PFAS National Environmental Management Plan

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National Chemicals Working Group of the Heads of EPAs
Australia and New Zealand

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PFAS National Environmental Management Plan Version 2.0

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Introduction

The environmental management of the group of manufactured chemicals known as PFAS (per-and poly-fluoroalkyl substances) is a high priority for environmental regulators around Australia. This reflects the widespread presence of PFAS in the environment, its unusual chemical properties, the uncertainties associated with its potential risks, and the resulting need for a precautionary approach to protect the environment and human health.

The PFAS National Environmental Management Plan (NEMP) provides nationally agreed guidance on the management of PFAS contamination in the environment, including prevention of the spread of contamination. It supports collaborative action on PFAS by the Commonwealth, state and territory and local governments around Australia. The NEMP is an Appendix to the Intergovernmental Agreement on a National Framework Responding to PFAS Contamination.

The first version of the NEMP, known as NEMP 1.0, was published in February 2018. It was developed by the Heads of EPAs Australia and New Zealand (HEPA) at the request of Environment Ministers around Australia. The NEMP reflects the current state of knowledge and is updated regularly to reflect new scientific evidence and guidance.

The widespread presence of PFAS in the environment in Australia and around the world is a result of its unique properties, which have led to it being widely used for many decades. For example, PFAS are persistent and highly resistant to physical, chemical and biological degradation. Consequently, PFAS are found in humans, animals and the environment around Australia.

Addressing the wide range of issues associated with PFAS contamination, including the management of PFAS contaminated materials, represents a challenge for us as environmental regulators. These are challenges best dealt with collectively.

The NEMP recognises the need for sound regulation of PFAS by each jurisdiction in a way that can adapt to local circumstances and emerging priorities.

Acknowledgements

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1.1 What the NEMP does

The NEMP:

- provides guidance about the environmental management of per- and poly-fluoroalkyl substances (PFAS), with a focus on preventing and managing PFAS contamination
- recognises that different PFAS production methods and subsequent degradation processes can create complex mixtures of many different intentionally produced and unintentionally generated PFAS compounds[1] requiring consideration, at least qualitatively.
- focuses on perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), and perfluorohexane sulfonate (PFHxS), and their direct and indirect precursors, as these are the most widely studied
- recognises that the globally accepted definitions of PFOS, PFOA and PFHxS include their salts and related chemicals, including precursors, as established by the listing of PFOS and PFOA and the proposed listing of PFHxS under the Stockholm Convention
- recognises that PFOS, PFOA, and PFHxS are usually primary indicators of the presence of a broad range of PFAS compounds including other short and long chain perfluoroalkyl acids (PFAAs) and precursors[2]
- recognises the need to respond to a rapidly evolving scientific understanding of PFAS characteristics, management techniques and environmental risks, including regular review of the guidance provided for specific PFAS
- recognises that in addition to primary sources such as contaminated sites where PFAS has been used, secondary sources for PFAS contamination may include facilities that receive waste and wastewater containing PFAS from a range of diffuse sources[3], such as landfills and wastewater treatment plants.
- recognises the importance of managing PFAS contamination, including beneficial reuse of PFAS-contaminated materials and wastes, in a way that maintains environmental values including future land use options
- considers the identification and implementation of site- and catchment-specific PFAS risk management actions
- recognises the role of Australia's health-based guidance on PFAS and ongoing research to better understand any human health effects, noting the recommendation that as a precaution, human exposure to PFAS be minimised since these chemicals remain in humans and the environment for many years[4]

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[1] For an overview of the PFAS chemical family see Appendix A. For further information about PFAS production methods, categorisation and variability see Buck et al (2011), ITRC (2018b, 2017), OECD (2018), NICNAS (e.g. 2015a, 2015b, 2015c, 2017, 2019a, 2019b), and Wang et al (2017).

[2] As well as PFOS, PFOA and PFHxS, other PFAAs classified as long chain include PFSAs with six or more perfluorinated carbons and PFCAs with seven or more perfluorinated carbons (OECD 2018).

[3] The majority of PFAS in the environment is attributed to diffuse sources, reflecting the wide range of historic and current consumer, commercial and industrial products and articles in which PFAS have been used.

[4] https://www1.health.gov.au/internet/main/publishing.nsf/Content/44CB8059934695D6CA25802800245F06/$File/health-effects-exposure-factsheet.pdf

- does not address current use and management of PFAS-containing products and articles, noting that environmental regulators may take action to restrict the use and management of PFAS-containing products and articles under their jurisdictional legislation
- recognises that managing PFAS is part of, and should be integrated into, the management of contaminants of concern more broadly.

1.2 An introduction to PFAS

PFAS is an abbreviation for per- and poly-fluoroalkyl substances. These are manufactured chemicals that have been used for more than 50 years. PFAS make products non-stick, water repellent, and fire, weather and stain resistant. PFAS have been used in a range of consumer products, such as carpets, clothes and paper, and have also been used in firefighting foams, pesticides and stain repellents.

The most well-known PFAS are PFOS, PFOA and PFHxS. These three PFAS are part of a broader group of PFAS known as PFAAs, which resist physical, chemical and biological degradation, and are very stable. This stability creates a problem as these PFAS last for a long time. A wide range of other PFAS, known as precursors, can transform into PFAAs in products in the environment, and are also considered environmentally significant. Appendix A provides an overview of the PFAS chemical family[5].

1.2.1 Chemical structure and resulting environmental behaviour

The distinguishing characteristic of PFAS compounds is a chain of carbon atoms bonded to fluorine atoms. Some PFAS compounds, including PFOS, PFOA and PFHxS, have a hydrophilic functional group at the end of the chain.

The chemical structure of PFAS, including variations in chemical structure between different types of PFAS, is an important consideration for understanding the behaviour of PFAS in the environment. The high solubility of PFAS in water means that PFAS may readily leach from soil to surface water and groundwater, where they can move long distances to enter creeks, rivers and lakes and become part of the food chain, being transferred from organism to organism. Research into the effects of PFAS on organisms, such as potential multigenerational effects on aquatic wildlife, is ongoing. Work is also underway to understand and predict the behaviour of different PFAS in the environment. Sections 8.3 and 8.4 provide an overview of selected PFAS pathways in the environment.

1.2.2 Use and resulting contamination

In Australia, PFAS have been used for a long time in a wide range of consumer products and industrial applications, including certain firefighting foams[6]. There are now PFAS-contaminated sites around Australia resulting from these various uses. Over time, the chemicals have worked their way across and through the soil to contaminate surface and ground water, and have migrated into adjoining land areas. PFAS are also present in waste streams, including at landfills and wastewater treatment facilities, and more broadly in the environment.

The NEMP uses terms including PFAS contamination and PFAS-contaminated when referring to environmental media in which detectable levels of PFAS are present. This reflects the fact that PFAS are synthetic organic compounds, for which there is no natural background level. The presence of PFAS in environmental media does not necessarily constitute an unacceptable human health or environmental risk. Risk depends on a range of factors including PFAS compounds present, PFAS leachability and concentration, degree of

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[5] See also www.nicnas.gov.au for information about PFAS compounds listed on the Australian Inventory of Chemical Substances.

[6] See www.nicnas.gov.au/chemical-information/Topics-of-interest2/subjects/Per-and-poly-fluorinated-alkyl-substances

exposure, types of receptors exposed, land use, environmental values present, level of environmental protection, potential for bioaccumulation, and environmental media in which the contamination occurs. Section 9 provides further information on the assessment of PFAS contamination.

2 Australia's international obligations

The Stockholm Convention on Persistent Organic Pollutants is a multilateral environmental agreement to protect human health and the environment from persistent organic pollutants[7]. It sets globally accepted standards for the use and management of persistent organic pollutants with specific provisions tailored to each listed chemical. Parties to the Convention, including Australia, participate in the listing process for identified chemicals of concern and consider the actions necessary to give effect to the final decision in each country.

Australia is also a party to the Basel Convention and the Rotterdam Convention which address other aspects of chemicals management with a focus on international trade in chemicals, pesticides and wastes. It is important to note that technical guidance issued under a convention may be adopted for the implementation of another convention[8].

2.1 International obligations in relation to PFOS and PFOA

To date, two large groups of PFAS compounds are listed as persistent organic pollutants under the Stockholm Convention:

- PFOS, its salts and perfluorooctane sulfonyl fluoride (PFOSF) were listed in 2009, noting the listing of PFOSF captures a wide range of PFOS-related compounds derived from PFOSF
- PFOA, its salts, and PFOA-related compounds were listed in 2019.

References to the listing of PFOS and PFOA, and potential listing of other PFAS, in the following discussion and throughout the NEMP include their respective salts and related compounds.

When a chemical is listed under the Stockholm Convention, a range of actions are required for Australia to ratify and implement these listings.

The first step is a treaty-making process to inform an Australian Government decision on ratification of the listing. The second step is to implement the management measures identified during the ratification process as necessary for Australia to be compliant with its international obligations.

The Australian Government is reviewing the remaining uses of PFOS, PFOA, and the PFOS- and PFOA-related compounds included in these listings, as part of the ratification process. This includes public consultation to inform the analysis. Public consultation was undertaken in late 2017 on a Regulation Impact Statement on options for a national phase-out of PFOS in the context of the Stockholm Convention.

2.2 Potential future obligations in relation to other PFAS

In 2017, PFHxS, its salts and PFHxS-related compounds were nominated for listing on the Stockholm Convention. The proposed listing was assessed against the Annex D criteria by the Convention's subsidiary scientific body, the Persistent Organic Pollutants Review Committee

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[7] Details on the Stockholm Convention are available at http://www.environment.gov.au/protection/chemicals-management/pfas#a6.

[8] For example, the technical guidelines on the environmentally sound management of PFOS wastes for the Basel Convention (UNEP 2015) are the source of the 50 mg/kg low persistent organic pollutant content limit for PFOS referenced in the Stockholm Convention. See Section 14.6 for details.

in October 2017. The Committee concluded that PFHxS meets the screening criteria for persistence, bioaccumulation, potential for long range environmental transport, and evidence for adverse impacts. In October 2018, the Committee adopted the risk profile developed for PFHxS and in October 2019, the Committee recommended that PFHxS be considered for listing in Annex A to the Convention[9]. Additional PFAS may be nominated in the future.

Australia will continue to participate in the Convention's processes and to address any domestic implementation requirements that may result if PFHxS or other PFAS are listed. In the meantime, the globally accepted standards outlined in the Convention for the use and management of persistent organic pollutants are a fundamental point of reference for the guidance provided in the NEMP.

Ratification of the PFOS and PFOA listings or future listings of PFHxS or other PFAS in the Stockholm Convention, would mean Australia accepting and implementing international standards for the management of these chemicals. For example, this would include requirements regarding waste that contains listed chemicals, including related substances as defined by the listing, at a level above the low content limit of 50 mg/kg. Section 14.6 provides guidance on management of waste above this limit.

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[9] The recommendation to consider PFHxS for listing is expected to be considered at the next Conference of the Parties in 2021. For current information about the technical review process, see the Committee website at http://www.pops.int/TheConvention/POPsReviewCommittee/OverviewandMandate/tabid/2806/Default.aspx.

3 Guiding principles

The following principles of sound environmental regulation guided the development of the NEMP and will continue to guide its further development and implementation.

1. A focus on protection of the environment, including flora and fauna, ecological communities and ecosystems and, as a precaution, protection of human health.
2. Consideration of the principles established by the Intergovernmental Agreement on the Environment, which is a Schedule to the National Environment Protection Council Act 1994 (Cth)[10], in all decision-making, including:
    i. The precautionary principle. This principle states that where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, public and private decisions should be guided by: careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment; and an assessment of the risk-weighted consequences of various options.
    ii. Intergenerational equity. This principle states that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.
    iii. Conservation of biological diversity and ecological integrity. This principle states that conservation of biological diversity and ecological integrity should be a fundamental consideration.
    iv. Improved valuation, pricing and incentive mechanisms. This principle states that:
        - Environmental factors should be included in the valuation of assets and services.
        - Polluter pays, i.e. those who generate pollution and waste should bear the cost of containment, avoidance, or abatement.
        - The users of goods and services should pay prices based on the full life cycle costs of providing good and services, including the use of natural resources and assets and the ultimate disposal of any wastes.
        - Environmental goals, having been established, should be pursued in the most cost effective way, by establishing incentive structures, including market mechanisms, which enable those best placed to maximise benefits and/or minimise costs to develop their own solutions and responses to environmental problems.
3. Regulatory actions and decisions that are risk-based, informed by scientific evidence, focused on identified PFAS exposure pathways to ecological and human receptors, and meet national and international obligations.
4. Quantitative PFAS assessment based on appropriate analytical methods and standards, with the required quality assurance and control.
5. Consistency across jurisdictions, supported by the NEMP, with consideration of accountability for pollution and for management actions.
6. Coordinated and cooperative action on cross-boundary issues, including within catchments.

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[10] The *National Environment Protection Council Act 1994* (Cth) is mirrored by complementary legislation in each state and territory.

7. Consideration of relevant legislative and policy frameworks for chemical and environmental management within and across jurisdictions and at the national and international level.
8. Integration with existing national governance mechanisms, including:
    i. the National Environment Protection (Movement of Controlled Waste between States and Territories) Measure 1998 (MCW NEPM)
    ii. the National Environment Protection (Assessment of Site Contamination) Measure 1999 (ASC NEPM)
    iii. the National Water Quality Management Strategy, including the Australian and New Zealand Guidelines for Fresh and Marine Water Quality
    iv. the Intergovernmental Agreement on a National Framework for Responding to PFAS Contamination.
9. Where existing principles, guidelines, approaches or management options do not adequately foresee or address an identified environmental risk, responses guided by available scientific approaches, the precautionary principle and the understanding that action may be required to reduce risks.
10. Consideration of sustainability, including environmental, economic and social factors, when assessing the benefits and effects of management options, acknowledging the limited management options for PFAS currently available in Australia.

3.1 General environmental obligations concerning PFAS

Environmental legislation in many jurisdictions includes obligations and duties to understand and prevent or minimise risks of, and report occurrences of, environmental harm, nuisances, waste mismanagement and contamination. For example, a general environmental duty to prevent offsite dispersal of PFAS and onsite environmental harm should be complied with in jurisdictions where such a duty exists. These provisions are relevant to PFAS contamination which can be environmentally significant due to its persistence, mobility and, for some PFAS, toxicity and potential for bioaccumulation in plants and animals.

The following actions will enable the responsible person or organisation to demonstrate compliance with these obligations and duties:

- understanding the PFAS content of products, articles and materials and/or the presence of PFAS contamination, for example, by determining the concentrations of PFAS present and/or the nature and location of PFAS sources
- understanding the environmental values that may be impacted by the contamination, both on- and off-site, such as:
    - determining the surface water and groundwater environments
    - determining what the water is used for
    - considering important issues including any off-site movement, PFAS transformations, and exposure pathways to receptors
- taking all reasonable and practicable measures to prevent or minimise potential environmental harm from PFAS-related activities and contamination, such as:
    - ensuring PFAS wastes, contaminated materials and products are effectively stored and/or remediated to prevent release
    - having appropriate contingency plans to deal with leaks and spillage
- undertaking appropriate monitoring to check the effectiveness of management measures implemented and to assess the extent and impacts of any contamination

- ensuring proper disposal of PFAS-contaminated waste, for example, by properly characterising waste and sending it to a facility licensed to accept it, noting dilution is not acceptable for example in soil, air, compost or other wastes or products
- ensuring PFAS-contaminated materials for reuse, including reused waste, are appropriately managed to prevent harm to land use, human health and the environment
- ensuring environmental regulators and any persons or organisations likely to be adversely affected by any releases are promptly advised of any incidents and contamination.

Non-compliance with these duties, including not taking actions such as those described above, may trigger a range of regulatory responses. Environmental regulators have produced guidance on how to meet these obligations for PFAS-containing products, articles and materials.

4 Communication and engagement

The following guidance provides advice for communication and engagement activities about PFAS contamination, particularly in areas impacted by point sources of PFAS contamination. It is designed to complement the Per-and Poly-fluoroalkyl Substances PFAS Information Sharing, Communication and Engagement Guidelines and the PFAS Contamination Response Protocol[11] and has a particular focus on the role of environmental regulators. The aim is to support all environmental regulators in being a partner and a protector of human health and the environment in delivering the best outcomes for the community and the environment.

This guidance is divided into three sections. The first sets out roles and responsibilities. The second includes principles that should be considered when undertaking any PFAS-related communication and engagement activities. The third provides approaches for environmental regulators working with stakeholders on this issue.

Clear and timely communication on PFAS, its impacts and its management, benefits everyone and is vital to increasing the community's understanding of the PFAS issue. By communicating in a way that is open, transparent, tailored to community needs, and easy-to-understand, confusion, anxiety and distrust are reduced. The way in which information is conveyed is critical to building trust between those responsible, polluters, regulators and the community.

4.1 Roles and responsibilities

The roles and responsibilities of all government agencies, including which agency has the lead responsibility, along with inter-agency communication arrangements, should be clear from the outset. These steps will help to ensure that communication and engagement about PFAS contamination is evidence-based, consistent and accessible to the public.

When industry and government are engaging with the community about PFAS, the community needs to feel confident that:

- Those responsible are focused on the wellbeing of people and their environment.
- Their concerns are being heard, acknowledged and understood.
- Information is tailored, easy to understand and available through multiple channels.
- They understand the uncertainties associated with risks of PFAS exposure, including the basis for precautionary measures and risks that PFAS pose relative to other risks.
- They understand what is happening in their area, how it will affect them, and steps they can take to manage any issues.
- They trust the information being provided to them, such that there is confidence that conclusions are based on the most up to date and credible information, and scientifically robust processes.

4.2 Principles for effective engagement

Early and well-considered engagement is important to establish a good foundation for working with communities and managing community expectations in relation to contaminated sites.

Industry and government should be transparent and clear in their communication about PFAS, accurately and swiftly communicating what is known and unknown, and presenting all relevant information and data. Where the data suggests that PFAS levels above the guidelines and exposure pathways are present, the government agencies responsible for providing health and

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[11] The PFAS Information Sharing, Communication and Engagement Guidelines and the PFAS Contamination Response Protocol are Appendices to the Intergovernmental Agreement on a National Framework for Responding to PFAS Contamination.

environment advice should ensure the community receives advice as soon as possible to explain how to minimise their exposure. Communication should be in plain language wherever possible, with sufficient context provided to ensure that the information is easy to understand.

Where contamination crosses jurisdictional boundaries, all relevant jurisdictions should be involved in identifying stakeholders and planning engagement. Effective collaboration between all levels of government is critical to successful communication and engagement with communities affected by PFAS contamination.

Site-specific, and where applicable, catchment-wide strategies, including the identification of key stakeholders, should be developed. This is particularly important for sites that are complex, sensitive and pose an increased risk to human health. It is important to be clear about the purpose of engagement when creating these strategies.

In developing a site-specific strategy, identifying and mapping stakeholders will help to target activities, tailor messages and materials. Stakeholders include:

- primary - those who are directly affected
- secondary - those with a vested interest and/or ability to lobby decision makers
- influencers - media, respected and trusted community members or spokespeople, and decision makers

4.3 Approaches for environmental regulators

The environmental regulator should be involved from the outset in planning and delivering communication and engagement activities. The environmental regulator should act as an accessible source of information for the community and ensure that polluters undertake appropriate engagement activities in accordance with the environmental legislation. It may also be appropriate to involve polluters in these discussions.

The role of the regulator is to ensure the best outcome for the community and the environment. There are a number of measures that environmental regulators can use to ensure that the best outcomes for the community are achieved.

These measures range from supporting engagement by a polluter with the community, to regulatory action which instructs a polluter to engage with the community. It may be a regulator’s preference to work collaboratively with polluters to ensure that accurate, timely and consistent messaging is delivered to the community. Working with a polluter to engage with the community does not undermine the role of the environmental regulator; rather, it can achieve the best results. By working with, and supporting engagement among, those responsible, site owners, and occupants, the environmental regulator can ensure accurate and consistent messaging. Should the need arise to direct a polluter to undertake specific engagement activities, this option remains available.

Equally, while it is important for an environmental regulator to work with site owners and occupants to ensure effective community engagement, the environmental regulator must maintain a distinct and separate identity to perform its function, and to maintain the community’s trust as effective and independent.

It is therefore important in all engagement and communications to distinguish and clearly communicate the roles and responsibilities of those responsible, the polluter, site owner and/or occupant and the environmental regulator.

5 PFAS monitoring

Environmental monitoring is used to determine if PFAS are present within an area of interest and to provide quantitative and qualitative data about the distribution, concentrations and types of PFAS within this area[12]. This data is used by site managers and environmental regulators to inform the assessment and management of PFAS contamination for the protection of human health and the environment.

For environmental regulators, monitoring also provides the evidence base for decision-making in relation to policy development, regulatory activities and site-specific management controls, such as whether the PFAS concentration in water meets water quality guidelines or licence discharge limits. The following guidance should be read in conjunction with Section 8 on environmental guideline values, Section 9 on contaminated site assessment, Section 18 on sampling, and Section 19 on analysis.

5.1 Planning and design of monitoring programs

The planning and design of a monitoring program should reflect its specific aims and the expected uses of the data being collected.

There are two main types of monitoring programs:

- Ambient monitoring programs provide data to assess the distribution, concentrations and types of PFAS. attributed to a range of sources within a region, such as a catchment, urban area or jurisdiction. This also includes reference site characterisation.
- Site-specific monitoring programs provide data to assess the distribution, concentrations and types, of PFAS attributed to a source or sources at a specific site. This also includes the extent of offsite contamination caused or contributed to by contamination at the site, and the potential on- and off-site impacts on human health and the environment.

In general, ambient monitoring programs are undertaken by environmental regulators or by other organisations with an interest in the area[13], and site-specific monitoring programs are undertaken by site managers. Site-specific monitoring may be triggered by legacy contamination or by an incident, such as a loss of containment of PFAS-containment material[14]. It is important to note that site-specific monitoring programs are driven by and should focus on the specific information needs relevant to the site, including identifying offsite impacts from contamination at the site. Site-specific monitoring is not a replacement for a broader ambient monitoring program.

It is essential to consider the likelihood of multiple PFAS sources within the same catchment, including point and diffuse sources, when designing monitoring programs. For example, the design of a site-specific monitoring program should account for the possibility of finding PFAS

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[12] This includes data on PFAS in receptors, such as wildlife.

[13] For example, a joint monitoring program may be established by businesses managing contaminated sites in the same area, or a catchment management organisation may include PFAS in an existing monitoring program.

[14] See Section 10 for guidance on containment of PFAS-contaminated materials. For nationally agreed guidance on roles and responsibilities in responding to site-specific contamination, see the Intergovernmental Agreement on Responding to PFAS Contamination and particularly Appendix A – PFAS Contamination Response Protocol. Typically, incident monitoring provides data to assess the source, cause, and extent of and the harm associated with a specific incident, such as a PFAS spill or inadvertent contamination of a resource being beneficially reused. It also includes clean-up monitoring.

contamination that originates offsite or is of unknown origin. The results of this consideration should inform the scope, scale, and geographic focus of the monitoring program[15].

To be fit for purpose, data collection should be, at a minimum, sufficient to:

- characterise the nature of PFAS that may be present
- map the distribution and spatial extent of PFAS in the area of interest
- characterise likely temporal variations associated with environmental patterns, including seasonal and intermittent weather variations[16]
- inform the development of a catchment model or conceptual site model identifying transport, fate and exposure pathways
- enable comparison against all relevant screening criteria[17]
- characterise the extent of any adverse impacts on the environment or human health

Assumptions regarding the presence, concentration, dispersal and environmental attenuation[18] of PFAS should be tested against site-specific data, as PFAS are mobile and persistent and some are bioaccumulative. The importance of site-specific data is heightened by the knowledge gaps that currently exist regarding the behaviour of PFAS in the environment[19].

The starting assumption should be that PFAS will travel from its sources into environmental media down-gradient within the catchment, or catchments, being monitored. The main pathway for movement of soluble PFAS compounds is expected to be in water along the hydrological gradient, with bioavailable PFAS taken up by aquatic biota and terrestrial plants and animals exposed to PFAS-contaminated water and, consequently, into the food chain. In the longer term, PFAS in water are likely to end up in a temporary or permanent geological reservoir such as aquatic or marine sediments. A proportion of the PFAS in these sediments is likely to be remobilised by biota. For some PFAS[20], other emission pathways include air transport and sediment-laden run-off. These varying pathways for environmental transport should inform the monitoring program for environmental media including soil, sediments, water, and biota.

5.2 Ambient monitoring programs

Ambient monitoring should test for a broad range of PFAS in environmental media to establish baseline information and identification of temporal and spatial trends in the concentration and

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[15] For example, a monitoring plan may include data tailored to identifying and evaluating PFAS distribution patterns attributable to different sources, areas of overlapping influence and background conditions.

[16] Depending on the environmental characteristics and risk profile of the monitoring area, it may be appropriate to use professional judgement to characterise likely temporal variations, without additional time series monitoring being required.

[17] Section 8 provides guidance on PFAS environmental guideline values and Section 19 provides extensive guidance on PFAS testing, including standard analytes and consideration of the broader PFAS family including precursors.

[18] Environmental attenuation is reduction in contaminant concentration through natural processes such as ion exchange, chemical precipitation, adsorption, filtration, biodegradation and hydrodynamic dispersion.

[19] Research shows that the behaviour of PFAS in environmental media - for example sorption in soil (Li et al 2018) and uptake from soil (Bräunig et al 2019) - is variable and relatively unpredictable, based on current knowledge, across a range of spatial scales.

[20] Air transport is relevant for volatile PFASs such as fluorotelomer alcohols and ketones, and for PFAS bound to airborne particles, and sediment transport is relevant for PFASs such as long-chain PFCAs that are strongly adsorbed to sediments.

presence of specific PFAS. The following environmental media should be considered for inclusion in an ambient monitoring program:

- soil - urban (e.g. residential, public open space, parks) and rural land use segments, to be used for assessment of changes to land over time, and to monitor impacts from reuse of materials (e.g. soils and biosolids)
- groundwater - within different land use segments, to assess changes to groundwater aquifers over time
- fresh and marine surface water - within different catchments and regions to assess impacts over time
- sediments - sampling of freshwater, estuarine and coastal sediments to assess impacts on receiving environments
- biota - assessment of flora and fauna (e.g. tissues from finfish, crustaceans and molluscs) to inform bioaccumulation trends
- air - sampling of air (including gaseous phase, condensed phase, and particulates e.g. dust), particularly where there is a high potential for airborne emissions, noting options for air sampling are not routine[21]

Some environmental media act as temporary or permanent PFAS sinks. It is important to include these in PFAS ambient environmental monitoring programs. For example, PFAS concentrations in sediments in surface water bodies (including drainage lines) are important to consider when assessing transport via wastewater and surface water pathways.

Ambient monitoring should include samples from a range of land uses across a catchment, as this will help to eliminate bias and to provide information about PFAS concentration variation (e.g. urban, industrial and agricultural areas within a catchment). This will also provide information about how PFAS are partitioning between environmental media.

The inclusion of environmental parameters relevant to PFAS behaviour (e.g. pH, redox and salinity) will ensure that the data collected can be appropriately compared. Some of this information may be available from existing programs in the area.

5.3 Site-specific monitoring programs

Site-specific monitoring guidance is provided in the ASC NEPM as part of the nationally-agreed process for characterising site contamination. This process is informed by the development of a robust conceptual site model, which takes into account the features of the surrounding land including other known or potential sources of PFAS contamination[22]. In general, the same media and sinks should be assessed as in an ambient program, as described above.

Due to the bioaccumulative and biomagnifying nature of PFAS, additional PFAS-specific considerations include the need to sample aquatic and other biota and animal/human food sources wherever a plausible transport pathway from a contaminated source exists, even if water concentrations are below the limit of reporting (LOR) (refer NSW EPA (2016) for further information).

Some types of monitoring, such as food and livestock testing, would be for the purpose of informing the conceptual site model.

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[21] Information on air sampling is provided in ITRC (2018d).

[22] Where other sources of PFAS contamination are known or potentially present, the site characterisation approach should be carefully considered with regard to effectiveness, efficiency, timeliness and sequencing. The ASC NEPM allows for both “inside-out” and “outside-in” approaches.

Well-designed site monitoring allows assessors to differentiate between ambient (diffuse) contamination, and point source contamination originating from the site, and the extent to which onsite source(s) are contributing to offsite impacts.

5.4 Case study - PFAS assessment pilot program - environmental monitoring

Victoria lacks comprehensive data on the presence of PFAS in the environment. In 2017, EPA Victoria completed a pilot environmental assessment program to assess the ambient concentration of a number of PFAS. While the assessment was limited, the results indicate that PFAS are present throughout the state. The program examined soil, groundwater, fresh surface water, marine biota, wastewater treatment plants and landfills.

There were PFAS in all types of media sampled, but not at all locations. The pilot program recommended further monitoring through an ambient environmental assessment program, allowing assessment of ambient environmental PFAS concentrations into the future.

6 PFAS inventory

The purpose of a PFAS inventory is to collect local, jurisdictional and national information to quantify and characterise[23] PFAS-containing products and PFAS-contaminated materials. For an environmental regulator undertaking a PFAS inventory, the objective is generally to use this information to identify areas or sites to prioritise regulatory action. The information required includes the types, locations and quantities of PFAS-containing products or PFAS-contaminated materials, management practices employed and where available, extent of contamination present in the environment. This information will assist those with management responsibilities for PFAS contamination, inform government policy development, and assist in evaluating the effectiveness of NEMP implementation.

Appendix B provides a list of activities that may be associated with PFAS, including a brief description of the relevant PFAS uses for each activity. This list can be used to support PFAS inventory activities.

6.1 Scope of a PFAS inventory

The scope of a PFAS inventory should include:

- liaising with other agencies to obtain government-held information on PFAS stocks or legacy issues
- identifying sites contaminated by PFAS including the location, level and distribution of on-and off-site contamination, and catchment information
- identifying major primary sources (major commercial, industrial and government facilities, infrastructure and activities that historically or currently use or store PFAS-containing products, noting that all PFAS formulations should be considered, such as surfactants used in chrome plating or firefighting, hydraulic fluids and lubricants, and wastes and waste liquids)
- identifying other primary sources (sites where PFAS is or has been used, such as firefighting training facilities, foam deluge system installations, metal plating works, car washes, and electricity generation and distribution facilities)
- identifying secondary sources (sites where diffuse PFAS inputs are or have been received such as landfills, wastewater treatment facilities, liquid waste treatment facilities, and biosolids stockpiles[24]).

6.2 Conducting a PFAS inventory

The steps in conducting a PFAS inventory include:

- Establish an inventory team. Depending on the objectives, this may include agencies responsible for chemicals management, customs services, representatives from major PFAS producers or consumers, research institutions, and non-government organisations.
- Identify key stakeholders. The involvement of appropriate stakeholders can help to clarify the relevant areas of industrial PFAS use, making the inventory process more practical and efficient.
- Define the scope of the inventory, which involves identifying the following:

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[23] Quantitative data includes mass, volume and PFAS concentration. Qualitative data includes PFAS type, storage and management arrangements and planned use or disposal.

[24] By way of example, a PFAS inventory could, in some instances, include sites with a long history of repeated biosolids use.

  - industry and government sectors that should be considered further, based on the relevant areas of industrial use from the stakeholder identification stage
  - existing and potential waste sources
  - the resources available to perform the inventory
  - spatial priorities, such as where there are areas of environmental significance or other values of specific interest.
- Plan the inventory. This involves agreement on aims, objectives, timeframes, outputs, resources, stakeholder engagement, governance, probity and conflict of interest.
- Data management. This involves arrangement for data acquisition, input, storage, integration, and issues such as QA/QC, probity and data security. Participant education should be considered where there is a risk that knowledge gaps may lead to misunderstanding or misrepresentation.
- Report, follow up, and review. This should include presenting the results of the inventory, legal and policy obligations and stakeholder communication.

