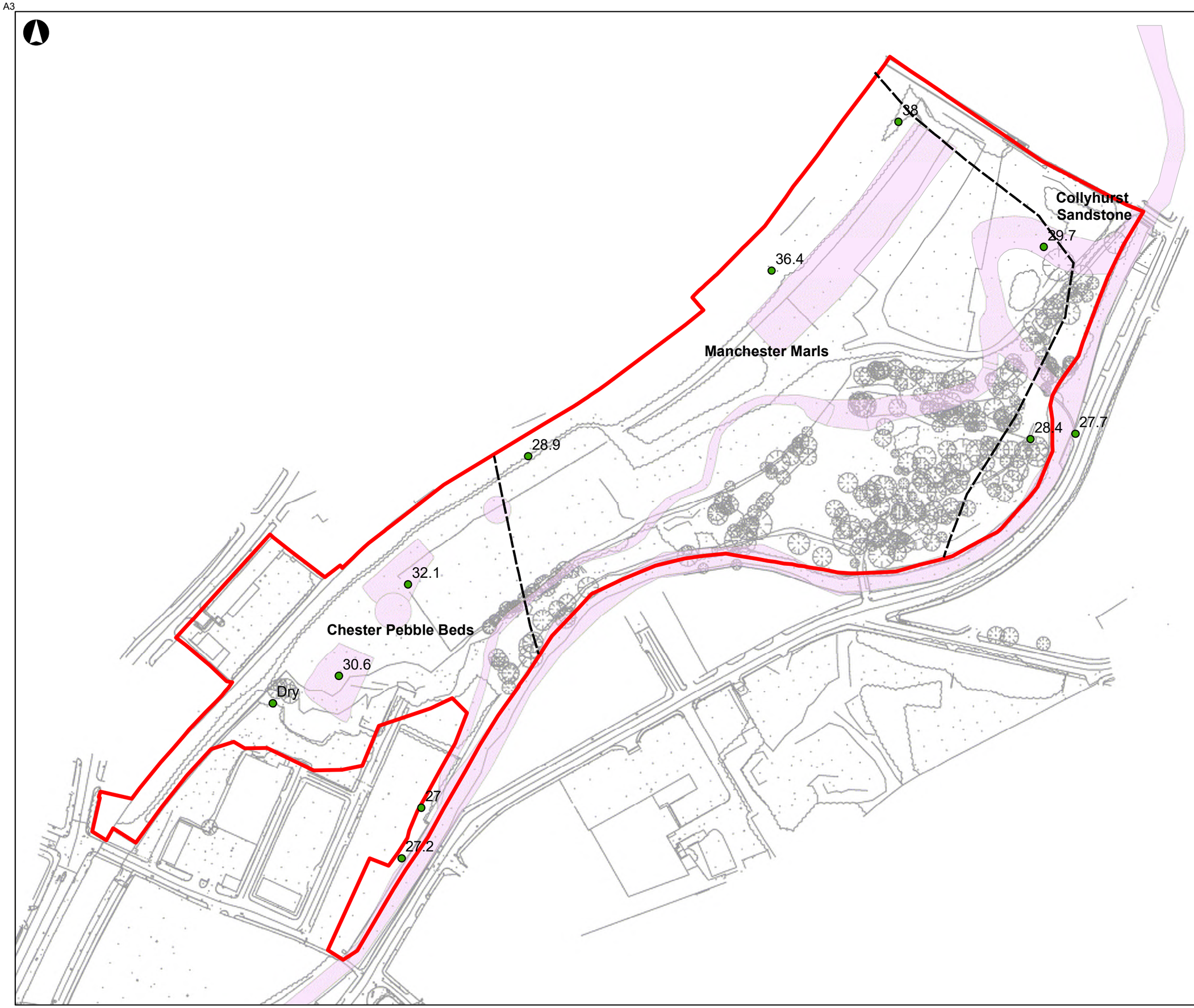
Arup Job No
282022-00

Suitability
Preliminary

Drawing No
Drawing 10

Rev
P0

A3



Key

- Site boundary
- Groundwater levels in bedrock (mOD)
- Inferred bedrock boundaries

