

BAM Nuttall Ltd

Victoria North
PFAS Human Health Risk Assessment

Reference: VNIF-ARP-ZZ-YYY-RP-CG-0014

P02 | 27 July 2023



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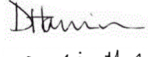
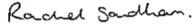
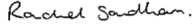
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Executive Summary

BAM Nuttall Ltd appointed Ove Arup and Partners Ltd (Arup) to provide environmental consultancy services in relation to the proposed development at Victoria North, Manchester.

A body of standing water was identified on the site during vegetation clearance, which has been linked to a pipe emerging from the embankment along the north-western side of the site. The emerging water has been found by sampling and analysis to contain PFAS. PFAS was not anticipated to be associated with previous railway activities within site, but a programme of background soil testing for PFAS was carried out across the plateau area. This testing identified a localised area of elevated PFAS concentrations in the north-eastern part of the site, with PFAS soil concentrations generally non-detectable in other areas.

This report presents risk based human health criteria for the PFAS (Per- and polyfluoroalkyl substances) contaminants of concern at Victoria North to support risk assessment and soil re-use as part of the development.

The assessment is based on a review of potential sources of PFAS and the results of all available soil testing. The assessment has concluded that the PFAS contaminants of most concern are listed below.

PFAS contaminants identified as being of most concern in soil

Perfluoroalkane sulfonic acids (PFSAs)	Perfluoroalkyl carboxylic acids (PFCAs)
Perfluorooctyl sulphonate (PFOS)	Perfluorooctanoic acid (PFOA) Perfluorononanoic acid (PFNA) Perfloropentanoic acid (PFPA) Perfluorodecanoic acid (PFDA) Perfluorododecanoic acid (PFDoA) Perfluoroundecanoic acid (PFUnA)

The conceptual model has identified several potential contaminant linkages to humans. However, many of the measures required to develop the site and to mitigate risks posed by other contaminants will also mitigate risks posed by PFAS. This includes use of physical barriers (clean cover system and hard surfacing) and use of barrier pipe for water supply pipes.

However, in the absence of UK published human health soil criteria, it is not possible to confirm the level of risk posed by re-use of PFAS impacted soils or these soils remaining in situ. Therefore, Arup has developed human health criteria based on the EA CLEA model and approach to assessing risks to human health posed by soils.

As PFAS are a contaminant of emerging interest there are 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. It is noted that the CLEA model is based on relatively conservative assumptions and therefore represents a minimal level of risk. The PFAS human health Site Specific Assessment Criteria (SSAC) derived within this report are considered to fall within Category 4 as described within the Part 2A Contaminated Land Statutory Guidance. The SSACs developed can be used for comparison to soil concentrations obtained during remediation verification testing and should be carried forward into the remediation strategy for the scheme.

Site Specific Assessment Criteria (SSAC) for PFAS in soil

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

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

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. If the ground in the area around TP422 and TP423 is to be excavated as part of the HIF IW, it should be either taken offsite or validated for re-use. The risks to controlled waters posed by this material are being considered separately.

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

1. Introduction

1.1 Background

The Victoria North HIF Infrastructure Works site is located in the Red Bank area of Manchester, to the north of Manchester Victoria railway station. A body of standing water was identified during site clearance in October 2022, which has been linked to a pipe emerging from the embankment along the north-western side of the site. The emerging water has been found by sampling and analysis to contain low concentrations of PFAS. This emerging water has now been diverted to discharge to a United Utilities sewer following treatment to remove dissolved methane, preventing further uncontrolled release to ground within Victoria North.

PFAS was not anticipated to be associated with previous railway activities within site, but a programme of soil testing for PFAS was carried out across the plateau area. This testing identified a localised area of elevated PFAS concentrations in the north-eastern part of the site, with PFAS levels generally non-detectable in other areas.

BAM Nuttall Ltd (BAM) has appointed Ove Arup and Partners Ltd (Arup) to advise on human health risk associated with PFAS contaminants of concern at the Victoria North HIF Infrastructure Works site.

1.2 Purpose and scope of this report

The purpose of this report is to present assessment of human health risk from PFAS at Victoria North. It considers risks to human health receptors that may exist when the site is redeveloped according to the current masterplan.

Risks to human health from contaminants other than PFAS in soil were assessed separately. The assessment of risks from other soil contaminants is presented in Arup’s GIR [1].

Risk-based soil human health criteria are derived to assess the risk posed by soils proposed for use, or remain in situ, in areas proposed for residential and public open space uses. The soil human health criteria presented in this report will be used to support materials management and the remediation strategy.

1.3 Report structure

The report follows the structure below:

- Section 2 summarises the site background including site history and summary of PFAS sources and PFAS contamination;
- Section 3 sets out the conceptual site model underpinning the human health risk assessment;
- Section 4 presents the methodology and outcome of the human health risk assessment; and
- Section 5 presents the conclusions of this work.

1.4 Use of report and limitations

This report was prepared by Arup on behalf of BAM Nuttall Ltd in connection with the Victoria North site in Manchester. It also takes into account our Client’s particular instructions and requirements and addresses their priorities at the time of report generation. This report was not intended for, and should not be relied on by, any third party and no responsibility is undertaken to any third party in relation to it.

All reasonable skill, care and diligence have been exercised within the timescale available and in accordance with the technical requirements of the brief. Notwithstanding the efforts made by the professional team in preparing the report it is possible that other ground contamination or conditions as yet undetected may exist and consequently reliance on this report must be limited accordingly.

2. Background

2.1 The site

The planning application boundary of the Victoria North HIF Infrastructure Works site is shown on **Figure 1**. The site has been divided into three areas listed below:

- Red Bank Plateau
- Red Bank Terrace
- St Catherine’s Wood.



Parts of Red Bank Plateau and St. Catherine’s Wood were historically occupied by a meander bend of the River Irk and sections of the former mill race. A corn mill, dye works, church, terraced housing and a school were all present in this area of the site until the early 1970s. Currently, St. Catherine’s Wood is largely woodland with occasional fly tipping.

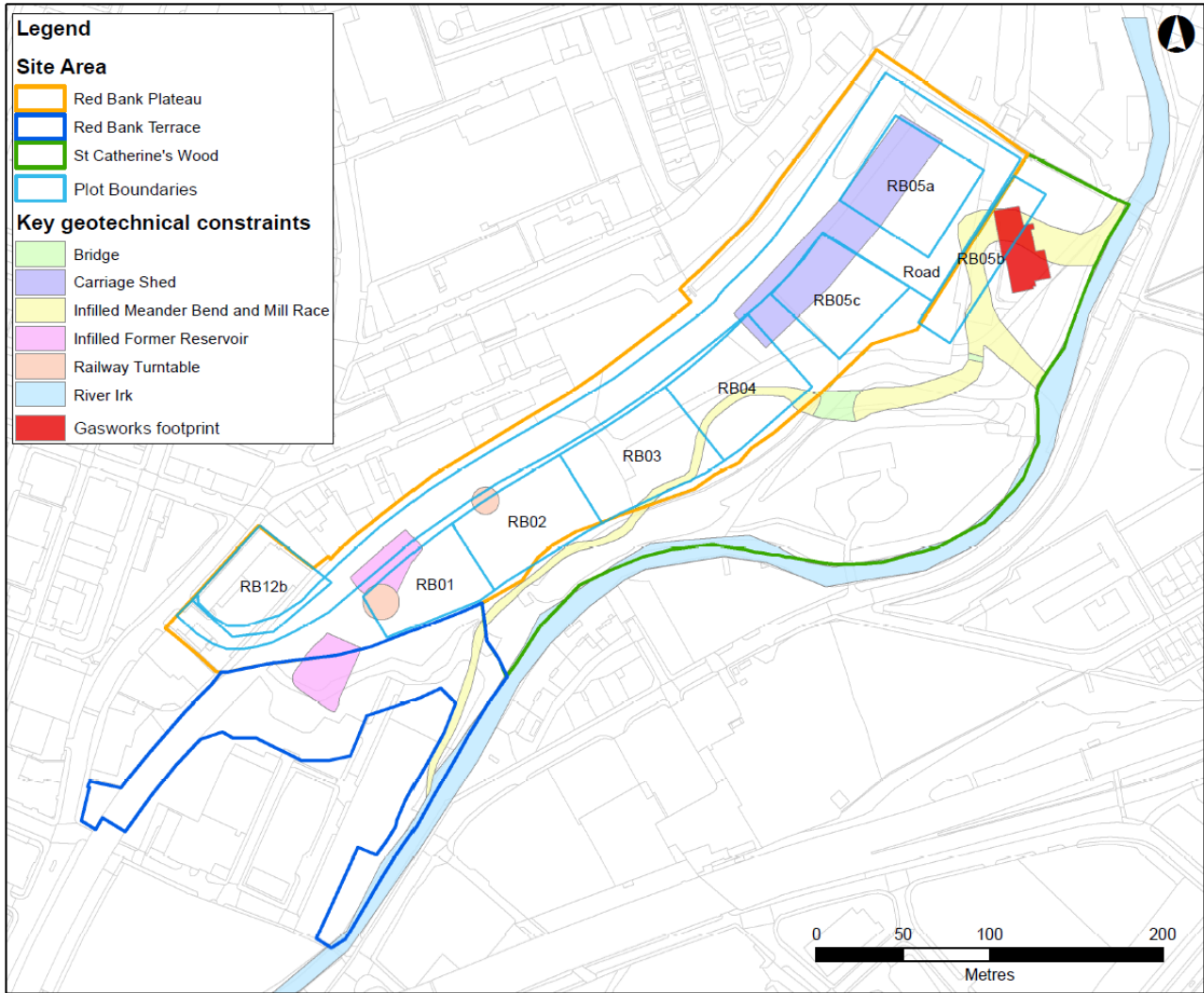


Figure 2: Historical land uses and proposed development plot layouts

2.3 Proposed development

The HIF Infrastructure Works (IW) proposals have been submitted as a full planning application to MCC and will comprise:

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

Ultimately, the site is to be developed for a predominantly residential use with landscaped areas of public open space. The proposed follow-on development in each of the three site areas is as follows (Figure 1):

- **Red Bank Plateau.** The current masterplan indicates that this will be the focus of proposed residential development within the site. The residential development will be apartments. Some local public open space (POS) development will be included within the generally residential development of this area.

