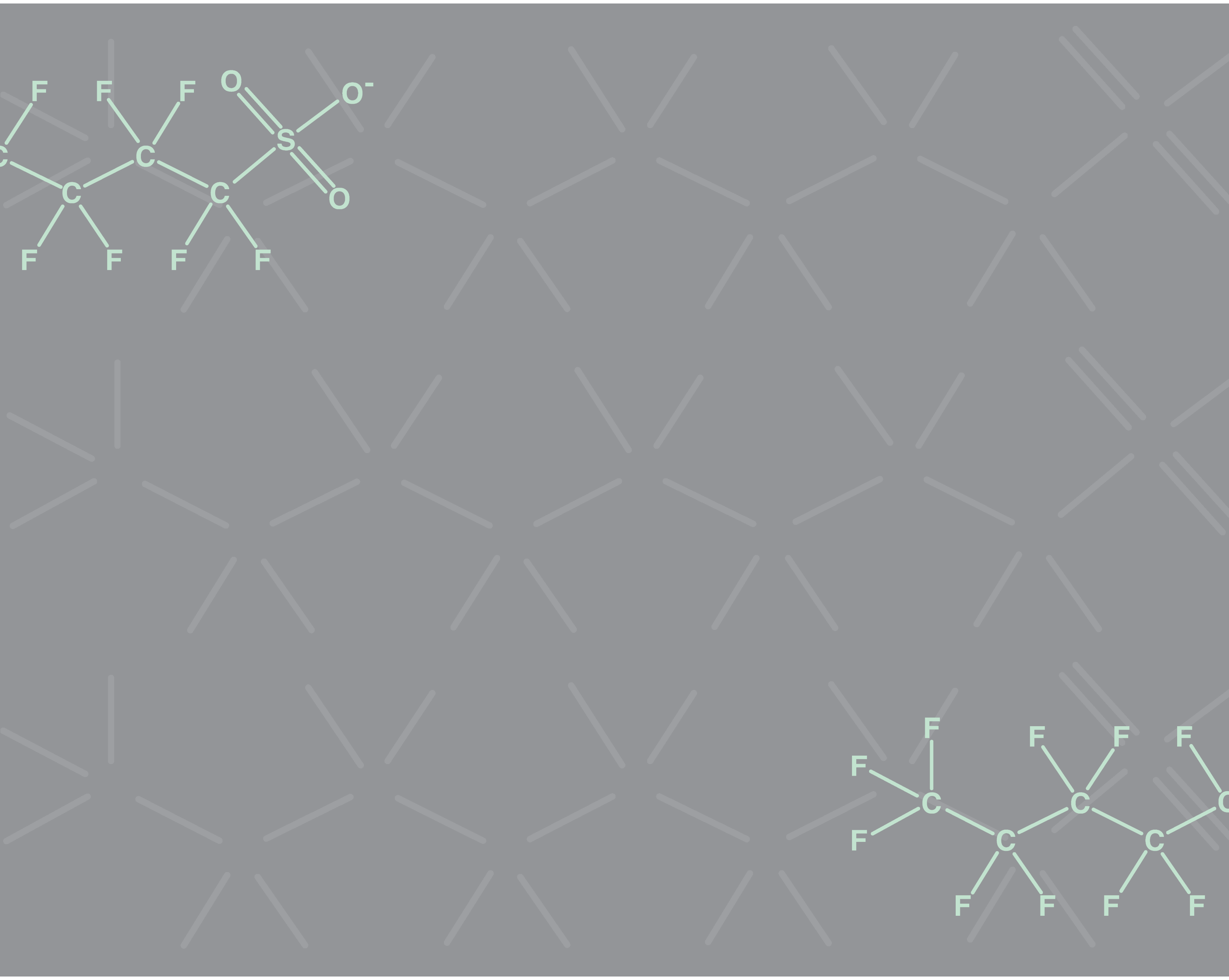
PFAS National Environmental Management Plan

JANUARY 2018



HEPA

Introduction

The environmental and potential human health impacts from exposure to a group of manufactured chemicals known as PFAS (per-and poly-fluoroalkyl substances) are of increasing concern worldwide. At the request of Environment Ministers around Australia, the Heads of EPAs Australia and New Zealand (HEPA) and the Australian Government Department of the Environment and Energy (DoEE) have collaborated to develop this PFAS National Environmental Management Plan (NEMP). The Plan is designed to achieve a clear, effective coherent and nationally consistent approach to the environmental regulation of PFAS.

