



Interim Guideline on the Assessment and Management of Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)

Contaminated Sites Guidelines

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Questions regarding this report should be directed to:

Department of Environment Regulation
Locked Bag 33 Cloisters Square
PERTH WA 6850
Phone: +61 8 6467 5000
Fax: +61 8 6467 5562
Email: info@der.wa.gov.au
Web: www.der.wa.gov.au

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Acronyms and Abbreviations

| | |
|----------------|---|
| 6:2 FtS | 6:2 fluorotelomer (C ₂ H ₄ perfluorooctane sulfonate) |
| 8:2 FtS | 8:2 fluorotelomer (C ₂ H ₄ perfluorodecane sulfonate) |
| AFFF | Aqueous film forming foam (fire-fighting foam) |
| APHA | American Public Health Association |
| ASTM | American Society for Testing and Materials Publications |
| ATC | Alcohol-Type Concentrate (fire-fighting foam) |
| CS Act | <i>Contaminated Sites Act 2003</i> |
| CS Regulations | <i>Contaminated Sites Regulations 2006</i> |
| CCD | Charge-coupled device (image sensor) |
| CSG | Contaminated Sites Guidelines |
| DER | Department of Environment Regulation |
| DoH | Department of Health |
| EPA | Environment Protection Authority |
| ETFE | Ethylene tetrafluoroethylene copolymer |
| FtS | Fluorotelomer sulfonate |
| GAC | Granular activated carbon |
| HDPE | High-density polyethylene |
| ISO | International Standards Organisation |
| LCD | Liquid crystal display |
| NATA | National Association of Testing Authorities |
| NEPM | <i>National Environment Protection (Assessment of Site Contamination) Measure</i> |
| NICNAS | National Industrial Chemicals Notification and Assessment Scheme |
| PFAS | Perfluoroalkyl and polyfluoroalkyl substances |
| PFCA | Perfluorinated carboxylic acids |
| PFHxA | Perfluorohexanoic acid |
| PFOA | Perfluorooctanoic acid |
| PFOS | Perfluorooctane sulfonate |
| PFOSF | Perfluorooctane sulfonyl fluoride |
| PFSA | Perfluorosulfonic acid |
| SMP | Site Management Plan |
| US EPA | United States of America Environmental Protection Agency |
| WA | Western Australia |

1 Purpose

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) are a family of manufactured chemicals which do not occur naturally in the environment. Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) are two of the most well-known PFAS and are contaminants of emerging concern in Australia and internationally. They have been identified in the environment at a number of known and suspected contaminated sites in Western Australia. PFAS have been detected worldwide in fauna, ecosystems and humans since first use in the 1950s (Danish Environmental Protection Agency 2013 and 2015).

The purpose of this Guideline is to provide guidance on the assessment and management of PFAS within the legislative framework provided by the *Contaminated Sites Act 2003* (CS Act) and the *Contaminated Sites Regulations 2006* (CS Regulations), and the national site assessment framework provided in the *National Environment Protection (Assessment of Site Contamination) Measure 1999* (NEPM).

This Guideline should be read in conjunction with the Department of Environment Regulation's (DER) *Contaminated Sites Guideline: Assessment and Management of Contaminated Sites* (DER 2014).

This document provides information on:

- the assessment and management of PFAS contamination;
- the assessment of risks to human health, the environment and environmental values;
- the availability and derivation of generic assessment levels; and
- remediation and management of PFAS impacted sites.

This Guideline has been prepared to assist environmental practitioners, including environmental consultants and auditors, when planning and implementing the assessment and management of contaminated sites. It will also assist contaminated site auditors when preparing reports to be submitted to DER under the CS Act and the CS Regulations. It may also be useful for other purposes, such as due diligence assessments. However, it may be necessary to discuss site-specific circumstances with DER, refer directly to the CS Act and CS Regulations and/or seek specific legal advice.

2 Introduction

DER has prepared this Guideline to help landowners, industry, consultants, auditors and other interested parties understand the specific requirements for PFAS when investigating/assessing and remediating/managing contaminated sites in WA.

In WA, contaminated sites are regulated by DER through the CS Act and CS Regulations (available from the WA State Law Publisher at www.slp.wa.gov.au). DER works in consultation with the Department of Health (DoH) in relation to public health issues at contaminated sites.

The *National Environment Protection (Assessment of Site Contamination) Measure* (NEPM) provides guidance on the assessment of site contamination and is available at www.scew.gov.au/nepms/assessment-site-contamination. When referring to the NEPM, practitioners should also consult this website for errata and additional information provided in the NEPM toolbox. The *National Environment Protection Council Act 1994* limits the scope of the NEPM to site assessment and does not include guidance on remediation of contaminated sites.

DER provides additional guidance (to that in the NEPM) within the Contaminated Sites Guidelines (CSG) series. The guidelines are available at www.der.wa.gov.au/contaminatedsites.

Practitioners should refer to the NEPM and DER guidelines when conducting site assessments. It is essential that practitioners keep up-to-date with current versions of guidance documents referred to herein and published errata.

3 Scope

This Guideline is intended for both internal and external audiences.

4 Overview

Perfluoroalkylated substances are a large group of compounds consisting of a fully fluorinated hydrophobic alkyl chain of varying length (typically 4 to 16 carbon atoms) and a hydrophilic end group.

The two main groups of perfluorinated chemicals used in industry are:

- perfluoroalkyl carboxylic acids (PFCA) including perfluorooctane sulfonate (PFOS); and
- perfluoroalkyl sulfonic acids (PFSA) including perfluorooctanoic acid (PFOA).

PFOS-related substances include salts of PFOS (for example, potassium and ammonium) and polymers that contain PFOS as a portion of their overall structure.

PFOA is primarily a reactive intermediate chemical, while its salts are used in the production of fluoropolymers (including fluorocarbon-based synthetic rubbers), and in other surfactant uses.