- **Red Bank Terrace.** This area is to be predominantly formal public open space with planted areas, connecting footpaths and cycleways and areas of public realm.
- **St Catherine’s Wood.** The current masterplan indicates that this area will be generally non-residential, with a school proposed in the north of the area (Plot RB05b, see Figure 2) and areas of public open space elsewhere. Outside Plot RB05b, existing vegetation is to be preserved as fully as possible with limited areas of enhancement to facilitate the proposed POS use, including planted areas, connecting footpaths and cycleways and areas of public realm.
- The follow-on developments on the plots prepared by the HIF IW, including residential and school developments, will be subject to separate planning applications.

2.4 PFAS at Victoria North

2.4.1 PFAS

PFAS (Per- and polyfluoroalkyl substances) are a group of contaminants that have risen to prominence of the last 10 years in the UK (and globally). The physical and chemical properties of PFAS are diverse. PFAS compounds are persistent, or transform to persistent by-products, and some may pose a risk to human health and the environment. However, whilst there are concerns around the potential toxicity of PFAS, there are no UK published soil screening values for assessing human health risk for any PFAS compounds.

2.4.2 Possible sources of PFAS at the site

Based on a review of historical site usage, there were no known sources of PFAS on the Victoria North site. The historical site uses pre-date the widespread use of PFAS in the UK, or they were not industries where PFAS would be expected to be routinely used, based on guidance published by CL:AIRE [3].

The identification of a small PFAS ‘hotspot’ in surface soil within the Red Bank Plateau area indicates that a PFAS-containing substance may have been used or stored within the site in more recent times, possibly as a result of a fire where PFAS-containing Aqueous Film Forming Foam (AFFF) was used to extinguish it, although no supporting evidence has been able to be found for this.

The emerging water from the pipe is coming from an offsite source and is also known to contain low concentrations of PFAS. As it has been leaking to ground for an unknown period of time, it may have potentially impacted shallow soils in the Red Bank Plateau area, where the water has been pooling at the surface.

2.4.3 PFAS ground investigation

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

- Initial PFAS ground investigation - January 2023
- Further PFAS ground investigation – March 2023

Initial PFAS Ground investigation – January 2023

BAM’s programme for the HIF Infrastructure Works identified an area of proposed excavation in the centre of Red Bank Plateau as a critical-path activity. The proposed excavation area was some distance from the emerging water, therefore these proposed earthworks were considered to be outside the area of emerging water impact. An initial phase of PFAS ground investigation was undertaken in January 2023 to validate this, in anticipation of the proposed earthworks proceeding under a phased remediation and enabling strategy that was to be developed for the site.

On 24th and 25th January 2023, five trial pits (TP401 to TP405) were excavated within the proposed earthworks area. In addition, TP406 was excavated in an area that had potentially been impacted by the emerging water. The trial pit locations are indicated on Figure 3. The scope of this investigation was defined by Arup.

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 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 PFAS.

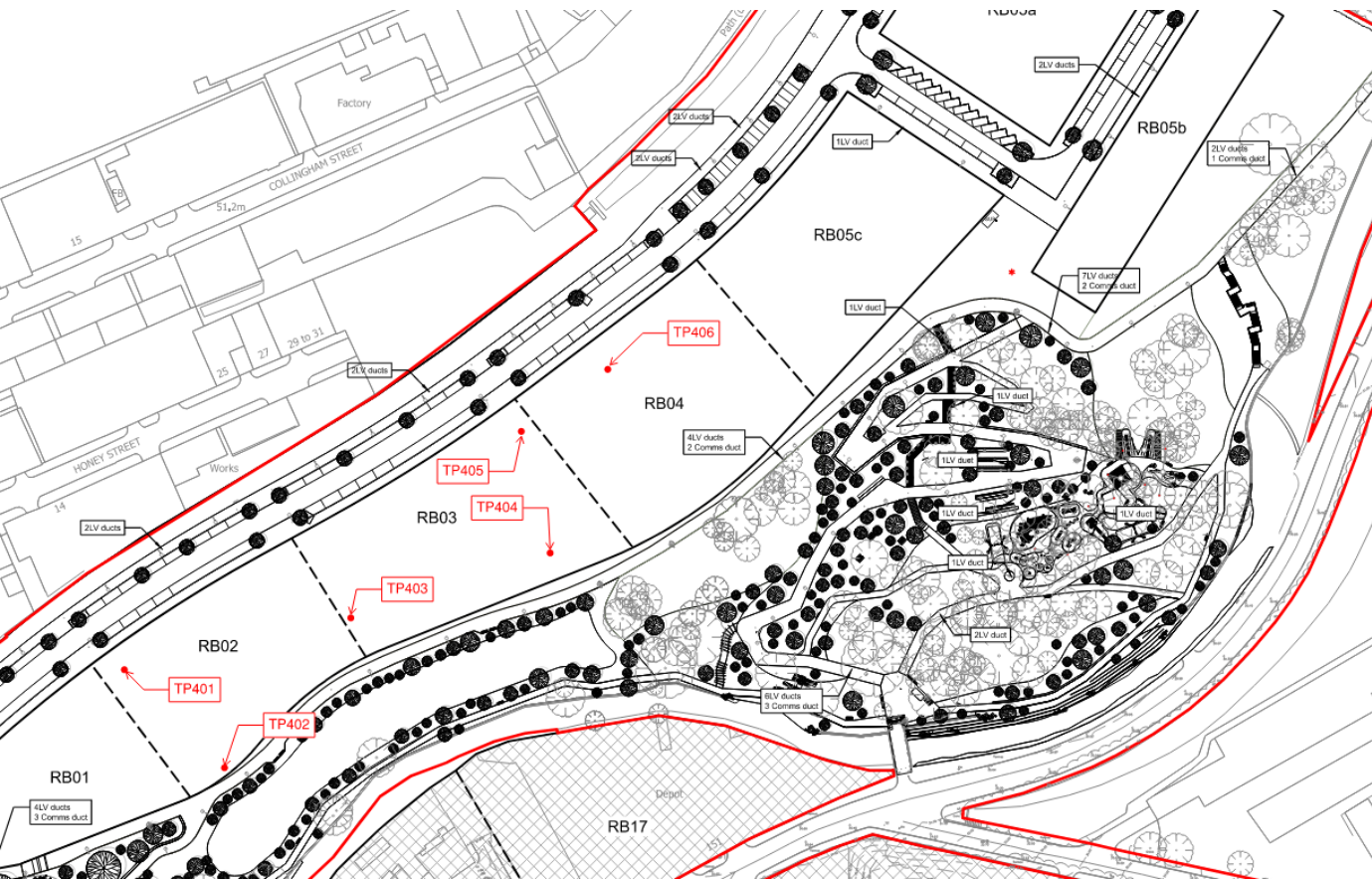


Figure 3: Initial PFAS ground investigation (January 2023) trial pit locations

Further PFAS ground investigation – 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 to validate the findings of the January 2023 analysis results (TP403A and TP405A).
- Widespread shallow sampling across the upper surface of the Red Bank plateau to further assess potential background PFAS contamination (400-series trial pits).
- 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 locations of the additional trial pits are shown in **Figure 4**.



Figure 4: Further PFAS ground investigation (March 2023) trial pit locations

2.4.4 Results of ground investigation

As described in **Section 2.4.3**, widespread soil testing has been carried out to assess the presence of PFAS in shallow soils across the Red Bank Plateau area, in addition to the area visibly impacted by the emerging water. Typically, PFAS has not been detected in soil and where it has been found, it has been in isolated locations. As there are no published soil assessment criteria to compare the concentrations against, it is considered appropriate to focus this assessment on the PFAS compounds that have been detected, as listed in **Table 1** below.

Some PFAS compounds can partially degrade or transform in the environment. The end products of degradation are usually perfluoralkylated acids (PFAAs), most commonly perfluoroalkylated sulfonic acids (PFSAs) and perfluoroalkylated carboxylic acids (PFCAs), which are highly resistant to further degradation and can persist in the environment for decades or more [4].

Table 1: PFAS contaminants detected in shallow soils

Perfluoroalkylated sulfonic acids (PFSA)	Perfluoroalkylated carboxylic acids (PFCA)
Perfluorooctyl sulphonate (PFOS)	Perfluorohexanoic acid (PFHxA)
	Perfluoroheptanoic acid (PFHpA)
	Perfluorooctanoic acid (PFOA)
	Perfluorononanoic acid (PFNA)
	Perfluorodecanoic acid (PFDA)
	Perfluorododecanoic acid (PFDoA)

In addition to testing for detectable PFAS compounds, a Total Oxidisable Precursors (TOP) Assay was carried out on selected soil samples. The TOP Assay allows PFAS precursors, which are not target analytes, to be detected. TOP Assay oxidises the sample, converting any PFAA precursors into detectable PFAAs, providing an indication of the potential for longer-chain PFAS compounds to degrade in the environment to shorter, more mobile ones.

The TOP Assay on soils identified some additional PFAAs, which are listed in **Table 2** below. The TOP Assay indicates that the PFAS in the soil may have the potential to transform into these persistent compounds over time.