6.3 Case study - firefighting foam survey

The Queensland Department of the Environment and Science effected the Operational Policy - Environmental Management of Firefighting Foam in response to growing concern regarding PFAS. A voluntary survey in early 2017 collected information on foam stocks, historical use, containment and waste management practices and compliance with the policy.

Participants included sites likely to store high volumes of firefighting foam, such as bulk fuel storage, chemical storage, chemical manufacturing, mining and petroleum, locations handling dangerous goods and major hazard facilities. Desktop identification of these included assistance from workplace health and safety authorities in addition to departmental records.

The survey received 468 responses. Approximately 425,000 kg of foam was reported, mostly at bulk fuel and chemical storage facilities. PFAS-containing foams were reported at 98% of sites, and it was estimated that 5% of sites were compliant with the policy at that time.

7 PFAS contaminated site prioritisation

Prioritising sites within a broader inventory of PFAS-contaminated sites involves determining which sites have a risk of causing harm to the environment and/or human health either on- or off-site or within the catchment. This gives agencies, site owners and managers the information they need to prioritise investigation, management and/or remediation actions, and ensure environmental regulators focus on activities that address the highest risk sites.

7.1 Site prioritisation process

This risk-based prioritisation involves an evaluation of both the likelihood and consequence of harm occurring. The likelihood of harm can be evaluated by accounting for the potential mass of PFAS likely to have been used at a site, taking into account any historical records and known incidents or discharges. If a PFAS inventory has been conducted, this will provide information on current PFAS stocks and/or contamination.

The likelihood of harm occurring is evaluated by the scale of PFAS contamination, the quantity of PFAS present, the physical features of the site and the location of nearby receptors. Air, soil, surface water, and groundwater pathways connecting the site with receptors are important considerations, as is the nature of the current and past site use and the efficacy of any measures taken to minimise emissions.

The consequence of harm will be influenced by the environmental, social and economic values that are affected, or could be affected. For example, contamination of a wetland could affect environmental values such as biodiversity, social values such as Indigenous cultural practices and economic values such as access to wild foods or the income derived from nature tourism.

Initially, priority should be given to sites where contaminant concentrations exceed established criteria or guideline values for the protection of human health and/or the environment, and where there are known or probable exposure pathways. As investigations proceed, the relative priority of a site may be revised, for example as exposure pathways are confirmed or eliminated, or as further data is gathered on the PFAS present and consequently the potential environmental and human health risks requiring consideration.

A similar prioritisation approach should be taken to determine the urgency of response when a PFAS contaminated site is newly identified.

7.2 Next steps after prioritisation

Once the initial scan of risks has been determined and site prioritisation has been completed, a decision should be made on further actions, including:

- urgent investigation (known or highly probable pathways involving groundwater or surface water)
- high priority for investigation
- standard priority for investigation
- low priority for investigation
- no further site assessments or investigation required for PFAS contamination.

7.3 Case study - preliminary PFAS prioritisation

Completed in October 2016, EPA Victoria's preliminary PFAS inventory assessed major industries and sites that hold, use, or have used or received, PFAS as well as a small number of sites where PFAS exists as a contaminant. The inventory involved a desktop study of major industries that were likely to have PFAS stocks or contamination, followed by data collection in which EPA Victoria searched its own records, requested data from other government agencies and sent questionnaires to identified sites.

This work identified fire training grounds, oil and gas industries, airports and chemical manufacturers as the main sites of potential concern for PFAS contamination.

The inventory included over 14,000 kg of PFAS-containing materials.

The identified sites were prioritised based on the risk they posed to human health and/ or the environment. An overall potential concern ranking was developed by assessing the proximity of sites to receptors and the likelihood of PFAS contamination, based on quantities historically used.

Scores were assigned by combining the PFAS inventory with GIS data on nearby geographic features, surface water, groundwater and land use. The consequence of harm from PFAS was determined by assessing the proximity of identified sites to sensitive receptors. The potential for complete exposure pathways for contamination was an important consideration. For human health, sensitive receptors included:

- residential areas, including home-grown produce
- schools and early childhood centres where risk has been identified
- aged care facilities and hospitals where risk has been identified
- agricultural areas, including aquaculture
- drinking water supply sources and infrastructure (such as stock and domestic bores, town water bores, and drinking water catchments and reservoirs)
- irrigation bores
- aquifer storage and recovery and reuse systems
- water used for recreation or fishing.

For ecological health, sensitive receptors included:

- areas identified with any of the nine matters of national environmental significance protected under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (the EPBC Act), and areas of environmental significance as identified in specific jurisdictions
- protected areas, such as parks and other reserves
- aquatic and terrestrial ecosystems, such as Ramsar sites
- ecological receptors
- wetlands
- dams, bores, stockwater, and irrigation water
- biota, such as aquatic flora and fauna, waterbirds, and those species at the top of affected food chains
- groundwater-dependent ecosystems
- predators of PFAS-affected aquatic fauna.

Assessing both the likelihood and consequence of PFAS contamination allowed the overall site priority to be determined and was used to inform the priority for regulatory action.

8 PFAS environmental guideline values

The purpose of a guideline value is to identify the level of a contaminant that will minimise human health and ecological risks, based on the best available scientific evidence. Guideline values are developed using methods designed to address the specific sensitivities of the receptors. For example, aquatic wildlife may experience continuous PFAS exposure from the water they live in, whereas for humans the main sources are usually food and drinking water. In some cases, ecosystem guidance can be more stringent than human health guidance. This can arise due to some organisms being more sensitive to a contaminant than humans, and the different mechanisms by which PFASs accumulate (such as accumulation from water, sediment, food sources and trophic structures).

The following guideline values represent a nationally-agreed suite that should be used to inform site investigations and consideration of environmental management. The purpose of the guideline values is not intended to be as clean-up criteria or an authorisation to pollute up to these values. The values include a degree of conservatism. This is necessary when deriving in screening assessments to be protective of human health in circumstances where multiple exposure pathways may be present, and protective of ecological health in circumstances where there is variability in species sensitivity. This is especially important for bioaccumulative chemicals such as PFOS, PFHxS and PFOA.

Where the guideline values refer to the sum of PFOS and PFHxS, this applies to PFOS only, PFHxS only, and the sum of the two.

8.1 Considerations for using guideline values

The identification of PFAS above relevant guideline values acts as a trigger to undertake further investigations (such as site-specific risk assessment, as opposed to the assumption that harm will have occurred). The guideline values can also prompt consideration of management action to meet the environmental values and mitigate, where practicable, human health and ecological risks.

When carrying out a site investigation, the following guidance should be considered (informed by the ASC NEPM guidance[25]):

- It is important that sufficient and appropriate characterisation of the contaminants is carried out when comparing site data with guideline values. This is required to ensure that the comparison is both meaningful and relevant for assessing potential risks to human health and the environment.
- The selection of the appropriate guideline values at a site should consider current, potential or future uses of the site, and any catchment or groundwater management requirements, with reference to the conceptual site model (CSM).

The selection of guideline values should have regard to the specific environmental values and characteristics of the site, drawing on relevant guidance[26] in consultation with the

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[25] ASC NEPM, Schedule B1, Section 3 - Application of investigation and screening levels.

[26] Relevant guidance could include the ASC NEPM, the NWQMS (including the WQGs), the Commonwealth Environmental Management Guidance for PFOS and PFOA, and jurisdictional tools such as Commonwealth, state and territory environment protection; catchment, groundwater basin, vegetation and biodiversity management plans; contaminated sites registers; waste and wastewater management strategies; and PFAS-specific guidance resources.

environmental regulator. It is important to note that regulators may specify, or environmental legislation may prescribe, the level of protection required.

For managing site-specific PFAS contamination, a site-specific CSM needs to consider the source area, off-site transport, relevant exposure pathways, potential receptors and any relevant environmental values. Section 9 provides further guidance on risk assessment and evaluation in the context of contaminated site management, and Section 13 discusses considerations for treatment and remediation. For sites where a PFAS Management Plan (PMP) or comparable management framework is already in place, this may include site-specific provisions in the PMP that have been agreed with the relevant regulators[27].

8.2 Basis for selection of the guideline values included in the NEMP

The guideline values in the NEMP are drawn from, and have been derived with reference to existing nationally-agreed and long-standing Australian frameworks including the National Water Quality Management Strategy (NWQMS) (Australian Government 2018) and the National Environment Protection (Assessment of Site Contamination) Measure (ASC NEPM) wherever possible. However, some of the guidance in these existing frameworks may not always be protective for mobile, persistent and bioaccumulative substances such as PFAS.

For guideline values where there are nationally recognised processes for the review and adoption of new criteria, such as the Australian and New Zealand Fresh and Marine Water Quality Guidelines (WQGs), appropriate draft criteria are recommended below. The NEMP will be updated to align with subsequent updates as these are published.

In other instances, interim guideline values have been derived as part of the NEMP process using methods from the ASC NEPM. Some of these guideline values are expected to be subject to additional work in the future, including addition of more recent literature as it becomes available.

Where the above options were not possible, internationally derived guideline values are provided.

8.3 Exposure pathways for human health assessments

Section 8.5 describes PFAS guideline values for human health assessments, including health-based guidelines for drinking water and recreational guidelines from the NHMRC, and health investigation levels (HILs) for soil. Note, these screening values do not cover all potential exposure pathways for human health. Therefore, to assess risks for human health, site-specific exposures need to be considered as part of any assessment (see Section 9 on contaminated site assessment and Section 10 on the potential need to consider atmospheric emissions). Figure 1 below indicates some of the key exposure pathways for a human health assessment.

Due to the bioaccumulative nature of PFOS, multiple exposures may need to be considered. Guidance should be sought from the environmental regulator to confirm specific jurisdictional requirements.

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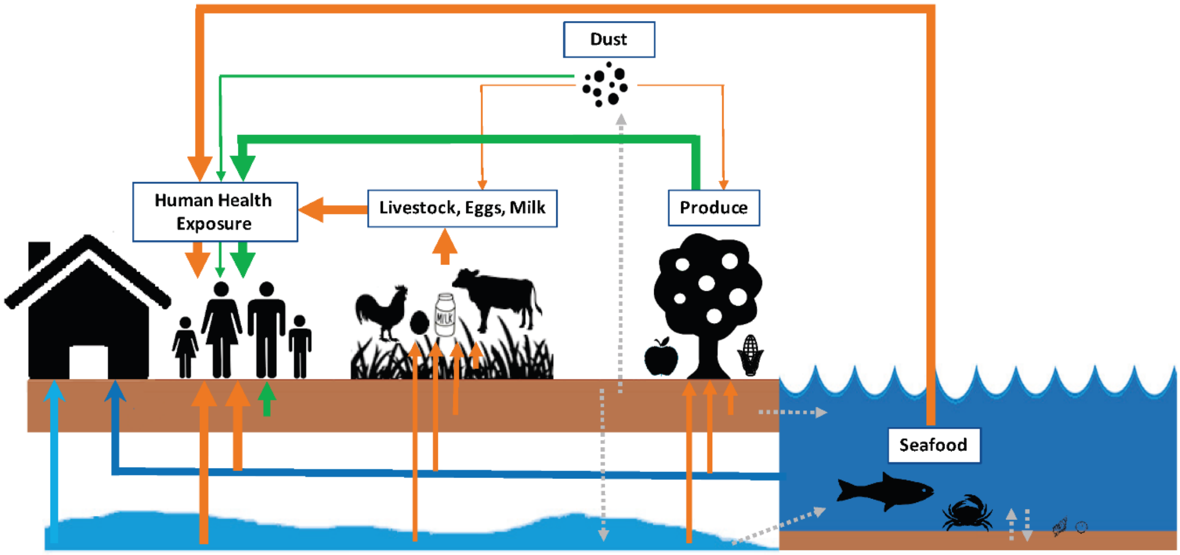
[27] For example, Section 12.1.1 discusses the use of a PMP to agree a site-specific approach to soil excavation and reuse.

Figure 1 An example of potential human health pathways for PFAS exposure



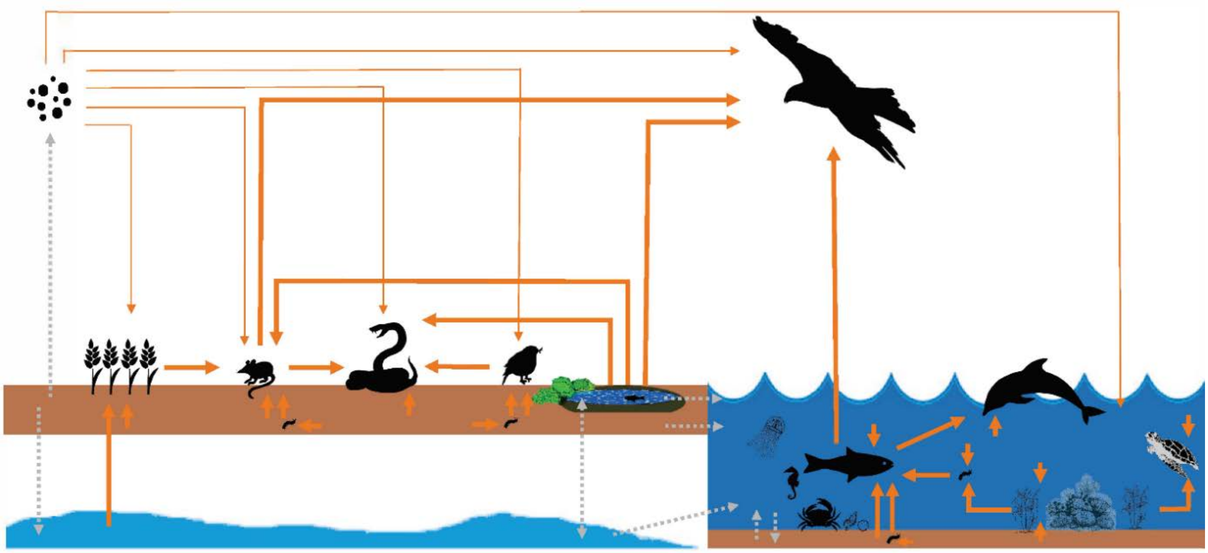
Note: Figure 1 depicts potential exposure pathways affecting human health and is a general example of potential exposure pathways to be considered in a site assessment. Note this is not intended as a comprehensive conceptual model covering all possible exposures. Dotted grey arrows indicate PFAS transport mechanisms in the environment. Solid orange lines indicate potential PFAS uptake and exposure pathways to human receptors. The green arrows indicate the exposure pathways that were considered in calculating the health investigation levels for soil (Table 2). These include exposure via soil, dust and consumption of a small amount of home garden produce (home-grown produce provides up to 10% of fruit and vegetable intake). The arrow's thickness infers relative magnitude of assumed exposure, showing that dust inhalation is considered typically a minor pathway.

8.4 Exposure pathways for ecological assessments

Section 8.6 describes PFAS guideline values for ecological assessments. These include interim ecological soil guidelines for direct and indirect exposure, biota guideline values based on tissue samples, and draft ecological water quality guidelines.

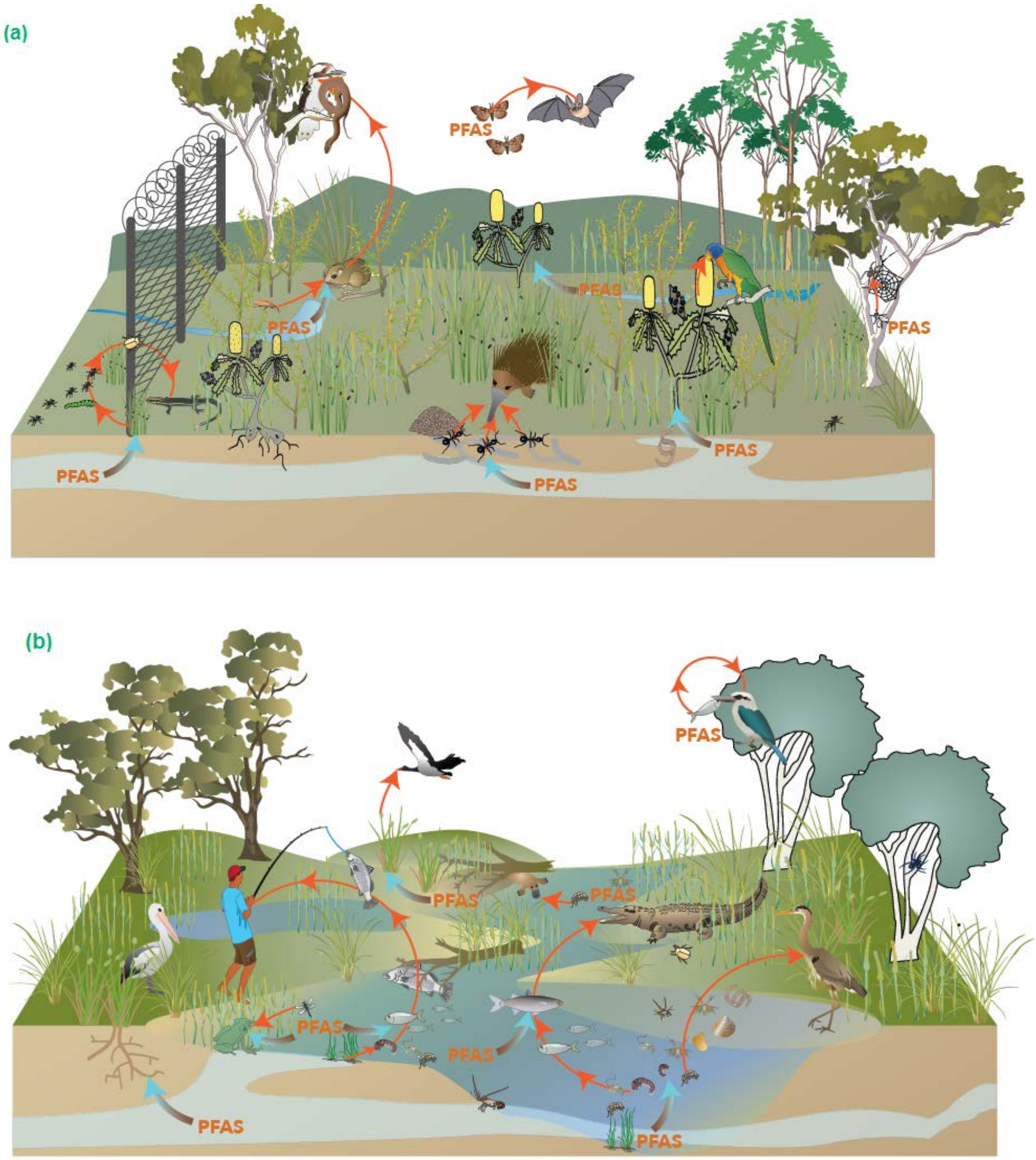
The ecological guidelines need to be applied with consideration to the relevant receptors and pathways in the environment. Figure 2 below indicates some of the key exposure pathways for an ecological assessment. Figure 3 below provides examples of key pathways to consider in terrestrial, wetland and coastal environments. For additional guidance on contaminated site assessment for PFAS, see Section 9. Guidance should be sought from the environmental regulator to confirm specific jurisdictional requirements.

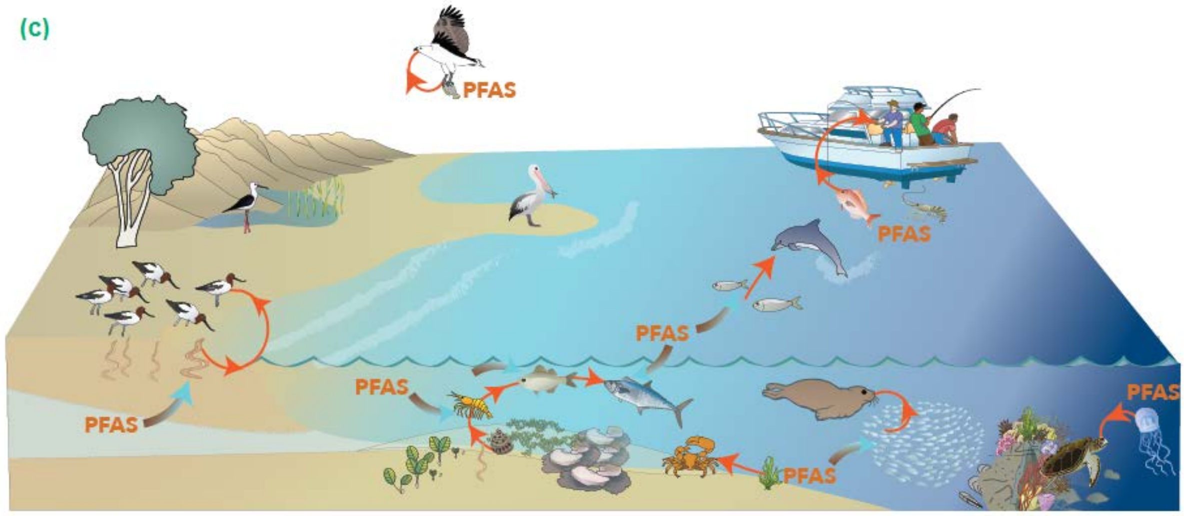
Figure 2. An example of potential ecological pathways for PFAS exposure



Note: The conceptual model shown in Figure 2 is a general example of potential exposure pathways to be considered in a site assessment, and is not intended as a comprehensive conceptual model covering all possible exposures. Dotted grey arrows indicate PFAS transport mechanisms in the environment. Solid orange lines indicate potential PFAS uptake and exposure pathways to ecological receptors. The arrow thickness is relative to the significance of the PFAS exposure pathway.

Figure 3. Examples of key pathways to consider in a risk assessment for PFAS in a) terrestrial ecosystems b) wetlands and c) coastal environments





Source: Lana Baskerville (2019). Symbols courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

Note:

Figure 3 is an extension of pathways included in Figure 1 and 2 and provides examples of pathways to consider in different environments such as terrestrial, freshwater and marine ecosystems. These diagrams are intended as examples and are not comprehensive conceptual models covering all possible exposures. Orange arrows indicate potential pathways for accumulation of PFAS.

8.4.1 Consideration of bioaccumulation

For PFAS, bioaccumulation in aquatic species cannot currently be predicted based on water concentrations. This is evident from site assessment data, where bioaccumulation in fish tissues has been measured, despite water concentrations being at the laboratory detection limits. Therefore, to consider risks as a result of bioaccumulation, direct measurement of aquatic biota is the preferred approach where exposure pathways and sensitive receptors (ecological and/or human) exist[28]. Any sampling program needs to consider if the assessment is for human health and or ecological purposes, as there may be different sampling considerations. Sampling biota will reduce uncertainty in assessing risks as a result of bioaccumulation. Additional details regarding consideration of PFAS bioaccumulation are discussed in section 9.3.2.

Where an assessment has to look forward in a predictive sense rather than investigate impact of existing contamination, multiple lines of evidence should be used. This can include:

- current studies on bioaccumulation in the area or similar areas of conservation and exposures
- use of published bioaccumulation data relevant to potential receptors and any relevant environmental values
- water and sediment quality data
- data on local environmental values and pressures

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[28] Taxonomic variability in PFAS elimination rates is an important consideration. For example, elimination may be relatively fast for water-breathing animals, e.g. fish, and relatively slow for air-breathing animals, e.g. marine mammals.

- use of passive samplers to monitor spatial and temporal trends and minimisation of PFAS flux from the site.

8.5 Human health guideline values

The human health guideline values are used to investigate and assess human health risks. The use of these values should take into account any additional guidance on human health protection from the relevant health and environment regulators, along with guidance from the NEMP[29] and ASC NEPM for monitoring, site assessment, sampling and analysis.

8.5.1 Human health guideline values developed by health regulators

For humans, the main sources of PFAS are via ingestion of food and drinking water. Health authorities have set health-based guidance values[30] indicating the amount of a chemical intake a person can consume on a regular basis over a lifetime without any significant risk to health.[31] The health-based guidance values for PFOS and PFOA were recommended by Food Standards Australia and New Zealand in the form of a tolerable daily intake (TDI) (FSANZ, 2017). The TDI was then used to calculate the human health-based guidance values provided here.

As a precaution, the Australian Government Department of Health has advised that the PFOS TDI should also apply to PFHxS. This means that the level of PFHxS exposure should be added to the level of PFOS exposure. The combined level should then be compared to the TDI for PFOS.

The national methodologies used by health agencies in deriving the values in Table 1 include a level of conservatism in the drinking water and recreational water health-based guideline values. The methods assume only a minor portion (10%) of the TDI is allocated to this source. Therefore, 90% of intake is attributed to other exposure pathways, which means that exceeding these values does not constitute a risk if other pathways are controlled.

The recreational water quality values have been updated from the values published in the NEMP 1.0 and are based on revised numbers derived by NHMRC (2019)[32]. The revised numbers are based on changes in the assumption for the frequency and likelihood of exposure during recreational activities.

NHMRC (2019) notes that there may be cases where recreational water may be used more frequently than the assumptions underpinning the guidelines. For example, surfing activities may be longer in duration and higher in ingestion risk, compared to the NHRMC assumptions. For such activities, more locally-appropriate recreational guidance based on actual event frequency should be considered in consultation with the state or territory health regulator.

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[29] See Sections 5 - PFAS monitoring, 9 - PFAS contaminated site assessment, 18 - PFAS sampling and 19 - PFAS analysis.

[30] The term health-based guidance values is used here for consistency with the Department of Health guidance.

[31] Details of the approach and guidance values are provided in Department of Health (2019) Health Based Guidance Values for PFAS for use in site investigations in Australia, available at https://www1.health.gov.au/internet/main/publishing.nsf/Content/2200FE086D480353CA2580C900817CDC/$File/HBGV-Factsheet-20190911.pdf.

[32] The guidelines address natural fresh, estuarine and marine recreational water bodies but specifically exclude swimming pools, spas and hydrotherapy pools (NHMRC, 2008).

Table 1. Human health guideline values developed by health regulators

Sum of PFOS and PFHxS	PFOA	Description	Comments and source
0.02 µg/kg $_{bw}$ /day	0.16 µg/kg $_{bw}$ /day	Tolerable daily intake (TDI)	FSANZ 2017
0.07 µg/L	0.56 µg/L	Drinking water quality guideline value	Australian Government Department of Health 2019
2 µg/L	10 µg/L	Recreational water quality guideline value*	NHMRC 2019
Notes: bw = body weight, µg = micrograms. Where the guideline values refer to the sum of PFOS and PFHxS, this includes PFOS only, PFHxS only, and the sum of the two. *NHMRC (2019) notes that people's use of recreational water is not the same, given Australia's climate and geography. Some recreational water resources may be used less frequently than the assumed guidelines (150 days/year), and (in rare cases) some may be used more frequently. In such cases more locally-appropriate event frequency based recreational guidelines can be considered in consultation with the state and regulatory health regulator.			

8.5.2 Human health investigation levels for soil

The following human health-based investigation levels for soil were derived using a methodology consistent with assumptions set out in the ASC NEPM for the health investigation levels (HILs). Note these values have not been derived under the ASC NEPM. The PFAS HILs (Table 2) should only be used to assess potential human soil exposure in-line with the same assumptions that underpin the ASC NEPM HILs. These values should be applied in conjunction with other lines of investigation to account for potential leaching, off-site transport, bioaccumulation and secondary exposure.

For residential with garden/accessible soil, the standard methodology under the ASC NEMP HIL A assumes that home produce makes up 10% of fruit and vegetables consumed. Note these criteria do not account for potential home consumption of eggs from home poultry, nor of milk or meat from stock on the premises. However, the HILs calculations are based on 20% of the TDI. In other words, this allows for 80% of intake to be attributed to other exposure pathways (e.g. consumption of other home grown produce, poultry eggs and recreational activities) as well as background exposure. This means that exceeding these values does not constitute a risk if other pathways are controlled. The guideline values for the sum of PFOS and PFHxS for Residential with garden/accessible soil (using HIL A assumptions) have been updated from the values published in the NEMP 1.0 and are considered higher reliability than the values they replace. The changes are a result of a technical review and re-derivation of the values, detailed in OEH (2019) [33].

- Relevant studies additional to those included in the original derivation were considered.
- A more robust treatment of the data was applied, by accounting for whether soil to plant transfer factors were based on PFAS concentrations per wet weight plant (where only data for dry weight were available these were converted to wet weights).

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[33] This technical review was led by NSW on behalf of the NCWG (OEH, 2019). Future work on soil guideline values is part of the Soil theme as described in Section 20.

- The uptake of PFOS and PFHxS from soils to plants has been explicitly accounted for.

Note that the PFOA value for Residential with garden/accessible soil (using HIL A assumptions) has been retained from the NEMP 1.0 given that the relevant literature is expanding rapidly. As new information becomes available, particularly any further development of transfer factors of PFAS from soil into edible portions of plants, it will be reviewed as part of the future work outlined in Section 20.

8.5.2.1 Comparison of PFOS and PFHxS concentrations

A review of soil to plant transfer factors for PFOS and PFHxS has shown that PFHxS accumulates more readily in plants compared with PFOS.

The Residential with garden/accessible soil investigation level was derived assuming that PFOS and PFHxS are present in a soil at equal proportions. This influences the total PFOS plus PFHxS concentration predicted in the plant. If a site has significantly more PFHxS in the soil than PFOS, the concentrations of total PFOS plus PFHxS in the plant will be higher than if they were present in equal proportions. In such a case, a re-calculation of the criterion based on site-specific conditions is recommended as the residential garden accessible soil criteria may not be protective. For any additional calculations, the methodology and soil to plant transfer factors are described in detail in OEH (2019).

As an example, if the ratio was 25% PFOS and 75% PFHxS for the total PFOS and PFHxS concentration in soil, then the PFOS + PFHxS screening value would be 0.007 mg/kg (compared with 0.01 mg/kg for a ratio of 50% PFOS and 50% PFHxS).

Table 2. Human health investigation levels for soil

Sum of PFOS and PFHxS	**PFOA**	**Land use**	**Comments and source**
0.01 mg/kg	0.1 mg/kg	Residential with garden/accessible soil (HIL A)	Assumes home-grown produce provides up to 10% of fruit and vegetable intake (does not account for consumption of any eggs from home poultry, nor of milk or meat from stock on the premises). Also includes children's day care centres, preschools and primary schools. The HILs were derived using the methodology consistent with assumptions set out in the ASC NEPM for HIL A. Note: If home-grown produce provides more than the 10% of fruit and vegetable intake assumed in the ASC NEPM generic example, a site-specific risk assessment is required. As an example, if home grown produce provides up to 50% of fruit and vegetable intake, the screening value would be 0.002 mg/kg for the sum of PFOS and PFHxS, and 0.02 mg/kg for PFOA.
2 mg/kg	20 mg/kg	Residential with minimal opportunities for soil access (HIL B)	Assumes no potential use of soil for consumption of home-grown produce. Includes dwellings with fully and permanently paved yard space such as high rise-buildings and flats. These were derived using the methodology consistent with assumptions set out in the ASC NEPM for HIL B.
1 mg/kg	10 mg/kg	Public open space (HIL C)	Relevant for public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools (except for soil used for agricultural studies) and footpaths. Excludes undeveloped public open space (such as urban bushland and reserves), which should be subject to a site-specific assessment where appropriate. These were derived using the methodology consistent with assumptions set out in the ASC NEPM for HIL C.
20 mg/kg	50 mg/kg	Industrial/ commercial (HIL D)	Assumes 8 hours is spent indoors and 1 hour spent outdoors at a site such as a shop, office, factory or industrial site. If the typical exposure for a site is predominantly outdoors with significant earthen areas, recalculation of a site-specific value is recommended. These were derived using the methodology consistent with assumptions set out in the ASC NEPM for HIL D. Note: the industrial/commercial direct exposure criterion for PFOA (including its salts and related compounds) has been set as 50 mg/kg in anticipation of the Stockholm Convention low content limit of 50 mg/kg.
Note: Where the guideline values refer to the sum of PFOS and PFHxS, this includes PFOS only, PFHxS only, and the sum of the two.			