PFAS also include partially fluorinated compounds which are referred to as 'polyfluorinated compounds'. These compounds include fluorotelomer sulfonates, for example 6:2FtS (C₂H₄ perfluorooctane sulfonate) and 8:2FtS (C₂H₄ perfluorodecane sulfonate). Longer chain polyfluorinated compounds may break down to produce PFOS or PFOA in the environment under certain circumstances.

Collectively, all these types of substances are referred to in this document as PFAS.

PFAS Properties

Certain PFAS, including PFOS and PFOA, have been identified as contaminants of emerging concern in Australia and internationally.

PFAS are fluorosurfactants and have complex and unique properties compared with most other potential contaminants of concern, which makes them a particular challenge for environmental practitioners.

PFAS are both hydrophobic and oleophobic and have extremely low surface tension (Lau *et al.* 2004). PFAS have many versatile properties, such as: dirt, grease and water resistance; heat, chemical and abrasion resistance; low friction; surfactant and dielectrical properties; and thermal stability, versatility, strength, resilience and durability.

PFOS and PFOA are known to be persistent, bioaccumulative and toxic and, due to their persistence in the environment and moderate solubility, can be transported long distances (Scheringer, 2009) in water and air, and transfer between different media (for example soil, sediment, surface water and groundwater).

PFAS Applications

PFAS are widely used in a range of industrial applications, such as textiles, preservatives, fluoropolymer and fluoroelastomer production, surface treatments, food packaging, hydraulic oil for aeroplanes, carpet-care treatments, floor wax and polish, and paint and lacquer, as well as fire-fighting foams (Seow 2013).

PFOS was an ingredient of Aqueous Film-Forming Foams (AFFF) and Alcohol-Type

Concentrate (ATC) used to extinguish Class B fires (flammable fuels)¹. Legacy foams may still contain PFOS and PFOA; however, current fluorinated AFFF formulations available in Australia are based on fluorotelomers rather than PFOS.

In addition, many consumer products contain certain types of PFCAs such as cosmetics, stain-resistant carpets, textiles and furniture, floor waxes and polish (US EPA 2009a, Fujii et al. 2013).

Stockholm Convention on Persistent Organic Pollutants

In August 2010, nine new chemicals, including PFOS, PFOS salts and perfluorooctane sulfonyl fluoride (PFOSF), were added to Annex B² of the Stockholm Convention on Persistent Organic Pollutants (Australia has yet to ratify this amendment)³. Details are provided in Table 1.

The National Industrial Chemicals Notification and Assessment Scheme (NICNAS) has been working since 2002 to reduce the importation and use of some PFAS in Australia, notably PFOS and PFOA. Further information is available at: www.nicnas.gov.au/news-and-events/Topics-of-interest/subjects/per-and-poly-fluorinated-chemicals-pfcs/pfc-derivatives-and-chemicals-on-which-they-are-based.

Table 1. Details of PFOS, its salts and PFOSF listing on Annex B of the Stockholm Convention in 2010

| Effect of listing of PFOS | Ban on production and use except for specified acceptable purposes and specific exemptions |
|---|--|
| <p>Acceptable purposes: (not time limited)</p> | <ul style="list-style-type: none"> • Photo-imaging. • Photo-resist and anti-reflective coatings for semi-conductors. • Etching agent for compound semi-conductors and ceramic filters. • Aviation hydraulic fluids. • Metal plating (hard metal plating) only in closed-loop systems. • Certain medical devices (such as ethylene tetrafluoroethylene copolymer (ETFE) layers and radio-opaque ETFE production, in-vitro diagnostic medical devices, and CCD colour filters). • Fire-fighting foam. • Insect baits for control of leaf-cutting ants from <i>Atta</i> spp. and <i>Acromyrmex</i> spp. |

¹ National Industrial Chemicals Notification and Assessment Scheme fact sheet – Per- and poly-fluorinated alkyl substances (PFASs) (updated May 2013).

² Annex B is a list of chemicals where the production and use, import and export is restricted.

³ www.environment.gov.au/protection/chemicals-management/pops/new-pops.

| Effect of listing of PFOS | Ban on production and use except for specified acceptable purposes and specific exemptions |
|---|---|
| <p>Specific exemptions: (five years initially, renewal possible)</p> | <ul style="list-style-type: none"> • Photo masks in the semiconductor and liquid crystal display (LCD) industries. • Metal plating (hard metal). • Metal plating (decorative). • Electric and electronic parts for some colour printers and colour copy machines. • Insecticides for control of red imported fire ants and termites. • Chemically driven oil production. • Carpets. • Leather and apparel. • Textiles and upholstery. • Paper and packaging. • Coatings and coating additives. • Rubber and plastics. |

5 Site Assessment

5.1 Conceptual Site Model

PFAS can be found in air, soil, sediment and water after release from the manufacture, use and disposal of products containing these chemicals.

In researching the site history and developing the conceptual site model, PFAS should be considered as potential contaminants of concern if any of the industries, activities and land uses listed in Table 2 may have occurred at or adjacent to the site. The presence of secondary sources (areas connected to the primary source via a migration pathway such as a surface water drain) and the potential for bioaccumulation in the food chain should also be considered. The extent of investigation required should take into account the scale and longevity of activities at the site.

Practitioners should note that PFOA and its homologues, including PFHA, is also produced by the breakdown of some fluorotelomers, such as 8:2FtS, which can be used in stain, grease and water resistant surface treatment products; paints; coatings; cleaning products; fire-fighting foams; and engineered coatings.

The list provided is not exhaustive and it may be necessary to consider whether PFAS could be present as a result of other activities and/or land uses as further information is published.