Table 2: Additional PFAAs detected in shallow soils following TOP Assay

Perfluoroalkylated sulfonic acids (PFSA)	Perfluoroalkylated carboxylic acids (PFCA)
None	Perfluorobutanoic acid (PFBA) Perfloropentanoic acid (PFPA) Perfluoroundecanoic acid (PFUnA)

3. Conceptual Site Model

3.1 Introduction

The UK guidance relating to contaminated land is outlined within the Land Contamination: Risk Management (LCRM) guidance [5]. This online guidance describes a risk assessment methodology which is based on the ‘source-pathway-receptor’ model, also known as a conceptual site model (CSM). This model comprises:

- The principal pollutant hazards associated with the site (the sources of contamination);
- The principal targets at risk from the identified hazards (the receptors), such as residents, construction workers and the environment;
- The existence, or absence, of plausible pathways that may exist between the identified hazards and targets.

For a risk to exist all three elements (source-pathway-receptor) of a contaminant linkage must be present.

A CSM has been developed specifically for PFAS sources and considers the risk to human health receptors based on current development proposals for the site (see **Section 2.3**) and is presented in the following sections.

3.2 Possible sources

The following sources of PFAS have been identified at the site:

- Emerging water from a leaking pipe discharging to Red Bank Plateau, and potentially the soil in contact with the emerging water;
- ‘Hotspot’ of detectable PFAS concentrations identified around TP422 and TP423 in the area of the former gasworks.

3.3 Receptors

Receptors both during the proposed HIF Infrastructure Works (HIF IW) and following completion of the HIF IW and future development that may be at risk from PFAS compounds detected at the site include:

- Construction workers and site neighbours during the HIF IW;
- Interim users of the site following HIF IW before follow-on plot development;
- Construction workers and site neighbours during future development of the site;
- Residents and workers in the proposed future buildings constructed on the site;
- Users of the proposed school (Plot RB05b);
- Future users of onsite public open space areas.

3.4 Pathways

Potential pathways that may be present during construction and following completion include:

- Dermal contact, ingestion and/ or inhalation of PFAS impacted soil/ soil dust.

The PFAS compounds of concern at the site are not volatile under atmospheric conditions and therefore the inhalation of vapours is not considered to be a plausible exposure pathway.

3.5 Conceptual model

A summary of the conceptual site model for potential contaminant linkages that would arise during the construction and operational phases of Victoria North are presented in **Table 3**.

Table 3: Conceptual model for PFAS risks to human health

Possible Source		Pathway		Receptor	Potential Contaminant Linkage
PFAS impacted soils	→	Dermal contact, ingestion of soil/ soil dust, inhalation of soil/ soil dust	→	Construction worker	PPL1
			→	Interim user	PPL2
			→	Site neighbours during development	PPL3
			→	Future site user (resident, open space user, school user)	PPL4
		Infiltration/ diffusion through cracks/ joints in potable water supply pipes and consumption	→	Future site user	PPL5

3.6 Mitigation proposed for development

The GIR report [1] identified that mitigation/ remediation is necessary to address risks associated with other contaminants. Such mitigation measures will also mitigate the risks posed by PFAS, discussed below.

3.6.1 Physical barriers

Following the completion of HIF Infrastructure Works (HIF IW), it is envisaged that the site will be left in an interim condition until follow-on development starts. A “site finish layer” is proposed, comprising a temporary 100mm thick layer of suitable hydroseeded material, placed across all areas of the site in which made ground soils remain exposed at completion of the HIF IW.

The PFAS present at Victoria North are not volatile contaminants and therefore they only pose a human health risk via dermal contact, ingestion or consumption.

For the proposed residential/school/open space development in Red Bank Plateau, most of the site will be covered by hard surfacing (buildings, roads, car parks), breaking direct pathways for human interaction with PFAS in soil. Exposure may occur in soft landscaping areas if PFAS impacted soils are present at the surface. A clean cover system is to be adopted within soft landscaping areas/public open spaces in order to mitigate against contaminants other than PFAS and such a clean cover system will also prevent contact with PFAS in soil.

Below roads and buildings, direct exposure to PFAS impacted soils and groundwater will be prevented by the structures which will form physical barriers.

For areas within Red Bank Terrace and St Catherine’s Wood, a clean cover system has also been identified as being necessary as part of the Victoria North development in order to mitigate against other soil contaminants [1]. This will provide sufficient protection to break the pathway with PFAS impacted soils (where present).

A similar clean cover system approach can be used in areas of public open space where PFAS exceed appropriate risk-based targets.

Risk-based PFAS soil targets should be developed to define concentrations of PFAS that are suitable for use (at surface) in areas proposed for residential development and public open space.

3.6.2 Barrier pipe

Barrier pipe is a type of water supply pipe formed of multiple layers and designed to mitigate the risk to the chemical quality of mains water supply posed by contamination in adjacent soil and groundwater.

Barrier pipes have already been identified as being required for use within the Victoria North development because of the presence of contaminants other than PFAS in the ground [1].

3.6.3 Updated conceptual site model

Table 4 4 presents an update of the conceptual model incorporating the mitigation proposed as part of the remediation strategy for the HIF IW development. Potential contaminant linkages which require further consideration to mitigate the risk posed by PFAS are highlighted and require further consideration in the supplemental remediation strategy.

Table 4: Summary of remediation/ mitigation requirements for the identified potential contaminant linkages

Potential Contaminant Linkage	Description	Existing remediation/ mitigation requirement
PPL1	Dermal contact, ingestion of soil/ soil dust, inhalation of soil/ soil dust with PFAS impacted soil by construction worker.	Existing requirements are to control the exposure of construction workers to PFAS and other contaminants in soil through the use of standard safe working practices e.g. use of gloves, hand washing, use of dust suppression
PPL2	Dermal contact, ingestion of soil/ soil dust, inhalation of soil/ soil dust with PFAS impacted soil by interim site user	Site finish layer is to be installed in all areas of soil left exposed following HIF-IW. This will prevent the creation of dust that could otherwise be blown onto neighbouring sites. In the interim condition, it is understood that the site will be made secure to prevent unauthorised access. If unauthorised access does occur, the site finish layer will limit contact with the made ground beneath.
PPL3	Ingestion of soil/ soil dust, inhalation of soil/ soil dust with PFAS impacted soil by site neighbours	During construction, good site working practices such as wheel washers and dust suppression are to be used to prevent the spread of soil/dust outside the site boundary. Soil re-use is to be kept within each site area, to prevent the need for transportation on neighbouring roads. Following construction, a site finish layer is to be installed to control dust generation.
PPL4	Dermal contact, ingestion of soil/ soil dust, inhalation of soil/ soil dust with PFAS impacted soil by future site users	A clean cover system has been recommended to protect against contact with other soil contaminants, including PFAS. The soil used in the clean cover system is to meet PFAS soil human health criteria appropriate to the proposed use.
PPL5	Infiltration/ diffusion of PFAS through cracks/ joints in potable water supply pipes and consumption.	Barrier pipe has been recommended to be installed to protect against ingress of contaminants other than PFAS.

3.7 Summary

The conceptual model has identified several potential human health contaminant linkages associated with PFAS at the site. However, several of the contaminant linkages will be mitigated by the existing works required as part of the Victoria North development.

It is recommended that risk-based soil human health criteria are developed to assess the risk posed by soils proposed for use, or remain in situ, in areas proposed for residential and public open space.

4. CLEA modelling

4.1 CLEA model approach

Risk based human health criteria have been calculated using the Contaminated Land Exposure Assessment (CLEA) model software (v1.07) developed by the Environment Agency and published in 2015. The approach is based on the Environment Agency approach for assessing risks to human health as set out in SR2, SR3, SR4, SR7 [6],[7],[8],[9]. The model estimates human exposure to soil contaminants for those potentially living, working and/or playing on contaminated sites over long time periods (chronic exposure). The CLEA model does not include short-term (acute) risks to humans or risks from groundwater to humans.

The CLEA model includes the following generic land uses, for which human health site-specific assessment criteria (SSAC) can be developed by the user:

- Residential development including homegrown produce consumption (assumed to be from private gardens within the development)
- Residential development without homegrown produce consumption
- Allotments
- Commercial
- Public Open Space forming part of a residential development (POSresi)
- Public Open Space park (POSpark).

There is no generic school land use and no specific criteria have been developed for the proposed school development as part of this assessment. The current development proposal is for a primary school, therefore SSACs developed for a residential without homegrown produce consumption have been conservatively applied which will be suitably protective for a school use, due to the underlying assumptions about child exposure and duration of exposure. Once further detail on the final development is available for this area, this risk assessment can be revisited to determine the need for future remediation measures.

In generating the SSACs, the exposure assumptions used to develop the Category 4 Screening Levels (C4SLs)[22] are adopted in preference to those described in the Environment Agency’s SR3 publication [9]. These revised exposure assumptions are embedded within the CLEA v1.07 software, alongside the unmodified SR3 exposure assumptions.

The following parameters are used in the CLEA model for the selected land use scenarios. The soil type, organic matter content and pH have been selected based on site-specific measurement in the made ground:

Table 5: CLEA model basic settings parameters

Parameter	Residential without homegrown produce	Public open space (on residential development) scenario	Public open space (park)
Receptor	Female (residential C4SL)	Female (residential C4SL)	Female (allotment)
Building	Small terraced house	Small terraced house	No building
Soil Type	Sandy loam	Sandy loam	Sandy loam
SOM (%)	6	6	6
pH	7	7	7
Start Age Class (AC)	1	4	1
End Age Class (AC)	6	9	6

4.2 Chemical, physical and toxicological data sources

4.2.1 Overview

In the absence of published CLEA toxicological and physical/chemical data for the PFAS compounds assessed in this study, Arup has carried out a literature search in line with the recommendations of the CLEA SR2 [8] guidance report to identify parameters for use in CLEA. SR2 identifies 33 sources of authoritative toxicological data, as well as 9 authoritative sources of physical chemical characteristics which were each consulted as part of this risk assessment. The values used in the CLEA software are presented in the following sections.