Issue	Date	By	Chkd	Appd
P0	2022-07-11	LH	LH	LH

Metres
0 25 50 100

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Client
BAM Nuttall Limited

Project Title
Victoria North, Controlled Waters Detailed Quantitative Risk Assessment

Drawing Title
Groundwater levels in deep aquifers

Scale at A3
1:2,009

Arup Job No	Suitability
282022-00	**Preliminary**

Name	Rev
Drawing 11	**P0**

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Distance along baseline (m)

0 20 40 60 80 100 120 140 160 180 200

Elevation (mOD)

46 44 42 40 38 36 34 32 30 28 26 24 22 20

GEO_BH215 (-3.9) N36 N23 N19 N22 N23 N20 N19 N23 N20

BH312 (4.5) N130* N300* N214* N38 N31 N97* N14 N6 N500* N1000*

BH313 (8.6) N375* N1500* N43 N27* N24 N17 N16 N12 N27 N23

GEO_BH211A (-19.5) N16 N11 N13 N3 N5 N9 N10 N4 N68* N333* N750*

BH314 (-8.1) N188* N429* N17 N12 N11 N7 N2 N4 N2

GEO_BH213 (-13.3) N691* N16 N16

BH307 (43.8) N214* N750* N750* N10 N6 N6

Made Ground

Glacial Till Deposits

Chester Pebble Beds bedrock

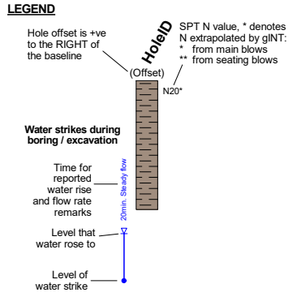
Ground level from EA LiDAR data

SCALE 1:144V 1:556H @ A3-L

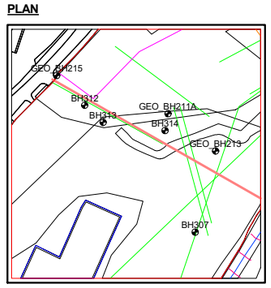
Library: arup_ukllb_4-s-002; Report: 2.1.01 SECTION WITH WATER & SPT (A3)
Database: c:\gint\x2dra nor\matrix * rw gint2d0.22 - 282022_victoria_north_stage 3 data_inc_riverworks.gpj RevP1.1 (SO - Work in progress)

ARUP gINT v10.00.01.07. Made by Jonny Tyrer on 7-Jul-22

LEGEND



PLAN



COLOUR LEGEND

- Made Ground - Granular [MG-G]
- Made Ground - Cohesive [MG-CO]
- Made Ground - Concrete [MG-Conc]
- Glacial Till Deposits - Cohesive [GTD - CO]
- Glacial Till Deposits - Granular [GTD - G]
- Chester Formation [CHES]

MATERIALS

- Fill (MADE GROUND)
- SANDSTONE
- Gravelly CLAY
- Clayey gravelly SAND
- Silty gravelly CLAY
- SAND and GRAVEL
- SAND
- Sandy CLAY
- Sandy gravelly CLAY