Table 2. Potentially contaminating industries, activities and land uses leading to the potential presence of PFAS

| Industry, activity or land use | Source of PFAS |
|---|---|
| Airports, aviation facilities major hazard sites (for example, refineries and major fuel storage sites) with fire-fighting facilities and/or training facilities. Aircraft and vehicle crash sites and other major incident sites where large quantities of AFFF have been used. | Surfactant in aqueous film forming foams (AFFF) containing PFAS.* Aviation hydraulic fluid. |
| Chrome plating baths. | Mist suppressant. |
| Manufacture of various commercial and domestic products. | Surfactant for alkaline cleaners. Emulsifier in floor polish/waxes. Surfactant for etching acids for circuit boards. Pesticide active ingredient for ant bait. Water/solvent repellent for leather and paper. Soil/water repellent for: <ul style="list-style-type: none"> - carpet; - fabric/upholstery; - apparel; and - leather and metal/glass. Oil/water repellent for: |

| Industry, activity or land use | Source of PFAS |
|---|--|
| | <ul style="list-style-type: none"> - food packaging; - containers; - carbonless forms; and - masking papers. Antistatic agent in photographic papers |
| Waste storage, treatment and disposal of the above products – including landfills, wastewater treatment works and depots. | Landfill leachate. Treated products including biosolids and wastewater (produced from primary and secondary treatment processes). |

Notes to Table 2

* Legacy AFFF (such as 3M Light Water™ 3 per cent and 6 per cent) contains PFOS and PFOA, newer AFFF formulations (such as Ansulite™) contain fluorotelomers such as 6:2 FtS to 10:2 FtS. Longer chain fluorotelomers (C8 and above) may degrade in the environment to produce PFOA homologues including perfluorohexanoic acid (PFHA).

5.2 Fate and Transport in the Environment

PFOS and PFOA are manufactured chemicals which are not found naturally in the environment. They are chemically and biologically stable and are resistant to typical environmental degradation processes, including atmospheric photo-oxidation, direct photolysis and hydrolysis (US EPA 2014). As a group, PFAS are persistent in soil and water. PFAS are mobile in soil and leach into groundwater.

PFOS and PFOA are non-flammable and can resist degradation by acids, bases, oxidants, reductants, photolytic processes, microbes and metabolic processes (Kissa 2001, Giesy and Kannan 2002).

Recent research, however, has shown that certain PFAS, such as fluorotelomer alcohols, can undergo biotic transformation to produce PFOS and PFOA (Buck et al., 2011; Paul et al., 2009, Prevedouros et al., 2006, Liu and Avendaño 2013, ATSDR 2015).

The role of microbial degradation has been the subject of much research in the past decade (Liu and Avendaño 2013). It was not recognised until recently that precursor biotransformation is a contributory factor for elevated values of PFOS and PFOA in soil and water. Due to the biotransformation of precursors with time, increased concentrations of PFOS and PFOA have frequently been observed in effluent from wastewater treatment plants relative to the influent concentration (Becker et al., 2008; Loganathan et al., 2007; Murakami et al., 2009b; Schultz et al., 2006; Sinclair and Kannan, 2006), and higher values have been detected in groundwater compared with the recharge concentration.

Martin et al. (2010) have reported on precursor exposure scenarios that may be significant sources of PFOS exposure to humans and wildlife. Similarly, D'eon and Mabury (2011) demonstrated that precursor exposure could represent a significant proportion of observed PFAS in people.

Although direct emissions of PFOA and PFOS have declined in recent years, it is becoming clear that exposure to various PFAS (which are converted into PFOS, PFOA and other perfluoroalkyl acids) is now a key factor for evaluating the total exposure and effect of PFAS.

[Interim Guideline on the Assessment and Management of Perfluoroalkyl and Polyfluoroalkyl Substances \(PFAS\)](#)

The potential for precursor transformation to PFOS and PFOA and other PFAS metabolites should be considered in the overall potential for environmental and human exposure and evaluation of risk to human health, the environment and environmental values when assessing site contamination caused by PFAS.

Properties

PFOS and PFOA comprise a long carbon chain that is both lipid and water repellent. The stability of these compounds is due to the strength of the carbon-fluorine bonds. The vapour pressure for PFOS at 20°C is 2.48×10^{-6} mmHg and for PFOA is 0.017 mmHg. The atmospheric half-lives are 114 days and 90 days respectively.

PFOS and PFOA are moderately soluble and have surface water half-lives of 41 years and 92 years respectively. They can be transported to surface waters and groundwater (as a result of run-off and leaching) and are persistent in the environment. As a result, they can be transported long distances from the source site.

PFOS adsorbs to soil, sediment and sludge with distribution coefficients (K_d) ranging from 9.7 L/kg to 35 L/kg and does not desorb readily, once adsorbed to these matrices (Jensen *et al.* 2012). PFOS adsorption is strongly related to higher pH, organic carbon and clay content (Das *et al.* 2013); however, PFOA does not show the same sorption properties and is unlikely to be found in soil or sediment to the same extent as PFOS.

With respect to partitioning relationships between soil, sediment and water:

- soil and sediment adsorption is likely to increase with increasing organic carbon and clay content (for PFOS);
- leaching from soil to groundwater has been documented and the absence of soil impacts should not be taken as an indication that contaminated groundwater is not present (applicable to both PFOS and PFOA); and
- leaching is highest around neutral pH and decreases in more acidic and alkaline conditions.

In summary, due to the contaminant fate and transport properties of PFOA and PFAS, these compounds may travel kilometres from the source site via surface water, groundwater and air.

PFAS have the potential to bioaccumulate and biomagnify in food webs as evidenced by their detection in fish and fish-eating birds. To date, PFOS is the only perfluorinated compound (PFC) that has been shown to accumulate to levels of concern in fish tissue (estimated bioconcentration factor of 1,000 – 4,000, US EPA 2014).

5.3 Occurrence in the Australian Environment

PFAS (note: most of the reported data are for PFOS and PFOA) have been detected in the Australian environment, with the majority of published information relating to fire-fighting facilities and fire-fighting training grounds at airports (including Department of Defence sites) and major hazard installations.

Fire-fighting training grounds investigated to date appear to have high concentrations of PFAS, particularly PFOS. Consequently, all current and historical fire-fighting training grounds and areas where AFFF has been stored or used in large quantities should be considered as a potential source of contamination.