The majority of toxicological studies carried out to date have been on PFOA and PFOS [10]. A complete set of the required data could not be found for the remaining eight compounds: PFHxA, PFHpA, PFNA, PFDA, PFDoA, PFPA, PFPA and PFUnA.

4.2.2 PFOS and PFOA

PFOS (Perflurooctane sulfonic acid) and PFOA (Perfluorooctanoic acid) are the most studied PFSA and PFCA respectively, being widely used and commonly encountered. They are extremely persistent and can be more mobile in groundwater than the precursors they originated from. Their high aqueous solubility and ineffective treatment by most wastewater treatment technologies means that they have widespread low level (ng/L) distribution in the biosphere.

PFOS was introduced in 1964 for use in firefighting foams but has also been used in the semiconductor and photographic industries, in hydraulic fluids used in the aviation industry, protective coatings for materials such as carpets and textiles and in various household and industrial cleaning products. It contains a chain of 8 fully fluorinated carbon atoms and comprises a mixture of linear and branched isomers, with approximately 70% linear and 30% branched. It does not readily partition from groundwater into air.

PFOA is mainly used in the production of fluoropolymers used in electronics, textiles and non-stick cookware. PFOA is the most studied perfluorocarboxylic acid (PFCA) to date. It consists of a chain of 7 perfluorinated carbon atoms and a carboxyl functional group forming an 8-carbon chain.

Following several reports on PFOS and its potential risks to the environment and human health, the manufacture of PFOS was prohibited in the European Union under directive 2006/122/EC that came into force in the UK in June 2008, however most production of PFOS ceased in 2002. The use of legacy firefighting foam products containing >0.001wt% PFOS has been banned in the EU since June 2011. PFOA is still manufactured, with the main producer being DuPont ([13],[15],[18]).

4.3 Use of PFOS and PFOA as surrogates for other PFAAs

An approach often used in human health risk assessment in the absence of compound-specific values is to use toxicity values developed for structurally or chemically similar surrogate compounds with similar biological activity. In the case of PFAS, this would be for PFAS from the same structural subgroup i.e. long-chain or short-chain perfluoroalkyl acids (PFAAs) [11]. CL:AIRE reports that, when assessing a foam spillage at Brisbane Airport in 2017, a ‘conservative but protective’ approach was adopted based on assessing compounds with similar structures and likely similar properties to PFOS and PFOA [13]. Therefore, it is considered that the use of surrogates is appropriate for the assessment of PFAS compounds.

PFAAs contain a chain of two or more carbon atoms with a charged functional group, commonly carboxylates (perfluoroalkyl carboxylic acids or PFCAs) or sulphonates (perfluoroalkane sulphonic acids or PFSAAs). PFSAAs with a chain length of 6 or greater are termed long-chain, whilst PFCAs with a chain length of 8 or longer are termed long-chain.

Table 6: Short-chain and long-chain PFSAAs and PFCAs

	PFSAAs (chain length)	PFCAs (chain length)
Long-chain	PFOS (C8)	PFOA (C8) PFNA (C8) PFPA (C8)

	PFSAs (chain length)	PFCAs (chain length)
		PFDA (C9) PFDoA (C11) PFUnA (C11)
Short-chain	None	PFBA (C3) PFHxA (C5) PFHpA (C6)

Long-chain and short-chain PFAS compounds are of similar toxicity, but because short-chain PFAS compounds generally have shorter half-lives, adverse effects typically require higher doses of short-chain compounds [12]. Sorption to organic carbon generally increases with increasing perfluoroalkyl chain length, indicating that the short-chain PFCAs (for example, PFHxA) are less retarded than their long-chain counterparts (e.g. PFOS and PFOA, respectively). In addition, PFSAs tend to sorb more strongly than PFCAs of equal chain length and branched isomers are less sorptive than linear isomers. PFOS, PFOA, and other long-chain PFCAs are typically the predominant PFAS identified in surface soils and sediments [11], which has been observed in the soils at Victoria North.

PFBA, PFHxA and PFHpA are short-chain PFCAs and therefore have a lower potential to persist than the longer chain PFCAs identified in the soil at Victoria North. For this reason, they have been discounted from further assessment.

PFPA, PFNA, PFDA, PFDoA and PFUnA have been considered further due to their longer chain lengths and therefore persistence in the environment.

PFOA and PFOS have similar toxicological endpoints, resulting in hepatic and metabolic toxicity. In a study of available toxicology data by ATSDR, PFNA was assigned the same minimal risk level as PFOA [14], indicating that PFNA may have similar potency to PFOA.

In 2020, EFSA consulted on a Tolerable Weekly Intake (TWI) of 0.008ug/kg bw based on a no observable adverse effect concentration (NOAEC) for the sum of PFOA, PFNA, PFHxS and PFOS [15]. Although current scientific opinion is that the EFSA study should be used with caution in the UK [16], it is used in this study as it represents a conservative approach to the assessment of PFAS. In the EFSA opinion, PFNA is considered alongside PFOS and PFOA as having similar toxicological endpoints.

In the ATSDR study [14], no minimal risk levels could be derived for PFDA, PFDoA and PFUnA due to insufficient data.

Based on the above, it is considered appropriate for the purposes of screening and in the absence of robust toxicology data for PFAS compounds other than PFOS and PFOA, that PFOA is used as a surrogate for the other PFCA compounds identified in the soil at Victoria North. In order to be even more protective and to allow for the potential additive effects of exposure to multiple PFAS compounds, the risk-based criteria will be applied to the sum of all PFCA/PFSAs.

4.4 Derivation of SSACs

The results of the CLEA assessment for PFOS and PFOA are presented in **Table 7** and the full output is presented in **Appendix A**.

Table 7: SSACs for PFAS derived using CLEA

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 (PFOS)	40.4	79.1	161.2
Total PFCAs (PFOA)	21.1	79	152.8

The results of the CLEA model showed that the human health risk from PFAS is largely driven by oral exposure (ingestion), rather than inhalation or dermal contact. This further confirms that a barrier solution, such as clean cover system, is appropriate to deal with the risk of exposure to PFAS in soil.

The PFOS SSAC is considered appropriate for use in assessing risks posed by PFOS in soil. The PFOA SSAC is considered appropriate for use in assessing risks posed by other PFCAs in soil at Victoria North.

4.5 Sensitivity analysis

The SR7 guidance compiles data for derivation of soil guideline values from nine authoritative sources. It also includes a preferred method of derivation for physical-chemical characteristics, using equations to calculate some parameters from core properties rather than literature values. However, in the absence of some core properties due to the emerging nature of PFAS research, some properties have been derived purely from literature sources and online databases. Therefore, a sensitivity analysis has been undertaken on various parameters based on the residential land use scenario (with plant uptake).

A sensitivity analysis has not been undertaken for the Tolerable Daily Intake (TDI) and Mean Daily Intake (MDI) values as these have been carefully selected based on the worst-case literature values available at the time of writing.

The results of the sensitivity analysis for PFOS and PFOA are presented in **Table 8** and **Table 9** respectively.

Table 8: Sensitivity analysis for PFOS assessment (unshaded cells are the results based on the values used in the model)

Parameter	Units	Values used for sensitivity analysis	Justification	CLEA result (residential without produce)
Air-water partition coefficient (Kaw)	Dimensionless	1.35 x10 ⁻⁷	Reported literature value	0.0404
		1.35 x10 ⁻⁶	Order of magnitude	0.0402
		1.35 x10 ⁻⁸		0.0404
Diffusion coefficient in air	m² s ⁻¹	3.02 x10 ⁻⁶	Reported literature value	0.0404
		3.02 x10 ⁻⁵	Order of magnitude of literature value	0.0404
		3.02 x10 ⁻⁷		0.0404
Diffusion coefficient in water	m² s ⁻¹	3.52 x10 ⁻¹⁰	Reported literature value	0.0404
		3.52 x10 ⁻⁹	Order of magnitude	0.0400
		3.52 x10 ⁻¹¹		0.0405
Vapour pressure	Pa	3.31 x10 ⁻⁴	Reported literature values	0.0404
		0.3		0.0404
		6.8		0.0404
Water solubility	mg l ⁻¹	5.19 x10 ²	Reported literature values	0.0404
		6.80 x10 ²		0.0404
Organic carbon – water partition coefficient (Koc)	Log cm³ g ⁻¹	2.8	Reported literature values	0.0404
		2.4		0.0403
		3.1		0.0405
Octanol – water partition coefficient (log Kow)	Log (dimensionless)	6.43	Reported literature values	0.0404
		5.61		0.0404
Notes:				
	No/negligible change to soil criteria, or higher			
	Minimal change to soil criteria, within the same order of magnitude			
	Significant change to soil criteria, order of magnitude lower			

Table 9: Sensitivity analysis for PFOA assessment (unshaded cells are the results based on the values used in the model)

Parameter	Units	Values used for sensitivity analysis	Justification	CLEA result (residential without produce)
Air-water partition coefficient (K _{aw})	Dimensionless	3.82 x10 ⁻⁵	Reported literature value	0.0211
		1.70 x10 ⁻⁵		0.0275
		1.02 x10 ⁻³		0.0064
Diffusion coefficient in air	m ² s ⁻¹	2.26 x10 ⁻⁶	Reported literature value	0.0211
		2.26 x10 ⁻⁵	Order of magnitude	0.0206
		2.26 x10 ⁻⁷		0.0212
Diffusion coefficient in water	m ² s ⁻¹	5.79 x10 ⁻¹⁰	Reported literature value	0.0211
		5.79 x10 ⁻⁹	Order of magnitude	0.0186
		5.79 x10 ⁻¹¹		0.0303
Vapour pressure	Pa	100	Reported literature values	0.0211
		12		0.0211
		4.2		0.0211
Water solubility	mg l ⁻¹	3.4 x10 ³	Reported literature values	0.0211
		2.3 x10 ³		0.0211
		4.3 x10 ³		0.0211
Organic carbon – water partition coefficient (K _{oc})	Log cm ³ .g ⁻¹	1.97	Reported literature values	0.0211
		1.31		0.0094
		2.63		0.0334
Octanol – water partition coefficient (log K _{ow})	Log (dimensionless)	5.3	Reported literature values	0.0211
		4.81		0.0211
Notes:				
	No/negligible change to soil criteria, or higher			
	Minimal change to soil criteria, within the same order of magnitude			
	Significant change to soil criteria, order of magnitude lower			

The sensitivity analysis has concluded uncertainty in parameter selection for the derivation of the human health soil criteria for PFOS and PFOA does not significantly affect the results.