8.6 Ecological guideline values

The ecological guideline values are used to assess and investigate potential risks to aquatic and terrestrial ecosystems.

The use of ecological guideline values should take into account any additional guidance on ecological protection by relevant environmental regulators, along with the extensive guidance provided in the NEMP and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality framework on considerations for monitoring, site assessment, sampling and analysis[34]. The general environmental duty to prevent offsite dispersal of PFAS and protect relevant environmental values should also be taken into account in jurisdictions where such a general environmental duty exists.

The ecological guideline values in Tables 3 and 4 are intended to be protective of wildlife, based on the current scientific evidence, to inform an overall assessment of the significance of PFAS concentrations for wildlife and trigger either appropriate management action or further investigation of risk. The ecological guideline values are intended to indicate concentrations that have a degree of confidence that there are unlikely to be risks, but are not intended to be generic site remediation criteria.

8.6.1 Ecological soil guideline values

The following interim ecological soil guideline values consider both direct exposure and indirect exposure. It is acknowledged that these guideline values are interim and may be refined by future work including as additional relevant research becomes available.

The direct exposure ecological soil guideline applies specifically to protection of organisms that live within, or in close contact with soil, such as earthworms and plants. This direct exposure value can be used to assess the possibility of direct harm to these organisms. In the absence of acceptable and sufficient published guideline values for direct exposure, human health soil criteria (Table 2) are recommended as an interim position. Other factors important for assessing exposure, for example bioaccumulation, leaching and off-site transport, must be accounted for by including other lines of investigation.

The indirect exposure ecological soil guideline (Table 3) accounts for the various pathways through which organisms can be exposed whether or not they are in direct contact with PFAS contaminated soil (i.e. exposure through the food chain). As discussed below, the values do not explicitly account for off-site environmental transport processes. The ecological soil guideline values set by Environment and Climate Change Canada (ECCC) were considered, and the value for exposure of a secondary consumer as the most sensitive exposure pathway was adopted as the PFOS indirect exposure value in the NEMP.

This guideline provides a default value to manage the potential level of exposure for wildlife feeding on organisms that have been exposed. For example, in an open space area, if plants and soil dwelling animals are present, it is likely that there will be birds, small mammals and/or reptiles present consuming these plants and animals (see Figure 2). It thus recognises that traditional land use categories are not relevant to ecological risks, and therefore a single guideline value is now applicable to all land use scenarios. This better reflects the possibility of indirect PFAS exposure from any land use where PFAS may be present in a large area of soil.

The indirect exposure value may be over-protective if the area of exposed soil is too small to have any material impact on food chain transfer to secondary consumers such as invertivores and carnivores. In this situation, considering site-specific characteristics may justify the use of a higher value (up to 0.14 mg/kg) as the trigger for a detailed site specific investigation of risk. Examples of relevant considerations include:

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[34] See Sections 5 - Monitoring, 9 - Contaminated site assessment, 18 - PFAS sampling and 19 - PFAS analysis.

- The site is intensively developed with greater than 80% of each hectare covered by hard surfaces (to be applied separately to each hectare).
- Secondary consumers are effectively absent from the site.
- The site is situated in an extensively built-up urban setting.
- The site is not in close proximity to waterways, drainage networks or groundwater.

These interim ecological soil guidelines do not consider the transport of soil, or PFOS or PFOA leaching from soil, into groundwater, surface water or onto adjacent sites. Therefore, these values do not cover impacts associated with PFAS transported into surface water on aquatic biota, or on wildlife that consume aquatic biota. Site-specific data should be considered wherever possible, as environmental variability may lead to locally elevated ecological risks.

Table 3. Ecological guideline values for soil

Exposure scenario	**PFOS**	**PFOA**	**Land use**	**Comments and source**
Ecological direct exposure	1 mg/kg	10 mg/kg	All land uses	Future work may be undertaken to review available soil guideline values proposed by Australian research and industry organisations[35]. The human health screening value for public open space is used as an interim value (see Table 2).
Ecological indirect exposure	0.01 mg/kg		All land uses	The guideline value is based on dietary exposure of a secondary consumer as the most sensitive exposure pathway assessed. This value may not be protective of specific animals relevant to Australia, including predatory animals such as quolls, antechinus and reptiles. For intensively developed sites with no secondary consumers and minimal potential for indirect ecological exposure, a higher criterion of up to 0.14 mg/kg may be appropriate as outlined in the accompanying text in section 8.2.1.

8.6.2 Biota guideline values

The interim wildlife diet values provided in the first version of the NEMP have been retained as the derivation of these criteria is consistent with the Australian context.

The bird tissue egg value adopted from the ECCC (2018) which was listed in the first version of the NEMP has been updated. The change is due to an additional uncertainty factor [36] that reflects the paucity of toxicological data for birds, and therefore the additional uncertainty factor accounts for potential for intra- and interspecies variability.

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[35] For example, CRC CARE (2017)

[36] The adjusted uncertainty factor is 100 while the original uncertainty factor was 10 (ECCC 2018).

The purpose of the tissue guideline for acceptable contaminant levels in bird egg is to assess potential risks to avian populations where these receptors may be relevant. When assessing sensitive avian receptors, some birds may be endangered species, and therefore sampling eggs may not be appropriate. In such instances, if bird eggs were to be sampled, this would need to rely on samples of other species which have similar relevant ecological niches.

Table 4. Biota guideline values

Exposure scenario	**Sum of PFOS and PFHxS**	**PFOA**	**Description**	**Comments and source**
Ecological direct exposure for wildlife diet	4.6 µg/kg		Mammalian diet - consumption of biota as wet weight food	Canadian Federal Environment Quality Guidelines (ECCC 2018). This guideline value is to be used on sampled biota tissue for assessing risk to mammal and avian receptors based on their diet. The avian diet value may not be protective of migratory wading birds that have a high food intake due to the need to gain weight rapidly. These diet values may also not be protective of reptiles and amphibians.
	8.2 µg/kg		Avian diet - consumption of biota as wet weight food	
Ecological exposure protective of birds	0.2 µg/g		Whole bird egg as wet weight	Adapted from Canadian Federal Environment Quality Guidelines (ECCC 2018) using an additional uncertainty factor. This guideline value is to be used on sampled bird eggs to assess risk to sensitive avian ecological receptors.

Notes: Where the guideline values refer to the sum of PFOS and PFHxS, this includes PFOS only, PFHxS only, and the sum of the two. The Canadian guidelines refer to the criterion for PFOS only; in the NEMP the guideline values for ecological direct exposure for wildlife diet refer to the levels of PFOS and PFHxS in food consumed by mammals or birds. This has been adapted to allow for uncertainties and potential similar toxicities of PFHxS with PFOS.

The guideline value for ecological exposure protective of birds refers to the levels of PFOS and PFHxS in bird eggs.

8.6.3 Ecological water quality guideline values developed by water regulators

The following ecological water quality guideline values (Table 5) are developed through the WQG Framework toxicant default guideline value (DGV) publication approval process[37] which is separate from the NEMP. Further information about the WQG Framework, including the development and application of DGVs and site-specific values, is available on the WQG website[38].

The WQG Framework provides species protection DGVs that are protective of differing proportions of species, ranging from 80% to 99% of species. These DGVs are applied according to the current or desired aquatic ecosystem condition and associated level of protection[39].

For contaminants that are not bioaccumulative, the relevant species protection DGV can be selected to reflect the conservation value of the aquatic ecosystem under consideration. However, the Water Quality Guideline Framework recommends a different approach for contaminants that are bioaccumulative.

For bioaccumulative contaminants, which includes many PFAS, the Water Quality Guideline framework[40] specifies that the 99% species protection DGV should be used for:

- assessing toxicity and bioaccumulation in high conservation value ecosystems
- assessing bioaccumulation in slightly to moderately disturbed ecosystems.

The species protection DGV may be below the ambient background concentration. Actions to determine reliable background concentrations for organic chemicals with widespread (e.g. global) contamination are discussed in the WQGs.

In short, jurisdictional guideline values may be developed, or site-specific guideline values for specific catchments, based on reference sites, subject to the proviso that the concentrations at the reference site are unlikely to be causing adverse impacts on environmental values.

Contamination in specific waterways arising from diffuse sources is a separate issue that should be addressed with reference to the water quality management objectives set by the relevant jurisdiction.

The NWQMS advises against the use of mixing zones for toxicants that bioaccumulate (ANZECC and ARMCANZ 2000, 8.3-45). Therefore, due to the persistent and bioaccumulative nature of PFAS the use of mixing zones, sometimes known as exclusion zones, is not appropriate.

This approach is consistent with the established practice across most jurisdictions for substances associated with contaminant accumulation in aquatic species, chronic impacts, or environmental risks, outside the mixing zone.

Guidance should be sought from the environmental regulator to confirm specific jurisdictional requirements.

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[37] Details of the default guideline value publication approval process are available at https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/draft-dgvs.

[38] www.waterquality.gov.au

[39] Importantly, the DGVs do not account for protection of terrestrial ecosystems dependent on the relevant aquatic ecosystem.

[40] https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/water-quality-toxicants/local-conditions#bioaccumulation.

Table 5. Ecological water quality guideline values developed by water regulators

Exposure scenario	**PFOS**	**PFOA**	**Exposure scenario**	**Comments and source**
Freshwater	0.00023 µg/L	19 µg/L	99% species protection - high conservation value systems	Australian and New Zealand Guidelines for Fresh and Marine Water Quality - technical draft default guideline values for PFOS and PFOA. Note 1: The 99% species protection level for PFOS is close to the level of detection. Agencies may wish to apply a 'detect' threshold in such circumstances rather than a quantified measurement. Note 2: The draft guidelines do not account for effects which result from the biomagnification of toxicants in air-breathing animals or in animals which prey on aquatic organisms. Note 3: The WQGs advise[41] that the 99% level of protection be used for slightly to moderately disturbed systems. This approach is generally adopted for chemicals that bioaccumulate and biomagnify in wildlife. Regulators may specify or environmental legislation may prescribe the level of species protection required, rather than allowing for case-by-case assessments.
	0.13 µg/L	220 µg/L	95% species protection - slightly to moderately disturbed systems	
	2 µg/L	632 µg/L	90% species protection - highly disturbed systems	
	31 µg/L	1824 µg/L	80% species protection - highly disturbed systems	
Interim marine	0.00023 µg/L	19 µg/L	99% species protection - high conservation value systems	As above. Freshwater values are to be used on an interim basis until final marine guideline values can be set using the nationally-agreed process under the Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Note 1: The WQG advise that in the case of estuaries, the most stringent of freshwater and marine criteria apply, taking account of any available salinity correction. Note 2: Marine guideline values developed by CRC CARE are under consideration through the nationally-agreed water quality guideline development process.
	0.13 µg/L	220 µg/L	95% species protection - slightly to moderately disturbed systems	
	2 µg/L	632 µg/L	90% species protection - highly disturbed systems	
	31 µg/L	1824 µg/L	80% species protection - highly disturbed systems	

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[41] https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/water-quality-toxicants/local-conditions#bioaccumulation.

9 PFAS contaminated site assessment

The complexity of PFAS contamination means that contaminated site assessment will commonly require a site-specific risk assessment to determine the risks associated with land and resource uses (i.e. potential risks to human health, to the environment and to environmental values).

The established national guidance document for the assessment of site contamination in Australia is the ASC NEPM.

The general advice provided in the ASC NEPM and other established guidance may not always account for the specific considerations applying to PFAS assessment, particularly in relation to the protection of ecological values. The following advice is provided as a supplement to support the application of the ASC NEPM and other established guidance, such as jurisdiction-specific guidance, for PFAS management.

Specific considerations for assessment of PFAS contaminated sites, reflecting the unique characteristics of PFAS, include:

- the persistence of PFAS in all environmental media
- the high mobility of most PFAS in water, as well as in some soils and sediments
- the ability of some PFAS to bioaccumulate in humans, plants and animals, and biomagnify with each trophic level of a food chain, in a way that differs from other contaminants such as the lipophilic POPs.

This means that particular attention should be given to the potential risks of PFAS contamination for ecological values, both on and off-site. These potential risks may include risks to terrestrial and aquatic wildlife exposed through the food chain, and risks to aquatic wildlife exposed through the transport of PFAS into aqueous environments.

PFAS include a wide range of compounds with varying physico-chemical properties. PFAS are relatively soluble in water and, although sorbing to some extent to soils and sediment, most of the mass will be transported over time in the aqueous phase via surface drainage to surface water bodies and via leaching to groundwater. Once dispersed in the aqueous phase, PFAS are highly bioavailable to aquatic organisms and plants.

If complete pathways of exposure to PFAS contamination are suspected or known to be present, including via ingestion of contaminated water or produce, then immediate mitigation or management strategies should be implemented to minimise human exposure.

Therefore, if a credible source of PFAS contamination is identified (see Appendix B), it should be assumed that contamination can reach surface water bodies connected to the site by a viable surface water pathway including drains and groundwater. The possibility of long-distance movement of contamination should be considered, noting that in Australia and overseas, groundwater plumes kilometres long have been identified.

When assessing contaminated sites, consideration should be given as soon as practicable to the potential for multiple exposure pathways affecting sensitive receptors in order to develop a robust conceptual site model and implement effective management controls. Early stakeholder engagement, including completion of water use and food surveys by people living and working in the area, is important to provide critical data for identifying complete exposure pathways. This will in turn inform decisions on precautionary measures to limit exposure and implement effective management controls.

9.1 Site investigation process

PFAS may come from a point source, from diffuse sources or a combination of the two. The nature of the potential source(s) is an important consideration for the desktop component of the preliminary site investigation and when developing the conceptual site model/sampling and analysis quality plan.

Consideration should be given to the presence of both primary sources (such as firefighting training areas, landfills or wastewater treatment plants) and secondary sources (such as sediment in surface water bodies in retention ponds and dams at, or connected to, the site) as well as past use including

The scale and longevity of PFAS use, as well as the potential for complex PFAS contamination due to the use of different product formulations (for example, change in firefighting foam usage from an electrochemical fluorination-based AFFF to a fluorotelomer- or fluoropolymer-based AFFF), should be considered.

9.1.1 Identification of off-site receptors

The ASC NEPM guidance allows for both the classic site assessment approach, starting with the on-site source, as well as where the assessment starts with the identification of risks to off-site receptors and moving inward to determine the source.

The classic detailed site investigation approach would be to characterise on-site sources of PFAS followed by delineation of the contamination extent in affected media off-site in a systematic manner. However, this approach may cause significant delays in identifying and evaluating risk to off-site receptors, in informing affected communities and in undertaking actions to mitigate unacceptable risks to sensitive receptors.

Following the identification of a credible source or sources of PFAS, priority should be given to early investigation of risks to sensitive off-site receptors. In practice, this should include targeted sampling of key PFAS migration pathways and receptors to inform a preliminary risk assessment and decision-making regarding precautionary risk management actions. The results of this targeted investigation should be used to inform the subsequent more detailed investigation and risk assessment.

9.2 Risk assessment

The ASC NEPM risk assessment process should be followed, giving due regard to the assumptions and limitations on use applicable to the available screening values as discussed in Section 8. In many cases the conceptual site model is likely to be complex and include multiple exposure pathways and/or land uses which are not considered in the screening values. Consequently, site-specific risk assessment will be required where screening values are not available and/or are not appropriate to the site-specific circumstances.

Considerations for both human health and ecological risk assessment include, but are not limited to:

- nature of the source and potential contribution from precursors to risk (qualitative assessment)
- mass load and flux of PFAS to, within and from the site
- leaching from soil to groundwater and surface water
- adsorption onto, and leaching from, sediments
- groundwater discharge to surface water
- bioaccumulation and biomagnification in the food chain
- wastewater discharge with potential for accumulation in biosolids and discharge in the treated effluent from wastewater treatment facilities
- reuse of biosolids and effluent, including recycled water
- irrigation with impacted surface water, groundwater and/or treated effluent and uptake by plants and possible accumulation in soil.

Considerations for human health risk assessment include, but are not limited to:

- ingestion by livestock of contaminated stockwater (surface water and/or groundwater) and of contaminated grazing material and soil
- human intake of contaminated water through drinking or cooking
- human exposure to contaminated water through activities such as cleaning, showering and swimming
- consumption by humans of foodstuffs (including seafood, meat, eggs, grains, milk, fruit and vegetables) produced in the impacted area.

Considerations for ecological risk assessment include, but are not limited to:

- exposure of terrestrial (including avian) and aquatic organisms to contaminated soil, sediments and/or water
- ingestion by terrestrial (including avian) and aquatic organisms of contaminated plants and/or animals
- types of species and trophic levels.

9.3 PFAS-specific considerations

Broadly, PFAS are produced from two processes: electrochemical fluorination (ECF) and telomerisation.

For example, firefighting foam products produced by ECF were based on PFOS and sulfonamide-based surfactants which are understood to be precursors to perfluorosulfonic acids (PFSA) such as PFOS.

Conversely, products based on fluorotelomers are considered perfluorocarboxylic acid (PFCA) precursors (D'Agostino and Maybury 2014). Thus, sites where only one type of product was used are likely to have one type of dominant precursor, whereas sites were both have been used may have both PFSA and PFCA precursors.

Source characterisation can be assisted when the identity and composition of products that have caused the contamination are known. Some studies have identified the classes of compounds present in various firefighting foam product formulations (e.g. Backe et al 2013; D'Agostino and Maybury 2014; Place and Field 2012). In spill incidents, the products may be available for sampling and characterisation.

Appendix A provides more information about the PFAS family.

9.3.1 Precursors and transformation

The characterisation of pathways and receptors should consider the likely or possible presence of a range of PFAS, including precursors[42]. For example, the sampling and analysis quality plan should investigate whether precursors and their transformation products, if present, have migrated along identified pathways and to receptor sites. If so, the conceptual site model should also incorporate potential transformation products. For example, pathways and receptors affected by a fluorotelomer-based source zone should consider PFCA rather than just fluorotelomers. It is therefore important that environmental assessments qualitatively consider the likely total mass and distribution of all PFAS present as well as PFOS, PFOA and PFHxS and other specific PFAS of concern. A screening approach is useful for investigations, where appropriate analyses are applied to a representative number of samples to indicate whether detailed consideration of precursors is required.

Commercially available analytical techniques based on LC-MS/MS will, depending on the analysis requested, typically identify and measure up to 33 PFAS compounds including the

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[42] See www.nicnas.gov.au for information about PFAS compounds listed on the Australian Inventory of Chemical Substances.

three PFAS of highest concern (PFOS, PFOA, and PFHxS). However, this may only contribute a small proportion of the PFAS present, since compounds such as fluorotelomers and fluoropolymers present in some formulations, and intermediate transformation products, are not within the typical analytical suite (Weiner et al 2013). Tools for screening for the presence of a broader range of PFAS include non-selective analytical techniques (such as TOP Assay and TOF Assay). If precursors are present and further information is required on the specific PFAS (e.g. discriminating between potential sources of PFAS emissions), more advanced analytical options are available such as untargeted high resolution mass spectrometry (e.g. Liquid Chromatography Quadrupole Time-of-Flight Mass Spectrometry (LC-QToF)). This approach is consistent with the ASC NEPM which requires that site conceptualisation and characterisation is undertaken to the extent necessary to reliably inform risk assessment and actions to manage unacceptable risks. These analytical options are discussed in greater detail in Section 19.

As the knowledge base on PFAS transformation and behaviour is evolving, it is advisable to seek expert advice when investigating precursors and transformation products. Fully fluorinated end-point perfluorinated compounds, such as PFOS and PFOA, will not degrade under typical environmental conditions. Polyfluorinated compounds can undergo transformation in the environment, during wastewater treatment processes and during some forms of remediation, for example when using strong oxidants to remediate petroleum hydrocarbons. There is a risk that remediation for hydrocarbon contaminants may inadvertently lead to transformation of PFAS if site assessments do not investigate the presence of PFAS precursors (McGuire et al 2014).

The degradation products of PFAS are often other measurable PFAS that contain a similarly sized (i.e., equivalent length or one to two carbons shorter) perfluorinated group. Due to their potential to form more persistent perfluoroalkyl acids (PFAA), these polyfluorinated compounds are often referred to as PFAA precursors or simply precursors. An example is the transformation of 8:2 and 10:2 fluorotelomer compounds to form the persistent endpoint products PFOA and PFDA. Various PFAS transformation processes that occur in the environment are described in Washington et al (2015).

The biotransformation of precursors can thus contribute to the total concentration of PFAS of concern at a site even if no remedial actions are undertaken. Where PFAS are present in anoxic reducing conditions, such as when PFAS co-occurs with hydrocarbon contaminants in groundwater at firefighting-foam-affected fire-training grounds, this biotransformation process can take decades (Houtz et al 2013).

However, if the source zone is not anoxic, for example where firefighting foam has been spilt or used during equipment testing or has migrated into the wider environment, aerobic conditions are likely to markedly facilitate transformation of precursors. This is also the case if PFAS precursors are discharged to aerobic wastewater treatment plants.

9.3.2 Bioaccumulation

Bioaccumulation is the uptake of a contaminant from food and/or water by an organism resulting in an increase in concentration of the contaminant in that organism. Further relevant information is provided in Section 8 on PFAS environmental guideline values and Section 18 on PFAS sampling.

The high water solubility and protein-binding characteristics of PFAS contrast with the behaviour of many other persistent organic pollutants which accumulate in fatty tissues[43]. Hence, using predictive models based on octanol-water partition coefficients (Kow) to predict PFAS exposure is inappropriate.

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[43] See for example Ng and Hungerbühler (2014).

Furthermore, PFAS bioconcentration factors for aquatic organisms have a high level of uncertainty.

In evaluating risks to human health, it is important that sampling be of edible portions. For example, samples of fish fillets and prawns without heads would be required, preferably from legal size specimens, rather than whole prey organisms used in ecological assessments. Sampling of specific organs (e.g. the liver) may be required for either human health or ecological risk assessment depending on the site-specific issues being investigated.

Modelling uptake based on literature values may be incorporated into a multiple lines of evidence approach. The information should be evaluated, however, to check for the quality of the study and applicability to the site conditions being assessed.

In relation to wildlife exposure to PFAS, there is a lack of available toxicity data relevant to Australian species, hindering quantitative risk assessment. Such information is unlikely to become available in the near future.

9.3.2.1 Bioaccumulative nature of PFAS in aquatic ecosystems

PFAS bioaccumulate in aquatic organisms. In Australia, the advice provided in the NWQMS and WQGs[44] when assessing bioaccumulative contaminants is to use a higher degree of species protection than would normally be used (ANZECC & ARMCANZ 2000; Australian Government 2018; Warne et al 2018).

In most situations, this means the 99% species protection level would be used as a screening value for slightly-to-moderately impacted systems, rather than the 95% value[45]. This advice is intended as a practical measure to provide an additional level of protection to account for bioaccumulation.

In the case of PFOS, the draft ANZECC freshwater guideline value for 99% species protection is 0.23 ng/L (0.00023 µg/L), which is around the trace limit of reporting (LOR) currently offered by commercial laboratories. As such, interpreting and applying this screening value may present challenges in some contexts. A point-in-time water concentration of PFAS below an LOR of 0.001 µg/L should not be assumed to mean that there is minimal risk to aquatic ecosystems and does not mean that there is no need to sample aquatic biota.

The recommended approach is to sample and analyse aquatic biota to account for bioaccumulation and comparison with relevant criteria. Environmental regulators or local catchment managers may be able to provide additional jurisdiction-specific information and guidance.

9.3.2.2 Bioaccumulative nature of PFAS in terrestrial environments

Some PFAS are known to bioaccumulate in terrestrial environments, although the mechanisms and potential for bioaccumulation are not yet well characterised. For the purpose of informing conceptual site models for contaminated sites, consideration should be given to humans and predatory species (birds, mammals, reptiles) that may be exposed to PFAS via the food chain, particularly from meat and eggs that have been exposed to PFAS-contaminated feed, soils or groundwater. Fruit and vegetables may also represent pathways for exposure.

In relation to human exposure to PFAS, direct measurement of PFAS in foodstuffs is advisable for informing the conceptual site model. Timely sampling should be prioritised to obtain produce that is representative of human exposure, as precautionary advice (for example,

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[44] https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/water-quality-toxicants/local-conditions#bioaccumulation.

[45] It is also important to note that the level of additional impact/disturbance permitted in aquatic ecosystems may be set by the environmental regulator and that the use of a value providing a lower level of protection may not be permitted.

ceasing bore water irrigation of vegetables and supply of bore water to stock) may result in a lack of suitable material to sample after the precautionary advice has been issued. This timely sampling should be done in a way that does not exacerbate exposure.

For the development of the conceptual site model, modelling food uptake of contaminants provides an alternative to direct measurement in foodstuffs, but there is limited availability of reliable transfer factors to estimate PFAS uptake from water, soil or vegetation into food products such as meat, eggs and plants. Studies following recognised techniques for evaluating residue levels in produce are a potential source of new information.

9.3.3 Biomagnification

Biomagnification occurs when the concentration of a contaminant is greater in an organism than in the food it eats, reflected in an increase in concentration with each trophic level of a food chain.

PFOS is unusual in that it can biomagnify through mechanisms that are different from the ‘conventional’ or hydrophobic persistent organic pollutants (POPs) that are considered in the ASC NEPM. Conventional POPs biomagnify in a manner such that it is reasonable to assume that larger predatory fish will have higher concentrations than fish lower in the food chain or in most invertebrates.

PFOS has been shown to biomagnify in organisms with lungs (e.g. mammals and birds). Therefore, in aquatic mammals and birds, PFOS concentrations are likely to be more elevated than in their prey, consistent with the other POPs. In organisms with gills (e.g. fish), however, PFOS bioaccumulates but does not appear to biomagnify. Investigations in Australia and elsewhere have confirmed that concentrations of PFOS are highly variable between species and are not necessarily higher in predatory fish than in fish lower in the food chain or in crustaceans such as prawns and crabs. Concentrations in individual species are also highly variable.

As a result, the following issues should be considered when sampling aquatic biota:

- identification of key species for human exposure and ecosystem health
- sampling of a range of biota rather than focusing on ‘sentinel’ predatory species
- sampling of sufficient individuals (for ecosystem health) or combined samples (for human health) to adequately capture representative concentrations in key species
- obtaining samples of edible portions for human health assessment, preferably at animal sizes caught and harvested (e.g. fish - fillet, skin on; prawns - head and shell removed; crab - extracted meat; molluscs - edible flesh)
- recognition that some ethnic communities may target less commonly sought species or less commonly consumed parts, such as the liver or eyes, necessitating a broader suite of sampled organs
- recognition that birdlife, such as wetland waders, may be particularly affected and require appropriate assessment.

10 On-site stockpiling, storage and containment

This section covers the on-site stockpiling, storage, and containment of PFAS-contaminated material[46], at locations that are not intended to be for permanent. storage or disposal. This guidance is designed to assist governments, regulators, developers, industry, and the community when considering on-site containment options for PFAS-contaminated materials. It is not intended to apply to more permanent off-site solutions such as the reuse of PFAS-contaminated material, remediation approaches such as capping, the off-site disposal of PFAS–contaminated wastes in licenced landfill facilities, the destruction of concentrated PFAS wastes, or management of PFAS associated with wastewater treatment plants. It includes detailed guidance on stockpiling, storage and containment during investigation, remediation and construction projects. Additional information is provided in Section 12 on the reuse of PFAS-contaminated materials, in Section 13 on the treatment and destruction of PFAS-containing wastes, and in Section 14 on the disposal of PFAS-contaminated wastes to landfill.

The preferred hierarchy for PFAS treatment and remediation options is discussed in more detail in Section 13. As set out in Section 13, consideration should be given to the following hierarchy of PFAS waste management options:

1. Separation, treatment and destruction. This involves on-site or off-site treatment of the PFAS-contaminated material so that it is destroyed, removed, or the associated risk is reduced to an acceptable level.
2. On-site encapsulation in constructed stockpiles or engineered storage and containment facilities, with or without chemical immobilisation. If the source site is hydrogeologically appropriate, on-site encapsulation may acceptably manage on- and off-site risks to direct and indirect beneficial uses and environmental values of soils, surface water, groundwater, and biota.
3. Off-site removal to a specific landfill cell. This may or may not include immobilisation prior to landfill disposal, noting that the conditions in the landfill may reverse or diminish the immobilisation chemistry in ways that are difficult to predict. Immobilisation prior to landfill disposal may require environmental regulatory approval. Leachate should be captured and treated to remove PFAS and the removed PFAS should be destroyed.

Section 13 also provides information about treatment, remediation, and destruction. The advice set out here in Section 10 regarding design of on-site storage and containment infrastructure does not necessarily apply to remediation approaches such as *in situ* or on-site capping. Additional technical guidance on the on-site containment of PFAS-contaminated soil is available in *Guidelines for the assessment of on-site containment of Contaminated Soil* (ANZECC 1999).

The management of PFAS-contaminated materials often includes on-site stockpiling, storage, and containment. The following types of materials commonly involve large volumes:

- PFAS-containing firefighting foam stocks

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[46] The description in this Section of materials as contaminated is premised on a range of on-site processes such as site investigation, construction, demolition, remediation, care and maintenance, and site management, and assumes that a decision has previously been made to manage these materials due in whole or in part to their PFAS content. This description is not intended to cover soils, sediments, surface water, or groundwater that contain PFAS and remain in situ and undisturbed.

- PFAS-contaminated solid material, such as soil, sludge, sediment, biosolids, timber, asphalt, tarmac, rock, concrete, and rubble
- PFAS-contaminated equipment such as appliances, pumps, pipes, fittings, nozzles, valves, extinguishers, filter material, membranes, and firefighting foam containers
- PFAS-contaminated liquids, including firewater, water generated through flushing, construction water (groundwater, surface water runoff, etc.), leachate, and wastewater.

On-site storage and containment is often required during the investigation, remediation and/or construction phases of a project, or where other treatment or remediation options are not yet available. Storage may be required for PFAS-contaminated material with a PFOS, PFOA, PFHxS and/or related substances content below 50 mg/kg[47]. However, if ongoing containment presents unacceptable risks or unsustainable management requirements, it is generally expected that materials will be removed for treatment, environmentally sound disposal, or destruction.

10.1 Risk-based management

Timeframes and risks are important considerations in planning stockpiling, storage and containment infrastructure. As outlined in Table 6, the design of infrastructure should be proportionate to the level of assessed risk (ANZECC 1999).

Table 6. Stockpiling, storage and containment infrastructure

Description	Timeframe	Storage infrastructure for solid wastes and contaminated equipment	Storage infrastructure for liquid wastes
Transient	Less than 48 hours with no rain predicted	Covered stockpile or storage area on impervious bottom liner (e.g. tarp, plastic sheeting, membrane, etc.)	Packaged liquid containers or self-bunded containment vessels on impervious bottom liner (e.g. tarp, plastic sheeting, membrane, etc.)
Temporary	From 48 hours to 6 months	Managed stockpile, covered, on impervious, bunded hardstand, with effective stormwater controls (e.g. diversion drains, banks, etc.)	Self-bunded containment vessels covered, with lockable access, on impervious, bunded hardstand, with effective stormwater controls (e.g. diversion drains, banks, etc.)
Short-term	From 6 months to 2 years	Constructed stockpile with robust anchored covers, impervious bottom liner, and effective stormwater controls to ensure that rainwater and	Packaged, double-walled containment vessels or self-bunded containment vessels, covered, with lockable access, on impervious

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[47] See Section 14.6 for further information about the management of waste material with a more than 50 mg/kg of PFOS, PFOA, PFHxS, and/or related substances. Consistent with agreed international approaches, if waste material contains a more than 50 mg/kg of these substances, it must be treated using a technique that will destroy or irreversibly transform the PFAS. Destruction is the preferred option. For example, techniques such as plasma arc or high temperature incineration (above 1100°C) are already agreed technologies for destruction. In circumstances where destruction or irreversible transformation may not be environmentally preferable options due to environmental or human health impacts, the relevant environmental regulator should be consulted.

		sheet flow do not contact impacted solids	constructed storage area with effective stormwater controls to ensure that rainwater and sheet flow do not contact contaminated liquids
Medium-term	From 2 to 5 years	Engineered containment facility, with effective stormwater controls	Packaged, double-walled containment vessels or self-bunded containment vessels, resistant to UV degradation, in engineered containment facility, with effective stormwater controls
Long-term	More than 5 years	Engineered containment facility, with effective stormwater controls	Packaged, double-walled containment vessels or self-bunded containment vessels, resistant to UV degradation, in engineered containment facility, with effective stormwater controls
Notes: PFAS-contaminated equipment should be stored under cover on a sturdy impermeable, bunded surface that captures any seepage from equipment and any contaminated stormwater. Equipment, when demonstrated by monitoring to be clean following flushing or rinsing, is not subject to the requirement). PFAS-contaminated liquids should be stored undercover within a secondary containment system so that any leakage due to spills, ruptures, crushing, or mishandling is effectively contained, preventing any release to soil, groundwater, or surface waters. A “first flush” stormwater management system should not be used in conjunction with PFAS storage infrastructure. For further guidance, see Sections 10.2.2, 10.2.3, and 10.3.2.			