5.4 Sampling and Analysis Quality Plans

The sampling methodology adopted should be generally consistent with methods for assessment of contaminated sites (refer to the NEPM and DER [2014]), supplemented by measures specific to PFAS. Specific precautions are necessary due to the potential for contamination from numerous commercial products and because PFAS strongly adsorb to glass. Prevention of cross-contamination is particularly important due to the very low screening values applicable to some exposure pathways (refer section 5.6). Refer to Appendix 1 for recommendations on detailed sampling procedures.

Practitioners should take into account the nature of co-contaminants present when developing sampling procedures and order of sampling.

Refer to Schedule B2 of the NEPM for general guidance on developing data quality objectives (DQOs) and Sampling and Analysis Quality Plans (SAQP).

5.5 Laboratory Analysis

Schedule B3 of the NEPM states that comparable established standard methods sourced from recognised sources such as Standards Australia, the US EPA, the American Public Health Association (APHA), the American Society for Testing and Materials (ASTM) and the International Standards Organisation (ISO) should be used when analysis is required for contaminants not included in the NEPM.

The available standard methods from these sources include:

- **US EPA Method 537** – *Determination of selected perfluorinated alkyl acids in drinking water by solid phase extraction and liquid chromatography/tandem mass spectrometry (LC/MS/MS) (applicable to drinking water);*
- **ISO 25101** – *Water quality – Determination of perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) – Method for unfiltered samples using solid phase extraction and liquid chromatography/mass spectrometry (applicable to drinking water, ground water and surface water);*
- **ASTM D7968** – *Standard Test Method for Determination of Perfluorinated Compounds in Soil by Liquid Chromatography Tandem Mass Spectrometry (LC/MS/MS);* and
- **ASTM D7979** – *Standard Test Method for Determination of Perfluorinated Compounds in Water, Sludge, Influent, Effluent and Wastewater by Liquid Chromatography Tandem Mass Spectrometry (LC/MS/MS).*

The reliability of historical data should be considered on a case-by-case basis.

PFOS and PFAS commercial mixtures are generally made up of linear and branched isomers. The proportion of each isomer which occurs in environmental samples is affected by the original composition and subsequent transport and degradation and precursor transformation processes.

Practitioners should ensure that the proposed analytical laboratories (primary and secondary) will:

- use a mixed linear/branched standard for calibration purposes;
- report analytical results representing the concentration of summed linear and branched isomers;
- use an isotopically labelled internal standard for each compound analysed; and
- report results corrected for internal standard recoveries together with a statement of the recovery.

General information on uncertainty in measurement is provided in NATA Technical Note 33. The measurement of PFOS/PFOA has been added to the National Measurement Institute’s proficiency testing program. The results of the first round of proficiency testing were published in June 2015 (NMI 2015).

Practitioners should confirm the target analyte suite of PFAS (refer to table below for the minimum recommended suite) and that the required method reporting limits can be achieved. Note that some commercial laboratories also offer an extended PFAS suite comprising 20 or more different compounds.

Table 3. Minimum recommended analytical suite for PFAS

| Abbreviation | Compound name | Abbreviation | Compound name |
|--------------|-----------------------------|--------------|---------------------------|
| PFOS | Perfluorooctane sulfonate | PFBS | Perfluorobutane sulfonate |
| PFOA | Perfluorooctanoic acid | PFBA | Perfluorobutanoic acid |
| 6:2 FtS | 6:2 Fluorotelomer sulfonate | PFHxA | Perfluorohexanoic acid |
| 8:2 FtS | 8:2 Fluorotelomer sulfonate | PFHxS | Perfluorohexane sulfonate |
| PFHpA | Perfluoroheptanoic acid | PFPeA | Perfluoropentanoic acid |

The analytical suite may be refined once the contamination and risks arising have been adequately characterised.

5.6 Interim Screening Levels

DER recommends that proponents and consultants adopt a staged approach to assessing and managing potential PFAS impacts. The interim screening levels in Table 4 may be used to indicate whether PFAS is likely to be a contamination issue for the site and to inform subsequent investigation.

If site data exceed the relevant levels (or the lowest achievable limit of detection where the 99 per cent level of protection would normally apply to the protection of aquatic ecosystems), further assessment of the risk posed by the contamination is required or a conservative management approach should be adopted (as per DER

2014 and the NEPM). With regard to assessment of risks to aquatic ecosystems, the evaluation will need to include assessment of leaching potential from soils and sediments, as well as consideration of the local background levels in the water body and the protection of predator species (such as birds and air-breathing mammals) which have not been considered in the derivation of the guidelines.

Depending on site-specific circumstances and the site conceptual model, additional exposure scenarios which are not included in Table 4 may be relevant to the site. If this is the case, the procedures in the NEPM for deriving site-specific criteria should be followed or a pragmatic management approach adopted.

The health based screening levels in this document should be applied in conjunction with guidance published by the Commonwealth [Department of Health](#) including:

- [enHealth Statement: Interim national guidance on human health reference values for per- and poly-fluoroalkyl substances for use in site investigations in Australia](#);
- [Per- and polyfluoroalkyl substances \(PFAS\) FactSheet](#); and
- [enHealth Guidance Statements on per- and poly-fluoroalkyl substances](#).

Currency of Screening Levels

Assessors should check the currency of the screening levels listed in Table 4 as this is a rapidly developing field of work and, consequently, these levels may be revised as and when new data are published.

The enHealth recommendations on tolerable daily intake (TDI) for PFOS/PFHxS and PFOA are provisional and will be replaced when Food Standards Australia New Zealand (FSANZ) publish relevant toxicity reference values. Further information can be found on the FSANZ website:

www.foodstandards.gov.au/consumer/chemicals/Pages/Perfluorinated-compounds.aspx.