5. Comparison Against Site Soil Data

The derived PFOS and PFOA SSACs have been compared against soil data obtained for the site (see **Appendix B**). As discussed in **Section 2.4**, the majority of the soil tested at Victoria North did not contain PFAS at detectable concentrations, even where soil had been tested in the vicinity of the emerging water, which is known to contain PFAS. PFAS was detected in the following locations:

- TP411 (linear PFOS detected 2.13µg/kg)
- TP422 (several PFAAs detected)
- TP423 (total PFOS detected pre- and post-oxidation of sample, maximum 20.04µg/kg)
- TPCS2 (linear PFOS detected 2.61µg/kg)
- TPCS6 (linear PFOS detected 1.87µg/kg)
- TPCS8 (linear PFOS detected post-oxidation of sample 1.52µg/kg)

Four samples contained PFOS at concentrations close to the limit of detection. An area of higher concentrations was identified at TP422/TP423. The distribution of detected PFAS is shown in **Figure 5** below:

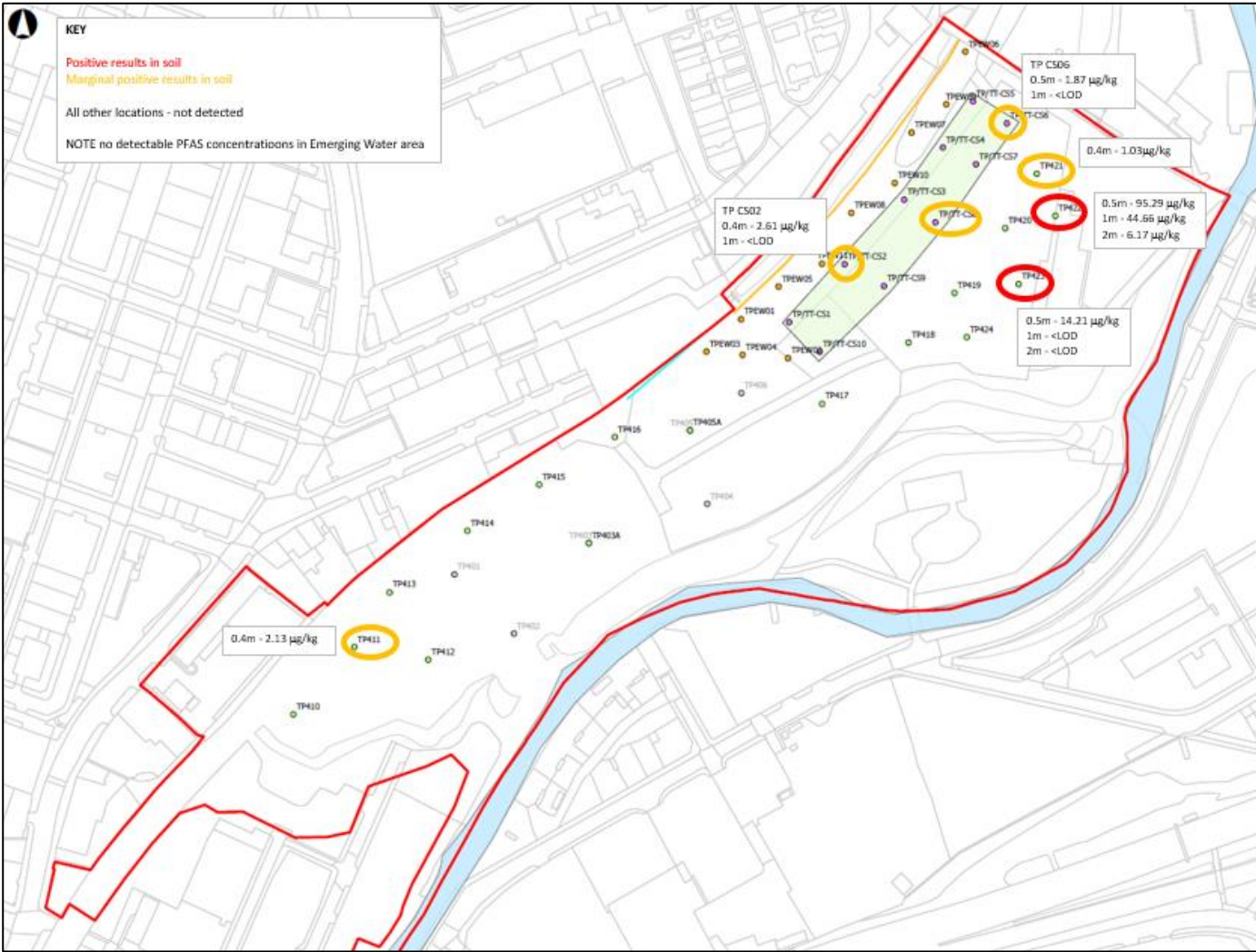


Figure 5: Locations of PFAS detected in soil

Comparison of the results from TP422/TP423 in **Table 10** shows that samples from TP422 at 0.5m and 1m contain PFCAs in excess of the SSAC for residential developments and marginally exceeds the SSAC for Public Open Space

near a residential development. None of the soil data exceeds the SSAC for Public Open Space park. It is concluded that the PFAS in soil at TP422 and TP423 is unrelated to the PFAS detected elsewhere within the site. The risk assessment has demonstrated that the material in these trial pits is not suitable for use where there is the possibility of human contact, but the made ground on site will not be exposed due to the provision of clean cover or buildings and hardstandings. If the ground in the area around TP422 and TP423 is to be excavated as part of the HIF IW, it should be either taken offsite or validated for re-use. It should be noted that the risks to controlled waters posed by this material are being considered separately.

All other PFAS results, including those obtained by TOP Assay, are below the SSACs generated. Therefore, it is 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.

The values presented in **Table 10** should be transposed into the remediation strategy for the scheme, to verify the base and sides of excavations where PFAS-contaminated soils are removed.

Table 10: Summary of PFAS screening against SSACs

PFAS compound		Units	SSAC for residential without plant uptake	SSAC for public open space in a residential area	SSAC for public open space (park)	Maximum recorded value (location)
Total PFASs	Perfluorooctyl sulphonate (PFOS)	µg/kg	40.4	79.1	161.2	20 (TP423)
Total PFCAs	Perfluorooctanoic acid (PFOA)	µg/kg	21.1	79	152.8	87.9 (TP422)
	Perfluorononanoic acid (PFNA)	µg/kg				
	Perfloropentanoic acid (PFPA)	µg/kg				
	Perfluorodecanoic acid (PFDA)	µg/kg				
	Perfluorododecanoic acid (PFDoA)	µg/kg				
	Perfluoroundecanoic acid (PFUnA)	µg/kg				

6. Conclusions

This report presents a human health risk assessment for PFAS at Victoria North. The assessment is based on a review of potential sources of PFAS and the results of all available soil testing. The PFAS contaminants identified as being of most concern are:

Perfluoroalkane sulfonic acids (PFSAs)	Perfluoroalkyl carboxylic acids (PFCAs)
Perfluorooctyl sulphonate (PFOS)	Perfluorooctanoic acid (PFOA) Perfluorononanoic acid (PFNA) Perfloropentanoic acid (PFPA) Perfluorodecanoic acid (PFDA) Perfluorododecanoic acid (PFDoA) Perfluoroundecanoic acid (PFUnA)

The conceptual model has identified several potential contaminant linkages to future site users following site redevelopment relating to PFAS. Many of the measures that will be implemented to mitigate risks posed by other contaminants will also mitigate risks posed by PFAS. This includes use of physical barriers (clean cover system and hard surfacing).

In the absence of any published human health soil targets for PFAS, Arup has developed human health criteria (SSACs) based on the EA CLEA approach to assessing risks to human health posed by soils.

As PFAS are a contaminant of relatively recent interest the data reported in literature for parameters used in the modelling is limited. 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. It is noted that the CLEA model is based on relatively conservative assumptions and therefore represents a minimal level of risk. The SSACs developed (see **Table 7**) can be used for comparison to soil concentrations obtained during the earthworks validation testing.

Sensitivity analysis undertaken for parameters with lower confidence levels has concluded the diffusion coefficient in water and organic carbon – water partition coefficient (Koc) were found to be most sensitive. Arup has used Koc values which are in line with the EA approach [7].

Comparison of the results from soil testing identified that samples from TP422 at 0.5m and 1m contain PFCAs in excess of the human health soil criteria in residential developments and public open space near residential developments, but the made ground on site will not be exposed due to the provision of clean cover in public open space, or buildings and hardstandings. The PFAS detected in TP422 and TP423 is not typical of the PFAS concentrations detected elsewhere within the site. If the ground in the area around TP422 and TP423 is to be excavated as part of the HIF IW, it should be either taken offsite or validated for re-use. The risks to controlled waters posed by this material are being considered separately.

All other PFAS results, including those obtained by TOP Assay, are below the human health soil criteria generated. Therefore, it is concluded that these soils do not pose a significant risk to human health from PFAS and will be suitable for re-use on the site.