Importantly, regulators may have specific regulatory requirements which should be considered in conjunction with this guidance. For example, there may be a requirement to have an environment protection licence or similar environmental approval, and this could include conditions on how stockpiles are stored. Similarly, regulators may require that stockpiles comply with particular height, slope, quantity, duration, and/or location requirements. There may also be requirements to immediately notify the environmental regulator if a loss of containment is detected.

10.1.1 Considerations for specific circumstances

Where the volume of material is minimal (for example, less than 10m^3 taken together or in aggregate), the proposed storage is transient (less than 48 hours) and rain is not predicted, then a practical approach to managing the material may be considered. This reflects the key design criterion of reducing or eliminating pathways for migration of PFAS contamination. For minimal volumes in transient stockpiles, particularly when rain is not predicted, implementation of the full range of recommended design criteria and engineering requirements may not be required.

In some circumstances, PFAS-contaminated materials may be treated using chemical binding and immobilisation processes, as part of on-site encapsulation within engineered containment facilities. There is limited information on the long-term effectiveness of these immobilisation techniques. If the site is hydrogeologically appropriate, the PFAS contamination is below 50 mg/kg, the facility is appropriately designed and engineered, and ongoing monitoring is guaranteed, chemical immobilisation and on-site containment may be acceptable. The full range of on- and off-site risks to soils, surface water, groundwater, and to direct and indirect receptors, and the potential for effective intervention in the event of a future loss of containment, should be considered in determining acceptability. The relevant regulators should be consulted and a site-specific risk assessment may be required. See Section 13 for more information on treatment and remediation, and Appendix C for more information on treatment technologies.

10.2 Design considerations

10.2.1 PFAS characteristics

The following guidance takes into account that there are a wide range of PFAS chemicals with varying chemical compositions, physical properties, and molecular chain length. The presence of PFAS precursor chemicals and PFAS breakdown derivatives adds to this complexity. Consequently, PFASs exhibit differing characteristics and behaviours in different environmental settings. These considerations, which are discussed in more detail in Section 9 and Appendix A, are a critical input to effective on-site management. For example, PFAS are capable of long-range transport through the environment, particularly in surface and groundwater, and can migrate through soil and soil-based construction materials. Infiltration through some liners, such as clay and geosynthetic liners, is expected to occur at a significantly slower rate than for other media.

In addition, some PFASs such as fluorotelomer alcohols and ketones are volatile. For these, air emissions need to be considered, noting that the options for air sampling of PFAS are not routine. Management options to reduce volatilization or capture fugitive emissions may need to be considered.

10.2.2 Essential functional requirements

Stockpiling, storage, and containment facilities should be designed to ensure they do not spread PFAS contamination or create any pathways for environmental or human health exposure. The development of a sound conceptual site model (CSM) can help to identify the functional requirements for the site and thereby inform the design process. Specific infrastructure and design requirements should be proportionate to the level of risk that is posed by the PFAS-contaminated materials being stored or contained. The goal is to provide a robust interim storage solution that meets these requirements until a more effective treatment or disposal solution becomes available. Accordingly, facilities for the stockpiling, storage and containment of PFAS-contaminated material should be designed with a whole-of-life approach to construction, operation and decommissioning to meet the following essential functional requirements:

- avoid or minimise to the greatest practicable extent infiltration into the PFAS-contaminated materials by precipitation, surface water, and/or groundwater
- detect, monitor, and collect any PFAS-contaminated liquid (leachate) generated during storage, to be extracted from the sumps for separate treatment or destruction
- ensure that the migration of leachate from sumps and other collection systems does not occur
- prevent seepage of leachate into groundwater or surface water
- avoid the release of PFAS-contaminated sediment as a result of erosion

- avoid the release of PFASs to the atmosphere[48]
- mitigate dust generation
- enable future recovery of stored materials
- account for local climatic, fire, flood, geotechnical, and groundwater conditions applicable to the site, property, area and region

See also Section 10.3.11 for guidance on design safety and verification.

10.2.3 Additional operational requirements

In designing a storage or containment facility for PFAS-contaminated material, consideration should be given to the following operational requirements:

- making use, where appropriate, of suitable on-site materials
- access, loading/unloading, and inspection
- segregated storage above and/or below ground of different material types and materials with different concentrations and, where relevant, types of PFAS contamination (e.g., solids, liquids, firefighting foam concentrates, firewater, groundwater, soils, organic material, asphalt, tarmac, concrete, steel, timber, etc.)[49]
- progressive or staged filling, capping, and/or extraction, if required
- monitoring, testing, and verification.

Although not comprehensive, the following operational considerations apply to stockpiling, storage and containment of PFAS-contaminated materials and should be taken into account in the design process:

- materials should be stored or stockpiled, handled and transferred in a proper and efficient manner so as to minimise the likelihood of any leakage, spillage, or release to stormwater, surface water, groundwater, land, or air
- unloading, loading and any internal transfer of liquids should be undertaken in a manner that minimises the possibility of spillage and occur on an area that is impervious to liquid, and sufficiently graded and bunded to retain any spillage or leakage
- unloading of solids should be carried out in a manner that minimises the creation of dust, and minimises or prevents emissions by any other manner
- smaller containers (e.g. not exceeding 15 litres) should be stored within a secondary containment vessel / container
- larger packages, bulk containers, and tanks must be stored in a bunded area at a sufficient distance from bund walls, unless splash shields or baffles of compatible, non-combustible materials, effective to prevent leakage or spillage, are installed that prevent any release beyond the bund wall
- packages and bulk containers should be stored in a bunded area and handled so that they cannot fall or crush lower containers and cause spillage outside of the containment

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[48] Depending on the specific PFAS present, this may require measures to capture and manage potential emissions of PFAS to air. Misting, steaming, evaporative, and other similar processes should also be avoided as PFAS is likely to be transferred via the water vapour into the atmosphere, unless the PFAS content is removed prior to emission.

[49] The type of PFAS present may be a consideration, e.g. for future remediation and treatment. Liquids should generally be stored above ground in appropriate containment vessels / containers and in an appropriately bunded and covered area.

- storage and stockpiles should be placed on an impervious base or hardstand, sufficiently graded, bunded, and drained to retain any spills or leaks and prevent infiltration
- wherever practicable, roofing or other impervious cover should be placed over bunded areas, noting that tarpaulins may be appropriate for smaller transient stockpiles.

In addition, the following also apply to containment of PFAS-contaminated materials:

- stormwater management systems such as first flush systems should not be relied upon for containment
- storage and containment systems should be impervious to the materials stored, resistant to fire, and managed and maintained to prevent any release of liquids and leachate to sewer, stormwater drains, waters, and land
- if co-located with flammable materials, allowance must be made in the design to contain fire-fighting water
- leachate management systems should be incorporated into the design of new facilities and existing containment facilities may also require review and/or upgrading, depending on the risks involved
- leachate that is extracted from the collection system should be sampled for laboratory analysis prior to treatment or disposal.

10.3 Detailed guidance on design, construction and management of on-site stockpiling, storage and containment

This detailed guidance applies to the design and construction of transient and temporary stockpiling and short- and medium-term storage of PFAS-contaminated material on-site during a range of on-site processes, including site investigation, construction, demolition, remediation, care and maintenance, and site management projects.

This guidance also applies to the design and construction of medium- to long-term containment of PFAS-contaminated materials on-site, where no other options exist for management. Containment may include immobilising, capping or covering, or may require more significantly engineered containment facilities. In the medium to long-term, particularly where ongoing storage or containment presents unacceptable risks, contained material should be removed for environmentally sound management or destruction.

The selection of suitable on-site storage and containment facilities should be considered as early as possible in the project planning process. It should consider the potential for PFAS to be released into the surrounding environment and the control measures required to prevent such a release. The assessment may be simple and straightforward, where risks are low; and more detailed where there is a significant risk of PFAS release to the environment. Effective control measures should be implemented and monitored to ensure their ongoing effectiveness.

The design of storage, stockpile, and containment facilities should include consideration of:

- the estimated mass, volume, and characteristics, including its leachability, of PFAS contamination (and co-contamination, if it exists) in the material to be stored
- the type of PFAS-contaminated materials to be stored at the site.

10.3.1 Key design criteria

The key design criterion is to reduce or limit the pathways for migration of PFAS contamination during and after the life of the project. This may require consolidating contaminated materials in an engineered or otherwise designed facility. Where co-contamination by other hazardous, non-PFAS contaminants is known in advance, considered likely, or discovered, the design of the facility should consider the risks of each contaminant.

As PFAS are soluble in water, migration of PFAS contamination via infiltration, seepage, leakage, and advection should be minimised. Engineered facilities for storage, stockpiling, and containment of PFAS-contaminated material should be designed to:

- limit the ingress of rainfall, runoff, groundwater and surface water into the facility
- collect PFAS-contaminated leachate generated throughout the life of the facility, including construction.

To achieve the above, the following minimum design requirements should be considered:

- access, loading / unloading, inspection / monitoring, drainage and leachate capture, and stormwater management systems
- composite cap liner or equivalent to reduce infiltration into the facility
- composite side liner(s) to reduce infiltration into and out of the facility
- composite base liner or equivalent to maximise the collection of leachate (to reduce the potential for seepage from the facility), and to allow monitoring and measurement of leachate
- leak detection, drainage systems, sumps and other detention storages.

10.3.2 Stockpiling and storage

As outlined earlier in this section, stockpiling and storage infrastructure should be planned and implemented in accordance with a risk-based approach designed to:

- minimise the potential for the storage facility or the stockpile to release PFAS into the environment
- addressing operational requirements for differing durations of storage.

PFAS-contaminated materials, particularly liquids, should be stored above ground in appropriately bunded storage areas or in containment vessels such as covered intermediate bulk containers (IBCs) and isotainers in bunded areas. The bunds or bunded tanks must be of low permeability and of a sufficient size to retain a major spill, including capacity for stormwater runoff[50]. The essential criterion is to ensure all PFAS remains completely contained.

Storage and stockpiling of PFAS-contaminated materials, including liquids, should be undertaken in such a way that PFAS cannot migrate into the surrounding soil or water and all runoff should be monitored for PFAS. This can often mean storage or stockpiling within a sealed and bunded area, where the material is in a suitable container or appropriately covered to minimise rainfall penetration and prevent runoff.

Along with ongoing monitoring, the condition of storage containers, stockpiles, covers and liners, on-site drainage systems, and the bunded area need to be monitored. Cracks or leaks in materials such as concrete may be difficult to detect and the integrity of bunding should never be assumed. If leaks are detected, further monitoring, assessment and action should be taken.

10.3.3 Containment

Key considerations for on-site containment include:

- the physical characteristics of the site

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[50] Unless otherwise required by the relevant regulators, the capacity of the containment bunding should be at least 100% of the planned storage capacity plus 25% of the storage capacity up to 10 000 L, together with 10% of the storage capacity between 10 000 L and 100 000 L, and 5% above 100 000 L.

- the site assessment outcomes
- the type of material that needs to be contained
- the duration of storage
- the PFAS chemicals present in the material
- their concentration, mass, volume, leachability, and distribution
- ongoing storage requirements
- the relevant approvals required by regulators.

A comprehensive on-site environmental management plan must provide for ongoing monitoring and management, including quality control and an auditable monitoring and management plan.

The volume of contaminated material at major sites may be very large, and this has implications for the options that are reasonable, practicable, or feasible.

On-site containment is subject to approval by regulators and is only an option when:

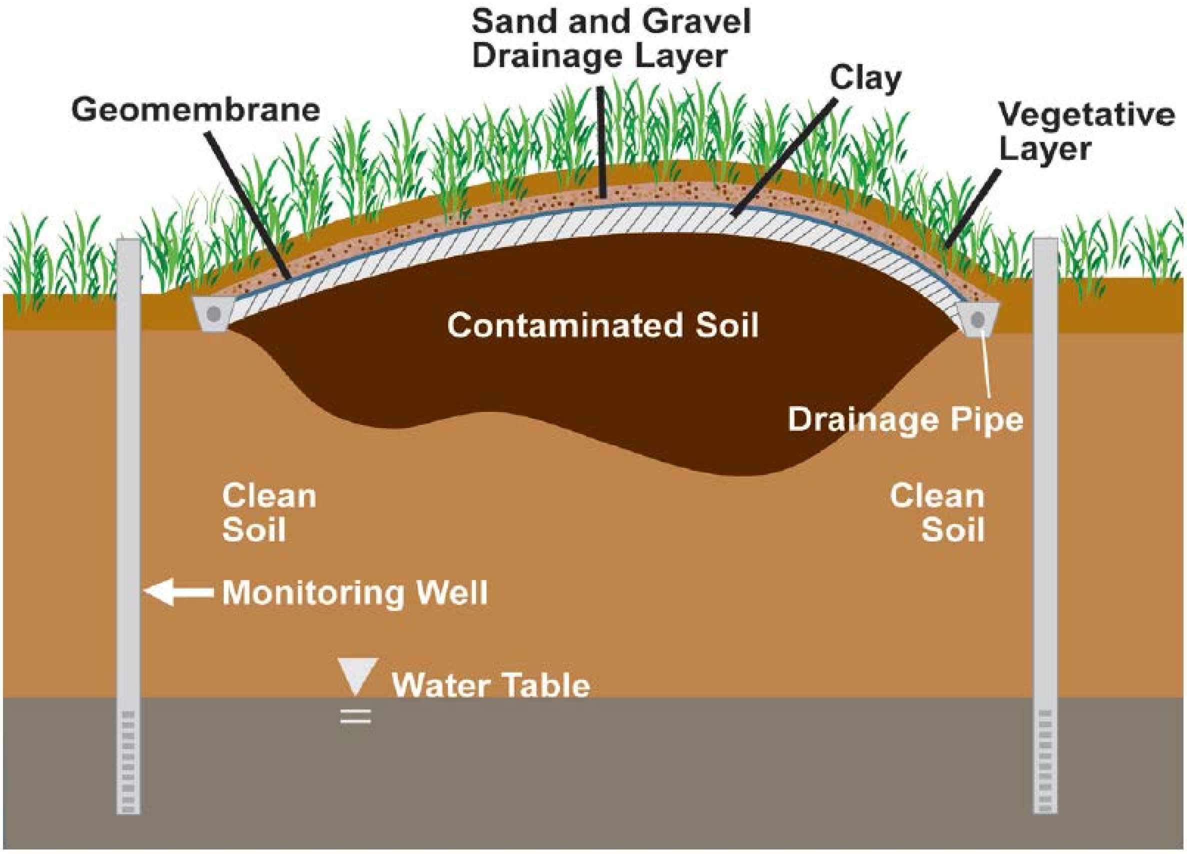
- the source site is hydrogeologically appropriate (with consideration of depth to water table and aquifer characteristics)
- it is possible to manage risks to on- and off-site beneficial uses (direct and indirect) and environmental values for soils, surface water, groundwater and biota
- there is capacity at the site for the proposed storage and any ancillary requirements
- the required environment and planning approvals have been obtained
- appropriate setback distances or buffer zones are available.

Methods for on-site containment may include, but are not limited to:

- engineered stockpiles for the containment of PFAS-contaminated material (e.g. soil, concrete, asphalt)
- capping and covering to minimise the movement of PFAS off-site
- engineered containment facilities, with appropriate lining and cap or other barrier.

Capping and containment is a common technique in the remediation of contaminated sites. If properly engineered and maintained, capping can significantly reduce the infiltration of rainwater and can help protect local groundwater. Depending on site conditions, capping may be an effective remediation option for low levels of PFAS contamination in large quantities of soil and other solid materials.

Figure 4. Example of a cap cover



Example of a cover with several layers.

Source: USEPA (2012)

Engineered containment cells can be an appropriate long-term remediation option for mobile or reactive contaminants where off-site disposal or destruction are not viable. A containment cell may be appropriate where the contamination is of higher concentrations, more mobile, or less contained. The prevention of rainwater infiltration and groundwater through-flow are important management considerations and are discussed in more detail below.

When material is contained on-site, stormwater should be diverted away from the containment facility and its cap, and a leachate and stormwater runoff system should be implemented. Cap and cover systems should be designed and maintained to prevent intrusion by plant roots and animals into the PFAS-contaminated material. Leachate and contaminated stormwater should be captured, analysed for PFAS, and if necessary, treated, removed and destroyed. However, if conditions are suitable for capping, then a robust and well-maintained impervious cover and suitable monitoring regime may be sufficient, making leachate management a less significant consideration.

10.3.4 Siting and location

The following considerations are relevant for selection of storage or stockpile sites, noting that a risk assessment undertaken by an appropriately qualified person may be required if potential exposure pathways to sensitive receptors are present:

- topography, geology and hydrogeology
- proximity to potential exposure pathways such as constructed drains, service trenches, natural rivers and streams, standing water bodies, groundwater, and paleochannels
- proximity to sensitive receptors, such as key flora, fauna, and ecological communities
- matters of national environmental significance and those protected by state and territory legislation
- risks from extreme weather events and flooding
- risks from seismic events, bushfires, etc.
- climatic, rainfall, and flood modelling to assess performance over the design life of the facility
- existing contamination (including baseline levels of contaminants within or near the storage pad footprint)
- infrastructure
- ownership of the land
- stakeholder interests and concerns
- local and state or territory regulations and controlling requirements.

Sites likely to include exposure pathways to potentially sensitive receptors would normally be considered unacceptable for storage or stockpiling of PFAS-contaminated material, based on risks to the environment and/or human health. See ANZECC (1999) and Section 12.3 of the NEMP for further information [51].

10.3.5 Rainfall, stormwater, groundwater, flood, and environmental management

Risks associated with environmental variability, including weather events and natural disasters, should be carefully considered. The facility should not be located within floodplains with less than a 1:100 year Annual Exceedance Probability (that is, < 0.01 AEP). Where this cannot be avoided due to site or operational constraints, or a lack of off-site alternatives, relevant regulators should be consulted and a site-specific risk assessment may be required. Careful consideration should also be given to local rainfall intensity-frequency-duration information, including estimates of Probable Maximum Precipitation [52] for the site. A detailed

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[51] Environmental regulators may consider sites such as those listed in section 12.3 on a case by case basis, based on an appropriate site-specific risk assessment and with consideration of applicable legislative requirements. Additional management and institutional controls, including monitoring, are likely to be required to ensure protection of the environment and human health. Contact with the environmental regulator must therefore be made before any proposal is made for storage, stockpiling, or containment facilities at the types of sites listed in section 12.3.

[52] http://www.bom.gov.au/water/designRainfalls/index.shtml#pmp.

risk assessment by a suitably qualified and experienced person should be conducted to ensure that safety, the integrity of the facility, and any environmental risks are comprehensively considered and mitigated[53].

10.3.6 Specific requirements for design and construction of containment infrastructure

Importantly, regulators may have specific regulatory requirements which must be considered in designing and constructing medium- to long-term containment facilities. Containment facilities should be designed in such a way that the PFAS-contaminated material is isolated from the surrounding environment by providing appropriate barrier systems. Depending on the type, mass and volume of PFAS-contaminated material, and considering the length of time storage will be required and the conditions likely to be encountered, the barrier system may include controls such as a primary (upper) and secondary (lower) composite liner, a primary leachate collection system and a secondary leachate detection and collection system.

Should a containment facility be required, it should be built in accordance with appropriate regulatory approvals, design specifications and construction quality assurance planning. The approved plan provides a means of demonstrating to the regulatory authority and the public that the construction of the facility meets design requirements. Existing containment facilities may also require review and/or upgrading, depending on the risks involved.

Once the containment facility is filled with PFAS-contaminated material, it must be capped and rehabilitated. The following guidance applies to caps provided at the end of the operational life of the containment facility, and should be read in conjunction with the guidance below on caps liners provided during the operational life of the facility prior to its closure.

A visual marker layer between the contaminated material and the cap should be used to delineate the material from the cap. The cap should be compatible with the liner system, provide an appropriate barrier to restrict water infiltration and provide separation between the PFAS-contaminated material and the surface. Following construction of the cap, the containment facility must be rehabilitated with an appropriate vegetative cover sufficient to maintain the integrity of the cap. A closure plan should be considered to monitor and maintain the ongoing effectiveness of the facility in containing the PFAS-contaminated materials.

10.3.7 Caps and cap liners

The following guidance applies to caps provided during the operational life of the containment facility, and should be read in conjunction with the guidance above in Section 10.4.3 on end-of-life caps.

Storage, stockpile, and containment facilities should always be designed to limit infiltration into the PFAS-contaminated materials. Consequently, consideration should be given to cap and cap liner requirements during the operational life of the facility. This includes provision of temporary covers (that can be placed and removed on a daily basis) and thicker, less permeable interim caps if the facility is to remain open for longer periods.

If required, a cap liner or equivalent should meet the following minimum criteria:

- inclusion of a composite cap lining system designed to limit infiltration
- provision for protection from damage related to construction activities and vandalism
- inclusion of liner design considerations and a liner integrity survey to minimise the risk of installation defects in the completed liner system

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[53] For example, the design should demonstrate that the PFAS-contaminated materials are protected from inundation and/or damage associated with an appropriate flood level for the designated site, its rainfall duration-intensity, and that a suitable height buffer between the facility’s stored materials and local groundwater levels will have been achieved. Regulators may require a commitment to the cleanup of any PFAS-contaminated material dispersed by a flood less than 0.01 AEP during the operating life of the storage infrastructure, and/or appropriate financial assurance.

- joining of the base liner to form a complete barrier system around the PFAS-impacted materials
- promotion of runoff and inclusion of a surface water management system to limit the head of water on the cap lining system
- inclusion of measures to minimise permanent wrinkles within the geosynthetic layers.

Cap liner criteria may also apply to any side liner design.

10.3.8 Base liner

Facility design should limit seepage of leachate to the groundwater and surface water, and the infiltration of groundwater into the facility. In order to limit seepage through the base liner, the design should meet the following minimum criteria:

- inclusion of a composite base lining system designed to limit the medium to long term seepage rate through the baseliner
- consideration of the suitability and stability of the sub-base
- provision for protection from damage related to construction and filling activities
- inclusion of liner design considerations and a liner integrity survey to minimise the risk of installation defects in the completed liner system
- grading and drainage towards a sump to limit the hydraulic head of leachate on the lining system and inclusion of a leachate collection layer to convey leachate to a sump
- consideration of the potential for interaction with groundwater in a manner that may compromise the performance of the liner
- inclusion of measures to minimise permanent wrinkles within the geosynthetic layers.

Base liner considerations should also apply to any side liner design.

10.3.9 Sump and leachate collection

The base liner is required to include a sump with an extraction system in which the seepage rate can be periodically measured and any leachate extracted. Consideration should be given to inclusion of a leak detection system. The leak detection system is intended to provide a second line of protection against the potential migration into the environment. The leak detection system should be installed where leachate may be periodically retained, before being pumped out. Leachate should not be discharged directly to sewerage or the environment.

The sump is a critical component of the facility and should be designed for the temporary retention of leachate between stages of leachate extraction. The sump is intended to collect leachate and the design levels and volume of leachate within the sump should be kept to the minimum amount practical during and following the filling of the engineered facility. Leachate should be pumped out to an enclosed tank. Potential transmission to other environmental media (for example, to air from aerosols or volatile PFASs, or into food webs via bioaccumulation through birds foraging in the pond) is considered a risk and should be avoided. Similarly, on-site evaporation processes are not generally supported as they may lead to the transfer of volatile PFASs to the atmosphere. Non-volatile PFASs may also be transferred into the atmosphere via water vapour, mist, steam, or similar processes.

The sump construction should allow for accurate leachate volume detection and an appropriate response procedure for when the maximum specified design storage depth of in the sump is reached. Monitoring should include, amongst other things, data measured at the bottom of the leak collection layer below the sump as well as in the sump itself.

The depth of stored leachate in the sump should be minimised, its depth monitored, and the subject of appropriate controls. The minimum thickness of the sump enclosure should be designed to limit the diffusion rate of PFAS through the sump system.

Any on-site leachate containment and/or treatment activities (such as the use of leachate ponds, passive or active evaporation, filtration, aeration, ozonation, recirculation, etc.) require careful consideration by environmental regulators to ensure potential emissions to the environment are avoided and any subsequent exposures are effectively minimised. The chemical characteristics of PFASs suggest a robust precautionary approach by regulators.

10.3.10 Side liner

Facility design should limit seepage through the side walls of the storage, stockpile or containment facility. Side liner design should consider the following minimum criteria:

- inclusion of a composite side lining system designed to limit seepage through the side walls of the facility
- consideration of the suitability and stability of the sub-base
- provision of protection from damage related to construction activities and vandalism
- inclusion of liner design considerations and a liner integrity survey to minimise the risk of installation defects in the completed liner system
- above and below ground requirements, including slope and batter; rigid, flexible, piled, and/or modular side wall construction
- grading and drainage to promote runoff and limit hydraulic head, hydrostatic pressure, etc.
- consideration of the potential for interaction with groundwater in a manner that may compromise the performance of the liner.

10.3.11 Maintenance and management planning

An environmental management, maintenance, and operating plan should be prepared and implemented to manage the containment and stockpiling facility. The plan should cover all aspects of maintenance and operation over the life of the facility, including after closure and during decommissioning.

The environmental management, maintenance and operating plan should include information on, amongst other things:

- key management roles, responsibilities, and stakeholders
- stocks and flows of stockpile volume and material types, including details of material types; PFAS concentrations, masses, and volumes; source locations; hazardous waste transport tickets; and any other relevant information.
- periodic monitoring, sampling, inspection, and maintenance, including triggers and contingency “actions on” the identification of an issue
- specified thresholds and actions to be taken if liquid or PFAS contamination are detected by the leak detection system above these specified thresholds
- protocols and procedures for monitoring the effectiveness of the containment
- environmental monitoring
- reporting of monitoring and inspection records (see Appendix E for examples of simple stockpile inspection checklists)
- facility performance review

- relevant documentation, such as construction records, inventories, safety data sheets (SDSs), supplier manuals for major components and maintenance of equipment
- commissioning, handover-takeover, and decommissioning processes.

The plan should also address stormwater management, indicating projected stormwater flows for the area at, and around, the containment facility. The objective of the stormwater management is to avoid contamination of stormwater flows and to contain and manage any contaminated stormwater. This must include provision for leachate and contaminated stormwater to be captured, analysed for PFAS, and appropriately managed.

The integrity of the containment facility must be maintained at all times. This means the leachate collection and management system should be kept in good condition with a regular inspection and maintenance program in place to monitor the integrity of the cap of the containment facility.

Ongoing monitoring of the site will also need to be undertaken to ensure risks to receptors are minimised, and there are no unacceptable off-site impacts. Where a containment facility is expected to be maintained over the long term, the potential for ongoing leaching from the contained materials must be considered because the long-term mass of PFAS to a receiving environment may represent a significant risk, even if point-in-time PFAS concentrations in leachate are low.

Some jurisdictions may require additional regulatory approvals and controls including, listing of waste containment facilities on contaminated land registers and/or land titles and regulatory approval/permits/controls for activities such as construction, ongoing management, and monitoring.

10.3.12 Design safety and verification

The design of storage, stockpile, and containment facilities should consider relevant hazards and associated risks. The following design issues should be considered during design or construction verification processes:

- human health, public health, and worker safety
- environment
- construction
- operations and maintenance, including the potential for leachate extraction and longer term decontamination/remediation
- durability
- monitoring systems, including leak detection for emissions to air, soils, groundwater surface water and, where relevant, stormwater and sewerage systems

Design, procurement, construction, installation, commissioning, operation (including monitoring), and decommissioning of the facility should satisfy all Work Health and Safety and environmental considerations in accordance with relevant Commonwealth, national, state/territory and local requirements.

Technical documentation, such as design specifications, construction drawings, design reports, site investigations, impact assessments, site-specific risk assessments, environmental management plans (EMPs), PFAS Management Plans (PMPs), verification documentation, and QA/QC documents should be developed and endorsed by relevant key stakeholders prior to construction commencing. Examples of simple stockpile inspection checklists are provided at Appendix E.

11 Transport of PFAS-contaminated material

The transport of PFAS-contaminated material should be planned with regard to the characteristics, environmental risks and destination of the material in consultation with the environmental regulator, except where the environmental regulator has issued standing guidance to cover transport arrangements.

11.1 Waste code for PFAS contaminated materials

The transport and tracking of waste PFAS contaminated materials (including PFAS-containing products that are waste) within and between jurisdictions are best managed with a single waste code. This provides clarity when regulating transport, tracking, treatment and disposal of this material.

Until the National Environment Protection (Movement of Controlled Waste between States and Territories) Measure 1998 (Movement of Controlled Waste NEPM) is reviewed, environmental regulators will adopt the following PFAS-specific waste code within their legislative frameworks based on the following:

> **Category**: Organic chemical (M)
>
> **Description**: Per- and poly-fluoroalkyl substances (PFAS) contaminated materials, including waste PFAS-containing products and contaminated containers
>
> **Waste** Code: M270

The associated waste descriptions must include a reference to the PFAS present, sufficient to accurately reflect the nature of the waste. Where multiple waste codes apply, the waste must be reported using the description ‘Per- and poly-fluoroalkyl substances (PFAS) contaminated materials, including PFAS-containing waste products and contaminated containers.

PFAS-contaminated materials, including waste PFAS-containing products, are considered to be Dangerous Goods Class 9.

11.2 Considerations for transport

PFAS-contaminated materials must be transported in accordance with the requirements of the environmental regulator. Decisions regarding authorisations for the transport of PFAS-contaminated materials, including interstate transport, must consider whether the receiving facility can lawfully receive these materials in relation to all the physical and chemical characteristics. These must only be delivered to facilities that are licenced to receive the material having considered all of its characteristics.

Interstate transport must only occur with approval from the required environmental regulator(s).

Facilities approved by the environmental regulator to receive PFAS-contaminated materials should explicitly state this in the approval documentation.

As required for the movement of contaminated materials, decontamination of vehicles and transport containers is important to eliminate contamination of subsequent loads. Containers must be managed as PFAS-contaminated materials until they have been appropriately cleaned.

12 Reuse of PFAS-contaminated materials including soils and water

Materials containing low levels of PFAS may be considered by environmental regulators for reuse under some circumstances, particularly for the purpose of resource recovery in accordance with the waste hierarchy. However, this must be discussed with the regulator as some may not approve reuse. If reuse is acceptable, many environmental regulators will require that an approval be granted.

Assessment of reuse options for PFAS-contaminated materials will be based on the principles that reuse must not lead to an unacceptable risk to human health and/or the environment, or an increase in the level of risk at or near the location in which it is used. It is important to consider that PFAS can travel long distances from the site, potentially affecting remote receptors. Dilution of PFAS contamination is not an acceptable waste management strategy to create material suitable for reuse. These principles apply to all PFAS-contaminated materials irrespective of source location and can include extracted material, virgin or otherwise.