Table 4. Interim screening levels for soil, surface water and groundwater.

| Exposure Scenario | PFOS / PFHxS | PFOA | Land use / environmental value |
|--|--------------------------------------|------------|--|
| Soil[†] | | | |
| Health-based screening levels | 4 mg/kg (sum of PFOS and PFHxS) | 40 mg/kg | Residential* |
| | 100 mg/kg (sum of PFOS and PFHxS) | 1000 mg/kg | Commercial and Industrial* |
| Surface water and groundwater | | | |
| Drinking water* | 0.5 µg/L (sum of PFOS and PFHxS) | 5 µg/L | All land uses |
| Non-potable and recreational uses* | 5 µg/L (sum of PFOS and PFHxS) | 50 µg/L | All land uses |
| Ecological – freshwater⁺ | 0.00023 µg/L | 19 µg/L | High conservation value systems (99 per cent species protection) |
| | 0.13 µg/L | 220 µg/L | Slightly – moderately disturbed systems (95 per cent species protection) |
| | 2.0 µg/L | 632 µg/L | Highly disturbed systems ^{††} 90 per cent species protection |
| | 31 µg/L | 1,824 µg/L | 80 per cent species protection |

Notes to Table 4

* Based on interim tolerable daily intake values of 0.15 µg/kg/d for PFOS/PFHxS and 1.5 µg/kg/d for PFOA:

[www.health.gov.au/internet/main/publishing.nsf/content/A12B57E41EC9F326CA257BF0001F9E7D/\\$File/PFAS-interim-health-reference-values-june2016.pdf](http://www.health.gov.au/internet/main/publishing.nsf/content/A12B57E41EC9F326CA257BF0001F9E7D/$File/PFAS-interim-health-reference-values-june2016.pdf).

** An area of ecological significance is one where the planning provisions or land use designation is for the primary intention of conserving and protecting the natural environment (Schedule B1 of the NEPM). This includes national parks and designated conservation areas.

+ Draft Australian and New Zealand Water Quality Guidelines applicable to aquatic organisms. The draft guidelines recommend that the 99 per cent level of protection be used for slightly to moderately disturbed systems, as PFOS and PFOA have been shown to bioaccumulate and biomagnify in wildlife.

[†]Site assessment must include assessment of leaching potential.

^{††}Ninety per cent species protection level applies to screening assessments (the 80 per cent value is provided for context in assessing any exceedances).

6 Management of PFAS-Impacted Sites

6.1 Source and Affected Sites

Persons that are responsible for land known or suspected to be contaminated with PFAS have a duty to report that site using the prescribed form.⁴ Refer to Contaminated Sites Guideline *Identification, Reporting and Classification of Contaminated Sites in Western Australia*, (DER, in prep) for further information on reporting known and suspected contamination.

Persons responsible for a site must also undertake appropriate assessment and remediation action, commensurate with the risk posed to human health, the environment and environmental values (DER, 2014).

6.2 Affected Sites – Developments Undertaken by Persons not Responsible for the Remediation of the Affected Area

Under the CS Act, the person responsible for remediation of a source site is also responsible for the remediation of any associated affected sites. However, a developer of an affected site may be held responsible for any additional contamination caused by that development.

Where development of an affected site (as defined in the CS Act) requires dewatering and the groundwater has been impacted by PFAS, management measures should be undertaken which will not increase the pre-development risk to human health, the environment or any environmental value.

Dewatering may be required to facilitate the excavation of soils as part of a site development. It is possible that the soils of an affected site may have been impacted by PFAS in groundwater. The impacted soils should be managed so that they do not increase the predevelopment risk that the soil represents to human health, the environment or any environmental value. Potential options include:

- reinstatement of soil to the excavation (not applicable to contaminated sediments removed from drains) (commercial/industrial sites);
- placement of soil at another location on the site with a similar or higher contamination risk profile, providing that the volume of soil to be added is substantially less than the total mass of the contamination already present in that area (site-specific assessment required to establish what would be 'substantially less') (commercial/industrial sites);
- containment of soil onsite (residential and commercial/industrial); and
- offsite treatment and/or disposal (all sites).

The preferred solution will depend on the site-specific factors for the development (such as contaminant concentrations including presence of other contaminants, available timeframe and volumes to be managed) and the overall risk profile of the source and affected sites.

⁴ Form 1 available from www.der.wa.gov.au/your-environment/contaminated-sites).

7 Remediation and Management

7.1 Remediation

The assessment process outlined in DER (2014) recommends assessment of site contamination to the extent necessary to provide sufficient information to enable risk-based decision-making. If the risk assessment process identifies unacceptable risks to human health, the environment and/or environmental values, early action (that is clean-up and/or management) will be required to mitigate those risks.

Due to the chemical properties of PFOS, PFOA and other PFAS (low volatility and resistance to biodegradation, photolysis and hydrolysis), there are only limited remediation options currently available. For contaminated soils and sediments these include: landfill disposal; encapsulating contaminated soil or sediments in purpose built lined repositories; direct and indirect thermal desorption; and pyrolysis.

For groundwater, the most common treatment methodology is extraction and filtration through granular activated carbon (GAC). This has been shown to be effective for removing PFOS at $\mu\text{g/L}$ concentrations; however, it is reportedly not as efficient at removing PFOA and other PFCs (ASTSWMO 2015). Other adsorbents (such as powdered activated carbon, polymers, maize-straw-derived ash, alumina and montmorillonite) have also been used, though not all are commercially proven. The spent adsorbent containing the contamination requires regeneration/chemical treatment or disposal (note that high temperature, greater than $1,100^{\circ}\text{C}$, is required for destruction).

Treatment of large volumes of low concentration PFAS in groundwater is extremely challenging, and it is likely that a management approach for diffuse groundwater plumes will need to be adopted as an interim measure to control unacceptable risks.

The following table summarises the technologies currently available in Australia, other than containment (mention of product names does not constitute product endorsement by DER).

Refer to DER (2014) for further information regarding remediation and validation requirements.