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Appendix A

Derivation of risk-based soil criteria

A.1 Review of Published Data for PFOS

A.1.1 Toxicity of PFOS

Data on the toxicity of PFOS in humans is greater than some other PFAAs as it has been one of the most widely detected in humans and the environment.

Human exposure to PFOS is mainly by ingestion of contaminated food or water, although household dust and breast milk may be important exposure pathways for infants and young children. Hand-to-mouth transfer from treated materials has also been identified as a significant source of exposure, particularly in children.

PFOS can cross the placenta, causing exposure to the developing foetus although Public Health England states that PFOS is not thought to be mutagenic.

PFOS is not metabolised in the body, so it binds to proteins, not fats, and is mainly detected in blood, liver and kidneys. Elimination of PFOS from the human body takes some years.

Studies on animals fed PFOS for a long period showed effects on the gastrointestinal tract, liver and thyroid hormones.

Animal studies also indicate that PFOS may cause cancer at relatively high levels, such as those resulting from occupational exposure. However, there is limited data for humans. US EPA concludes that evidence of carcinogenicity of PFOS is “suggestive” but not definitive, because tumour incidence does not indicate a dose response (CL:AIRE, 2019; IRTC, 2021; PHE, 2009a).

A.1.2 Background intake of PFOS

A.1.2.1 Intake from food

PFAS are present in food, mainly through two processes: accumulation in aquatic and terrestrial food chains and transfer from materials used in food packaging and processing.

Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) (2016) undertook a human health review of PFOS. A number of studies across Australia have collected and analysed serum samples. PFOS concentrations appear to have decreased from 2002 to 2011 in the Australian population, due to the decline in global use of PFAS chemicals since 2002. The mean concentration for PFOS in the Australian population in 2011 was considered to be 10.2ng/mL. Based on the half-life of 5.5 years (2007 days) for PFOS, the total daily intake for PFOS was calculated at 0.89ng/kg bw/day.

Clarke et al (2010) estimated the dietary intake of PFOS in UK retail foods, with an upper bound of 10ng/kg bw/day. COT quotes a 95th percentile intake by adults from food of 4 PFAS, including PFOS, of 13ng/kg bw/day. Based on this, the figure quoted by Clarke et al of 10ng/kg bw/day is taken as the MDI as this is likely to be an upper bound estimate of intake of PFOS from food. Assuming an adult bodyweight of 70kg gives an MDI from food of 0.7µg/day.

A.1.2.2 Intake from water

A national survey across Australia in 2011 detected PFOS in drinking water at levels of 0 to 15.6ng/l with corresponding uptake rates estimated to be 0 to 11ng of PFOS per day (Thompson, Eaglesham and Mueller, 2011).

The UK Drinking Water Inspectorate suggests the concentration that should be used for PFOS in drinking water derived from surface water is 5 ng/l. This is the approximate level found in river water which will be subject to treatment and is therefore reasonably conservative. Assuming an adult drinks two litres of water a day, a daily intake from water of 0.01µg/l can be assumed (COT, 2022).

A.1.2.3 Intake from food and water (MDI_{oral})

Based on the data identified for food and water intake of PFOS, the background intake is already much greater than the TDI set by EFSA for the sum of 4 PFAS. Where this occurs, the CLEA guidance (Environment Agency (2009)) recommends that a minimum proportion of the TDI should be reserved for exposure from land of 50% or:

MDI_{oral} = TDI x 0.5

Based on the EFSA TDI of 0.000629µg/kg bw/day, corrected for an adult bodyweight of 70kg gives an MDI_{oral} of 0.022µg/day.

A.1.2.4 Intake from air

The Committee on Toxicity (2006) reported airborne PFOS in UK air in 2006-07, giving a range of 0.23 to 111 picograms/m³. Assuming an adult inhales 20m³/day, within this range daily intake ranges from 4.60x10⁻⁶ to 0.00222 µg/day.

Concentrations of PFAS in indoor air generally exceed those of outdoor air and therefore exposure via inhalation is mainly due to indoor air. The average maximum PFOS concentration in indoor air in homes in the UK was calculated as 200pg/m³. The daily estimated exposure was calculated at 0.0027 to 0.0083µg/day (COT, 2022).

A.1.2.5 Intake from other sources

No data is available for PFOS intake from sources other than air, water and food.

A.1.2.6 Recommendation of Mean Daily Intake (MDI)

Based on the above values, the recommended oral MDI for use is 0.0723µg/day. This is a combination of the CRC CARE research into the food pathway and the DWI drinking water pathway.

The recommended inhalation MDI is 0.0083µg/day, based on the upper limit of daily exposure in indoor air in UK homes (COT, 2022).

A.1.3 Recommendation of Health Criteria Values for PFOS

A literature review of available Health Criteria Values was undertaken in line with the CLEA SR2 guidance report. A summary of this research is presented in **Table A1**, **Table A2** and the text below.

Table A11: Health Criteria Values for PFOS for the oral route of entry (including background intakes, where relevant)

Does PFOS exhibit threshold or non-threshold effects via ingestion?			
	Threshold? YES (TDI and MDI required)	Non-threshold? NO (ID required)	Both? NO
Parameter	Units	Value	Reference
Oral TDI (sum of 4 PFAS)	µg /kg bw/day	0.000629	EFSA, 2020
Oral TDI (PFOS)	µg /kg bw/day	0.3	COT, 2009
Oral MDI for 70kg adult	µg /day	0.71	Clarke et al, 2010 COT, 2022
Oral MDI for 70kg adult for sum of 4 PFAS	µg /day	0.022	EA, 2009
Oral ID	µg /kg bw/day	No data	-

Table A12: Health Criteria Values for PFOS for the inhalation route of entry (including background intakes, where relevant)

Does PFOS exhibit threshold or non-threshold effects via inhalation?			
	Threshold? YES (TDI and MDI required)	Non-threshold? NO (ID required)	Both? NO
Parameter	Units	Value	Reference
Inhalation TDI	µg /kg bw/day	No data	-

Does PFOS exhibit threshold or non-threshold effects via inhalation?			
Inhalation MDI for 70kg adult	µg /day	0.0083	COT, 2022
inhalation ID	µg /kg bw/day	No data	-

EFSA

In 2008, the European Food Safety Agency (EFSA) scientific opinion set a TDI for PFOS of 150ng/day. This was reduced following a review in 2018 to a TWI of 13ng/kg bw/week.

In 2020, EFSA consulted on a Tolerable Weekly Intake (TWI) of 0.008ug/kg bw based on a no observable adverse effect concentration (NOAEC) for the sum of PFOA, PFNA, PFHxS and PFOS in a study on vaccination response in one year olds. This TWI was lowered to 4.4ng/kg bw/week following public consultation to take account of the accumulation of PFAS in the body over time. This equates to a TDI of 0.000629 µg/kg bw/day (EFSA, 2020).

COT

In 2006, the Committee on Toxicology (COT) published a statement on tolerable daily intakes (TDIs) for PFOS, recommending a TDI value of 0.3µg/kg bw/day (COT, 2006a; COT 2006b). In 2009, COT confirmed its previous recommendation on PFOS (COT, 2009).

COT has considered the 2020 EFSA opinion (COT, 2022) and noted that there are uncertainties in the biological significance of the response on which the EFSA TWI is based. COT was unable to suggest an alternative TWI at present and no changes have currently been made to published UK guidance on PFOS as a result.

Health Canada

Health Canada recommended a TDI (Tolerable Daily Intake) of 0.06µg/kg bw based on a NOAEL of 0.021mg/kg bw/day following a study on liver effects in rats. An uncertainty factor of 25 was applied (DWI, 2021).

Food Standards Australia and New Zealand

A TDI of 0.02µg/kg was set in 2017, based on a NOAEL of 0.1mg/kg/data from a study of decreased body weight gain in rats with an uncertainty factor of 30 (DWI, 2021).

US EPA

In 2016, the US EPA set an oral Reference Dose (RfD) of 0.02µg/kg bw/day, which is based on a LOAEL of 1mg/kg/day from a study of reduced pup weight in rats with an uncertainty factor of 300 applied (DWI, 2021).

Conclusions

Authoritative UK data exists for PFOS, but the most recently published TDI (0.3µg/kg/day) is from 2009, and this value is an order of magnitude higher than guidelines published in more recent years.

The most recent European toxicity data was published by EFSA in 2020 (TDI of 0.0006µg/kg bw/day), but this relates to the sum of four PFAS compounds, including PFOS. This risk assessment will use the EFSA TWI of 4.4 µg/kg bw/week to generate a site-specific screening level for PFOS. This is considered to be a highly conservative approach.

No Health Criteria Values for inhalation routes of exposure were identified.

A.1.4 Physical-chemical characteristics of PFOS

Air-water partition coefficient (Kaw, dimensionless)

Kaw can be estimated from the Henry’s Law Constant and is sometimes referred to as the Dimensionless Henry’s Law Constant (Environment Agency, 2008b).

A value of 1.35 x10⁻⁷ was calculated for air-water partition coefficient, which has been estimated using the Clayperon relationship using the Henry’s Law constant at 25C.

Diffusion coefficient in air (Dair, m² s⁻¹)

An estimated value of 3.02x10⁻⁶ is given by the Michigan Department of Environmental Quality (2015a).

Diffusion coefficient in water (Dwater, m² s⁻¹)

An estimated value of 3.52x10⁻¹⁰ is given by the Michigan Department of Environmental Quality (2015a).

Relative molecular mass (g mol⁻¹)

A value of 500.13 g mol⁻¹ is given as the molecular weight of PFOS (Michigan DEQ, 2015a and CONCAWE, 2016).

Vapour Pressure (Pv, Pa)

A value of 3.31 x10⁻⁴ Pa is given by Public Health England (2018).

Water Solubility (S, mg L⁻¹)

A value of 5.19x10² mg L⁻¹ is given by Public Health England (2018), which is stated as being the recommended literature value at 20°C. The CL:AIRE Technical Bulletin 19 also quotes a solubility of PFOS of 520mg/L.