In the NEMP, the term ‘reuse’ is intended to apply to situations involving the permanent or long-term placement of materials for a beneficial purpose in compliance with environmental legislation. This does not include short to medium-term storage or stockpiling of PFAS-contaminated materials which is covered in Section 10.

Environmental regulators may require that the reuse of PFAS-contaminated materials be informed by a site-specific risk assessment to ensure that the placement of PFAS-contaminated materials will not increase the risk at the destination site or lead to an unacceptable risk to the environment and/or human health. Multiple lines of evidence should be considered to support a decision on reuse.

12.1 Reuse of soil

Reuse of PFAS-contaminated soils remains subject to state and territory oversight and the guidance provided here, including the decision tree in Figure 5, does not override applicable regulations or national frameworks. The application of this guidance should therefore be done in consultation with the relevant regulatory authority [54].

The decision tree is intended to be applied only to soil, and should not be used to inform the use of other materials such as solid organic wastes, biosolids or other resource recovery materials. However, if the soils proposed for reuse have become PFAS-contaminated due to incorporation of these materials into the soil, the decision tree is applicable to those soils. Note also, that the decision tree does not address reuse of PFAS-contaminated soil in agriculture, which can entail higher risks that require specific assessment. The decision tree is focused on beneficial soil reuse and does not address operations that are essentially landfilling operations.

12.1.1 Considerations for reuse without a detailed risk assessment

A principle that must inform consideration of reuse of soil is that the levels of PFAS must be sufficiently low that they will not pose an increased or unacceptable risk to any receptor or to the environmental values of waters. Thus, to be suitable for reuse, soil must meet the criteria for both total concentration and leachable concentration. The resulting PFAS concentrations at the reuse site should be sufficiently low to be protective of terrestrial flora and fauna and human health.

A second principle is the application of the waste hierarchy whereby reuse of low level PFAS-contaminated soil off-site only occurs after all options for on-site use, waste avoidance,

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[54] The decision tree for reuse of soil may not be applicable in New Zealand.

waste treatment and volume reduction have been considered and implemented wherever reasonable and practicable.

Leachate criteria should be protective of groundwater and surface water quality and aquatic ecosystems both at the site of reuse and anywhere there is a reasonable possibility that transported PFAS from that site may impact sensitive receptors and environmental values, noting that PFAS can be transported many tens of kilometres from the originating site.

Adding soil with low levels of PFAS to areas that have even lower or no levels of PFAS should be considered only in consultation with the relevant regulatory authority in exceptional circumstances where there is no feasible, practicable alternative. Where reuse is proposed for areas with higher levels of PFAS, then the decision tree may permit reuse without a detailed assessment of risk. However, users of the decision tree should consult the relevant regulatory authority to maximise confidence in application of the decision tree under such circumstances.

For large sites where soil excavation and reuse may be a recurring issue, the decision tree may be a useful tool to support development of overarching PFAS management strategies for the site, such as PFAS Management Plans (PMPs), through consultation with all relevant regulators.

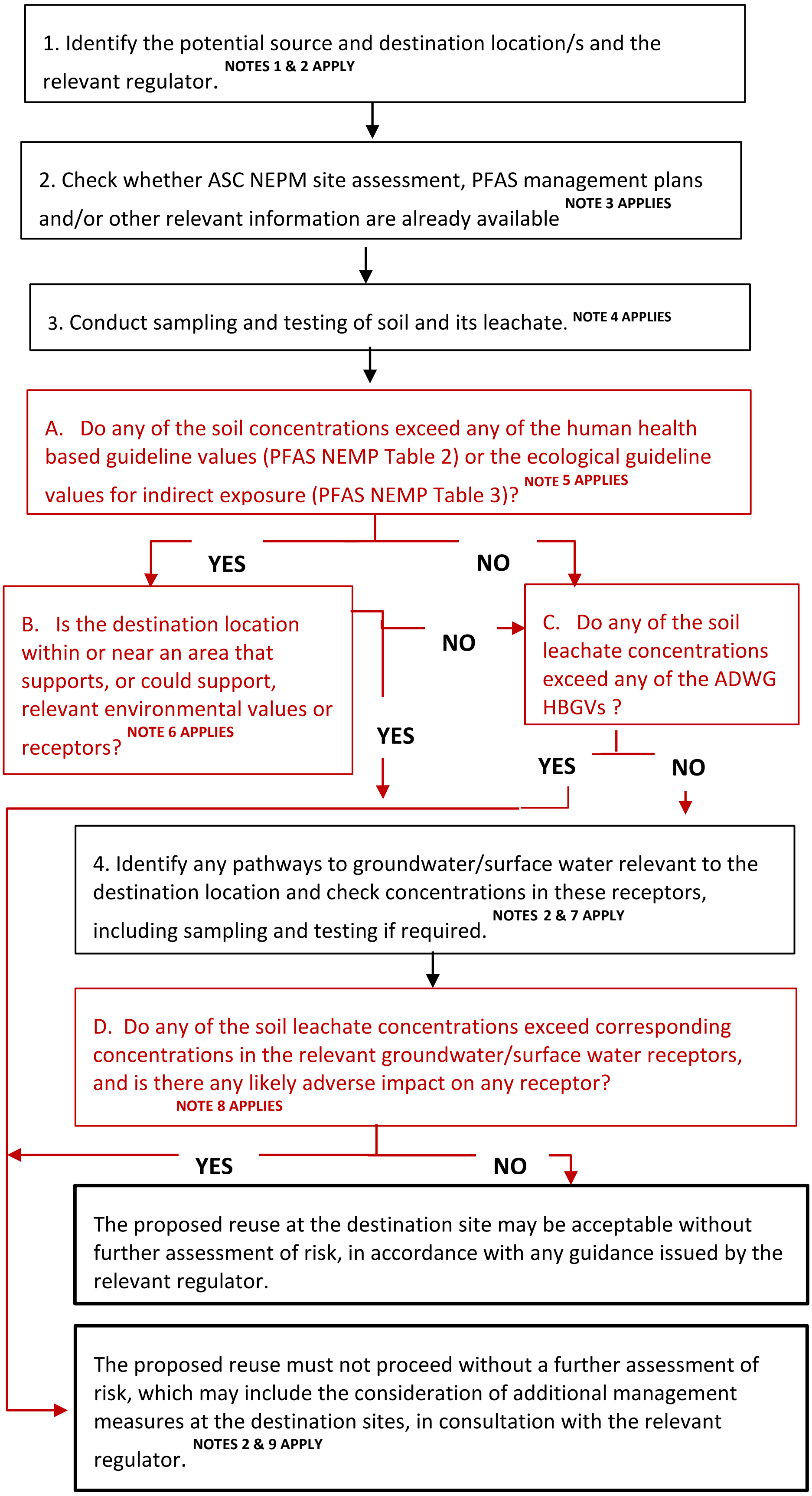
12.1.2 Decision tree for screening risk assessment for reuse of soil

A screening risk assessment may be acceptable in instances where PFAS concentrations in the soil are at or below the relevant health and ecological assessment criteria, and where PFAS concentrations in the material can be demonstrated to be lower than concentrations of PFAS in and around the proposed reuse location. A decision tree outlining the process for a screening risk assessment is presented in Figure 5 below.

Figure 5. Decision tree for reuse of soil

Decision Tree for Reuse of Soil

to be applied consistent with PFAS NEMP provisions and local regulatory requirements



1. Identify the potential source and destination location/s and the relevant regulator. **NOTES 1 & 2 APPLY**

2. Check whether ASC NEPM site assessment, PFAS management plans and/or other relevant information are already available **NOTE 3 APPLIES**

3. Conduct sampling and testing of soil and its leachate. **NOTE 4 APPLIES**

A. Do any of the soil concentrations exceed any of the human health based guideline values (PFAS NEMP Table 2) or the ecological guideline values for indirect exposure (PFAS NEMP Table 3)? **NOTE 5 APPLIES**

B. Is the destination location within or near an area that supports, or could support, relevant environmental values or receptors? **NOTE 6 APPLIES**

C. Do any of the soil leachate concentrations exceed any of the ADWG HBGVs ?

4. Identify any pathways to groundwater/surface water relevant to the destination location and check concentrations in these receptors, including sampling and testing if required. **NOTES 2 & 7 APPLY**

D. Do any of the soil leachate concentrations exceed corresponding concentrations in the relevant groundwater/surface water receptors, and is there any likely adverse impact on any receptor? **NOTE 8 APPLIES**

The proposed reuse at the destination site may be acceptable without further assessment of risk, in accordance with any guidance issued by the relevant regulator.

The proposed reuse must not proceed without a further assessment of risk, which may include the consideration of additional management measures at the destination sites, in consultation with the relevant regulator. **NOTES 2 & 9 APPLY**

Notes

1. This decision tree must be applied in consultation with the relevant regulator/s. As guidance, it does not replace local regulatory requirements. All approval and reporting requirements set by the regulator must be identified and met.
2. At the destination site, the level, distribution and mobility of PFAS must remain sufficiently low to prevent increased or unacceptable risks to any receptor or to the environmental values of waters, considering all relevant line of evidence including site-specific factors such as soil type, drainage and human activities.
3. If a current PFAS management plan, consistent with the PFAS NEMP, and approved by the relevant regulator/s is already in place then it may take precedence over this decision tree.
4. Sampling should comply with the methodology in Section 7.5 of Schedule B2 (Guideline on Site Characterisation) of the ASC NEPM, the PFAS-specific sampling and analysis guidance in the PFAS NEMP, and any requirements of the relevant regulator/s. Specific advice on leaching tests is provided in Sections 2.7 and 12 of Schedule B3 of ASC NEMP and Section 14.6 of PFAS NEMP. Sampling design should ensure that limits of reporting are appropriate for comparison of results with relevant environmental guideline values and water quality at the reuse site.
5. The PFAS NEMP guideline values are not default acceptance values or remediation values.
6. The ASC NEPM focuses on protecting environmental values related to ecological functions, such as soil microbial processes, and species. In practice, relevant environmental values could include native vegetation, parkland, wetlands, waterways, and areas accessed by wildlife.
7. Information on ambient background concentrations is essential to support application of this decision tree. Such information is becoming available from a number of sources, including investigations being undertaken by jurisdictional regulatory agencies to support future revisions of the PFAS NEMP. If no information on ambient background concentrations is available, then sampling and testing of suitable reference sites will be necessary.
8. Confirm that concentrations at the reuse site do not pose any current adverse impacts to the environmental values of aquatic receptors, and that the proposed reuse is consistent with management targets for those receptors.
9. Should additional management be required, guidance provided in Section 10 may be relevant.

Reuse with a detailed risk assessment

The most important pathways posing a risk to human health and/or the environment are:

- transport of PFAS to surface water and groundwater through leaching from PFAS-contaminated material
- bioaccumulation in plants and animals, in particular, those consumed by humans and animals.

Therefore, any assessment of risks associated with reuse of PFAS-contaminated soil should consider the proximity and sensitivity of surface or groundwater receptors, potential for bioaccumulation, and secondary or tertiary exposure to humans and animals.

12.1.3 Considerations for reuse with a detailed risk assessment

The following factors should be considered when assessing the potential for reuse of PFAS-contaminated materials:

- potential for pre-existing ‘background’ PFAS impacts at the destination site and potential to add to the overall mass of PFAS in the receiving area
- if the receiving environment already contains PFAS, whether the addition of more PFAS to that system increases the potential for harm
- current and likely future land uses at the destination site
- hydrogeology at the destination site, including erosion, runoff and infiltration rates, nature of the aquifer systems, the potential for these to be impacted and the actual and potential beneficial uses of groundwater
- proximity of the destination site to pathways such as open drains, storm water systems, water bodies, including groundwater, and to sensitive environmental receptors, groundwater-dependent ecosystems and sensitive animals
- potential for the receiving environmental conditions to accelerate mobilisation of PFAS in the contaminated material or in existing PFAS at that site.

Based on the legislative requirements of the environmental regulator, including whether the associated approval is lawful, the following uses may be appropriate subject to the environmental setting and findings of a risk assessment:

- use as fill material in commercial/industrial developments with minimal access to soil
- use as fill beneath sealed surfaces, including but not limited to car parks/roads/paving/runways
- use as construction fill on road embankments, noting that risks should be assessed for stormwater runoff that may mobilise PFAS
- use as fill material in areas where background PFAS levels present a similar or higher contamination risk profile, providing that the volume of contaminant in the soil to be added is substantially less than the total mass of the contamination already present in that area
- reuse as construction material, e.g. bricks, rammed earth and gabions, noting the need to consider PFAS leachability.

12.2 Reuse requiring consultation with the environmental regulator

The following reuse situations are likely to include exposure pathways to potentially sensitive receptors and would therefore normally be considered unacceptable uses for PFAS-contaminated material, based on risks to the environment and human health.

The environmental regulator may consider these uses on a case by case basis based on an appropriate site-specific risk assessment and with consideration of applicable legislative requirements. Additional management and institutional controls, including monitoring, are likely to be required to ensure protection of the environment and human health, including food production.

Contact with the environmental regulator must be made before any proposal for the following uses is made:

- fill or burial less than 2.0 metres above the seasonal maximum groundwater level
- reuse within 200 metres of a surface water body or wetland area
- reuse in (or in the vicinity of and able to be transported to) areas which can be identified with any of the nine matters of national environmental significance protected under the EPBC Act, and areas of environmental significance as identified in specific jurisdictions
- fill, burial or reuse in locations potentially affected by reasonably foreseeable future rises in groundwater or sea level, or near stormwater drains
- reuse on agricultural land
- reuse as fill in residential developments
- reuse as fill on public open space/parkland/recreational land
- inclusion in compost, fertilisers or soil conditioners.

There could be other reuse scenarios that may not be acceptable from the perspective of human health protection, e.g. food production areas.

The reuse of PFAS-contaminated material above the Stockholm Convention low content limit of 50 mg/kg will not be considered. See Section 14.6 for more information.

12.3 Reuse of PFAS-contaminated water

The following guidance should be read in conjunction with Section 15 and Appendix D on wastewater treatment, which also discuss the reuse of biosolids.

If PFAS-contaminated water is proposed for reuse, the proposed reuse must not result in an unacceptable or increased risk to human health and/or the environment. The reuse also must not breach environmental and/or health laws such as those pertaining to the contamination of drinking water, groundwater, stormwater and soil.

Human health and ecological guideline values for water provide primary guidance on the suitability of PFAS-contaminated water for reuse. These guideline values must be considered along with the potential for water to impact groundwater or aquatic ecosystems. Local catchment risk assessments in sensitive areas may require that the overall PFAS mass within the catchment should be reduced to achieve the agreed objectives for water quality.

Reuse of PFAS-contaminated water must not be undertaken until consultation with the relevant regulators has taken place, as reuse activities may require specific approval. Acceptable reuse options may include:

- irrigation of non-edible crops
- construction project dust suppression
- re-infiltration to maintain environmental values
- managed aquifer recharge
- industrial process water.

Where reuse involves the discharge of PFAS-contaminated water to land, the risk assessment should not only consider the potential for PFAS transport to off-site sensitive receptors, but also the potential for long-term build-up of the total PFAS mass in the receiving soils, groundwater and plants. Where water is to be used for managed aquifer recharge and recovery, water quality criteria should be derived with consideration of the receiving aquifer (i.e. protected environmental values, sedimentary/confined aquifer versus fractured rock; potential for future beneficial uses; long-term transport). Under some environmental legislation, waste discharge to groundwater is the least preferred management approach and may only be considered as a pump and treat scenario. Use as industrial process water must consider potential human health impacts, such as in food industries, and impacts of any reuse-derived products on the environment and/or human health.

Reuse must be for a clearly demonstrated beneficial purpose. Accepting and applying large volumes of PFAS contaminated water to land without implementing the waste minimisation hierarchy and absent a clearly demonstrated beneficial purpose is considered dispersal into the environment and waste disposal rather than reuse.

13 PFAS treatment and remediation

Treatment and remediation to destroy or remove PFAS from contaminated materials, including solids and liquids, represents an important option in the management of PFAS. Remediation and treatment can be impeded by:

- the resistance of PFAS to common physical, chemical, and biological processes
- the solubility and mobility of PFAS in the environment
- the potential for production of other PFAS during the treatment process.
- the generation of additional contaminated by-products and wastes if appropriate precautions are not implemented.

The availability, practicability and feasibility of treatment options must be considered when evaluating options for PFAS treatment and remediation. Storage and/or containment may be required where treatment options are not available. For further guidance on storage and containment see Section 10 including the discussion of capping in Section 10.3.3.

Listed below is the preferred hierarchy of treatment and remediation options:

1. Separation, treatment and destruction. This involves on-site or off-site treatment of the PFAS-contaminated material so that it is destroyed, removed, or the associated risk is reduced to an acceptable level.
2. On-site encapsulation in constructed stockpiles or engineered storage and containment facilities, with or without chemical immobilisation. If the source site is hydrogeologically appropriate, on-site encapsulation may acceptably manage on- and off-site risks to direct and indirect beneficial uses and environmental values of soils, surface water, groundwater, and biota.
3. Off-site removal to a specific landfill cell. This may or may not include immobilisation prior to landfill disposal, noting that the conditions in the landfill may reverse or diminish the immobilisation chemistry in ways that are difficult to predict. Immobilisation prior to landfill disposal may require environmental regulatory approval. Leachate should be captured and treated to remove PFAS and the removed PFAS should be destroyed.

The range of treatment facilities and technology options commercially available to remove and/or destroy PFAS compounds is limited. More technologies are becoming available or are emerging to remove or immobilise PFAS contamination, but there is limited information on the long-term effectiveness of these methods and their suitability for very large volumes of material. High temperature destruction is available in a small number of facilities in Australia. Appendix C lists treatment technologies that are available in Australia commercially and/or are undergoing trials.

Staff handling PFAS-contaminated materials must be appropriately trained and there should be mechanisms in place to check and review environmental performance. On-site management strategy

The implementation of a management strategy and associated environment plan for on-site management can be undertaken where the site assessment indicates that remediation would have no net environmental benefit at the local site or within the broader catchment, would have a net adverse environmental effect (e.g. determined via a site-specific risk assessment), or where management of exposure pathways rather than treating at source would be acceptable particularly as an interim measure while other options are considered.

An on-site management strategy would be appropriate provided that:

- Unacceptable risks to off-site ecosystems and/or human health exposure such as by surface water or groundwater migration is not occurring or is managed.

- The land owner agrees and has sufficient expertise and financial capacity to implement and maintain the management measures, the polluter should monitor and report on the efficacy of the measures for the duration of the activity.
- The environmental regulators implement appropriate statutory tools for requiring compliance, including the ongoing provision of information (for example, publicly available fishery advice), with such strategies and ensuring community right to know.

Before choosing a remediation or treatment option, the following should be considered:

- **Proportionate to risks** - The selection of an option should be proportionate to the risks being managed.
- **Sustainability of option** - When deciding which option to choose, the sustainability (environmental, economic, and social) of each option should be considered in terms of achieving an appropriate balance between the benefits and effects.
- **Views of affected communities and jurisdictional regulators** - Stakeholder views will contribute to a comprehensive understanding of the context and the potential impacts of options.
- **Availability of the best treatment or remediation technologies** - While ‘best practice’ criteria are not yet available, as remediation and treatment technologies are developed, best practice technologies should be the preferred solution.
- **Site specific issues** - The appropriateness of any specific option will vary depending on a range of local factors. The choice of a specific option or mix of options is therefore a matter for the site manager in consultation with, or as directed by, the environmental regulator.
- **Effectiveness of technology as demonstrated by destruction efficiency or the reduction in PFAS concentration** - This should be considered when choosing an option in combination with appropriate remediation/treatment criteria. As most of the methods available in Australia are in the research and development stage, this information may not be published. If information is unavailable, the technology provider must provide specifications and validation of the effectiveness of the technology to reduce the PFAS concentration and the destruction efficiency. Noting that some treatments will result in the transformation of PFAS, thus changing the PFAS present in the treated materials.
- **Treatment strategy** - The selection of an approach should consider the preferred hierarchy for treatment and remediation in combination with other contaminants that may be present (e.g. mixed contamination) and the availability of on-site land to accommodate in-situ treatment options. If information regarding a particular approach is unavailable, seek details from the technology provider including the efficiency and effectiveness of the process and which other contaminants the process will treat. Some technologies are more effective at treating longer carbon chain length compounds from water-borne contamination. It may be important to consider a multistage treatment (also referred to as a treatment train), depending upon composition of the waste and the nature of the contamination.
- **Validation** - Consideration must be given to independent validation of the treatment or remediation outcomes to determine whether the measures of success (including remediation objectives) have been achieved.
- **Understanding PFAS precursors** - Studies of site remediation have emphasised the need to monitor and understand the presence of precursors. Some treatment processes transform precursors creating an apparent increase in PFAS following remediation. Understanding of the range of potential PFAS present, including

precursors, is also necessary to identify all contaminants of potential concern. Refer to (Section 9 on PFAS contaminated site assessment for further information.

14 PFAS disposal to landfill

This section covers the permanent disposal of PFAS-containing waste to landfill. Additional information that may be relevant to aspects of managing PFAS in landfills is provided in Section 10 on storage, stockpiles and containment.

Every jurisdiction has policy and regulatory frameworks in place for waste disposal to landfill and to manage the associated environmental and human health risks[55]. All environmental regulators and landfill operators must consider the risks and management challenges associated with the widespread presence of PFAS in household, commercial and industrial waste streams. Acceptance of PFAS-contaminated materials is a commercial decision for the landfill operator and must be approved by the environmental regulator. Site-by-site assessment will be required when determining whether or not a current or new landfill is appropriate for accepting PFAS-contaminated materials or whether a closed landfill may require additional monitoring or controls.

14.1 Landfill siting and design

For all new landfills, siting and design are the primary controls to minimise risk to the environment and human health. Landfill siting and design must give regard to topography, geology, hydrogeology, proximity to groundwater and surface water and sensitive ecological and human receptors. The widespread presence of PFAS in Australian waste streams means that the PFAS specific characteristics (e.g. mobility and persistence) should be taken into account.

Where siting and design are of concern for existing facilities, the environmental regulator will consider these landfills as having a higher risk to the environment, human health and/or amenity and will require further consideration through a detailed site assessment, which may result in a refusal to accept solid PFAS contaminated-materials for disposal.

Design requirements will vary by jurisdiction. However, as a minimum the following should be considered for new and existing landfills.

New sites:

- geotechnical aspects and site preparation
- landfill liner system design and construction
- leachate management system design and construction
- stormwater management controls
- construction quality assurance.

Existing sites:

- performance of landfill liner system
- performance of leachate management system
- review of existing stormwater management controls
- review of construction quality assurance for landfill liner and leachate system.

Historic groundwater and surface water monitoring results will provide the necessary information to inform the above considerations.

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[55] The guidance in this Section is supplementary to, and should be applied in conjunction with, the existing guidance issued by jurisdictions on the siting, design, management, operation and closure of landfills.

14.2 Landfill operation

The following operational practices of the landfill should be reviewed and strengthened where necessary, as part of a broader site-specific assessment when considering landfill acceptance of solid PFAS-contaminated materials:

- Waste acceptance, handling and placement - Landfill operators should consider the appropriate handling of the material once accepted onto the landfill site, including leachate collection and management systems. If possible, consideration should be given to offloading PFAS-contaminated materials directly into the receiving landfill cell where they can be moved and worked within the cells for final waste placement.
- Waste cover - The placement of daily cover over wastes is an essential part of landfilling operations.
- Dust controls - The handling and placement of PFAS-contaminated materials may require dust suppression measures.

14.3 Leachate management practices

Leachate should be collected in a sump and pumped to a storage location (usually a suitably engineered/ lined evaporation/storage pond or tank). Before treatment, disposal or reuse of the water, it should be analysed for PFAS. When detected, options for treatment and remediation or destruction should be considered and implemented as required to prevent PFAS distribution to the environment. Further guidance is provided in Section10 on storage and containment of PFAS-contaminated liquid wastes and in Section 15 on wastewater treatment that is relevant to leachate management options, such as trade waste discharge, which should be discussed with the environmental regulator and the water utility or authority.

14.4 Monitoring at landfills

Monitoring of landfill leachate and groundwater, surface water and land receptors should include PFAS in accordance with the regulatory requirements, specifically, conditions imposed for landfills approved to accept solid PFAS-contaminated materials. If regulatory requirements do not exist, monitoring programs should include PFAS.

14.5 Closure considerations

Closure of the landfill should consider ongoing containment strategies, including leachate management and maintenance of capping and groundwater management systems. Monitoring of landfill gas condensate should consider PFAS as some, such as fluorotelomer alcohols, are volatile. Decommissioning, such as of leachate collection dams, should be assessed for the presence of PFAS and be managed accordingly.

For closed landfills with ongoing monitoring requirements, PFAS monitoring in groundwater should also be considered.

14.6 Landfill acceptance criteria

The following criteria apply to the disposal of solid PFAS-contaminated materials to landfill. These have been determined based on existing jurisdiction approaches to the derivation of landfill acceptance criteria for a number of standard landfill designs, but recognise that individual jurisdiction approaches may differ, particularly in the base values and multiplication factors used.

Waste concentrations must be less than both the relevant total and leachable concentration in the Australian Standard Leaching Procedure (ASLP) conducted at both pH 5 and un-buffered reagent water - approximating the “worst case” for leaching conditions.

Based on individual landfill siting, design, operation and ongoing management requirements, as well as individual environmental regulator approaches to the derivation of landfill acceptance criteria, the environmental regulator may determine that these criteria are not suitable for a specific landfill or landfills and derive and implement alternative criteria.

Landfill acceptance criteria for total concentration have been capped at 50 mg/kg. This is based on the Stockholm Convention, which requires the following:

- Wastes must be disposed of in such a way that the persistent organic pollutant content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of persistent organic pollutants or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the persistent organic pollutant content is low, taking into account international rules, standards, and guidelines, including those that may be developed pursuant to the Stockholm Convention, and relevant global and regional regimes governing the management of hazardous wastes.[56]
- Waste is not permitted to be subjected to disposal operations that may lead to recovery, recycling, reclamation, direct reuse or alternative uses of persistent organic pollutants.[57]

Further to this, the Basel Convention on the Transboundary Movements of Hazardous Waste and their Disposal provides the low content limit for PFOS wastes for the purposes of Article 6, paragraph 1(d) (ii) of the Stockholm Convention at 50 mg/kg[58].

The following criteria do not provide permission for any landfill to receive solid PFAS-contaminated materials. Rather, individual landfills must seek approval from the environmental regulator to receive these wastes. In determining whether a landfill will be suitable to accept solid PFAS-contaminated materials, considerations include:

- ensuring the landfill is not located on a vulnerable groundwater system[59]
- depending on the landfill liner design, whether the landfill is located within 1000 m of a surface water body that supports an aquatic environment (including groundwater dependent ecosystems), or within 1000 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 or other fauna species that may be caught and consumed
- performance of landfill liner and leachate management system (giving consideration to historical groundwater and surface monitoring results for existing sites)
- leachate management practices at the landfill, in particular whether landfill leachate is recirculated through the landfill or sent to a wastewater treatment plant, whether treatment occurs prior to release, or if leachate is likely to be reused either on- or off-site

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[56] Stockholm Convention on Persistent Organic Pollutants, Article 6, paragraph 1(d)(ii).

[57] Stockholm Convention on Persistent Organic Pollutants, Article 6, paragraph 1(d)(iii).

[58] The guidelines are available from the Basel Convention web site at: http://www.basel.int/Implementation/POPsWastes/TechnicalGuidelines/tabid/5052/Default.aspx

[59] See Australian Government (2013) and, for PFAS-specific advice, DER (2017) adapted from Appleyard (1993).

- other factors as relevant to the specific landfill siting, design, operation and ongoing management
- whether there are significant additional PFAS compounds present in addition to PFOS, PFHxS and PFOA
- where PFAS-contaminated soils are used as day cover, more stringent requirements are likely to apply to prevent stormwater contamination.

Future work will be undertaken to better understand the diffusion of PFAS through landfill liners and the consideration of precursors, which will support the review of these criteria.

Table 7. Landfill acceptance criteria

Landfill type		**Interim landfill acceptance criteria** [60, 61]		**Comments**
		Sum of PFOS + PFHxS	**PFOA**	
Unlined	ASLP leachable concentration (µg/L)	0.07 µg/L	0.56 µg/L	Drinking water x 1 (Department of Health 2017)
	Total concentration (mg/kg)	20 mg/kg	50 mg/kg	Soil - Human health industrial/commercial x 1 Total concentration for PFOA of 50 mg/kg based on the low content limit
Clay/single composite lined	ASLP leachable concentration (µg/L)	0.7 µg/L	5.6 µg/L	Drinking water x 10 (Department of Health 2017)
	Total concentration (mg/kg)	50 mg/kg	50 mg/kg	Soil - Human health industrial/commercial x 10 Total concentration for PFOS + PFHxS and PFOA of 50 mg/kg based on the low content limit
Double composite lined	ASLP leachable concentration (µg/L)	7 µg/L	56 µg/L	Drinking water x 100 (Department of Health 2017)
	Total concentration (mg/kg)	50 mg/kg	50 mg/kg	Soil - Human health industrial/commercial x100

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[60] Waste concentrations must be less than both the relevant leachable concentration and the total concentration values for the type of landfill.

[61] Where significant PFAS are present beyond PFOS, PFHxS and PFOA, these solid PFAS-contaminated materials may not be acceptable for landfill disposal. This should be discussed with the environmental regulator.

				Total concentration for PFOS + PFHxS and PFOA of 50 mg/kg based on the low content limit
Note: Where the criteria refer to the sum of PFOS and PFHxS, this includes PFOS only, PFHxS only, and the sum of the two.				

15 PFAS in the wastewater treatment system

The following guidance focuses on sewerage networks managed by water utilities and authorities. It also identifies issues relevant to organisations responsible for on-site management and treatment of wastewater and trade waste. Further work, in collaboration with the water industry, will be undertaken to establish PFAS management criteria and guidance for water authorities and environmental regulators based on current science, and will inform future versions of the NEMP.

Sound management of PFAS contamination in the wastewater treatment system is critical. PFAS in the wastewater treatment system originate from many different sources, including domestic and industrial discharges.

[In relation to preventing further release of industrial chemicals (such as PFAS) into the environment from the use of products and articles, work is underway to establish a framework for controlling the import, sale, use and disposal of industrial chemicals in Australia. Additional work is also underway to communicate to industry regulatory intent in relation to phasing out the use of particular PFAS in Australia.]

Criteria for existing environmental contaminants, including PFAS, are generally established by the environmental regulator, with input from the relevant wastewater utility, as part of the broader approach to managing water quality set out in each jurisdiction’s environmental legislation. A common point of reference for water quality management, agreed by all jurisdictions, is the National Water Quality Management Strategy (NWQMS) and the Australian and New Zealand Water Quality Guidelines (Australian Government 2018). The use of a framework provides a systematic way to plan, develop and manage performance.

The NWQMS and the Guidelines provide detailed guidance on the development and application of guideline values to protect environmental values, also known as community values or beneficial uses[62].

15.1 PFAS Management Framework

The application of a precautionary approach, guided by a PFAS management framework, makes good business sense while guidelines are being developed. This approach will minimise future risks to wastewater utilities that could otherwise arise once such criteria are established. It is also prudent in light of the rapid advances being made in the scientific understanding of PFAS and its behaviour in the environment.

The PFAS management framework should address the specific needs and circumstances of each wastewater utility, in consultation with relevant regulators[63]. It is recognised that adaptations may need to be made to such a framework to accommodate differences in scale and other challenges faced by smaller water utilities. An effective framework would be expected to address the following key areas:

- wastewater inputs (e.g. trade waste and domestic wastewater)
- wastewater processing (e.g. infrastructure and biological treatment processes)
- wastewater outputs (e.g. effluent discharged to the environment, effluent used as recycled water, biosolids used for soil conditioning, and biosolids disposed to landfills or other waste disposal pathways).