PFAS have been widely used for many decades in household products such as non-stick cookware, stain protection and food packaging as well as industrial and commercial applications, such as firefighting foams, mist suppressants and coatings. PFAS are persistent and highly resistant to physical, chemical and biological degradation. Consequently, they 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. As such, the development of the Plan began in April 2017 with the PFAS Regulator's Summit. Following the Summit, the HEPA National Chemicals Working Group (NCWG), in collaboration with DoEE, developed a Consultation Draft, which was released in August 2017 for public comment.

Information sessions were held in all jurisdictions with over 400 people providing comments and feedback on the Consultation Draft. In addition, there were over 180 responses to the public call for comments, including over 80 submissions and many requests for further information. These comments have been summarised in the Consultation Summary Report, published with this Plan. The insights shared by community, industry, government representatives, consultants and researchers during the public consultation were an important contribution to the development of the Plan.

The Plan: Guiding environmental regulation of PFAS

The Plan provides an evidence-based approach that will be adapted to reflect increasing scientific knowledge relevant to environmental regulation of PFAS. It has been prepared to guide environmental regulators in their regulation of PFAS contaminated sites, PFAS contaminated materials and, where applicable, PFAS-containing products. It is structured to provide general guidance as well as specific Guidance notes, both of which will be implemented through individual jurisdictional mechanisms and associated regulatory activities, allowing for the implementation of actions in a way that becomes 'business as usual' for environmental regulators. The Plan recognises the need for sound regulation of PFAS by each jurisdiction in a way that can adapt to local circumstances and emerging priorities.

The Plan reflects the current state of knowledge and will be adapted as further information becomes available. Ongoing review and adaption will ensure that the Plan continues to support a nationally consistent approach to the environmental regulation of PFAS. The Plan includes a list of further work to be completed by the NCWG. The outcomes of this work will contribute to a review and update of the Plan, expected in mid-2018.

Acknowledgments

The Heads of EPAs Australia and New Zealand (HEPA) acknowledge the contributions to this Plan of Commonwealth, State and Territory agencies.

Contents

Abbreviations

µg	micrograms (10−6 g)
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	American Society for Testing and Materials
bw	body weight
CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
DoEE	Australian Government Department of the Environment and Energy
DW	drinking water
ECF	electrochemical fluorination
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
HDPE	high-density polyethylene
HEPA	Heads of EPAs Australia and New Zealand
HIL	health investigation level
kg	kilogram
km	kilometre
L	litre
LC-MS	liquid chromatography – mass spectrometry
LC-MS/MS	liquid chromatography – tandem mass spectrometry
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
PFAS	per- and poly-fluoroalkyl substances; refer to Appendix A for a list of PFAS compounds
POP	persistent organic pollutant
PSI	preliminary site investigation
QA/QC	quality assurance/quality control
RAAF	Royal Australian Air Force
RWQ	recreational water quality
TDI	tolerable daily intake
TOFA	total organic fluorine assay
TOPA	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

1 Scope

The Plan:

- provides guidance about per- and poly-fluoroalkyl substances referred to as PFOS, PFOA, and perfluorohexane sulfonate (PFHxS), and their direct and indirect precursors, as these are the most widely studied
- recognises that PFOS, PFOA, and PFHxS are usually primary indicators of a broad range of PFAS, including short chain and other long chain perfluorocarboxylic acids (PFCA) and perfluorosulfonates (PFSA)
- recognises that PFAS produced by different methods can create many different precursor compounds. These can degrade in the environment to numerous products and intermediates. This complexity needs to be considered, at least qualitatively.
- 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 contaminated sites, facilities such as landfills and wastewater treatment plants receiving PFAS-contaminated materials, may also be contributing to broader catchment PFAS contamination
- considers the identification and implementation of site- and catchment-specific risk management actions
- recognises the role of Australia's health-based guidance on PFAS and ongoing research to better understand the human health effects. Since these chemicals remain in humans and the environment for many years, it is recommended that as a precaution, human exposure to PFAS be minimised[1].
- does not address current uses of PFAS-containing products. However, environmental regulators, under their jurisdictional legislation, may take action to restrict the use of PFAS-containing products.