Log Organic carbon-water partition coefficient (Koc, log values, cm³ g⁻¹)

The reported literature values range between a value of 2.4 to 3.1 Log cm³ g⁻¹. Due to the relatively narrow range reported in the literature a value of 2.8 Log cm³ g⁻¹ was used for the assessment (around the mid-point of the literature range).

Log Octanol-water partition coefficient (Kow, log values, dimensionless)

A value of 6.43 is predicted by the US EPA (n.d.) chemical database. This same value is also quoted by CONCAWE (2016).

Dermal Absorption Fraction (ABSd, dimensionless)

The default value of 0.1 was used in the absence of chemical specific data (Environment Agency, 2008d).

Soil-to-dust transport factor (TF, dimensionless)

A default value of 0.5 is selected, based on the guidance provided in Environment Agency (2008d).

Table A13: Parameter values used in deriving the human health criteria for PFOS

Parameter	Units	Value	Reference/Comment
Air-water partition coefficient (Kaw)	dimensionless	1.35 x10 ⁻⁷	Environment Agency, 2008b
Diffusion coefficient in air (Dair)	m² s ⁻¹	3.02 x10 ⁻⁶	Michigan DEQ, 2015a
Diffusion coefficient in water (Dwater)	m² s ⁻¹	3.52 x10 ⁻¹⁰	Michigan DEQ, 2015a
Relative molecular mass	g mol ⁻¹	500.13	Michigan DEQ, 2015a
Vapour pressure (Pv)	Pa	3.31 x10 ⁻⁴	PHE, 2018
Water solubility (S)	mg L ⁻¹	520	PHE, 2018 CL:AIRE, 2019
Log Organic carbon-water partition coefficient (logKoc)	Log (cm³ g ⁻¹)	2.8	Based on literature (see Section Error! Reference source not found.). CONCAWE, 2016
Log Octanol-water partition coefficient (logKow)	Log (dimensionless)	6.43	USEPA, n.d. CONCAWE, 2016

Parameter	Units	Value	Reference/Comment
Dermal absorption fraction (ABSd)	dimensionless	1	Environment Agency, 2008d
Soil-to-plant uptake parameters (literature review)			
Soil-to-plant concentration factor for green vegetables	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-plant concentration factor for root vegetables	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-plant concentration factor for tuber vegetables	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-plant concentration factor for herbaceous fruit	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-plant concentration factor for shrub fruit	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-plant concentration factor for tree fruit	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-dust transport factor (TF)	g g ⁻¹ dw	0.5	Environment Agency, 2008d
Other useful data (if required for temperature conversions)			
Chemical formula	-	C8HF17O3S	Environment Agency, 2004
Boiling point (Tb)	K	492.15	USEPA, n.d.
Enthalpy of vapourisation at Tb (ΔHb)	J mol ⁻¹	No data	-
Henry’s Law Constant (H)	Pa m ³ mol ⁻¹	3.19 x10 ⁻⁴	Environment Agency, 2004
Melting point (Tm)	K	458.15	EPA, n.d.

See (Environment Agency, 2008a; Environment Agency, 2008d) and (Environment Agency, 2008b) for further guidance and an explanation of the parameters required by the CLEA model.

A.2 Review of Published Data for PFOA

A.2.1 Toxicity of PFOA

Data on the toxicity of PFOA in humans is greater than some other PFAAs as it has been one of the most widely detected in humans and the environment.

Human exposure to PFOA is mainly by ingestion of contaminated food or water, although household dust and breast milk may be important exposure pathways for infants and young children. Hand-to-mouth transfer from treated materials has also been identified as a significant source of exposure, particularly in children.

PFOA can cross the placenta, causing exposure to the developing foetus although Public Health England states that PFOA is not thought to be mutagenic.

PFAAs are not metabolised in the body, so it binds to proteins, not fats, and is mainly detected in blood, liver and kidneys. Probable links with high cholesterol, thyroid disease, pregnancy-induced hypertension, ulcerative colitis, testicular cancer and kidney cancer, have been published for PFOA based on a large population human health screening study. Elimination of PFOA from the human body takes some years.

Studies on animals fed PFOA for a long period showed effects on the gastrointestinal tract, liver and thyroid hormones. However, these studies showed PFOA to be less toxic than PFOS.

Animal studies also indicate that PFOA may cause cancer at relatively high levels, such as those resulting from occupational exposure. However, there is limited data for humans. A risk assessment study performed in 2005 categorised PFOA’s carcinogenicity as “suggestive” (CL:AIRE, 2019; IRTC, 2021; PHE, 2009a).

A.2.2 Background intake of PFOA

A.2.2.1 Intake from food

Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (2016) undertook a human health review of PFAS. A number of studies across Australia have collected and analysed serum samples. PFOA concentrations appear to have decreased from 2002 to 2011 in the Australian population, due to the decline in global use of PFAS since 2002. The mean concentration for PFOA in the Australian population in 2011 was considered to be 4.5 ng/mL. Based on the half-life of 3.2 years (1168 days) for PFOA, the total daily intake for PFOA is 0.50 ng/kg/day.

Following a UK study in 2004 by the Food Standards Agency (FSA), estimated adult intake of PFOA from the whole diet was 0.003 to 0.1 µg/kg bw/day. Correcting for a 70kg adult, gives an upper bound MDI of 7µg/day (PHE, 2009b).

A.2.2.2 Intake from water

A national survey across Australia in 2011 detected PFOA in drinking water at levels of 0 to 9.6 ng/l with corresponding uptake rates estimated to be 0 to 13 ng of PFOA per day.

The UK Drinking Water Inspectorate suggests the concentration that should be used for PFOA in drinking water derived from surface water is 5 ng/l. This is the approximate level found in river water which will be subject to treatment and is therefore reasonably conservative. Assuming an adult drinks two litres of water a day, a daily intake from water of 0.01 µg/l can be assumed (COT, 2022).

A.2.2.3 Intake from food and water (MDI_{oral})

Based on the data identified for food and water intake of PFOS, the background intake is already much greater than the TDI set by EFSA for the sum of 4 PFAS. Where this occurs, the CLEA guidance (Environment Agency (2009)) recommends that a minimum proportion of the TDI should be reserved for exposure from land of 50% or:

MDI_{oral} = TDI x 0.5

Based on the EFSA TDI of 0.000629 µg/kg bw/day, corrected for an adult bodyweight of 70kg gives an MDI_{oral} of 0.022 µg/day.

A.2.2.4 Intake from air

Concentrations of PFASs in indoor air generally exceed those of outdoor air and therefore exposure via inhalation is mainly due to indoor air. The average maximum PFOA concentration in indoor air in homes in the UK was calculated as 270 pg/m³ for all population groups. The daily estimated PFOA exposure was calculated at 0.36 to 1.1ng/kg bw per week (5.13E-07 to 1.57E-04 µg/kg bw/day) (COT, 2022).

A.2.2.5 Intake from other sources

No data.

A.2.2.6 Recommendation of Mean Daily Intake (MDI)

The recommended oral MDI for use is 7.01 µg/day. This is a combination of the FSA research into the food pathway and the DWI drinking water pathway.

The recommended inhalation MDI for PFOA is 0.011 µg/day, assuming the upper end of the average maximum in indoor air and a 70kg adult.

A.2.3 Recommendation of Health Criteria Values

A literature review of available Health Criteria Values was undertaken in line with the CLEA SR2 guidance report. A summary of this research is presented in **Table A4** and **Table A5** and the text below.

Table A14: Health Criteria Values for PFOA for the oral route of entry (including background intakes, where relevant)

Does PFOA exhibit threshold or non-threshold effects via ingestion?			
	Threshold? YES (TDI and MDI required)	Non-threshold? NO (ID required)	Both? NO
Parameter	Units	Value	Reference
Oral TDI	µg /kg bw/day	0.000629	EFSA, 2020
Oral MDI for 70kg adult	µg /day	7.01	PHE, 2009 COT, 2022
Oral MDI for 70kg adult for sum of 4 PFAS	µg /day	0.022	EA, 2009
Oral ID	µg /kg bw/day	No data	-

Table A15: Health Criteria Values for PFOA for the inhalation route of entry (including background intakes, where relevant)

Does PFOA exhibit threshold or non-threshold effects via inhalation?			
	Threshold? YES / NO (TDI and MDI required)	Non-threshold YES / NO (ID required)	Both? YES / NO
Parameter	Units	Value	Reference
Inhalation TDI	µg /kg bw/day	No data	-
Inhalation MDI for 70kg adult	µg /day	0.011	COT, 2022
inhalation ID	µg /kg bw/day	No data	-

EFSA

EFSA published a TDI for PFOA in 2008 of 1500 ng/kg bw/day. This was changed in 2018 to a tolerable weekly intake (TWI) of 6 ng/kg bw/week.

In 2020, EFSA published a scientific opinion which considered a decreased response of the immune system to vaccination to be the most critical human health effect when determining the Tolerable Weekly Intake (TWI). EFSA set a group TWI of 4.4 ng/kg bw/week for four PFAS compounds: PFOA, PFOS, PFNA and PFHxS.

COT

In 2006, COT published a statement on tolerable daily intake (TDI) for perfluorooctanoic acid (PFOA), recommending a TDI of 3 µg/kg bw/day for PFOA (COT, 2006a; COT 2006b). In 2009, the UK Committee on Toxicology (COT) amended the TDI for PFOA to 1.5 µg/kg bw/day in light of opinions from EFSA and the US Environmental Protection Agency (US EPA).

COT has considered the 2020 EFSA opinion (COT, 2022) and noted that there are uncertainties in the biological significance of the response on which the EFSA TWI is based. COT was unable to suggest an alternative TWI at present and no changes have currently been made to published UK guidance on PFOA as a result.