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[62] These guideline values focus on assessing potential risks to the ecosystems, and do not necessarily represent discharge criteria. It is also important to consider potential risks from toxicity in aquatic species, and bioaccumulation in both aquatic and terrestrial species, as well as potential risks to human health.

[63] As well as the environmental regulator, this may involve other regulators such as a utility regulator.

The following outcomes provide a common starting point for developing a framework, noting that the first three outcomes listed address external accountabilities, while the remaining outcomes would be at the discretion of the wastewater utility:

- All relevant legal and regulatory requirements are met so that consistency with the NEMP is achieved.
- The health and safety of staff, customers and the general public are protected.
- The ecosystem function, biodiversity, and amenity of receiving environments are protected.
- The condition of wastewater treatment infrastructure and processes are maintained across the life cycle, including:
    - production of outputs acceptable for disposal and reuse and
    - affordable disposal of infrastructure at the end of its working life.
- The costs for acceptance of trade waste are appropriately understood and recovered.

An example framework is provided for reference in Appendix D. Addressing each element of the framework, as per the example framework provided, will enable water utilities to demonstrate compliance to regulators, stakeholders and the broader community. The example framework is included to highlight the key aspects that wastewater utilities should consider when developing an approach to manage risk from PFAS. The specific risks from different PFAS inputs into a wastewater network will inform how much of the example framework wastewater utilities will need to consider including. Regulators may also set a requirement for a framework to be developed via wastewater utility conditions of license.

15.2 Additional management tools

Drawing on the advice provided in this Plan, in the ASC NEPM, and in the NWQMS, additional management tools relevant to managing PFAS in wastewater may, depending on the potential risks and the size of the water utility, include:

- PFAS inventories for specific wastewater catchments or priority areas within catchments[64]
- stakeholder engagement plans for specific wastewater catchments or industries
- remedial action plans, transition plans or continual improvement plans prioritising short, medium and long-term actions to address identified issues
- risk assessments for specific discharges and products for beneficial reuse[65]
- applied research strategies to address knowledge and technology gaps
- infrastructure management and development plans
- communication strategies to publicise relevant information such as monitoring results and progress against the outcomes listed above

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[64] In addition to point sources, PFASs are present in a wide range of products, which contributes to the PFAS inputs to wastewater systems. Options to manage these diffuse sources of PFAS and reduce any associated environmental and human health risks are covered by other national processes outside of the PFAS NEMP.

[65] Detailed guidance around biosolids and recycled water is planned as part of the future work in the theme on Water outlined in Section 20.

15.3 Case study - PFAS contamination of a wastewater treatment system

A large volume of aqueous film-forming foam containing fluorotelomer precursors and small quantities of PFOA and PFSA was accidentally discharged. The company reported that most of the spill was contained, but some of the foam entered the stormwater drainage channel and subsequently escaped into the wastewater treatment system and local waterways. The PFAS appeared at the wastewater treatment plant and in local waters as frothy bubbles and contaminated the wastewater treatment system infrastructure.

To manage further contamination of the wastewater treatment plant, the following activities were undertaken:

- consultation between all stakeholders to understand impacts and options
- turning off pump stations to prevent further PFAS being released downstream
- extraction of material from the affected sewers and the pipework cleaned
- diversion and collection of sewage that would normally flow through the system
- PFAS-contaminated wastewater was contained
- ongoing monitoring of PFAS in sewage onsite and at the affected wastewater treatment plants
- disposal of affected biosolids to a landfill capable of receiving PFAS-contaminated materials
- ongoing management of the site, including adaptive management to ensure no ongoing impact
- treatment of the PFAS-contaminated material to meet relevant criteria, including thermal destruction of the PFAS concentrates

16 Data sharing

Data sharing, including the publication of data, is important for openness and transparency and to avoid duplication of effort. However, not all data can be shared or made public and some may need to be withheld for privacy, commercial in confidence or other reasons.

Environmental regulators will share data according to the following criteria:

- If data is already public, it will be shared.
- If there is no reason that data cannot be made public, it will be shared.
- If data cannot be made public, but there is a need to share, specific arrangements will be put in place.

This approach will be supported by future work to formally establish a structured way of sharing data and information arrangements.

17 PFAS notification

Many environmental regulators require mandatory or voluntary notification of PFAS-containing products, PFAS-contaminated material stockpiles and/or sites. These requirements are based on the relevant environmental legislation (e.g. duty to notify, general environmental duty, requirements concerning land contamination). Generally, the environmental regulator should be notified where PFAS are found in the environment and there is a potential risk of adverse impacts to human health or the environment or PFAS have caused land contamination.

Notification is not further considered in the NEMP.

However, it is expected that notification will require further consideration as part of the national implementation arrangements if the listings of PFOS and PFOA under the Stockholm Convention are ratified by the Australian Government.

17.1 Case study - General environmental duty

The Northern Territory Environment Protection Authority applies the general environmental duty (Section 12) and the notification requirements (Section 14) in the *Waste Management and Pollution Control Act 1999*. Section 14 has the effect of creating a requirement for a person to notify the Authority if they are undertaking an activity that may cause, spread or enhance contamination (such as spill of a hazardous substance, or earthworks which disturb or expose contaminated soil), that could result in material environmental harm or serious environmental harm. The Northern Territory Contaminated Land Guideline (Sections 6 and 7) provides further detail about how this is applied in practice.

18 PFAS sampling

The approach to PFAS sampling should be generally consistent with established methods for contaminated site investigation, as outlined in the ASC NEPM Schedule B2 – Guideline on Site Characterisation and references therein[66]. However, the characteristics of PFAS mean that additional steps need to be undertaken to ensure that sampling adequately characterises the site and that analytical results are reliable.

For example, environmental guideline values for PFAS for ecosystem protection are generally very low. As a result, PFAS investigations will often require quantification of analytes at concentrations close to the practical limits of reporting for the available analytical methods. This in turn requires particular attention to avoiding sample contamination from the wide range of materials in which PFAS is used.

As a starting point, the guidance in this Section should be read in conjunction with the information in Section 8 on environmental guideline values, Section 9 on PFAS-specific considerations in site assessment, Section 19 on PFAS analysis, and Appendix A on the PFAS family.

18.1 Sampling and analysis quality plans

The purpose of a sampling and analysis quality plan (SAQP) is to ensure the collection and evaluation of representative data to provide a robust basis for decision-making. This minimises the likelihood of inconclusive or ambiguous results. Drawing on expert advice, including analytical testing service providers and environmental regulators where relevant, is helpful to ensure the SAQP achieves its purpose.

Consideration should be given in the SAQP to the type of sample to be collected, the expected PFAS concentrations and the need to take additional precautions to limit sample contamination. This is particularly important when the data will be compared against low environmental guideline values. The SAQP sampling procedure should also consider the order of sampling at each location based on the nature of other contaminants present and the likely level of impact.

Consistent with the guidance in the ASC NEPM, the SAQP should be informed by a robust conceptual site model (CSM). For example, the SAQP should investigate whether precursors and their transformation products have migrated along identified pathways and to receptor sites. Section 9 provides further guidance relevant to CSM development. As data is collected and analysed, the understanding of the site may evolve, leading to modification of the CSM. Consequently, the SAQP should be updated as required to reflect any updates to the CSM.

18.2 Responsibility for sampling

Sampling should be undertaken based on environmental regulatory requirements, including allocation of responsibility between the environmental regulator and the responsible person or organisation. For example, if the sampling is part of an investigation by environmental regulators associated with regulatory action, then sampling may be by the environmental regulator. However, if it is part of an approval application or other site activity, the responsible person or organisation must ensure that a suitably qualified person undertakes the collection of samples. For contaminated site investigations, sampling is generally undertaken by suitably qualified consultants appointed by the responsible person or organisation. The PFAS Contamination Response Protocol[67] provides further guidance about roles at government-owned sites and sites where government activities have resulted in PFAS contamination.

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[66] The guidance in this Section should be applied in conjunction with any other relevant sampling guidance issued by jurisdictions.

[67] The PFAS Response Protocol is an Appendix to the Intergovernmental Agreement on a National Framework for Responding to PFAS Contamination.

18.3 Quality assurance and quality control

As discussed above, quality control is a particular concern for PFAS for two main reasons:

- Environmental guideline values for PFAS are generally very low which requires quantification at concentrations close to the practical limits of reporting.
- PFAS samples are at high risk of contamination in the field and in the laboratory,
- Consequently, quality control samples should be collected at a higher frequency than would normally be applied in the investigation of other contaminants (i.e. greater than the 1 sample in 20 recommended in AS4482.1-2005 Guide to the investigation and sampling of sites with potentially contaminated soil and in the ASC NEPM).

To provide greater confidence in the reproducibility of results, blind replicates, split samples and rinsate blanks should be collected at a rate of at least one for every ten primary samples. Inter-laboratory blind replicates, and re-submission of previously analysed samples, should also be used to confirm reproducibility of analytical results.

Rinsate blanks should be collected wherever uncertainty may arise regarding the potential for contamination, or where there is doubt about whether materials are PFAS-free. Field and trip blanks should be collected to verify the integrity of sampling and decontamination procedures. Laboratories will generally supply on request certified PFAS-free water for rinsates and blanks.

18.4 Preventing sample contamination

The following detailed guidance reflects the particular importance of preventing contamination of PFAS samples, as discussed above.

Attention should be given to the range of products that can cause PFAS contamination of samples, including new clothing, footwear, PPE and treated fabrics stain and water- resistant products, sunscreen, moisturisers, cosmetics, fast food wrappers, polytetrafluoroethylene (PTFE) materials (such as Teflon©), sampling containers with PTFE-lined lids, foil, glazed ceramics, stickers and labels, inks, sticky notes, waterproof papers, drilling fluids, decontamination solutions and reusable freezer blocks. These should not be worn or used during any stage of sampling (at site, during transport etc.) where sample contamination could affect analytical results.

Information on whether field consumables, such as decontamination solutions, have been confirmed to be PFAS-free may be available from suppliers. If this information is not available, the product should be tested for the presence of PFAS, and only used where it has been demonstrated to be PFAS-free. Further details are provided below on specific considerations for sampling, handling and processing.

The order of sampling in the field is particularly important to reduce the chance of sample contamination - moving from areas of likely low concentrations of PFAS contamination towards likely higher concentrations. It is good practice to inform laboratories of any samples that may be highly contaminated.

18.4.1 Handling and processing

Conventional sample handling and processing practices can generally be applied to groundwater, surface water, soil, and sediment samples for analysis of PFAS. Exceptions to this statement include the following, particularly where PFAS concentrations are expected to be low.

- Prior to sampling, the sampling personnel must wash their hands with plain soap and rinse thoroughly in tap water before donning a clean, new pair of disposable nitrile gloves.
- Teflon®-coated materials and aluminium foil may not come into contact with the sample.

- All samples should be double-bagged.
- During sample processing and storage, minimise the exposure of the sample to light.
- Chemical or gel-based coolant products (e.g. BlueIce®) to maintain samples at 4 °C following sample collection is not recommended.

If in doubt, use trip blanks to determine if there is any cross contamination.

The exceptions presented above should not result in the sample being damaged or contaminated, nor should they put sample collection or laboratory staff at risk of exposure.

18.5 Considerations for specific environmental media

The following guidance includes general considerations for sampling of environmental media along with provisions to prevent sample contamination.

18.5.1 Groundwater

Conventional groundwater drilling and well development practices are generally suitable for monitoring wells where groundwater samples will be analysed for PFAS (e.g. ASC NEPM).

Exceptions include the following, particularly where low PFAS concentrations are expected.

- Drilling fluids that contain PFAS must not be used.
- For each sample, the required minimum volume of groundwater is 250 mL per USEPA (2009).

Sampling requirements may vary by laboratory and analytical method. Prior to sampling, always confirm requirements with the selected analytical laboratory.

- For drinking water, each 250 mL sample bottle may be required to contain a small amount (1.25 g) of Trizma®, a buffering reagent that removes free chlorine from chlorinated finished water (USEPA 2018), or similar sample additive specified by the analytical laboratory. Prior to sampling drinking water for PFAS analysis, the need for additive should be confirmed with the selected analytical laboratory.
- Use polypropylene or HDPE sample containers. Glass containers with lined lids are not suitable for PFAS analysis.
- Decontamination of drilling equipment must avoid the use of detergents unless they have been confirmed to be PFAS-free. Use tap water (tested to ensure it is PFAS free) or deionised water instead.
- Sampling must include submission of representative sample(s) of water used for drilling/ decontamination purposes.
- Avoid using equipment (such as pumping equipment, water meters, etc.) containing PTFE unless it has been confirmed not to impact water quality.
- Use class 18 u-PVC casing with a lower section of slotted screen (also minimum Class 18 u-PVC). PVC casing should not be reused.
- Prior to well development, any personnel handling decontaminated well development equipment that directly contacts bore water must wash their hands with plain soap and rinse thoroughly in tap water before donning a clean, new pair of disposable nitrile gloves. A new pair of nitrile gloves must be worn for each well developed. Decontamination soaps must not be used unless confirmed to be free of fluoro-surfactants.
- Following the completion of well development, purged groundwater must be treated as PFAS-contaminated waste (i.e. assumed to be contaminated until verified, and then managed accordingly).

- Equipment recommended for obtaining groundwater samples includes low-flow peristaltic pumps using silicone or HDPE tubing or polypropylene HydraSleeves (or similar products). Consumable sampling equipment must not be reused.
- Rinsate samples should be collected if there is any doubt about whether or not materials or personnel are PFAS free, including when detergents are being used and secondary containers.
- Larger sample volumes may be necessary if the required LOR are ultra-trace and/or a TOP Assay or TOF Assay analysis is to be performed on the same sample.

18.5.2 Soil, sediment and surface water

Conventional soil drilling and aquatic sampling techniques for surface water and sediment can generally be used to obtain samples for analysis of PFAS. Exceptions to this statement include the following, particularly where the PFAS concentration is expected to be low.

- For each sample, the required minimum amount of soil or sediment is at least 5 g on a dry weight basis, per ASTM (2017). The soil in the sampling container (minimum 50 ml container) must be well mixed prior to removing the 5 g subsample for analysis. These sampling requirements may vary by laboratory. Prior to sampling, confirm sample size requirements with the analytical laboratory.
- For drinking water, each 250 mL sample bottle may be required to contain a small amount (1.25 g) of Trizma®, a buffering reagent that removes free chlorine from chlorinated finished water (USEPA 2018), 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.
- Use polypropylene or HDPE sample containers. Glass containers with lined lids are not suitable for PFAS analysis.
- Avoid the use of labels, stickers and inks unless confirmed to be PFAS-free.
- Decontamination of drilling equipment must avoid the use of detergents unless they have been confirmed to be PFAS-free. Use tap (tested to ensure it is PFAS free) or deionised water instead.
- Equipment that contacts soil, sediment, or surface water must not contain or be coated with PTFE unless the PTFE is internal to the equipment and does not contact the external environment.
- Prior to sample collection, any personnel handling decontaminated soil, sediment, or surface water sampling equipment that directly contacts the environmental media to be sampled must wash their hands with plain soap and rinse thoroughly in tap water before donning a clean, new pair of disposable nitrile gloves. Decontamination soaps must not be used unless confirmed to be free of fluoro-surfactants.
- Surface water must be collected by inserting a sampling container (polypropylene or HDPE) with the opening pointing down and the bottle opened underwater to avoid the collection of surface films.
- Soil and sediment core samples must be collected directly from single-use PVC liners that must not be reused.
- For aquatic samples collected from shore or via wading, ensure that waders are constructed of fabric that has not been treated with waterproofing coatings.
- Check the cross-contamination checklist above for any other further issues. Rinsate samples can be collected if there is any doubt about whether or not materials or personnel are PFAS free.

- Other quality assurance samples for water sampling include transport blanks and field blanks.
- Larger water sample volumes may be required if the required LOR are ultra-trace and/ or a TOP Assay analysis is to be performed on the same sample.
- If leach testing (e.g. ASLP, toxicity characteristic leaching procedure) of soils is required, a larger sample size is required.

18.5.3 Biota

Requirements for biota sampling should be carefully considered, in consultation with the environmental regulator and relevant experts. The issues requiring consideration may include representativeness, statistical significance, sample compositing or pooling, protection of biodiversity and compliance with ethical standards. There are currently no guidelines for sampling potentially PFAS-contaminated biota. Further work will establish guidelines for sampling potentially PFAS-contaminated biota.

If analysis is intended to inform human health assessment, edible portions should be sampled (e.g. for seafood skin on fillets, or de-headed and de-veined prawns). Samples of the same species should be bulked/composited to allow larger sample numbers. However, there may be a need for additional sampling due to local consumption patterns such as consumption of the whole organism or specific parts of the organism by specific groups.

For assessment of ecological risk, sampling of the whole organisms, fillets and organs (especially liver) is recommended and samples generally should not be composited or bulked, although compositing may be useful in some instances, such as for small sediment-living organisms when assessing risks to wading birds.

19 PFAS analysis

The following guidance covers a range of PFAS analysis methods suitable for different site investigation, assessment and management scenarios. This guidance should be read in conjunction with Section 8 on environmental guideline values, Section 9 on contaminated site assessment, Section 18 on PFAS sampling, and Appendix A on the PFAS family. As PFAS analysis is a rapidly evolving field, the guidance in this Section should be considered with reference to any subsequent advances in analytical systems and techniques.

19.1 Standard and non-standard analysis methods

In general, PFAS analysis methods can be categorised into standard or validated methods, and non-standard, emerging, or supplementary methods. The available standard methods test for and quantify specific target analytes, known as standard analytical suites. The non-standard methods include a range of approaches to characterise the presence of the PFAS chemical family more broadly, including non-specific, or non-target, PFAS, which may not be individually quantifiable. Standard methods of analysis and selected non-standard methods are listed in Table 8 along with selected non-standard methods. The Table includes the method, the analytes typically included in the analysis, the sample type, minimum internal standards required[68] how the method can be used, its limitations and a reference. Considerations for soil leachate analysis are discussed in section 14.6, including a method to approximate the worst case for leaching conditions.

Table 8. Methods of PFAS analysis - standard and selected non-standard methods

Method	**Use**	**Sample matrices**	**Limitations**	**Analytes**	**Internal standards**	**References**
USEPA Method 537.1-1[69] Determination of selected per- and polyfluorinated alkyl acids in drinking water by SPE and LC-MS/MS	To analyse for specific analytes in drinking water	Drinking water, ground and surface water	Only analyses for specific PFAS Does not require results to be corrected for Internal Standard recovery Limited internal standards Further details in	HFPO-DA, NEtFOSAA, NMeFOSAA, PFBS, PFDA, PFDoA, PFHpA, PFHxS, PFHxA, PFNA, PFOS, PFOA, PFTA, PFTrDA, PFUnA, ^{11}Cl-FP3OUdS, ^{9}CL-PF$_3$ONS,	$^{13}C_2$-PFOA, $^{13}C_4$-PFOS and d_3-NMeFOSAA	Shoemaker and Tettenhorst (2018)

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[68] An internal standard is a pure isotopically labelled version of each compound used as a reference for quantitation of native compounds. A known amount of this compound is spiked into the sample prior to extraction to measure the relative response of other method analytes and surrogates. Use of a commercially available, isotopically labelled internal standard for each PFAS analysed is recommended where available. If not available, a suitably scientifically justified alternative should be used that meet the method quality control requirements.

[69] The 2018 USEPA Method 537.1-1 is for identifying and measuring selected per- and polyfluorinated alkyl acids in drinking water by SPE and LC-MS/MS. It includes additional analytes compared to the original 2009 version. Some laboratories may use a modified USEPA Method 537 or 537.1 to obtain additional analytes, such as 6:2 and 8:2 fluorotelomers.

			the reference	ADONA, PFTrA, PFTeA,		
USEPA Method EPA-821-R-11-007 Draft Procedure for Analysis of Perfluorinated Carboxylic Acids and Sulfonic Acids in Sewage Sludge and Biosolids by HPLC/MS/MS December 2011	To analyse for specific analytes in sewage sludge and biosolids	Sewage sludge and biosolids	Only analyses for specific PFAS Further details in the reference	PFBA, PFPA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTriDA, PFTeDA, PFBS, PFHxS, PFHpS, PFOS, PFOSA, NMeFOSA, NEtFOSA, NMeFOSE, NEtFOSE	$^{13}C_4$-PFBA, $^{13}C_2$-PFHxA, $^{13}C_4$-PFOA, $^{13}C_5$-PFNA, $^{13}C_2$-PFDA, $^{13}C_9$-PFDA, $^{13}C_2$-PFUnDA, $^{13}C_9$-PFUnDA, $^{13}C_2$-PFDoDA, $^{18}O_2$-PFHxS, ^{13}C-PFOSA, d_7-NMeFOSE Linear and branched isomers should be included	USEPA 2011 Method EPA- 821-R-11-007
Total Oxidisable Precursor Assay (TOP Assay)	Can be used in conjunction with a USEPA method to estimate the total PFAS, and sometimes the approximate end point PFAS.	Water samples and extracts including soil, biota, firefighting foam products and wastes	Cannot be used to target exact PFAS precursors, as it is a semi-quantitative[70] method Allows for some inferences as to precursor	Total PFAS chains (C4-C14)	Linear and branched isomers should be included	Houtz and Sedlak 2012

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[70] The method is semi-quantitative as it has not yet been extensively developed and validated. As it is further developed, it should become more quantitative. This method cannot be used to identify exact PFAS precursor because the oxidation transforms them so that they can be measured

	Can help inform risk assessment.		chain length.			
Total Organic Fluorine Assay (TOF Assay) as combustion ion chromatography (the most common method available)	Can be used in conjunction with a USEPA method to understand the total presence of organic fluorine in a sample and compare this to the organic fluorine equivalent detected by the USEPA method.	Water samples and extracts including soil, biota, firefighting foam products and wastes	Cannot be used to target exact PFAS precursor compounds	Total organic fluoride corrected to remove inorganic forms	Linear and branched isomers should be included	Laboratory reported methods only

19.1.1 Standard methods

The methods published by the USEPA are most commonly used in Australia. These methods test for a standard analytical suite of PFAS in each case, using LC-MS/MS with additional methodological adaptations for specific environmental media[71].

The cost of standard methods is influenced by a range of factors, such as a request for analytical reporting at lower levels (generally referred to as ultra-trace analysis). Ultra-trace analysis is often used to compare PFAS at low levels with environmental guideline values. Ultra-trace limits of reporting are also typically utilised to delineate the extent of spread of PFAS contamination in soils, surface water, groundwater, or biota.

Analytical laboratories may also offer different versions of the standard methods, such as USEPA Method 537 and 537.1 and USEPA Method 821-R-11, or modified methods, including proprietary methods such as ASTM Method D7968-17a and Method ASTM Method D7979-17. These methods include additional sample media or additional PFAS. Any modifications to the USEPA methods that result in poorer method performance are not supported[72].

19.1.2 Non-standard methods

Several techniques exist and are available in Australia to determine the presence of PFAS not included in standard methods, including precursors. The TOF Assay considers the total mass of organic fluorine[73]. The TOP Assay considers PFAS with perfluorinated carbon chain lengths from C4 to C14. The use of advanced spectroscopy techniques allows screening for unknown or non-targeted substances. These techniques include liquid chromatography quadrupole time

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[71] The USEPA is developing further validated methods for determining PFAS in various media.

[72] See for example Shoemaker and Tettenhorst 2018, p.3.

[73] The fluorine extracted by TOF represents extractable organic fluorine. The results reported by TOF analysis do not include inorganic fluorine, such as that contained in fluoride added to drinking water, as inorganic fluorine is subtracted from the total.

of flight mass spectroscopy (LC-QToF-MS) and particle-induced gamma emission (PIGE) spectroscopy.

High resolution, accurate mass LC-QToF-MS is available in Australia to identify which PFAS are present in media, including precursors. This technique is helpful in circumstances such as:

- when the composition of PFAS is unknown,
- when TOF Assay shows the presence of a significant proportion of unknown organic fluorine, and
- when carrying out PFAS fingerprinting to identify different PFAS sources and differentiate their respective contributions to contamination.

Considerations for the use and interpretation of the TOP Assay and TOF Assay are discussed in detail below.

19.2 Considerations for selecting an analysis method

The following guidance should be read in conjunction with the information on standard and non-standard methods above. The selection of an analysis method should consider the type of sample, the information being sought and therefore what needs to be analysed for (i.e. what the method can help you understand), and the quality assurance and control required. Each method has specific advantages and limitations.

For all methods, care needs to be taken in analysing the results, with an understanding of the aforementioned advantages and limitations. This is particularly important where non-standard methods are used.

The following environmental indicators may potentially affect the mobility of PFAS and the degradation of precursors: pH, electrical conductivity, redox potential, metals (iron etc.), soil particle size, and biological activity.

19.2.1 Limit of reporting

The sensitivity of PFAS analysis should be matched to the decision-making requirements. Consequently, it may not always be appropriate to select the lowest cost analysis available from analytical service providers. This is particularly important when results will be compared to environmental guideline values.

In general, the limit of reporting (LOR) for PFAS available at standard commercial rates is 0.01-0.05 µg/L for water, 1-5 µg/kg for soils, 0.3-0.5 µg/kg for biota, and 5-20 µg/kg for biosolids. Trace and ultra-trace analyses, which are more sensitive, are also available, usually at a higher cost, and may be necessary depending on the purpose of the assessment. The LOR obtainable is dependent on the matrix and method.

The limit of reporting may be affected by the presence of other contaminants or components in individual samples that cause analytical interferences that raise the achievable LOR. This problem is more likely to occur in complex matrices such as soil, waste, biosolids and biota samples.

The requirement for ultra-low limit of reporting depends on the sample type. For example, a sample with very low levels of PFAS will need to be submitted for trace analysis (i.e. with a lower LOR) compared to a firefighting foam that has a high concentration of PFAS.

Not all Australian laboratories have low LOR capabilities.

19.2.2 Managing uncertainty

Commercially available analytical techniques generally measure up to 33 of the more than 4,700 PFAS compounds known to exist (OECD 2018). Some of the remaining compounds can be identified through advanced analytical techniques. However, there are still thousands of PFAS that cannot be measured.

Measuring individual chemicals (e.g. PFOS, PFHxS and PFOA) is important for assessment against guidelines and criteria. Further, toxicological and ecotoxicological data are usually generated for individual chemicals.

Of the specific PFAS that have been identified (see Appendix A), comprehensive toxicological data is available for only a few. Moreover, in products, articles, and in the environment, PFAS are always found as complex mixtures. For any mixture of PFAS, there is a lack of data to determine whether the toxicity of the compounds will act in an additive, synergistic or antagonistic manner. Moreover, the amount and variety of PFAS may be influenced by the nature of the PFAS source, the time the PFAS have been present in the environment, movement and dispersion from the source and the characteristics of the environment. Despite these uncertainties, the community, industry and other stakeholders expect environmental regulators to act decisively in areas of identification, assessment, monitoring, remediation and the overall management of PFAS-contaminated materials and sites.

The TOP Assay and TOF Assay can provide a more complete indication of the amount of PFAS present in a sample. When such an estimate is compared to the mass of the PFAS in the standard suite of analytes, the difference will indicate the amount of other fluorinated organic compounds present, including PFAS. If the percentage of other PFAS compounds is low, this provides more certainty that the specific PFAS present are the main PFAS. Conversely, if the percentage of other PFAS is high, there is more uncertainty and a greater potential risk to manage. These analyses can also provide useful information to differentiate sources of contamination.

A recent development available commercially in Australia, as discussed in section 19.1.2, is high resolution accurate mass LC-QToF-MS. This technique can further reduce uncertainty by providing information on the structures of unidentified PFAS compounds. In turn, knowledge of structure allows some inferences to be drawn regarding potential degradation pathways, including whether the unidentified compounds may ultimately transform into PFAA end products of concern such as PFOS, PFOA or PFHxS.

19.2.3 Laboratory requirements

When choosing a method, practitioners should ensure that the proposed analytical laboratories (primary and secondary) can provide the following:

- details on the method being used and the target PFAS analytes
- details on whether the requested quality criteria were met or not (including flagging within the lab's analytical and QA/QC reporting)[74]
- details on accreditation or validation of the method[75]
- sufficiently sensitive limits of reporting that are relevant to the environmental criteria and, if known, the expected concentration levels in the samples
- whether the method reporting limits can be achieved for the specific guidelines and criteria being applied (e.g. for USEPA Method 537.1)

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[74] For example, as specified in Table B-15 in QSM 5.3 (USDoD and USDoE, 2019). Importantly, QSM 5.3 is not an analytical method - it provides quality control criteria to manage uncertainty and provide assurance of confidence and consistency in laboratory reporting.

[75] Schedule B3 of the ASC NEPM states that comparable established methods from recognised sources such as Standards Australia, the US EPAUSEPA, the American Public Health Association (APHA), ASTM International (formerly 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 ASC NEPM, as where such methods adequately address the requirements of the situation (e.g. scope of the matrix type or analytes). While nationally-agreed methods and standards are preferred, in-house analytical methods may be used so long as they are properly validated against performance criteria (e.g. limit of detection (LOD)/limit of quantification (LOQ)) and measured uncertainty.

- whether the minimum requirements are met for control, internal and surrogate standards for the method
- whether or not the method has been, or is, affected by other contaminants present in the sample
- details as to whether a linear only or a mixed linear/branched standard is used for calibration purposes, including which PFAS standard was used
- analytical results representing the concentration of summed linear and branched isomers
- whether they use an isotopically labelled internal standard for each compound analysed
- a statement on whether internal standards are used for each target compound where several different PFAS and derivative compounds are being analysed
- correction of report results for internal standard recoveries, including when in the analysis process the internal standards are added - this information should be included with a statement of the recovery, noting typical recoveries are between 50-150% (± 50%) depending on media and the specific analyte.
- if undertaking TOP Assay, that validation of the methods of oxidation using detectable oxidisable precursors (e.g. labelled internal standards) is undertaken and reported, and that dilutions are also recorded and reported

Additional quality assurance measures for TOP Assay include:

- the total PFAS concentration post-TOP Assay should be greater or equal to the total PFAS concentration pre-TOP Assay, which signifies no material losses observed in preparation steps, noting a decrease of up to 10% might be expected due to normal analytical variability
- the sum of PFCA post-TOP Assay should be equal to or greater than the sum of PFCA pre-TOP Assay, which signifies any precursors being converted to PFCA products
- the sum of PFSA post-TOP Assay should approximate the sum of PFSA pre-TOP Assay, signifying that precursors did not convert to PFSA products
- for a full oxidation, no PFAA precursors (e.g. 6:2 FtS, FOSA) are detectable post oxidation, signifying complete oxidation
- for situations where a near complete oxidation is acceptable, minimal PFAA precursors are detectable post oxidation signified by
- for aqueous samples, sum of [PFAA precursors] divided by sum of [Total PFAS] <5%
- for soil samples, sum of [PFAA precursors] divided by sum of [Total PFAS] <10%
- greater leniency may be applied for samples where PFAS were detected ≤ 10 times LOR.

See Ventia (2019) for detailed consideration of technical challenges associated with the TOP Assay, including consideration of the significance of pre- and post-TOP Assay levels of PFCA, PFSA, and PFAA precursors. Laboratories will determine maximum sample dilution that can be performed to achieve the adopted reporting limits. An understanding of the sample dilution undertaken for sample analysis is important when comparing results from the primary and secondary laboratories.

19.3 Consideration of non-standard methods including relevance to site assessment and broader environmental assessment

This section discusses the application of the TOP Assay and TOF Assay to site assessment and to broader environmental assessment.