ARUP

Job Title

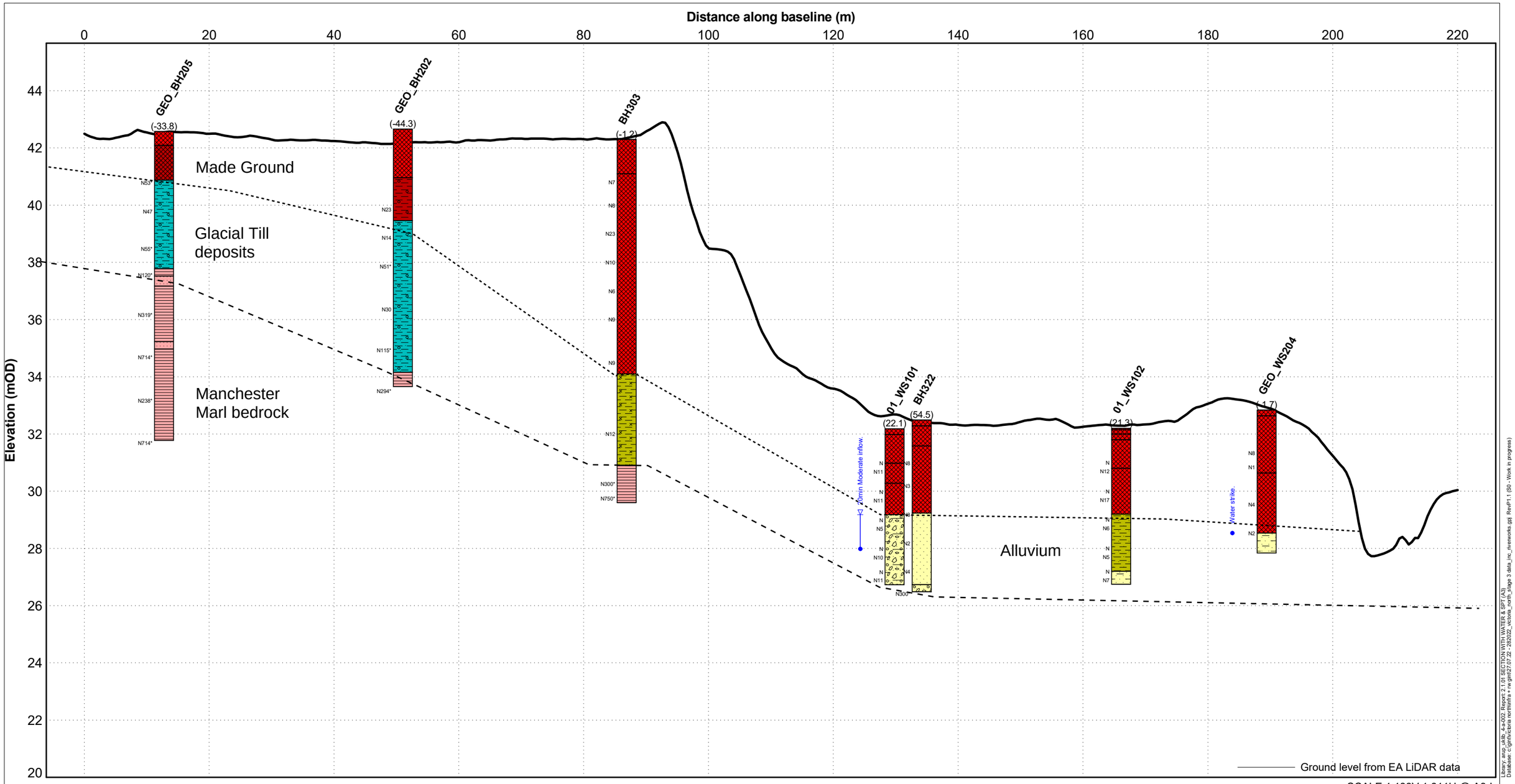
Victoria North, Controlled Waters Detailed Quantitative Risk Assessment

Geological cross section

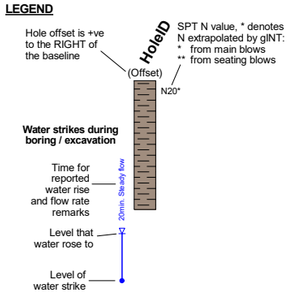
Red Bank Terrace

Job No **282022**

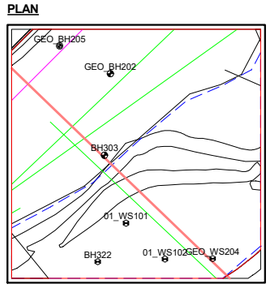
Drawing 12



LEGEND



PLAN



COLOUR LEGEND

- Made Ground - Granular [MG-G]
- Made Ground - Cohesive [MG-CO]
- Alluvium Cohesive [ALV-CO]
- Alluvium granular [ALV-G]
- Glacial Till Deposits - Cohesive [GTD - CO]
- Manchester Marls Formation [MM]