Table 5. Treatment technologies* currently available in Australia

| Process | Australian examples | Media |
|--------------------|---|----------------------|
| Adsorption | Activated carbon (powdered (PAC) or granular (GAC)), resins, ion exchange polymers, MyCelx™ Various providers in Australia | Water and wastewater |
| Reverse osmosis | Various providers in Australia | Water and wastewater |
| Pyrolysis | PLASCON® – high temperature plasma arc www.toxfreeblog.wordpress.com/2014/09/08/pfos-and-pfoa/ | Soil and water |
| Thermal desorption | In-direct and direct-fired thermal desorption | Soil and wastes |
| Immobilisation* | Activated carbon (powdered (PAC) or granular (GAC)) – various providers including: Rembind® – blend of activated carbon, aluminium hydroxide, kaolin and other proprietary additives www.ziltek.com.au/rembind.html matCARE™ – amine modified clay sorbent www.crccare.com/products-and-services/technologies/matcare | Soil and wastewater |

Notes to Table 5

* Mention of product names does not constitute endorsement by DER.

7.2 Waste Disposal

Stockpiles of impacted soils and other solid wastes such as concrete must be managed to prevent contaminants leaching to groundwater or adversely affecting surface water bodies.

Contaminated soil (and other solid wastes), groundwater and wastewater must be correctly identified and transported by a licensed waste disposal contractor when being transported to an appropriate treatment or disposal facility.

Disposal to sewer is subject to a trade effluent disposal agreement with Water Corporation.

Landfill Disposal

Landfill operators licensed under Part V of the *Environment Protection Act 1986* (EP Act) intending to accept PFAS contaminated waste must apply to DER for an amendment to their licence to allow this waste to be accepted. When assessing amendment applications, DER will give consideration to:

- siting issues (including hydrogeology and proximity to sensitive environments);
- landfill controls (including standard of liners, cover management, leachate management, landfill gas management and capping);
- landfill management practices (including site supervision and waste screening);
- monitoring program (including groundwater, surface water and leachate); and
- closure issues (monitoring and maintenance to minimise infiltration and leakage).

The procedures outlined in the *Landfill Waste Classification and Waste Definitions 1996 (As amended December 2009)* should be followed when assessing contaminant concentration in soil and wastes for disposal.

Contaminated solid waste – if solid waste intended to be disposed of to landfill exceeds the relevant leachable concentration in Table 6, the waste may be pre-treated to meet the leachable concentration for that landfill class subject to Steps 5 and 6 in the *Landfill Waste Classification and Waste Definitions 1996 (as amended December 2009)*; or disposed of to a more secure landfill class (if the relevant concentration and leachable concentrations can be met).

If the contaminant concentration exceeds:

- 50 mg/kg for the sum of PFOS and PFHxS; or
- 500 mg/kg of PFOA

treatment of the waste to destroy or irreversibly immobilise the contaminants must be carried out. Alternatively, the waste should be disposed of as intractable waste (Class V) subject to EPA approval.

Table 6. Interim leachable concentration (ASLP) and concentration limit (CL) values for waste classification*

| Contaminant | Leachable Concentration ASLP (µg/L) | Concentration Limit CL (mg/kg) | Leachable Concentration ASLP (µg/L) | Concentration Limit CL (mg/kg) | Leachable Concentration ASLP (µg/L) | Concentration Limit CL (mg/kg) | Leachable Concentration ASLP (µg/L) | Concentration Limit CL (mg/kg) |
|--------------|-------------------------------------|--------------------------------|-------------------------------------|--------------------------------|-------------------------------------|--------------------------------|-------------------------------------|--------------------------------|
| | Unlined Class I and II | | Lined Class II | | Lined Class III | | Lined Class IV | |
| PFOS + PFHxS | <0.001 | <0.02 | 1.3 | 5 | 1.3 | 5 | 13 | 50 |
| PFOA | 20 | <0.02 | 2,200 | 50 | 2,200 | 50 | 22,000 | 500 |

Notes to Table 6

*Waste concentrations must be less than both the relevant leachable concentration (ASLP conducted at both pH 5 and pH 7 [approximating ‘worst case’ for leaching conditions]) and the concentration limit values for the relevant class of landfill to enable consideration for disposal at a specific landfill.

Landfills accepting waste containing PFOS/PFHxS or PFOA must not be located:

- on very high¹ or high² vulnerability aquifers;
- within 1,000 m of a surface water body that supports an aquatic environment (including groundwater dependent ecosystems); or
- within 1,000 m of a surface water drain that is connected to groundwater and/or discharges directly into an aquatic environment (including groundwater dependent ecosystems) or a water body that supports fish species that may be caught and consumed.

¹ Very high vulnerability aquifers:

limestone with known karst features; and
sand, peat and clay deposits (wetland areas) with a shallow water table (≤3 m).

² high vulnerability aquifers:

sand and limestone with a shallow to intermediate water table (≤ 30 m); and
fractured rocks with a high permeability (≥40 m/d) and a shallow to intermediate water table (≤ 30m).

Definitions of high and very high aquifer vulnerability are adapted from Appleyard (1993) *Explanatory notes for the groundwater vulnerability to contamination maps of the Perth Basin*, Record 1993/6 Geological Survey of Western Australia, Department of Minerals and Energy.

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Appendix 1. PFAS-Specific Sample Collection Methods, Equipment and Equipment Decontamination Methods

The material in Appendix 1 has been adapted from Geosyntec (2016) *Methodology for soil, sediment, groundwater and surface water sampling and analyses for PFAS investigations* unpublished report prepared for the Public Transport Authority.