19.3.1 TOP Assay

The TOP Assay is a method for indirectly measuring the total precursor concentration in environmental samples. This includes circumstances where the presence of precursors is suspected, for example from information in the literature, and also when the monitoring objective is to effectively characterise the PFAS content of a sample. As the TOP Assay is designed to characterise the extent of overall PFAS contamination in a sample, it can be used where the USEPA methods may not adequately measure all the PFAS likely to be present.

The TOP Assay is particularly useful to identify source areas and characterise the potential presence of precursors that may convert to end-point PFAS compounds of interest. Examples include contamination where the PFAS product composition is unknown, where the known PFAS composition extends beyond the USEPA suite or where PFAS may have been subject to transformation, such as in wastewater treatment, contaminated site remediation, and in the wider environment. For example, in an immediate spill, TOP Assay provides information on whether precursors are present and informs risk management, e.g. considerations such as whether the environment is oxidative; and whether remediation might transform the precursors.

The TOP Assay involves standardised pre-treatment of samples or sample extracts designed to reveal PFAS not identifiable by standard analysis. It has been used for water samples and extracts including soil, biota, firefighting foam products and wastes. The pre-treatment step consists of oxidant digestion under strong alkaline conditions at 85°C for 6 hours. The digestion converts previously undetectable PFAS to PFCA and PFSA. Treated samples are then neutralised and analysed via LC-MS/MS. The process enables detection of the component previously not available for analysis.

As for TOF Assay, similar results would indicate absence of substantial precursors whereas a large divergence in results would suggest that there are large quantities of precursors present that the standard analysis does not detect.

Unless there are adverse matrix effects or the need to dilute samples, as in the case of firefighting foam samples, the LOR achieved by TOP Assay is generally similar to standard analysis.

As transformation processes in the environment may differ from laboratory-simulated oxidation, the laboratory results may not necessarily align with the environmental end point. For example, it is possible that in the laboratory, some PFSA precursors oxidise to PFCA, whereas in the environment, they would transform to PFSA.

The TOP Assay relies on sufficient oxidation, so an oxidation validation should be included. Absence of fluorotelomers in TOP Assay results is an indicator of full oxidation. Laboratories find it helpful if the nature of the sample can be advised, e.g. product concentrate, groundwater, mixed with organic waste.

Inter-laboratory studies have found that applying the original method developed by Houtz and Sedlak (2012) without modification may lead to insufficient oxidation for samples with high organic content or high concentrations of PFAA precursors[76]. Consequently, some laboratories have developed modified methods.

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[76] For an in-depth discussion see Ventia (2019).

19.3.2 TOF Assay

TOF Assay analysis is useful when there is uncertainty as to whether the USEPA methods adequately measure all the PFAS likely to be present. Examples include contamination where the PFAS product composition is unknown and where known PFAS composition extends beyond the USEPA suite; and where there is likely to be some transformation of PFAS or where the precursors are unknown. In an immediate spill, it provides information on whether precursors are present and informs risk management of precursors, e.g. whether the environment is oxidative and whether might remediation might transform them.

Where the oxidation process in the environment is different from the laboratory simulated oxidation, the results from the laboratory will not represent what is occurring in the environment. A precursor standard should be included to demonstrate oxidation is complete.

The TOF Assay is not specific to chain length or PFAS precursors or end point compounds; it is an estimate of the total organic fluorine content in a sample.

is derived from the isolation of organofluorine compounds with activated carbon and subsequent measurement of fluorine by combustion ion chromatography. The technique cannot be used to determine the approximate carbon chain length of precursors as it relies on comparing the mass of fluorine present in a standard analysis for PFAS with the mass found in the TOF Assay analysis. Similar results indicate the absence of substantial precursors, whereas a large divergence in results suggests that large quantities of precursors are present that the standard analysis does not detect.

The TOF Assay has a significantly higher limit of reporting (LOR) when compared to that usually available with the TOP Assay and hence may not be suitable with low screening levels. However, it may be a helpful screening tool for higher impact source zones and circumstances where information on the approximate carbon chain length is not required; an understanding of the amount of precursors may be sufficient.

The TOF Assay can also be used to check the degree to which TOP Assay analysis accounts for potential precursors, noting that any PFAS with a carbon chain length shorter than C4 and longer than C14 would be missed by either TOP Assay or standard LC-MS/MS analysis.

19.3.3 Interpreting results

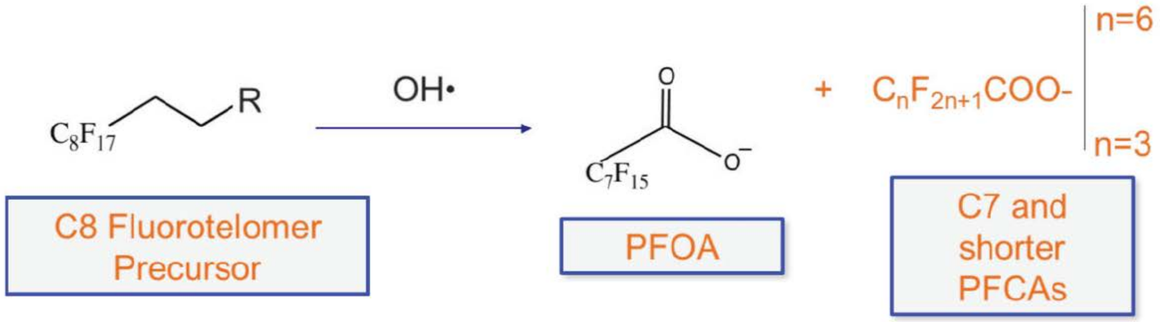
The TOP Assay and TOF Assay analyses are useful for making comparisons with the standard LC-MS/MS analysis results to ascertain the relative degree to which precursors may be present. They help answer the question: are precursors present in the sample? The TOP Assay provides further additional insights about the nature of the precursors not available with TOF Assay. Below are some important points concerning the use of total PFAS measurement methods like TOP Assay and TOF Assay:

- Oxidation via TOP Assay is not equivalent to the process or the rate of oxidation in the environment.
- For an old contaminated site, if all possible oxidation has already occurred, the TOP Assay and standard analysis should yield similar PFAS levels. If there is a difference, this would suggest that the environmental oxidation process is slow and the rate of transformation is likely to remain slow provided the environmental conditions remain the same.
- Legacy contamination and new spills are not equivalent. A new spill may benefit from TOP Assay as no oxidation in the environment has yet occurred.

- Risk assessment of precursors requires consideration of where they are found, with different risks related to presence in sources zones, pathways and at receptors[77].

For PFCA precursors such as fluorotelomers, the TOP Assay oxidation generally follows what happens in the environment. It converts precursors to a range of PFCA with some partial de-fluorination, which creates a result that includes some slightly shorter chain PFAS products, as shown in Figure 6.

Figure 6. Example of PFCA precursor oxidation in the TOP Assay



In contrast, PFSA precursors oxidise to an equivalent carbon chain length PFCA in the digestion, as shown in Figure 7. This differs from oxidation in the environment where they would transform to the equivalent PFSA. For example, a PFHxS precursor in the TOP Assay digestion would oxidise into PFHxA rather than PFHxS, as would occur in the environment.

Figure 7. Example of PFSA precursor oxidation in the TOP Assay

As can be seen, the TOP Assay transforms both sulfonamide and fluorotelomer precursors to carboxylate, while sulfonamide precursors are more likely to form perfluoroalkyl sulfonates when transformed by biological processes in the environment, or *in vivo* if ingested.

A technique used to infer prediction of eventual transformation end products relies on the finding (Martin et al 2010) that PFAS produced by ECF process contain both linear and branched isomers, whereas those produced by telomerisation contain no branched perfluoroalkyl chains.

These differences can be detected if the quantification of PFASs uses both branched and linear isomeric analytical standards of perfluoroalkyl carboxylates in the analysis.

If an increase in branched perfluoroalkyl carboxylates is found in the TOP Assay results, an inference can be drawn that the precursors are likely to form perfluoroalkyl sulfonates. Conversely, if only linear perfluoroalkyl carboxylates are found, perfluoroalkyl carboxylate precursors can be inferred.

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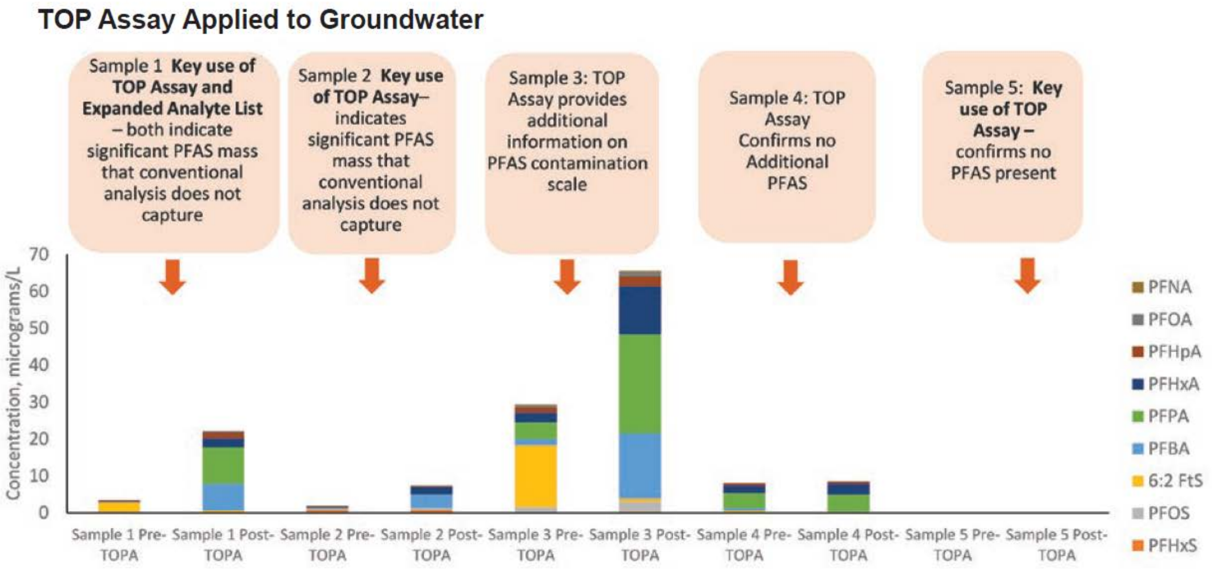
[77] Precursors have been found to oxidise into PFAA in receptors, including when taken up into plants (Zhao et al 2018) and when fish are exposed to them (Chen et al 2015).

Finally, the digestion occurs over a number of hours in the laboratory, compared to a wide range of rates environmentally, depending upon conditions, which will also increase the difference between laboratory and environmental samples.

Figure 8 illustrates possible different outcomes of TOP Assay analysis for contrasting cases, including where significant precursors are present, where there is no additional PFAS resulting from precursor oxidation and where there is no PFAS (including precursors) present.

Figure 8. TOP Assay applied to groundwater



Source: Courtesy Erica Houtz, 2017

Another broad-brush assessment approach would be to look at the approximate carbon chain length and use this information to infer which aspects of the environment that PFAS tend to accumulate in. For example, longer carbon chain precursors (>C7) would present more of a bioaccumulation risk to animals, and shorter chain to plants (refer Martin *et al* 2003 and Blaine *et al*. 2014).

20 Future work

The NEMP work program is organised into six themes to focus resources and expertise and drive progress on the main priorities for environmental regulation and management of PFAS contamination. The NCWG works in partnership with researchers, industry, and other external partners to address common priorities within these themes.

20.1 Theme 1 - The PFAS chemical family

This theme includes, for example, activities to progress validation of analytical methods including TOPA, additional guidance on sampling and the analysis of PFAS other than PFOS, PFOA and PFHxS, and consideration of the need for additional advice on PFAA precursors.

20.2 Theme 2 - Environmental data and monitoring

This theme includes, for example, activities to progress ambient monitoring and data sharing.

20.3 Theme 3 - Water

This theme includes, for example, activities to progress the development of ecological guideline values and underpinning research, additional guidance on managing PFAS in wastewater including biosolids, wastewater treatment effluent and groundwater, and further guidance on the importance of considering bioaccumulation in risk assessment.

20.4 Theme 4 - Soil

This theme includes, for example, activities to progress the further development of indirect and direct ecological guideline values for soil, PFAA behaviour and the influence of soil chemistry, and guidance on managing PFAS in soil, such as potential criteria for reuse of soil.

20.5 Theme 5 - Resource recovery and waste management

This theme includes, for example, activities to progress the development of additional guidance on managing PFAS in resource recovery for non-organic and organic waste, and sampling of unusual matrices including those found in construction waste.

20.6 Theme 6 - Site-specific application of the NEMP guidance

This theme includes, for example, activities to progress guidance on site assessment, remediation and treatment trials, site prioritisation, sampling, and on-site containment.

21 Review

The NEMP is a living document designed to reflect the current state of knowledge. It will be updated regularly to reflect new scientific evidence and guidance.

21.1 Informal review

The NCWG, in consultation with other working groups appointed by HEPA, will:

- monitor PFAS research and information
- monitor relevant developments in other national frameworks and policy processes
- consider lessons learned from NEMP implementation
- consider the outcomes of the future work listed in Section 20
- engage and consult with stakeholders
- provide recommendations to HEPA on proposed updates

21.2 Formal review

The NEMP will be subject to a formal review every five years, with the first formal review due in 2023.

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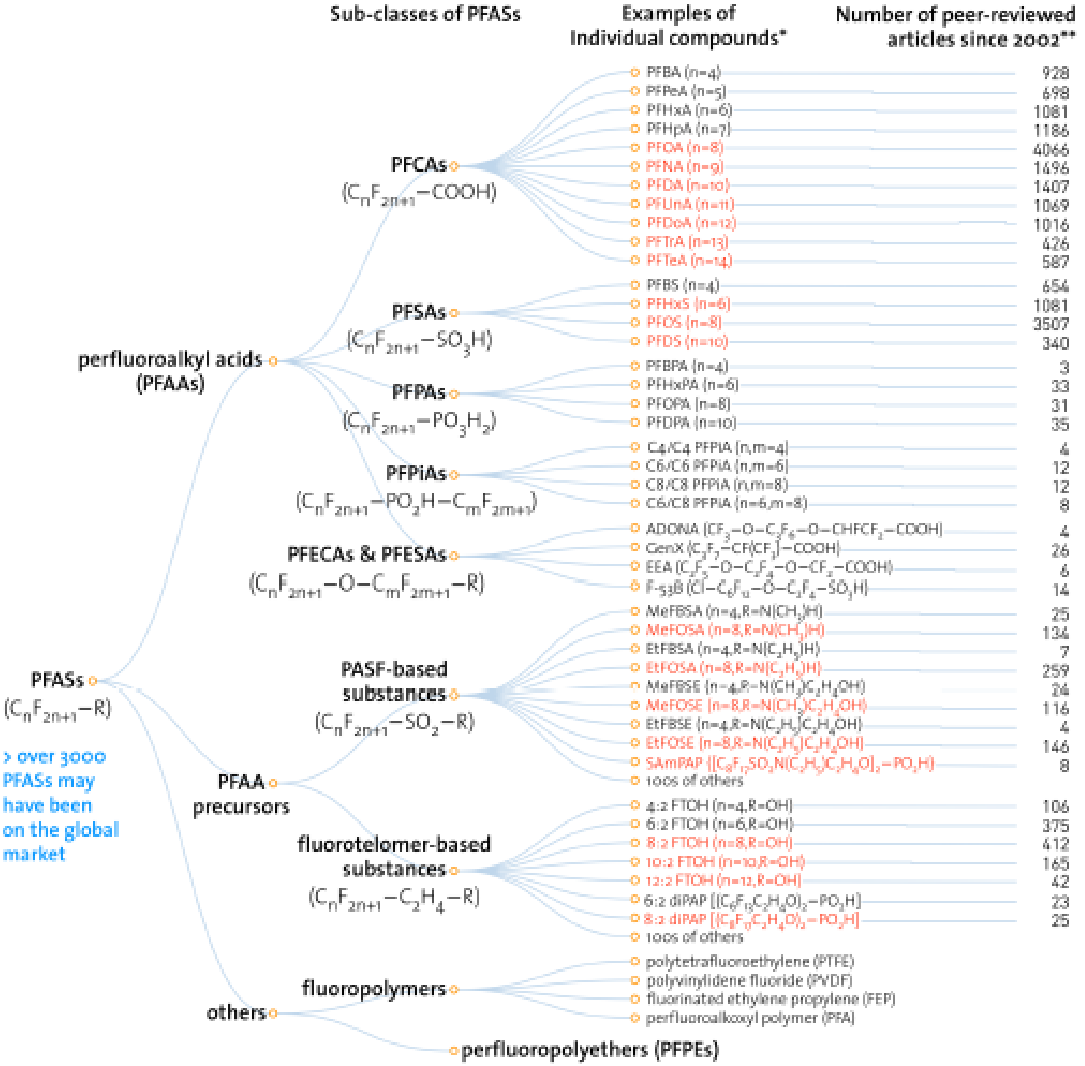
Appendix A. The PFAS chemical family

For detailed information about the PFAS compounds on the Australian Inventory of Chemical Substances see www.nicnas.gov.au.

Figure A1. The PFAS chemical family with examples of individual compounds



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* PFASs in RED are those that have been restricted under national/regional/global regulatory or voluntary frameworks, with or without specific exemptions (for details, see OECD (2015), Risk reduction approaches for PFASs. http://oe.cd/1AN).

** The numbers of articles (related to all aspects of research) were retrieved from SciFinder® on Nov. 1, 2016.

From Wang et al (2017). See also Buck et al (2011), ITRC (2018), and OECD (2018).

Table A1 Common PFAS abbreviations

Sub-classes	
FTS	fluorotelomer sulfonate
PFAA	perfluoroalkyl acid
PFCA	perfluorocarboxylic acid
PFSA	perfluoroalkane sulfonic acid
PFSAs	
PFBS	perfluorobutane sulfonic acid
PFDS	perfluorodecane sulfonic acid
PFHxS	perfluorohexane sulfonate, or perfluorohexane sulfonic acid
PFHpS	perfluoroheptane sulfonate
PFOS	perfluorooctane sulfonate, or perfluorooctane sulfonic acid
PFPeS	perfluoropentane sulfonic acid
PFCAs	
PFBA	perfluorobutanoic acid
PFDA	perfluorodecanoic acid
PFDoA or PFDoDA	perflurododecanoic acid
PFHpA	perfluoroheptanoic acid
PFHxA	perfluorohexanoic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoate, or perfluorooctanoic acid
PFPeA	perfluoropentanoic acid
PFUnA or PFUnDA	perfluoroundecanoic acid
PFTeDA	perfluorotetradecanoic acid
PFTrDA or PFTriDA	perfluorotridecanoic acid
FTSs	
N:2 FTSAs	N:2 fluorotelomer sulfonic acids
4:2 FTS	1H,1H,2H,2H-Perfluorohexanesulfonic Acid
6:2 FTS	1H,1H,2H,2H-Perfluorooctanesulfonic Acid
8:2 FTS	1 H,1H,2H,2H-Perfluorodecanesulfonic Acid
10:2 FTS	1H, 1H, 2H, 2H-perfluorododecane sulfonate
Other	
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid
11CL-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
ADONA	4,8-dioxa-3H-perfluorononanoic acid
HFPO-DA	hexafluoropropylene oxide dimer acid
FOSA or PFOSA	perfluorooctane sulfonamide
N-EtFOSA	N-ethyl perfluoro-1-octane sulfonamide
N-EtFOSAA	N-ethyl perfluorooctanesulfonamidoacetic acid

N-EtFOSE	2-(N-ethylperfluoro-1-octane sulfonamido)-ethanol
N-MeFOSA	N-methyl perfluoro-1-octane sulfonamide
N-MEFOSAA	N-methyl perfluorooctanesulfonamidoacetic acid
N-MeFOSE	2-(N-methyl perfluoro-1-octane sulfonamido)-ethanol

Appendix B. Activities associated with point sources of PFAS contamination

Tables B1 and B2 identify activities associated with PFAS contamination, with a focus on primary and secondary sources.

Table B1. Activities associated with PFAS contamination due to a risk of fire

Activity	**Description**
Airports and aviation infrastructure	On-site firefighting - see also further information below
Aluminium production	On-site firefighting
Battery production	On-site firefighting- see also further information below
Bitumen production	Kerosene use and storage
Brewing, distilling and refining	Ethanol production
Coal works	On-site firefighting
Dangerous goods production	On-site firefighting - likely to use specialised firefighting products and systems due to the presence of a range of hydrocarbons, polar solvents etc.
Explosives production	On-site firefighting - explosions
Food production	On-site firefighting associated with use of bulk oils and solvents - see also further information below
Fuel exploration, assessment, production, transport and storage including petrochemicals, other fossil fuels and renewable liquid fuels	On-site firefighting, also used as a surfactant for gas well stimulation
General chemical storage	On-site firefighting - likely to use a range of hydrocarbons, polar solvents etc.
Generation of electrical power	On-site firefighting - see also further information below
Hardware retailers	Firefighting foam deluge systems - see also further information below on the construction industry
Mining	On-site firefighting
Paints, polishes, adhesives production	On-site firefighting- see also further information below
Petroleum products other than fuels	On-site firefighting, potential use in processing
Underground infrastructure including car parks and tunnels	Firefighting foam deluge systems

Table B2. Activities associated with PFAS contamination more broadly

Activity	**Description**
Agriculture	Potentially used as an adjuvant or active ingredient in fertilisers and pesticides, firefighting foam used in the poultry industry to destroy infected flocks
Automotive industry including retailing, detailing and car wash facilities	Surface treatments including polishing, cleaning, stain and water protection products, lubricants, hydraulic fluids, tubing, oil pan, head gaskets, sealant, wire and cabling, fire retardant and metal plating applications
Aviation, aerospace and defence	As for automotive industry plus aviation-specific products, articles and activities, such as aviation hydraulic fluid
Battery use and disposal	Used in batteries, particularly for high-end use such as lithium-style batteries
Boating and marine supply industry	As for automotive industry plus marine-specific products, articles and activities, such as awnings, painting, waterproofing and sealant applications, and shipboard firefighting
Chrome/metal plating industry	High concentration PFAS mist suppressants used to reduce chromium exposure to workers
Commercial laundries and dry cleaners	Effluent from cleaning of fabrics containing or treated with PFAS
Construction industry	Tile coatings, stone coatings, paints, varnishes, sealants, other architectural coatings for films, facades and infrastructure, rigid foams, silicone rubber, thread sealant tapes and pastes and PPE
Electricity, telecommunication and information technologies	Wireless devices, hard drives, fibre optic cables, dirt-repellent coatings on glass surfaces such as smartphone screens, flame-resistant devices, fittings, coatings and wrappings, semiconductor etching, firefighting at electricity generation sites and in electricity distribution networks with oil-containing equipment such as transformers, reactors, large regulators, circuit breakers, pipe-type cable systems and bulk storage tanks, reported to be in high-end lithium batteries
Firefighting and fire protection sales and services	Storage and disposal of large quantities of firefighting foam associated with formulation, transport, sale and servicing of firefighting and fire protection products and services including refurbishment of deluge systems and fire extinguishers at fire protection retailers, rural supply stores, council depots and outstation service centres
Manufacturing of building products	As for construction industry
Manufacturing of chemicals, fertilisers and pesticides	Equipment and fittings including pipes, tanks and valves, use as an intermediate in the production of other substances, potentially used as an adjuvant in fertilisers and pesticides

Manufacturing of food, food packaging and food preparation products	Baking paper, aluminium foil, fast food wrappers, non-stick equipment including food processing facility surfaces, pipes, tanks and valves, and firefighting especially at facilities where bulk oil is used
Manufacturing of healthcare products	Surface protection for medical garments, small quantities in X-ray film, charged-coupled devices (CCDs), artificial blood, flexible tubing, needle coatings, denture cleaners, potentially in contact lenses
Manufacturing of household appliances	Heaters, heat lamps, irons, stoves, refrigerators, other flammable components, and high-end (lithium) batteries
Manufacturing of personal care products	Cosmetics, shampoo, shaving cream, dental floss, sunscreen, nail polish, talc, lotions
Manufacturing of textiles, leather, upholstery, carpets, clothing, shoes, outdoor gear	Widespread use of fluorinated compounds to provide stain, water and fire protection
Manufacturing of safety gear	Widespread use of fluorinated compounds to provide stain, water and fire protection for Personal Protective Equipment (PPE) and bulletproof clothing
Manufacturing of paints, polishes, coatings and adhesives	Historically used in sealants, adhesive products, coatings, paint and varnishes
Manufacturing of paper or pulp	Used in internal and surface sizing agents for paper manufacturing
Printing, packaging and merchandising	Used to apply grease, oil and water resistance to packaging product, also used in inks particularly for inkjet and photo printing
Recovery of waste oil	Collection and processing of PFAS-containing waste oil
Soap and detergents production	Household goods such as shampoos and cosmetics, commercial and industrial cleaning products such as floor polishes and vehicle cleaning agents
Solar energy	Used in photovoltaic solar cells to repel dirt and in lithium batteries
Sporting goods manufacturers and suppliers and sports facilities	Ski wax, high performance textiles including outdoor clothing, water-resistant treatments
Waste processing and disposal	PFAS-containing solid and liquid waste and leachate in landfill, high temperature incineration, chemical and other treatment regimes
Waste storage - hazardous, restricted solid, liquid, clinical, asbestos waste	On- and off-site storage and/or collection of waste PFAS-containing products
Wastewater treatment	Inputs from domestic sewage and commercial and industrial wastewater and outputs applied to land or discharged to the environment

Appendix C. Treatment technologies potentially available in Australia

Table C.1 provides a summary of PFAS treatment technologies which may be available in Australia, adapted from the following documents:

- Australian Government Department of Environment and Energy (DoEE), 2016. Draft Commonwealth Environmental Management Guidance on Perfluorooctane Sulfonic Acid (PFOS) and Perfluorooctanoic Acid (PFOA). October 2016.
- Government of Western Australia Department of Environment Regulation (DER), 2017. Interim Guideline on the Assessment and Management of Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) - Contaminated Sites Guidelines. Version 2.1, January 2017.

The PFAS treatment technologies listed below includes technologies that may be at the experimental, proof of concept and field trial stages. As such, this list has not taken into account commercial availability or feasibility, and does not imply regulatory endorsement of the technology or process. The available treatment technologies, disposal options and associated regulatory requirements may vary in each jurisdiction.

Table C1. PFAS treatment technologies which may be available in Australia

Process	**Definition**	**Australian example**	**Media**
Destruction or transformation			
In-situ oxidation or reduction	Application of chemicals and often heat to break down the PFAS into more environmentally friendly forms	Current trial	Soils and groundwater
Pyrolysis and oxidative thermal destruction	Alteration of chemical composition using high temperature in the absence or presence of oxygen	High temperature plasma arc, cement kilns and medical waste treatment facilities - current and proposed trials	Soil, aqueous film-forming foam concentrates, solid concentrates from adsorption, liquid concentrates from reverse osmosis, nanofiltration and ion exchange
Ultrasonication/ sonochemistry	Treatment using intense ultrasonic- wave energy to change the PFAS compounds into more environmentally friendly forms.	Current trial	Water and wastewater
Electrochemical oxidation/reduction	Defluorination of PFAS using electrodes	Current trial	Water and wastewater
Separation and concentration			

Adsorption (stabilisation/ immobilisation)	Adhesion of PFAS to the surface of an adsorbent	Activated carbon (powdered or granular), resins, ion exchange polymers, proprietary adsorbents	Water and wastewater
Foam fractionation/ separation	Separation of PFAS from groundwater and wastewater into a foam.	Current trial Currently in use (wastewater)	Surface, groundwater and wastewater
Reverse osmosis and nanofiltration	Removal of PFAS from water using semi-permeable membranes	Various systems available Currently in use (wastewater)	Water and wastewater
Thermal desorption	Separation of PFAS from solid materials using high temperatures to increase the volatility of the PFAS	Indirect and direct-fired thermal desorption	Soil and waste
Stabilisation and immobilisation			
Binding	Addition of a binding agent to soil to reduce the mobility of PFAS	Activated carbon (powdered or granular), resins, proprietary adsorbents	Soil and waste

Appendix D. Example PFAS Management Framework for a Water Utility

This deliberative document provides initial sample text to illustrate the key elements of a potential PFAS Management Framework that could be applied by a wastewater utility. It includes references to a model wastewater utility, Example Water, and a model regulator, Example Environment Protection Authority, which are not intended to represent or resemble any specific organisation. As it is not possible to reflect the situation of every wastewater utility in one example framework, it will need to be adapted to address differences such as scale. The text in square brackets is example text provided for readability purposes.

The example framework is not intended to be used as an enforcement tool but to provide an overview of potential considerations in the development of such a PFAS management framework. Any legal implications of development and implementation would need to be scoped on a case by case basis and are not considered further here.

It is acknowledged that some water utilities may have already undertaken extensive PFAS risk assessment and/or sampling. Water utilities should consider the need for a PFAS Management Framework on a case by case basis accordingly.

The environmental regulator, along with other regulators where relevant, should be consulted for details of the specific requirements, guidelines and criteria applying in each jurisdiction. Where the example requirements, guidelines and criteria referenced here differ from those set by jurisdictions, the latter will take precedence.

1. Introduction

Example Water (EW) acknowledges that the sound environmental management of per- and poly-fluoroalkyl substances (PFAS) in wastewater is an important responsibility.

This responsibility arises from the risks and uncertainties that science has identified regarding the mobility, persistence and effects that PFAS has on environmental values, also known as beneficial uses[78] or community values. Protection of environmental values, including freshwater and marine animals (such as air breathing mammals) as well as other wildlife, is important to EW and to the whole community.

This framework sets out the key elements of effective management of PFAS in wastewater. It focuses on EW’s core business of delivering wastewater services to the Example Region in order to maintain and improve quality of life for the community while protecting the local environment and beyond.

2. Governance

The [EW Board and senior leadership] have endorsed this framework as the authoritative reference for managing PFAS across EW’s operations.

The PFAS National Environmental Management Plan (NEMP), agreed by all Australian environment ministers, provides the expert guidance that underpins this framework. The framework is consistent with the [Month Year] version of the NEMP and will be reviewed within three months of any subsequent version being published.

The Example Environment Protection Authority (EPA) is the authority providing ongoing advice and direction on the NEMP, its application and any other PFAS management requirements within Example Jurisdiction[79].

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[78] This term is separate from beneficial reuse.

[79] This term covers the relevant Commonwealth, state, territory and environment agency/authority as appropriate.

3. Purpose

The purpose of this framework is to support the sustainable management of PFAS across EW's operations and to ensure that EW is well positioned to anticipate and respond to PFAS-related issues.

The outcomes sought from implementing this framework include:

- All relevant legal and regulatory requirements are met.
- Consistency with the NEMP is achieved.
- The health and safety of staff, customers and the general public are protected.
- The ecosystem function, biodiversity, and amenity of receiving environments are protected.
- The condition of wastewater treatment infrastructure and processes are maintained across the life cycle, including:
  - the ability to produce outputs acceptable for disposal and reuse and
  - affordable disposal of infrastructure at the end of its working life.
- The costs for acceptance of trade waste are appropriately understood and recovered.

4. Scope

This framework applies to all of EW's operations and services where PFAS inputs are to be managed. It addresses PFAS management at all stages of the wastewater treatment life cycle including:

- Input stage - including trade waste and domestic waste
- Processing stage - including infrastructure and biological treatment systems
- Output stage - including products for beneficial reuse

5. Risks

The following identification of the risks for EW that may be linked to PFAS in wastewater is consistent with guidance provided in the NEMP and additional advice from EW's industry partners and regulators, including the Example Jurisdiction EPA and the Example Jurisdiction Department of Health.

Recognising that scientific knowledge on PFAS is rapidly evolving, this is a point in time assessment as at [Month Year]. It will be regularly reviewed and updated in accordance with EW's corporate risk management processes.

5.1 Risk sources

The key source of risk addressed by this framework is the release of PFAS into the EW sewage network.