MATERIALS

- Fill (MADE GROUND)
- Silty Clay
- MUDSTONE
- Gravelly CLAY
- Sandy gravelly CLAY
- SANDSTONE
- Clayey sandy GRAVEL
- Sandy CLAY
- Clayey SAND
- SAND
- SAND and GRAVEL

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Victoria North, Controlled Waters Detailed Quantitative Risk Assessment

Figure Title

Geological cross section

St Catherine's Wood

Job No

282022

Drawing 13

ARUP. gINT v10.00.01.07. Made by Jonny Tyrer on 5-Aug-22

Library: arup_uklib_4-a-002. Report: 2.1.01 SECTION WITH WATER & SPT (A3)
Database: c:\gint\victoria northlatfra + rw gint\27.07.22 - 282022_victoria_north_stage 3 data_inc_riverworks.gpj RevP1.1 (S0 - Work in progress)

A3

384400

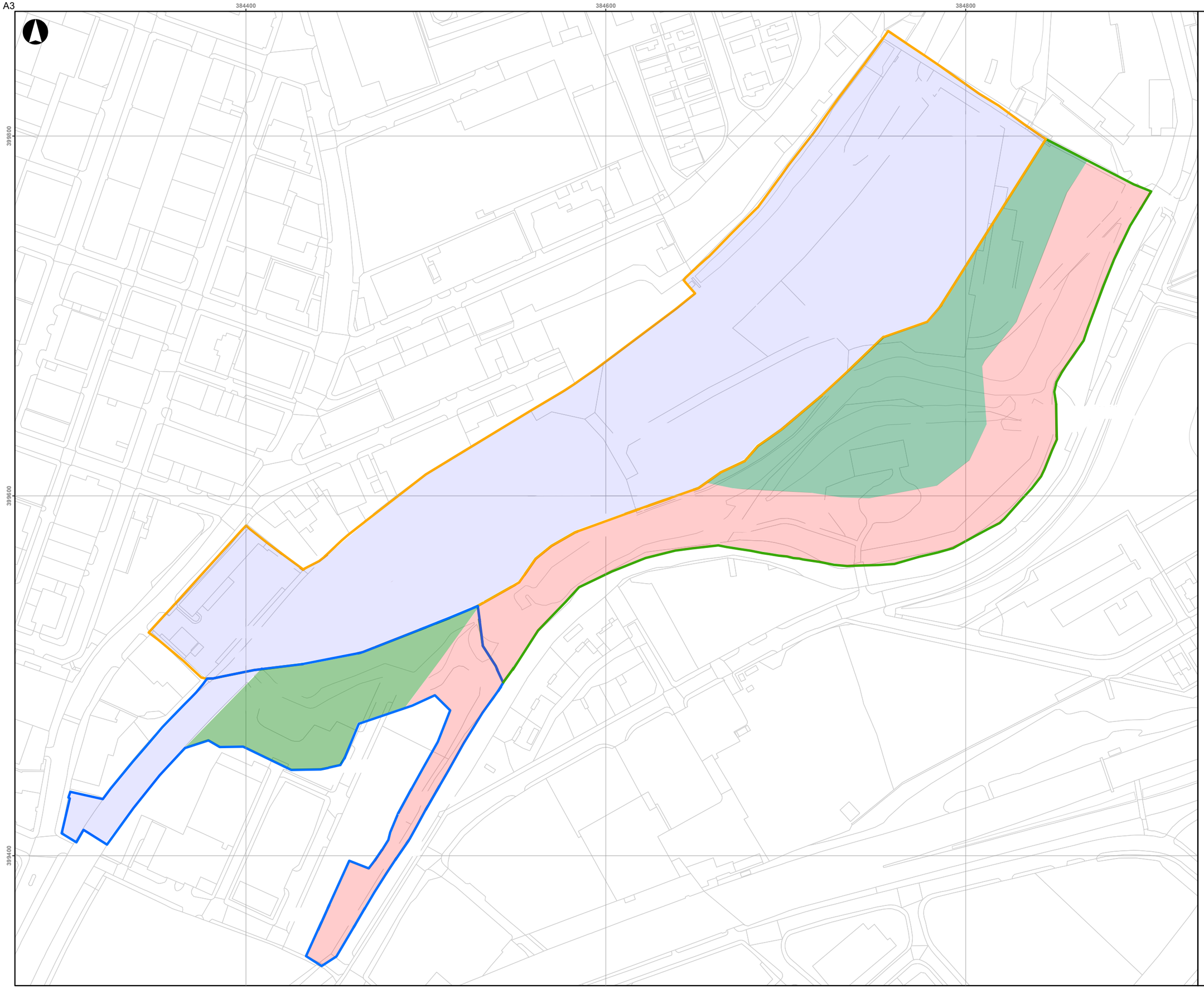
384600

384800

399800

399600

399400



Legend