Health Canada

Health Canada recommended a TDI (Tolerable Daily Intake) of 0.019 µg/kg bw based on a BMDL of 0.05 mg/kg bw/day following a study on liver effects in rats. An uncertainty factor of 25 was applied (DWI, 2021).

Food Standards Australia and New Zealand

A TDI of 0.16 µg/kg was set in 2017, based on a NOAEL of 1 mg/kg/data from a foetal toxicity study in mice with an uncertainty factor of 30 (DWI, 2021).

US EPA

In 2016, the US EPA set an oral Reference Dose (RfD) of 0.02 µg/kg bw/day, which is based on a LOAEL of 1 mg/kg/day from a mice-feeding study with an uncertainty factor of 300 applied (DWI, 2021).

Conclusions

Authoritative UK data exists for PFOA, but the most recently published TDI (1.5 µg/kg/day) is from 2009, and this value is an order of magnitude higher than guidelines published in more recent years.

The most recent European toxicity data was published by EFSA in 2020 (TDI of 0.0006 µg/kg/day), but this relates to the sum of four PFAS compounds, including PFOA. This risk assessment will use the EFSA TWI to generate a site-specific screening level for the sum of long-chain PFCAs. This is considered to be a highly conservative approach.

No Health Criteria Values for inhalation routes of exposure were identified.

A.2.4 Physical-chemical characteristics of PFOA

Air-water partition coefficient (Kaw, dimensionless)

Kaw can be estimated from the Henry’s Law Constant and is sometimes referred to as the Dimensionless Henry’s Law Constant (Environment Agency, 2008b).

A value of 3.82 x10⁻⁵ was calculated for air-water partition coefficient, which has been estimated using the Clayperon relationship using the Henry’s Law constant at 25C.

Diffusion coefficient in air (Dair, m² s⁻¹)

An estimated value of 2.26x10⁻⁶ is given by the Michigan Department of Environmental Quality (2015b).

Diffusion coefficient in water (Dwater, m² s⁻¹)

An estimated value of 5.79x10⁻¹⁰ is given by the Michigan Department of Environmental Quality (2015b).

Relative molecular mass (g mol⁻¹)

A value of 414.1 g mol⁻¹ is given as the molecular weight of PFOS (ITRC, 2020).

Vapour Pressure (Pv, Pa)

A value of 100 Pa is given by Public Health England (2018).

Water Solubility (S, mg L⁻¹)

CL:AIRE (2019) quotes a solubility of PFOA of 3400mg/L at 20C. This is the lower bound of a range quoted in CONCAWE (2016) of 3400 to 9500mg/L.

Log Organic carbon-water partition coefficient (Koc, log values, cm³ g⁻¹)

The reported literature values range between A value of 1.31 to 2.63 Log cm³ g⁻¹. Due to the relatively narrow range reported in the literature a value of 1.97 Log.cm³ g⁻¹ was used for the assessment (around the mid-point of the literature range).

Log Octanol-water partition coefficient (Kow, log values, dimensionless)

A value of 6.30 is predicted by the Michigan Department of Environmental Quality (2015b). A value of 5.30 is quoted in CONCAWE, 2016. The lower value has been selected for use in risk assessment.

Dermal Absorption Fraction (ABSd, dimensionless)

The default value of 0.1 was used in the absence of chemical specific data (Environment Agency, 2008d).

Soil-to-dust transport factor (TF, dimensionless)

A default value of 0.5 is selected, based on the guidance provided in Environment Agency (2008d).

Table A16: Parameter values used in deriving the human health criteria for PFOA

Parameter	Units	Value	Reference/Comment
Air-water partition coefficient (Kaw)	dimensionless	3.82 x10 ⁻⁵	Environment Agency, 2008b
Diffusion coefficient in air (Dair)	m2 s ⁻¹	2.26 x10 ⁻⁶	Michigan DEQ, 2015b
Diffusion coefficient in water (Dwater)	m2 s ⁻¹	5.79 x10 ⁻¹⁰	Michigan DEQ, 2015b
Relative molecular mass	g mol ⁻¹	414.1	ITRC, 2020 CONCAWE, 2016
Vapour pressure (Pv)	Pa	100	Public Health England, 2018
Water solubility (S)	mg L ⁻¹	3400	CL:AIRE, 2019
Log Organic carbon-water partition coefficient (logKoc)	Log (cm³ g ⁻¹)	1.97	Based on literature (see Section Error! Reference source not found.).
Log Octanol-water partition coefficient (logKow)	Log (dimensionless)	5.30	CONCAWE, 2016
Dermal absorption fraction (ABSd)	dimensionless	1	Environment Agency, 2008d
Soil-to-plant uptake parameters (literature review)			
Soil-to-plant concentration factor for green vegetables	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-plant concentration factor for root vegetables	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-plant concentration factor for tuber vegetables	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-

Parameter	Units	Value	Reference/Comment
Soil-to-plant concentration factor for herbaceous fruit	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-plant concentration factor for shrub fruit	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-plant concentration factor for tree fruit	mg/kg plant (FW or DW) per mg/kg soil (DW)	No data	-
Soil-to-dust transport factor (TF)	g g ⁻¹ dw	0.5	Environment Agency, 2008d
Other useful data (if required for temperature conversions)			
Chemical formula	-	C8HF15O2	PubChem, n.d.
Boiling point (Tb)	K	462.15	PubChem, n.d.
Enthalpy of vapourisation at Tb (ΔHb)	J mol ⁻¹	46800	ChemSpider, 2021
Henry’s Law Constant (H)	Pa m ³ mol ⁻¹	0.09	CONCAWE, 2016
Melting point (Tm)	K	273	PubChem, n.d.

See (Environment Agency, 2008a; Environment Agency, 2008d) and (Environment Agency, 2008b) for further guidance and an explanation of the parameters required by the CLEA model.

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RESULTS

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	Average Daily Exposure ($\text{mg kg}^{-1} \text{ bw day}^{-1}$)	Distribution by Pathway (%)
	Direct soil ingestion Consumption of homegrown produce and attached soil Dermal contact with soil and dust Inhalation of dust Inhalation of vapour Background (oral) Background (inhalation)	Direct soil ingestion Consumption of homegrown produce and attached soil Dermal contact with soil and dust Inhalation of dust Inhalation of vapour (indoor) Inhalation of vapour (outdoor) Background (oral) Background (inhalation)
1 PFOS (Arup)	2.79E-07 0.00E+00 2.76E-08 7.33E-11 7.67E-09 1.24E-06 5.03E-07	44.38 0.00 4.39 0.01 0.00 1.22 35.55
2 PFOA (Arup)	2.65E-07 0.00E+00 2.62E-08 6.95E-11 2.38E-08 1.24E-06 6.67E-07	42.05 0.00 4.16 0.01 0.00 3.78 32.50
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	Average Daily Exposure ($\text{mg kg}^{-1} \text{ bw day}^{-1}$)	Distribution by Pathway (%)
	Direct soil ingestion Consumption of homegrown produce and attached soil Dermal contact with soil and dust Inhalation of dust Inhalation of vapour Background (oral) Background (inhalation)	Direct soil ingestion Consumption of homegrown produce Dermal contact with soil and dust Inhalation of dust Inhalation of vapour (indoor) Inhalation of vapour (outdoor) Background (oral) Background (inhalation)
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	Average Daily Exposure ($\text{mg kg}^{-1} \text{ bw day}^{-1}$)	Distribution by Pathway (%)
	Direct soil ingestion Consumption of homegrown produce and attached soil Dermal contact with soil and dust Inhalation of dust Inhalation of vapour Background (oral) Background (inhalation)	Direct soil ingestion Consumption of homegrown produce and attached soil Dermal contact with soil and dust Inhalation of dust Inhalation of vapour (indoor) Inhalation of vapour (outdoor) Background (oral) Background (inhalation)
1 PFOS (Arup)	2.94E-07 0.00E+00 1.93E-08 1.03E-09 1.77E-10 8.02E-07 3.08E-07	46.74 0.00 3.07 0.16 0.00 0.03 36.13
2 PFOA (Arup)	2.94E-07 0.00E+00 1.93E-08 1.03E-09 5.77E-10 8.02E-07 4.08E-07	46.68 0.00 3.07 0.16 0.00 0.09 33.14
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	Average Daily Exposure (mg kg ⁻¹ bw day ⁻¹)	Distribution by Pathway (%)
	Direct soil ingestion Consumption of homegrown produce and attached soil Dermal contact with soil and dust Inhalation of dust Inhalation of vapour Background (oral) Background (inhalation)	Direct soil ingestion Consumption of homegrown produce and attached soil Dermal contact with soil and dust Inhalation of dust Inhalation of vapour (indoor) Inhalation of vapour (outdoor) Background (oral) Background (inhalation)
1 PFOS (Arup)	3.00E-07 0.00E+00 1.34E-08 6.68E-10 7.19E-10 1.24E-06 5.03E-07	47.65 0.00 2.12 0.11 0.11 0.01 35.55 14.45
2 PFOA (Arup)	1.56E-07 0.00E+00 6.98E-09 3.49E-10 1.51E-07 1.24E-06 6.67E-07	24.88 0.00 1.11 0.06 23.94 0.01 32.50 17.50
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	Average Daily Exposure ($\text{mg kg}^{-1} \text{ bw day}^{-1}$)	Distribution by Pathway (%)
	Direct soil ingestion Consumption of homegrown produce and attached soil Dermal contact with soil and dust Inhalation of dust Inhalation of vapour Background (oral) Background (inhalation)	Direct soil ingestion Consumption of homegrown produce Dermal contact with soil and dust Inhalation of dust Inhalation of vapour (indoor) Inhalation of vapour (outdoor) Background (oral) Background (inhalation)
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[illegible]

[illegible]

[illegible]

[illegible]

Appendix B

Soil screen against risk-based criteria

[illegible]