PFAS is known to be released constantly into Australian sewage networks at a relatively low background level due to a wide range of domestic[80] and non-domestic activities. Consequently, the identification and prioritisation of risk sources is an important step in focusing control efforts on significant and readily actionable controls at the sources. At present there is limited evidence on the sources of PFAS in wastewater. Some Australian data

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[80] PFASs are present in a wide range of products. Other national processes outside of the PFAS NEMP are looking into options to reduce any environmental and human health risks associated with this. One such process is the development of a National PFAS Position Statement.

indicates that trade waste from certain high risk activities is likely to be a significant source of PFAS in wastewater, particularly for substances such as PFOS that are thought to be no longer in general use. Relevant management actions to address PFAS risks in relation to trade waste are discussed below in Section 7.1.

The flow of PFAS through the wastewater system results in chronic contamination of wastewater infrastructure and the release of a mass load of PFAS, contributing to chronic exposure in the receiving environment. Day-to-day flows are the key sources of PFAS risk. In addition, temporal and spatial fluctuations in PFAS concentrations above this level, including peak events, can occur due to the use or handling of PFAS-containing products such as foam suppressants or aqueous film forming foam (AFFF)[81] by specific businesses. The resulting additional quantities may impact the effectiveness of biological treatment processes and other aspects of WWTP operations, and environmental risks associated with the release of an increased mass load of PFAS (and potentially an increased PFAS concentration, depending on the management measures applied). An important consideration in relation to all of these PFAS risks is the significant uncertainties regarding the behaviour of PFAS, including the scientific evidence that PFAS precursors in WWTP influent may transform into persistent PFAS end products in effluent and biosolids.

The geographical distribution of PFAS use is an important consideration. Businesses using firefighting foam, like most other types of businesses linked to high volume PFAS releases, are likely to be located in industrial areas. However, it is important to take into account that some businesses that use or handle high volumes of PFAS-containing products, possibly including car washes and laundries, are likely to be located in residential or commercial areas.

5.2 Risk assessment

The following model assessment of risks (Table D.1) is a high-level summary to inform detailed risk assessments for each wastewater treatment plant (WWTP) with its catchment area. It will be updated with additional information as these detailed risk assessments are developed.

Table D1. Example WWTP risk assessment

Example WWTP risk assessment		
Hazardous event	Risk type	Consequence
Staff health and safety at risk due to elevated PFAS within sewage network including WWTP	WHS/OHS	Psychological distress Potential harm to health
Environment at risk from elevated PFAS in discharged effluent or any other emissions from WWTP	Environmental	Environmental harm
Beneficial reuse of effluent/recycled water affected due to elevated PFAS	Health Environmental Financial	Potential harm to health Environmental harm Financial costs

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[81] Over the past two decades, a widespread transition away from the use of PFAS-containing firefighting foam has taken place. However, some organisations have advised EW that PFAS-containing firefighting foam is still in use. Firefighting foam also contains a range of other substances that may pose a risk to WWTP biological treatment systems and to the environment.

Example WWTP risk assessment		
Hazardous event	Risk type	Consequence
Beneficial reuse of biosolids/sludge affected due to elevated PFAS	Health Environmental Financial	Potential harm to health Environmental harm Financial costs
Biosolids/sludge disposal to landfill or other disposal method affected due to elevated PFAS	Health Environmental Financial	Potential harm to health Environmental harm Financial costs
Cost and/or feasibility of infrastructure disposal at end of life affected due to elevated PFAS	Financial	Financial costs Logistical burdens
Reputation and/or regulatory compliance affected due to elevated PFAS	Reputational Legal	Financial costs Reputational harm

5.3 Risk prevention

The preventative measures identified to address these hazards are described in subsequent sections of this framework. The primary focus of risk prevention activity will be on minimising the key source of risk identified above, i.e. the release of PFAS into the EW sewage network.

6. Monitoring and analysis

Monitoring of PFAS levels through systematic, catchment-based sampling and analysis is a critical element of responsive management to address PFAS in wastewater. The levels and types of PFAS in wastewater provide a starting point to identify sources, risks and potential management actions for each wastewater catchment.

The monitoring program has been designed in consultation with the Example Jurisdiction EPA to align with the guidance in the NEMP. The aim is to generate a representative picture of PFAS and its potential impacts across EW's operations to inform preventative action.

6.1 Sampling

The sampling strategy targets relevant media. The following locations will be considered:

- influent from high-risk trade waste (and potentially other commercial) premises
- influent in the sewage network, stratified to separately identify sewage from domestic, general non-domestic and industrial catchments
- effluent at critical control points within WWTPs
- treated effluent and any other emissions discharged to the environment
- WWTP products for beneficial reuse prior to sale
- sites where beneficial reuse products have been used in the environment.

The sampling strategy, including the laboratory analytical methodology, for PFAS data is consistent with the NEMP and additional guidance issued by Example Jurisdiction EPA. The Example Jurisdiction EPA guidance requires testing for a standard set of 28 analytes comprising perfluoroalkyl acids (PFAAs) and selected PFAA precursors at a level of resolution relevant to the environmental values being protected. In addition, summative measures and holistic analytical methods, such as Total Oxidisable Precursor Assay (TOP Assay) and non-target analysis, are used as required by regulators and to build a weight of evidence understanding of total PFAS loads and associated transformation within the sewage network.

Whenever possible, data held by EW on PFAS in wastewater is shared with the Example Jurisdiction EPA and the research community as a contribution to the scientific understanding of PFAS in the environment across Example Jurisdiction. Quality control and customer privacy protection procedures are applied before any PFAS-related data is released.

6.2 Catchment-based monitoring and analysis

For each WWTP managed by EW, the background levels of PFAS and patterns of variation over time are characterised. This may include using 24-hour composite influent samples collected as part of routine monitoring for higher risk WWTPs. Consideration is also given to the influence of seasonal and day-to-day weather patterns, with supplementary data collected as needed if there are concerns about the quality and representativeness of the data originally collected.

WWTP monitoring data is supplemented with PFAS monitoring data from the upstream sewerage network. This consists of targeted sampling at junction points proceeding upstream along major sewerage lines to discharge points from specific areas of interest such as residential suburbs, industrial estates, landfills etc. As well as providing a general catchment-wide understanding of PFAS contamination, the analysis of upstream sampling will also assist EW to identify and work with industries and specific customers to address higher-risk PFAS contamination in trade waste discharges.

The WWTP and sewerage network data are then combined and analysed to improve the understanding of PFAS inputs and behaviour for each catchment and for prototypical urban, peri-urban and rural catchments within EW's service area. Further work will look at specific areas of interest such as [the major industrial estate at Example Meadows]. Data from ongoing monitoring is fed into the analysis to better understand PFAS trends over time including identification of improvements delivered by EW's targeted PFAS management activities.

7. Input stage

For the input stage of the wastewater system, the main PFAS intervention is source control. As well as standard measures to control known sources of contamination, such as trade waste agreements, EW recognises that customers often may not know that their premises are discharging PFAS to the wastewater system. EW will cooperatively work with customers to identify and address sources of unintentional and legacy PFAS pollution.

7.1 Trade waste controls

The initial focus of work for the input stage will be working with trade waste customers, i.e. trades, businesses, and manufacturing sites, to identify and manage PFAS in trade waste.

Trade waste customers are responsible for managing PFAS in trade waste in accordance with the requirements set by EW and by relevant legislation or policies. The specific authority for EW to require its customers to take action on environmental contaminants, including PFAS, is established by the *Wastewater Act 2020* (Example Jurisdiction).

Customers are encouraged to raise any queries with EW about the availability of, and the conditions for, acceptance of PFAS-containing trade waste, and any concerns associated with the effect of this framework on their individual trade waste agreement. EW will also draw on guidance in the NEMP to proactively identify and engage with industries, and specific customers, identified as being at risk of discharging PFAS to trade waste.

Key industries with the potential to be significant sources of PFAS in trade waste include:

- airport operations
- landfill operations

- liquid waste collection and treatment operations (including tanker operations)
- aerospace, aviation and defence manufacturers and processors
- metal manufacturers and processors
- textile manufacturers and processors
- paper manufacturers and processors
- chemical manufacturers and processors
- vehicle manufacturers
- car retailers, car detailers and car washes
- commercial laundries and dry cleaners

As outlined in the EW Trade Waste Management Plan, EW may use any or all of the following tools to support the appropriate management of PFAS by trade waste customers:

- trade waste agreements for customers with routine needs
- trade waste audits to identify issues
- trade waste improvement plans for customers with identified issues
- compliance orders for customers with recurring breaches
- potential withdrawal of trade waste services as a last resort.

Where potentially significant sources of PFAS are identified, EW will aim to work with affected customers to ensure trade waste discharge is consistent with the customer's trade waste agreement and EW's trade waste management policy. For significant or complex issues, is likely that customers will need to seek professional advice from a consultant with specific expertise in PFAS management.

The risk of accidental PFAS contamination events, discharging significantly elevated levels of PFAS in the wastewater system, is not covered by the routine control measures described above. Consequently, EW also requires all trade waste customers who use or generate substances high in PFAS, such as fume suppressants, firefighting foam concentrate, foam and associated firewaters, to have measures in place to prevent these substances entering the wastewater system. A range of enforcement measures are employed to ensure compliance with these conditions, such as unannounced site visits and effluent sampling. EW recognises that not all emitters of PFAS contamination hold trade waste licenses. EW will work with its customers, experts and regulators to identify risks associated with accidental PFAS contamination events and ensure measures are implemented to anticipate and manage any issues in this regard.

7.2 Domestic controls

The role of domestic wastewater as a vector for PFAS, mainly from consumer products[82], is also recognised. However, in the short term, there is limited opportunity for EW or its domestic customers to identify or control PFAS in consumer products. The manufacturers and suppliers of consumer products, and the manufacturers and suppliers of the chemicals included in these products, bear the primary responsibility for taking action to reduce the levels of PFAS reaching domestic wastewater.

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[82] For legacy PFASs of high concern, such as PFOS, PFOA and PFHxS, domestic wastewater may not be a major source, although this is yet to be confirmed by field data. For PFAS still on the market in consumer products, however, domestic wastewater is highly likely to be a major source.

In the meantime, EW will draw on data from its monitoring program to build a better understanding of the contribution of domestic wastewater to the burden of PFAS, including temporal and spatial variation, PFAS types and total PFAS load. This data will contribute to assessment of the risks arising from this source and the identification of possible management responses.

In consultation with the Example Jurisdiction EPA, EW will actively consider the suitability of new technologies and any other opportunities that may arise to assist with controlling PFAS in domestic wastewater.

8. Processing stage

For the processing stage of wastewater treatment, a range of strategies are being employed to better understand and manage PFAS impacts. [Further details of the measures planned and in place at each WWTP are provided in the WWTP Environmental Management Plans which are available on the EW website].

Routine monitoring, as described above, is a critical element of managing PFAS risks in the processing stage. It provides the baseline data enabling EW to understand PFAS flows through its systems under business as usual conditions and to identify significant deviations from these patterns. This in turn informs follow-up actions such as cost recovery from polluters to cover the costs of measures such as additional environmental sampling, diversion of effluent, and environmentally sound disposal of PFAS-contaminated material that would otherwise go to beneficial reuse. Over the longer term, EW will draw on routine monitoring to identify any emerging trends in PFAS levels within the processing stage of its operations.

As limited information is currently available to inform action at the processing stage to address the chronic risks associated with the day to day flow of PFAS, a key focus for the first phase of this work is addressing the acute risks to wastewater processing that may arise from short-term pulses of elevated PFAS, such as major contamination events. This is discussed in more detail below.

EW will continue to work with regulators and experts to review options to better manage PFAS contamination across the board at the processing stage. A key focus for this work will be identifying affordable, efficient and scalable infrastructure or other technologies to control PFAS before it reaches the environment. This consideration will take place in the context of EW's broader capital investment strategy informed by a cost benefit analysis and confirmation of appropriate cost recovery arrangements.

The mix of strategies selected will be consistent with local Example Jurisdiction regulations or policies and may reflect considerations such as:

- protection of the environment
- protection of biological treatment systems[83]
- prevention of contamination that could impact on the cost and logistical burden of appropriate disposal of sewage infrastructure at the end of its working life.

8.1 Managing processing impacts from major contamination events

A key immediate focus for PFAS management in the processing stage is ensuring that EW has robust strategies in place to effectively identify and respond to the impacts of major PFAS contamination events.

The foundation of effective preparation for major PFAS contamination events is maintaining strong working relationships with trade waste customers, particularly those with significant fire

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[83] EW has identified a knowledge gap in relation to the impacts of PFAS, including firefighting foam effluent, on biological treatment systems and is contributing to research on this issue.

protection requirements. This ensures that EW will be immediately alerted to a potential contamination event as soon as it is discovered by the responsible customer allowing EW to immediately implement management actions to minimise impacts on processing, treatment, effluent discharge and beneficial reuse due to elevated PFAS levels.

If a major contamination event does occur, EW will consider the full range of response strategies in consultation with the Example Jurisdiction EPA. Possible strategies, depending on the severity of contamination, could include diversion of PFAS-contaminated wastewater from specific sites or sewer lines, altered processing arrangements within the affected WWTP to prevent or minimise PFAS impacts such as reduced treatment effectiveness, and diversion to environmentally sound disposal or destruction of PFAS-contaminated materials.

9. Outputs stage

The outputs stage of PFAS management is a significant focus for EW, as this is the stage where any PFAS contamination that is not successfully controlled within the wastewater system reaches receiving environments. It is therefore the final opportunity for EW to take action to protect environmental values from any PFAS-related risks.

The management actions to be implemented in this stage are designed to address the risks of PFAS across all WWTP outputs including:

- effluent discharged to fresh, estuarine and marine ecosystems
- recycled water used in the built environment or in products, discharged to stormwater systems, applied to terrestrial ecosystems, or injected into groundwater
- biosolids applied to terrestrial ecosystems or in products
- biosolids disposed to landfill or other forms of treatment such as incineration.

The detailed requirements set by Example Jurisdiction EPA for management of PFAS in effluent, recycled water and biosolids are provided on the EW website and may be updated from time to time.

9.1 Standards and principles

The NEMP provides extensive guidance on managing PFAS in the environment, including standards and criteria for a wide range of PFAS-containing substances to protect environmental values. It also refers to and is consistent with the detailed guidance provided in the National Water Quality Management Strategy and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality on achievement of catchment water quality objectives as they relate to toxicants such as PFAS that may reach aquatic environments.

Although common principles apply across the board to responsible management of PFAS risks at the outputs stage, it is also critical to consider the specific characteristics and values of the receiving environment. EW works closely with the Example Jurisdiction EPA and Parks and Wildlife Services to tailor management actions to ensure these actions are protective of environmental values. EW also works with the Commonwealth Department of the Environment and Energy in relation to Matters of National Environmental Significance.

9.2 Effluent discharged to aquatic ecosystems

The monitoring program described above is the foundation of effective identification and management of PFAS risks in effluent discharged to aquatic ecosystems.

Consistent with the NEMP, EW aims to reduce the concentration and load of PFAS in effluent as low as possible and, in the long term, towards the limit of detection[84] for perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA) and perfluorohexane sulfonate (PFHxS)

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[84] It is noted, however, that due to technical advances the limit of detection may be reduced so low that this is impracticable.

and any other PFAS identified as being of high concern. This reflects the fact that PFAS are anthropogenic contaminants that biological systems, including plants, animals and humans may accumulate and are not adapted to deal with. Consequently, the potential long-term risks of PFAS to the environment and human health are not known.

In practice, EW aims to work towards the reduction of PFAS in effluent over the long term, in partnership with the Example Jurisdiction EPA, other stakeholders and the community, to work towards achieving water quality and environmental management objectives. This level of protection recognises the persistent, mobile and bioaccumulative nature of PFAS consistent with the National Water Quality Management Strategy.

The exception is the Example Bay catchment, where the Example Jurisdiction EPA has set a site-specific guideline value adapted to the environmental values in that catchment.

As discussed above, one option for minimising the level of PFAS in effluent is investing in trialing and implementing effective WWTP-scale treatment technologies as they are introduced to the market place. EW will continue to work with the Example Jurisdiction EPA and industry organisations to consider and evaluate treatment technology options.

9.3 Recycled water used in the built environment or in products, discharged to stormwater systems, applied to terrestrial ecosystems or injected into groundwater

The use of recycled water requires careful management to avoid contamination of sensitive environments or food webs with repeated applications of persistent substances, including PFAS. The standards and criteria provided in the NEMP and the NWQMS for environmental water and water recycling provide the basis for sound management actions.

At present, EW does not direct significant quantities of treated effluent to beneficial use as recycled water. Where recycled water is already being used, EW is working with the Example Jurisdiction EPA to understand PFAS management and impacts on environmental values from recycled water. Options are also being explored for water recycling in several additional locations.

In consultation with the Example Jurisdiction EPA, EW will consider what trials will be conducted before water recycling is rolled out at scale. This may include testing of receiving soils, groundwater and downstream environments for PFAS contamination before the application of recycled water, testing of recycled water, and testing of receiving soils, groundwater and downstream environments after the application of recycled water across several years.

If water recycling is approved as a broadscale use of effluent, ongoing monitoring will be conducted to ensure that its use in this way remains safe. The locations, volumes and monitoring results for recycled water use will be precisely recorded. This will enable the swift identification of and response to any emerging issues.

The use of recycled water in the built environment (i.e. residential, commercial and industrial settings) and the discharge of recycled water to stormwater and groundwater (i.e. aquifer recharge) are not known to occur in EW’s management area. Should these measures be proposed, EW will work with the proponent and the environmental regulator to ensure that the environmental and human health risks of the proposal are carefully assessed, including risks associated with PFAS accumulation at the point of use and in downstream receptors, and that any financial impacts are fully cost-recovered.

The beneficial reuse of recycled water in products, such as soil conditioners, is a matter for the Example Jurisdiction EPA. However, EW recommends against this use.

9.4 Biosolids applied to terrestrial ecosystems or in products

The considerations described above for recycled water regarding transport and dispersal of PFAS contamination also apply to biosolids. Consequently, the standards and criteria provided in the NEMP for direct and indirect soil exposure, and the additional guidance on reuse of soil with low PFAS levels, including PFAS in leachate, should be taken into account for biosolids[85]. Further information and specific criteria are provided [on the EW website] and will be supplemented with additional information under development. This is expected to include a biosolids lifecycle risk assessment and an inventory of PFAS in biosolids produced across the EW WWTP network.

The rationale for requiring management actions for biosolids consistent with the NEMP is the behaviour of PFAS in solid materials such as soil. Although biosolids are intended to remain in the location where they are applied as a soil conditioner, it is well recognised that PFAS leaches out of soil and other solid materials to reach groundwater and aquatic ecosystems offsite. As PFAS behaves differently than other contaminants, existing management controls are unlikely to be sufficient as there is also the potential for a proportion of sedimentary particles from the biosolids to be transported offsite in most receiving environments and these are likely to carry adsorbed PFAS and other contaminants.

9.5 Biosolids disposed to landfill or other disposal

The disposal of biosolids to landfill or other forms of waste disposal is at the discretion of the operator of the waste facility. The NEMP provides further guidance, including national criteria for landfill acceptance of PFAS-containing material. Authoritative guidance, oversight and licensing on this issue is provided by the Example Jurisdiction EPA.

In some locations, EW operates on-site landfills or incineration facilities. These are managed in accordance with the NEMP and all available guidance. For incineration facilities, the combustion temperature and duration required to destroy PFAS is a critical consideration. The incineration facilities operated by EW are licensed to destroy PFAS as they achieve combustion temperatures and durations that are consistent with the current advice provided by the Example Jurisdiction EPA. The beneficial reuse of the outputs from the incineration process is managed in accordance with the guidance on biosolids above.

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[85] Although the PFAS NEMP soil guideline values do not include risks associated with the transport of soil, or of PFAS in soil, to groundwater, surface water or nearby sites, the PFAS NEMP provides extensive guidance on these considerations. Detailed guidance around biosolids and recycled water is planned as future work for inclusion in the next version of the NEMP.

Appendix E. Example stockpiling, storage and containment checklist and framework

Table E1. Example checklist for storage of unused chemicals containing PFAS

Storage of unused chemicals containing PFAS	
Control	Achieved?
Install appropriate signage.	
Store chemicals / unused stocks in accordance with legal requirements.	
Wherever possible, store chemicals under a roof or within a building. Where this is not possible outline the alternative control measures:	
Store in approved containers.	
Provide appropriate secondary containment.	
Prevent rain from entering the bunded area.	
Label containers appropriately as to the contents, relevant inspection dates and relevant instructions on storage and handling including prohibitions on disposal.	
Ensure emergency response documentation is prepared and in place.	
Test Emergency Response Plan.	
Ensure verification of controls by authorities or experts.	
Insert relevant section of NEMP or reference to other legislation for more information and assistance.	

Table E2. Example framework for short-term stockpile management

Short-term stockpile management framework – For temporary storage only - up to 6 months

Risks	Design considerations and management requirements
Permitting and authorisation	Ascertain regulatory status of the proposed activity. Ensure all licenses / authorisations have been obtained prior to commencement, including the landowner's permission.
Health and safety	Determine all exposure pathways for site users and adjacent land users. Ensure adequate space for safe access, loading / unloading and inspection. Ensure compliance with stockpile height and maximum slope angle requirements. Implement demarcation / fencing of excavations, confined spaces, etc. Management measures for specific risks present at site, such as excavations, confined spaces, hazardous atmospheres, working at height, machinery guarding, etc. As relevant, ensure site induction includes instructions on the rules regarding the stockpile for workers and contractors assessing the site.
Contaminant-specific risks	Consider specific properties of PFAS compounds, including: • Transport in soil, water, groundwater • Volatility • Ability to infiltrate liners or clay Consider other contaminants present.
Contamination levels	Ensure PFOS, PFOA or PFHxS content <50 mg/kg – relevant in terms of managing wastes in accordance with the Stockholm Convention on Persistent Organic Pollutants.
Sensitive receptors	Determine whether any sensitive receptors are located on the site, adjacent to the site, or in close proximity. Implement measures to block pathways to sensitive receptors.
Climate – rainfall	Determine whether proposed location is on land prone to flooding, landslips, etc. In high rainfall areas, stockpiles should be protected from rainfall at all times. Avoid temporary stockpiling during rainfall, or when rainfall is likely. Ensure stockpiles are not in stormwater flow paths.
Climate – wind	Characterise the wind direction, speed and frequency at the site. Prevent wind transport of stockpile material.
Discharge to stormwater drains or waterways	Check as-built plans for infrastructure and verify accuracy of the plans. Locate all stormwater drains and waterways prior to planning the location of stockpiles. Protect stormwater drains and waterways from receiving contaminated runoff.
Risk to groundwater	Prevent contamination of permeable substrate. Locate stockpiles away from sensitive groundwater areas.
Any additional requirements.	As necessary for each activity and site characteristic.

Appendix F. Abbreviations and Glossary

Table F1 Abbreviations

See also the list of PFAS abbreviations in Appendix A.

µg	micrograms (10^{-6} g)
ADWG	Australian Drinking Water Guidelines
AELERT	Australasian Environmental Law Enforcement and Regulators network
AFFF	aqueous film-forming foam
ASC NEPM	National Environment Protection (Assessment of Site Contamination) Measure
ASLP	Australian Standard Leaching Procedure
ASTM International	Former American Society for Testing and Materials
bw	body weight
CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
CSM	conceptual site model
DoEE	Australian Government Department of the Environment and Energy
DW	drinking water
ECF	electrochemical fluorination
EMP	Environmental Management Plan
enHealth	Environmental Health Standing Committee of the Australian Health Protection Principal Committee
EPA	Environmental Protection Agency/Environment Protection Authority
EPBC	Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth)
FSANZ	Food Standards Australia New Zealand
GAC	granular activated carbon
GIS	geographic information system

HBGVs	health-based guidance values
HDPE	high-density polyethylene
HEPA	Heads of EPAs Australia and New Zealand
HIL	health investigation level
HPLC	high performance liquid chromatography
IBC	intermediate bulk container
kg	kilogram
km	kilometre
L	litre
LC-MS	liquid chromatography - mass spectrometry
LC-MS/MS	liquid chromatography - tandem mass spectrometry
LOQ	limit of quantitation
LOR	limit of reporting
mg	milligrams (10^{-3} g)
NATA	National Association of Testing Authorities
NCWG	National Chemicals Working Group
NEMP	National Environmental Management Plan
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
ng	nanograms (10^{-9} g)
NHMRC	National Health and Medical Research Council
NMI	National Measurement Institute
NWQMS	National Water Quality Management Strategy
PCB	polychlorinated biphenyl
PFAA	perfluoroalkyl acid - refer to Appendix A for information on the PFAS chemical family
PFAS	per- and poly-fluoroalkyl substances - refer to Appendix A for information on the PFAS chemical family

PMP	PFAS Management Plan
POP	persistent organic pollutant
PPE	personal protective equipment
PSI	preliminary site investigation
QA/QC	quality assurance/quality control
RAAF	Royal Australian Air Force
RWQ	recreational water quality
SPE	solid phase extraction
TDI	tolerable daily intake
TOF Assay	total organic fluorine assay
TOP Assay	total oxidisable precursor assay
UNEP	United Nations Environment Programme
WQG	Water Quality Guidelines (Australian and New Zealand Guidelines for Fresh and Marine Water Quality)
ww	wet weight

Table F2 Glossary

adsorption	adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface
ambient monitoring	monitoring program producing chemical, physical and/or biological condition data
analyte	the chemical being measured in a sample
aqueous film-forming foam	a type of PFAS-containing firefighting foam product, commonly known by its acronym AFFF - see also the definition for firefighting foam
aquifer	underground layer of permeable rock, sand or gravel that is saturated and sufficiently permeable to store and transmit quantities of water
attenuation	reduction in contaminant concentration through natural processes such as ion exchange, chemical precipitation, adsorption, filtration, biodegradation and hydrodynamic dispersion
beneficial uses	environmental values and human activities that need protection from the effect of pollution and waste
bioaccumulation	accumulation of a substance in organisms from all routes of exposure so that the concentration of the substance in or on the organism is increased relative to the concentration in the surrounding medium
bioavailability	proportion of a chemical substance that is available to an organism for uptake through, or adsorption onto, its cellular membrane
biomagnification	increase in concentration of a substance in organisms with each trophic level of a food chain
biosolid	organic residuals remaining after domestic sewage treatment
biota	living organisms in a given area
bund	structural barrier built to retain water or to hold waste
conceptual site model	description of a site including the environmental setting, geological, hydrogeological and soil characteristics, the nature and distribution of contaminants and

	potentially exposed populations and exposure pathways
consequence	the result or effect of an action
contaminant	substance which causes contamination
contamination	condition of land or water where any chemical substance or waste has been added as a direct or indirect result of human activity at above natural background level and represents, or potentially represents, an adverse health or environmental impact
criteria	concentrations that indicate a potential risk to the environment or human health
diffuse source	widespread, usually small-scale sources of contamination without a single identifiable point source
ecological	referring to ecology
ecology	the study of the relationships among organisms as well as the relationships between them and their physical environment
ecosystem	a community of organisms and their environment with all the interactions that transfer energy and recycle resources
environmental regulator	a HEPA member agency, or another agency with regulatory responsibility for the environment, at the Commonwealth, state or territory level
environmental risk assessment	assessment, including human health risk assessment and ecological risk assessment estimating the potential impact of a chemical, physical, microbiological or psychosocial hazard on a specified human population or ecological system, under a specific set of conditions and for a certain timeframe
exposure	amount of a chemical released to the environment, the route by which it is released and the consequent contact of organisms with the chemical
firefighting foam	a foam used to suppress fire, that is made by mixing air with foam solution, that is made by mixing air with firefighting foam concentrate – note that firefighting foam products may or may not contain PFAS

groundwater system	groundwater and associated processes, including recharge, flow, discharge and interaction with other aquifers and surface water, at a specific location
hazard	for a chemical, the inherent characteristics of the substance that have the potential to cause harm to an organism or any other aspect of the environment
hydrogeology	the study of groundwater and the geological factors influencing its presence, flow, availability and chemistry
indicator	physical, chemical or biological characteristic used as a measure of environmental quality
infiltration	the passing of water into the soil or into a drainage system
intermediate bulk container (IBC)	a pallet-mounted industrial grade reusable container for storing and transporting bulk liquids, pastes, granules and powders
internal standard	an isotopically labelled version of each compound used as a reference for quantitation of native compounds spiked into the sample prior to extraction
isotainer	a tank container, built to an ISO (International Organisation for Standardisation) standard, that is designed to carry both hazardous and non-hazardous liquids in bulk and is made of stainless steel surrounded by various types of protective layers
landfill	a facility for the disposal of waste by burial
leaching	the release of contaminants from solid materials, such as soil or waste, into liquids
lead agency	government agency responsible for coordinating interagency work on a specific issue
level of protection	degree of protection based on current or desired ecosystem condition
likelihood	probability that something might happen
long term	greater than 5 years - also used for a very long timescale such as greater than 20 years
medium term	2-5 years

pathway	the route by which a contaminant can reach a receptor
per- and poly-fluoroalkyl substances	group of manufactured chemicals, containing a component with multiple fluorine atoms, with many specialty applications - examples are perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA)
persistent	a chemical substance that has a half-life in water greater than two months, or a half-life in soil greater than six months, or a half-life in sediment greater than six months, or a half-life in air greater than two days, taking into account environmentally relevant considerations
PFAS-contaminated material	PFAS-contaminated soil, sediment, timber, asphalt, concrete, containers etc.
point source	specific location where a contaminating substance is present that is then emitted from that location into the environment – see also primary source and secondary source
precursor	a substance from which another substance is transformed
primary source	specific location where a contaminating substance has been used that is then emitted from that location into the environment – see also point source and secondary source
receptor	living organisms including humans, the habitat which supports such organisms, or natural resources that could be adversely affected by environmental contamination resulting from a release at, or migration from, a site
rehabilitation	restoration of original or alternative environmental values or beneficial uses at a site
remediation	removal or other treatment of contamination from soil, groundwater, sediment, surface water, or biota to mitigate or minimise environmental and/or human health risks
risk	the probability of adverse effects caused under specified circumstances by an agent, in an organism, a population, or an ecological system, based on the hazard of a chemical and its level of exposure for a specific use and location

risk management	the process by which policy and regulatory actions are chosen and implemented to control risks identified in the risk assessment, involving consideration of the scientific evidence and risk assessment and, if needed, any social and economic factors
screening	process of comparison of site data to screening criteria to obtain a rapid assessment of contaminants
secondary source	specific location where contamination originating from other point sources and/or diffuse sources is collected and then emitted from that location into the environment – see also point source and primary source
short term	6 months to 2 years
temporary	up to 6 months – see also transient
toxicity	the degree to which a substance is toxic (i.e. has an adverse biochemical effect)
trade waste	wastewater from commercial and/or industrial sites
transient	less than 48 hours – see also temporary
vulnerable aquifer	aquifer potentially exposed to contamination - for the purposes of PFAS management a very highly vulnerable aquifer has one or more of the following: limestone with known karst features or sand, peat and clay deposits (wetland areas) with a shallow water table ≤3 m while a highly vulnerable aquifer has sand and limestone with a shallow to intermediate water table ≤30 m, or fractured rocks with a high permeability ≥40 m/d or a shallow to intermediate water table ≤30 m (DER 2017 adapted from Appleyard 1993)
wastewater	water that has been used and is not suitable for reuse for the same purpose without treatment, including sewage and trade wastewater
wastewater treatment facility, or wastewater treatment plant	facility for treatment of wastewater, including domestic sewage and commercial and/or industrial wastewater
weight of evidence approach	approach based on collecting, analysing and evaluating a combination of different qualitative, semi-quantitative and/or quantitative lines of evidence to form an overall

	assessment, including judgements about data quality, quantity, relevance and congruence