Site Area

- Red Bank Plateau
- Red Bank Terrace
- St Catherine's Wood

Screening Criteria Zones

- Zone 1
- Zone 2
- Screening criteria not required

Issue	Date	By	Chkd	Appd
P1	2022-08-01	LH	LH	LH

Metres

0 25 50 100

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Client

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Project Title

**Victoria North,
Controlled Waters Detailed
Quantitative Risk Assessment**

Drawing Title

Site zoning plan for fill materials placed close to the river

Scale at A3

1:1,900

Arup Job No	Suitability
282022-00	**Issue**

Name	Rev
Drawing 14	**P1**

\\globalgis\UK\282000\282022-00 Vic North\Workspaces\VN Phase 3 GIR - Drawing 02 onwards.mxd

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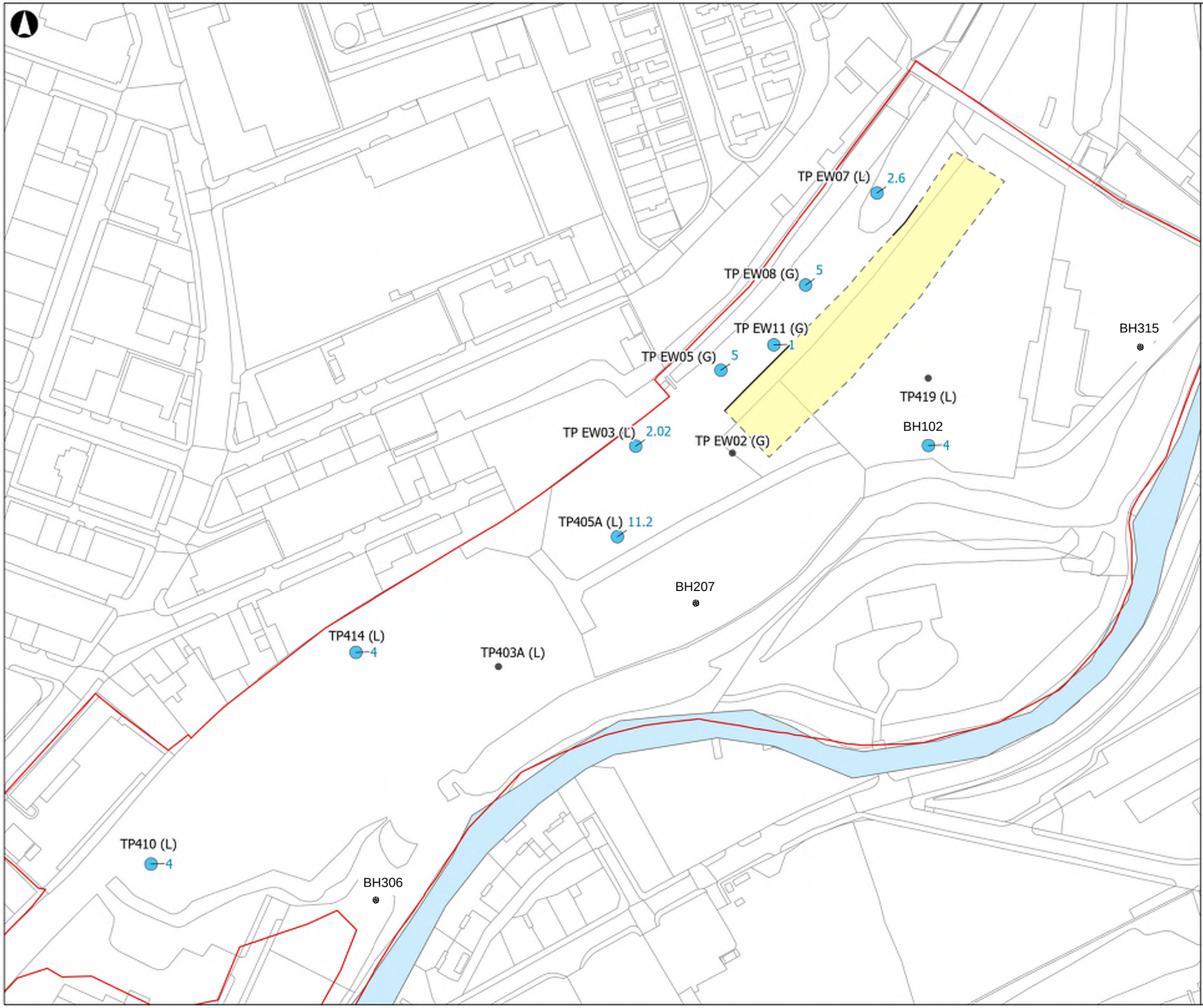