Table A1. Known or commonly-suspected sources of environmental sample contamination during PFAS investigations, and recommended mitigation practices and alternatives

| Product | Mitigation practice | Alternative product or practice when PFAS sampling is to be undertaken |
|--|--|--|
| Clothing and food | | |
| New clothing | Not to be used/consumed by sampling personnel ¹ | Wash all field clothing a minimum of six times after purchase to remove surface coatings before using at the site. |
| Clothing with stain-resistant, rain-resistant, or waterproof coatings/ treated fabric (for example GORE-TEX [®]) | | Avoid sampling during rain if possible; polyethylene rain gear (for example disposable LDPE), vinyl or polyvinyl chloride (PVC) clothing are acceptable. |
| Tyvek [®] clothing | | None |
| Fast food wrappers and containers | | Use rigid plastic containers or bags or stainless steel containers for all food brought to site. |
| Pre-wrapped foods and snacks (for example chocolate bars, energy bars, granola bars and potato chips) | | Use plastic (rigid containers or bags) or stainless steel containers to bring food to site. |
| Sampling equipment and containers | | |
| Teflon [®] containing or coated field equipment (tubing, bailers, tape and plumbing paste) | Do not use at site ² | High Density Polyethylene (HDPE) or silicone tubing, and HDPE or polypropylene field equipment recommended. Concawe (2016) reports that although high purity Teflon tubing does not cause 'blank contamination' in contrast to common Teflon tubing, some researchers have found that Teflon could adsorb PFAS. |
| Teflon [®] lined lids on containers (for example sample containers, rinsate water storage containers) | Do not use at site ² | Polypropylene lids ³ for sample containers and polypropylene or HDPE containers for rinsate. |

| Product | Mitigation practice | Alternative product or practice when PFAS sampling is to be undertaken |
|---|---------------------------------|--|
| Glass sample containers with lined lids | Do not use | Use polypropylene or HDPE for sample containers ³ (PFAS adsorb strongly to glass). |
| Other products | | |
| Aluminium foil | Do not use ¹ | Thin HDPE sheeting (commonly used as drop cloths for painting or home improvement) can be used. |
| Self-sticking notes and similar office products (for example 3M Post-It notes) | Do not use at site ² | Avoid the use of these products at the site. |
| Waterproof paper, notebooks, and labels | Do not use at site ² | Standard paper and paper labels. |
| Drilling fluid containing PFAS | Do not use at site ² | PFAS-free drilling fluids or use alternative techniques (for example sonic drilling) which do not require drilling fluids. |
| Detergents and decontamination solutions (for example Decon 90 [®] Decontamination Solution) | Do not use | Follow water-only decontamination approach. |
| Reusable chemical or gel ice packs (for example BlueIce [®]) | Do not use | Ice contained in plastic (polyethylene) bags (double bagged). |

Notes

¹ Sampling personnel includes all personnel who:

- are directly involved in the collection, handling and/or processing of samples prior to the samples leaving the site;
- handle any part of well development equipment that directly contacts bore water being sampled;
- handle any part of equipment that directly contacts surface water or aquatic sediment;
- are within 2–3m of the borehole during soil sampling; or
- are within 2–3m of the collection and processing area on aquatic vessels during sediment or surface water sampling.

Personnel are not included as sampling personnel if they remain at least 2–3m away from sample collection areas prior to and during sampling.

² Entire sample collection and processing area, including vehicles used by sampling personnel.

³ USEPA and ASTM method for the analysis of PFAS in solid and liquids specify polypropylene or HDPE with polypropylene lids. Check with the laboratory with regards to preference for polypropylene or HPDE.

Groundwater Well Drilling, Development and Sampling

Conventional groundwater drilling and well development practices can generally be used to install monitoring wells where groundwater samples will be analysed for PFAS. Exceptions requiring alternative action, include:

1. Decontamination of drilling equipment should avoid the use of detergents. All equipment should be scrubbed with a plastic brush and rinsed thoroughly in tap water to clean away any debris or material on exposed surfaces and then triple-rinsed in distilled or deionised water (Grade 3 or Millipore water).
2. Sampling should include submission of sample(s) representing any water used by the driller for drilling purposes.
3. Equipment that contacts well water within the well (pumping equipment, water meters and so on) should not contain or be coated with Teflon[®] unless the Teflon[®] is internal to the equipment and does not contact the external environment.
4. Class 18 u-PVC casing should be used, with a lower section of slotted screen (also minimum Class 18 u- PVC). Well casing should be installed as either a pre-packed screen (stainless steel) or using conventional well construction methods if the borehole is cased to termination depth in order to prevent collapse, and the addition of gravel pack to appropriate depths around the screened interval can be measured and confirmed. Do not re-use u-PVC material which has been used previously at sites where PFAS is known or suspected to be present.
5. Prior to well development, any personnel that handles decontaminated well development equipment that directly contacts bore water should wash their hands with soap and rinse thoroughly in tap water before donning a clean, new pair of disposable nitrile gloves. A new pair of nitrile gloves should be worn for each different well developed. Additional hand washing prior to donning the new pair of gloves is necessary if the old pair of gloves was compromised or ungloved hands touched items that may represent potential PFAS contamination (refer Table A1) since last being washed.
6. Following the completion of well development, purged groundwater must be transported by a licensed waste disposal contractor for appropriate disposal at a facility licensed to receive PFAS-impacted materials.
7. Equipment recommended for obtaining groundwater samples includes low-flow peristaltic pumps using silicone or HDPE tubing or polypropylene HydraSleeves (or similar products). Sampling equipment should not be decontaminated and/or reused at different locations. If the depth to groundwater prevents the use of peristaltic pumps, then bladder pumps may be considered; however, bladders and other internal parts (check balls, o-rings, compression fittings) should not be made of Teflon. Bladders and o-rings should be changed between sample locations.
8. Table A1 should be reviewed to identify other products that may contaminate the well during drilling and development or obtaining the groundwater sample. If in doubt about a particular product or item in contact with environmental media to be sampled or in close proximity to operations, collect and analyse a rinsate sample using laboratory-supplied PFAS-free water.