A3

Site Boundary

Trial Pit Locations - Total PFOS (Pre-Ox) (ng/l)

- <LOD
- 6.51 - 50.00
- 50.01 - 200.00
- 200.01 - 3300.00

Carriage Shed (Confirmed Boundary)

Carriage Shed (Indicative Boundary)

River Irk

G - Groundwater
L - Leachate

Coordinate System: British National Grid

--

Metres
0 20 40 80

Rev	Date	By	Chkd	Appd	Authd
--	13/07/23	KB	CR	--	--

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Client
BAM Nuttall Limited

Project Name
Victoria North, Controlled Waters Detailed Quantitative Risk Assessment

Drawing Title
Summary of Residual Leachability and Shallow Groundwater Analysis - Total PFOS (Pre-Ox)

Scale at A3
1:1,600

Role
--

Suitability
--

Project Number
282022-00

Rev
01

Drawing Number
Drawing 15

B:\280000\282022-00 Vic North\Workspaces\GI Drawings\Drawing 7a - Summary of residual leachability and perched groundwater analysis - Total PFOS (Pre-Ox).aprx

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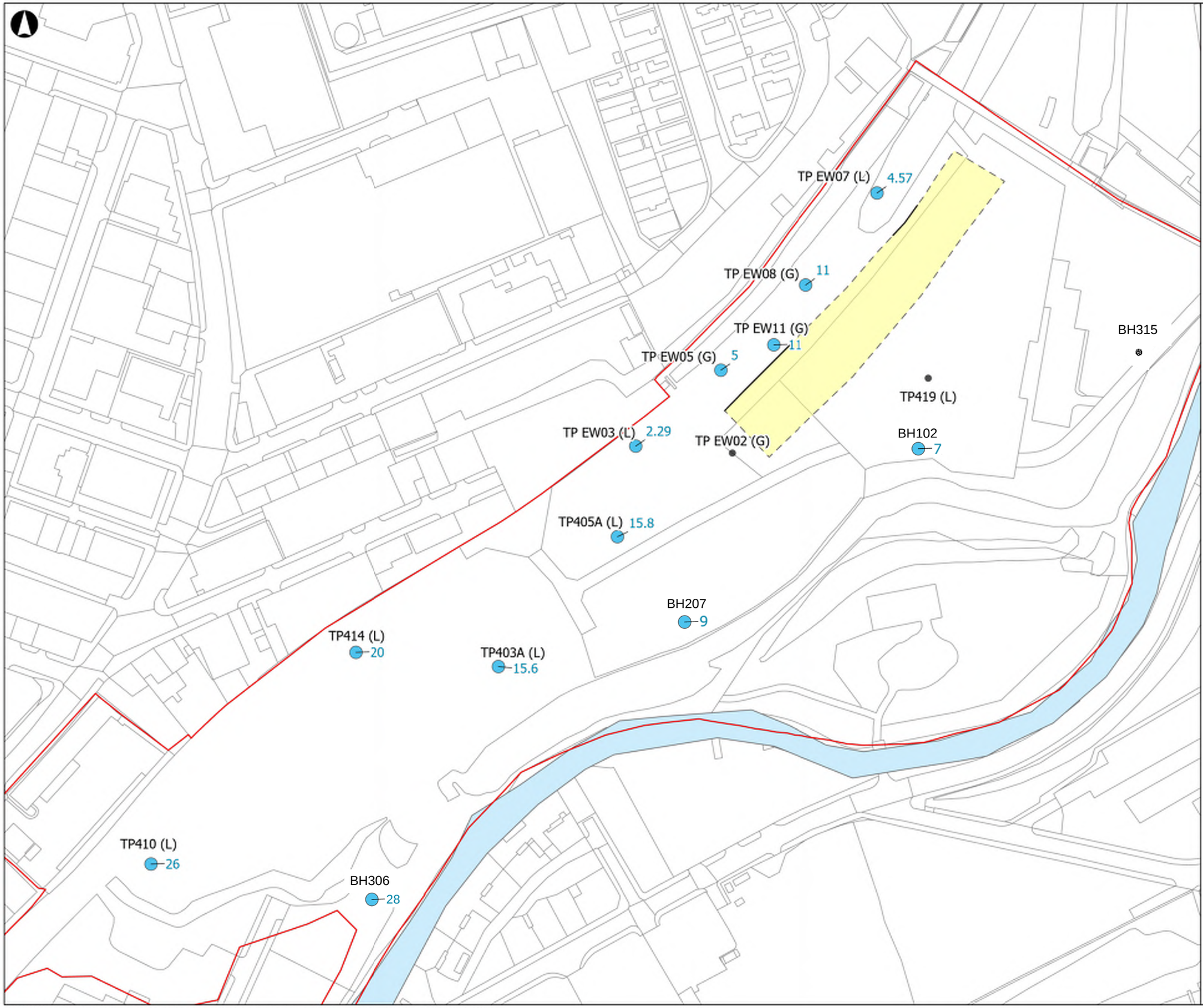

A3

Site Boundary

Trial Pit Locations - Total PFOA (ng/l)

- <LOD
- LOD - 50.00
- 50.01 - 200.00
- 200.01 - 3300.00

Carriage Shed (Confirmed Boundary)

Carriage Shed (Indicative Boundary)

River Irk

G - Groundwater
L - Leachate

Coordinate System: British National Grid

--

Metres
0 20 40 80

Rev	Date	By	Chkd	Appd	Authd
--	13/07/23	KB	CR	--	--

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Client
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Project Name
Victoria North Controlled Waters Detailed Risk Assessment

Drawing Title
Summary of Residual Leachability and Shallow Groundwater Analysis - Total PFOA (Pre-Ox)

Scale at A3
1:1,600

Role
--

Suitability
--

Project Number	Rev
282022-00	**01**

Drawing Number
Drawing 16

B:\280000\282022-00 Vic North\Workspaces\GI Drawings\Drawing 8a - Summary of residual leachability and perched groundwater analysis - Total PFOA (Pre-Ox).aprx