Soil Drilling and Aquatic Sampling

Conventional soil drilling and aquatic sampling (surface water and sediment) can generally be used to obtain samples for analysis of PFAS. Exceptions include:

1. Decontamination of soil drilling and sampling equipment and of sediment sampling equipment (cores, grabs) should avoid the use of detergents. Equipment should be scrubbed with a plastic brush and rinsed thoroughly in tap water to clean away any debris of material on exposed surfaces and then triple-rinsed in distilled or deionised water (Grade 3 or Millipore water).
2. Equipment that contacts soil, sediment or surface water should not contain or be coated with Teflon[®] unless the Teflon[®] is internal to the equipment and does not contact the external environment.
3. Prior to sample collection, any personnel that handle decontaminated soil, sediment or surface water sampling equipment that directly contacts the environmental media to be sampled should wash their hands with soap and rinse thoroughly in tap water before donning a clean, new pair of disposable nitrile gloves. A new pair of nitrile gloves should be worn for each different sampling location. Additional hand washing prior to donning the new pair of gloves is necessary if the old pair of gloves was compromised or if ungloved hands touched items that may represent potential PFAS contamination (refer Table A1) since last being washed.
4. Surface water should be collected by inserting a capped sampling container (polypropylene or HDPE) with the opening pointing down to avoid the collection of surface films. At the time of the container opening, the container should be more than 10cm from the sediment bed and more than 10cm below the surface water level and as close to the centre of the channel as possible, where practicable. Point the container up so that gloved hands, sample container and sampler are downstream of where sample is being collected.
5. Soil and sediment core samples should be collected directly from single-use PVC liners that are discarded (do not decontaminate and reuse at another location).
6. For aquatic samples collected from shore or via wading, ensure that waders are constructed of fabric that has not been treated with waterproofing coatings (refer Table A1).
7. Review Table A1 to identify other products that may contaminate the sampling area or surface water, sediment or soil sample. If in doubt about a particular product or item in contact with environmental media to be sampled or in close proximity to operations, collect and analyse a rinsate sample using laboratory-supplied PFAS-free water.
8. Support personnel that handle any part of equipment that directly contacts surface water or aquatic sediment, personnel that are within 2–3 m of the borehole during soil sampling, or personnel that are within 2–3 m of the collection and processing area on aquatic vessels during sediment or surface water sampling, are considered subject to the same restrictions related to precautionary measures for clothing and food, as applied to sampling personnel (refer Table A1).

PFAS-Specific Sample Handling and Processing Methods

Conventional sample handling and processing practices can generally be applied to groundwater, surface water, soil and sediment samples for analysis of PFAS.

Exceptions include:

1. Prior to sampling, the sampling personnel should wash their hands with soap and rinse thoroughly in tap water before donning a clean, new pair of disposable nitrile gloves. A new pair of nitrile gloves should be worn for each sample collected. Additional hand washing prior to donning the new pair of gloves is necessary if the old pair of gloves was compromised or if the personnel's ungloved hands touched items that may represent potential PFAS contamination (refer Table A1) since last being washed.
2. Teflon[®] coated materials and aluminium foil may not come into contact with the sample (refer Table A1). Sample handling equipment or tools made of HDPE or stainless steel are acceptable, provided they are decontaminated prior to use via scrubbing and rinsing thoroughly in tap water to clean away any debris or material and then triple-rinsed in distilled or deionised water (Grade 3 or Millipore water).
3. Samples containers should be comprised of polypropylene or HDPE (refer Table A1). Glass containers with lined lids are not suitable as PFAS can be adsorbed onto glass. Prior to sampling, confirm sample container composition (polypropylene versus HDPE) with the selected analytical laboratory.
4. For each sample, the required minimum volume of surface water and groundwater is 250 mL per USEPA (2009) and the required minimum amount of soil or sediment is at least 2 g on a dry weight basis per ASTM (2014). These sampling requirements may vary by laboratory. Prior to sampling, confirm sample size requirements with the selected analytical laboratory.
5. For drinking water, each 250mL sample bottle may be required to contain a small amount (1.25 g) of Trizma[®] – a buffering reagent that removes chlorine from chlorinated drinking water (USEPA, 2009) or similar sample additive, as specified by the selected analytical laboratory. Prior to sampling drinking water for PFAS analysis, confirm the need for additive with the selected analytical laboratory.
6. During sample processing and storage, minimise the exposure of the sample to light.
7. As noted in Table A1, the use of chemical or gel-based coolant products (for example BlueIce[®]) to maintain samples at 4°C following sample collection is not recommended. The acceptable alternative is ice which has been double-bagged (polyethylene plastic) and secured to avoid meltwater from contacting sample containers in the esky during overnight or same-day delivery to the analytical laboratory.
8. Table A1 should be reviewed to identify other products that may contaminate the sampling processing area. If in doubt about a particular product or item in contact with environmental media to be sampled or in close proximity to operations, collect and analyse a rinsate sample using laboratory-supplied PFAS-free water.

9. Support personnel that are within 2–3 m of the processing area. These personnel are considered subject to the same restrictions related to precautionary measures for clothing and food, as applied to sampling personnel (refer Table A1).

PFAS-Specific Laboratory Analysis Specifications

During communication with the selected analytical laboratory prior to sampling or during pre-project communications with candidate analytical laboratories, it is recommended to confirm the following:

1. The laboratory uses polypropylene or HPDE sample containers with polypropylene lids, and if there is a preference for either sample container type.
2. The analytical method being followed by the laboratory conforms to a standard agency or association analytical protocol (for example, USEPA 537, USEPA 537–Modified for solids or waters, ASTM D7968, ASTM D7979, ISO 25101:2009, etc.) and the laboratory is NATA accredited for PFAS analysis.
3. The target analyte list of PFAS and the required method reporting limits can be achieved.
4. Sample results will represent the sum of the linear and branched isomers for each PFAS. Many PFAS (for example, PFOS) have several isomeric forms that may show up as separate or partially-merged peaks in the analytical chromatograms. It should be confirmed that these peaks will be integrated and the areas summed such that the result represents the concentration of the sum of the linear and branched isomers, as per USEPA (2009). Laboratories must also note in their analytical reports the type of analytical standards used and the approach used in quantification.
5. Reagent or ultra-pure water used in the laboratory will be confirmed to be free of PFAS above the method reporting limit during the analyses, and that this water can be provided in HPDE containers with polypropylene lids for use at the site for conducting equipment rinsate sampling (as needed).