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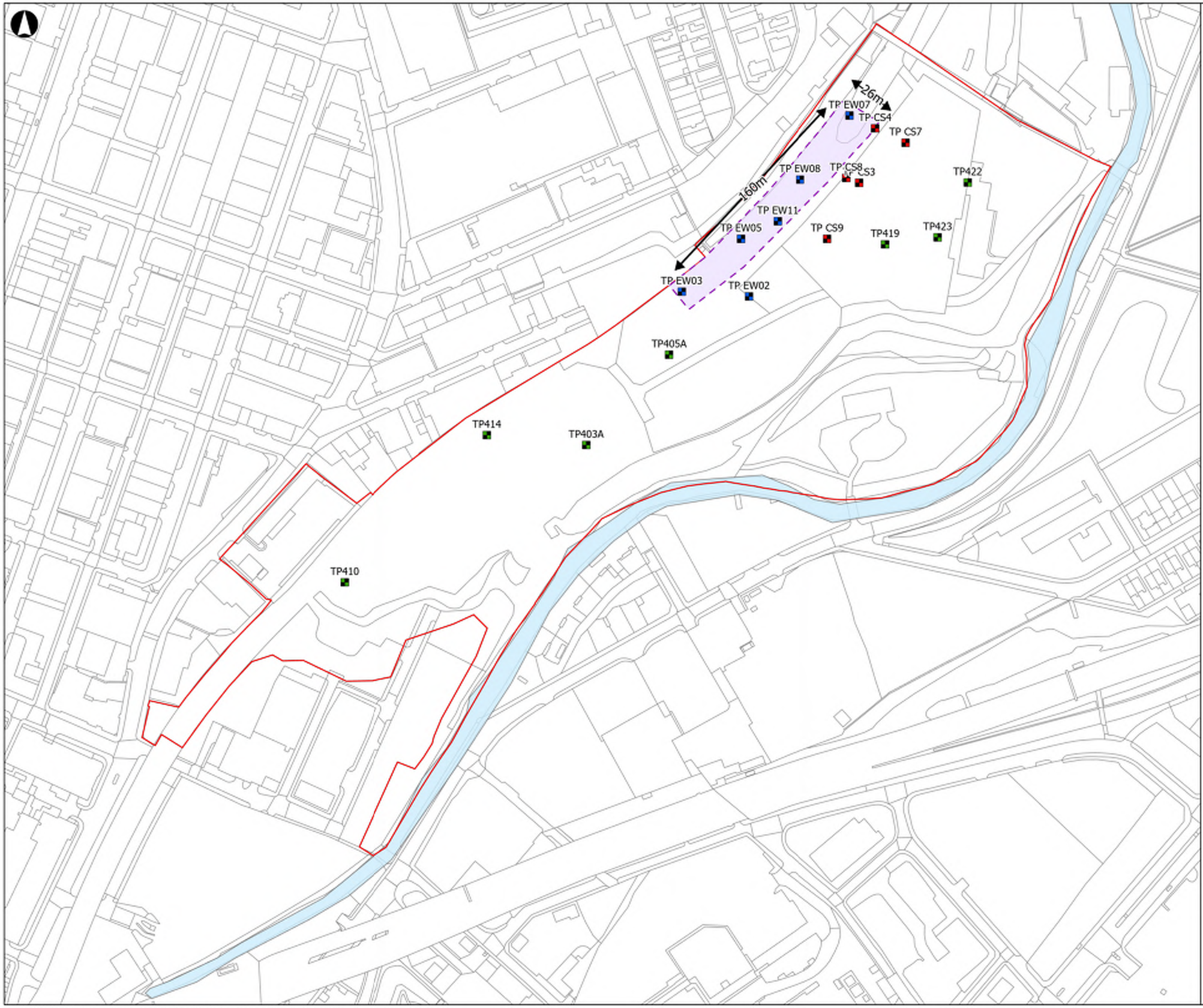

A3

- Site Boundary
- Liquid Trial Pit Locations
  - TP40X
  - TP EW0X
  - TP CS0X
- Emerging Water Area
- River Irk

Coordinate System: British National Grid

--

Metres

0 30 60 120

Rev	Date	By	Chkd	Appd	Authd
--	13/07/23	KB	CR	--	--

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www.arup.com

Client
BAM Nuttall Limited

Project Name
Victoria North
Controlled Waters Detailed Risk Assessment

Drawing Title
Made Ground in the Emerging Water Area

Scale at A3
1:2,300

Role
--

Suitability
--

Project Number
282022-00

Rev
01

Drawing Number
Drawing 17

8/17/2023 1:48 PM

B:\280000\282022-00 Vic North\Workspaces\GI Drawings\Drawing 8 - Made Ground in the Emerging Water Area.aprx

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