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.

PFAS resist physical, chemical and biological degradation, and are very stable. This stability creates a problem: PFAS last for a long time. There are many types of PFAS, with the best known being perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA) and perfluorohexane sulfonate (PFHxS).

Molecules of PFAS are made up of a chain of carbon atoms flanked by fluorine atoms, with a hydrophilic group at their head. Their high solubility in water means that PFAS readily leach from soil to groundwater, where they can move long distances. When the groundwater reaches the surface, the PFAS will enter creeks, rivers and lakes. There it can become part of the food chain, being transferred from organism to organism.

In Australia, PFAS have been used for a long time in both consumer products and industrial applications and there are now PFAS contaminated sites resulting from these various uses, including from the use of firefighting foams that contained PFAS. Over time, the chemicals have worked their way through the soil to contaminate surface and ground water, and have migrated into adjoining land areas. PFAS are also present in our landfills and wastewater treatment facilities and more broadly in the environment.

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[1] Per- and Poly-Fluoroalkyl substances (PFAS): Health effects and exposure pathways, Australian Government, Department of Health (http://www.health.gov.au/internet/main/publishing.nsf/Content/44CB8059934695D6CA25802800245F06/$File/Health-effects-exposure-pathways.pdf)

2 Australia's international obligations

If Australia decides to ratify the listing of PFOS, its salts and PFOS-related chemicals on the Stockholm Convention on Persistent Organic Pollutants, or future listings of other PFAS, additional actions will be required to implement the globally accepted standards outlined in the Convention for the use and management of persistent organic pollutants. The Australian Government is reviewing the remaining uses of PFOS, its salts and PFOS-related chemicals as part of the ratification process.

The objective of the Stockholm Convention is to protect human health and the environment from persistent organic pollutants. PFOS, its salts and PFOS-related chemicals were listed on Annex B (restriction) of the Stockholm Convention in 2009, with continued use permitted in some applications. The Australian Government Department of the Environment and Energy is conducting a treaty-making process to inform an Australian Government decision on ratification of the listing of PFOS. The treaty-making process includes analytical, consultative and parliamentary steps. These steps are critical to ensure any management measures deliver the desired environmental outcomes, and that potential impacts (such as economic impacts on industry) are manageable. Public consultation was undertaken in late 2017 on the Regulation Impact Statement of options for the national phase-out of PFOS in the context of the Stockholm Convention.

PFOA, its salts and PFOA-related chemicals were nominated in 2015 for listing on the Stockholm Convention, while PFHxS, its salts and PFHxS related chemicals were nominated in 2017. The earliest date for the Convention's decision-making body to decide on the listing of PFOA is 2019. PFHxS was assessed against the Annex D criteria by the Convention's subsidiary scientific body, the Persistent Organic Pollutants Review Committee, 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. It will proceed to the second of three technical review stages in 2018. Australia will continue to participate in the Convention's processes and to address any domestic implementation requirements that may result if PFOA, PFHxS or other PFAS are listed.

Ratification of the PFOS listing or future listings of PFOA, PFHxS or other PFAS in the Stockholm Convention, would mean accepting international standards for the management of these chemicals. For PFOS, this would include requirements regarding waste that contains PFOS at a level above 50 mg/kg.

3 Guiding principles

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

1. a focus on protection of the environment and, as a precaution, protection of human health
2. consideration of the principles established by the Intergovernmental Agreement on the Environment[2] in all decision-making, including
    a. the precautionary principle. The precautionary 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.
    b. intergenerational equity. The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.
    c. conservation of biological diversity and ecological integrity. Conservation of biological diversity and ecological integrity should be a fundamental consideration.
    d. improved valuation, pricing and incentive mechanisms. 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; and 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.

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[2] http://www.environment.gov.au/about-us/esd/publications/intergovernmental-agreement

3. regulatory actions and decisions are risk-based, informed by scientific evidence, focused on the identification of PFAS exposure pathways, and meet national and international obligations
4. quantitative PFAS assessment is to be based on appropriate analytical methods and standards, with the required quality assurance and control
5. consistency across jurisdictions, supported by the Plan, with consideration of accountability for pollution and management actions
6. coordinated and cooperative action on cross-boundary issues, including within catchments
7. consideration of legislative and policy frameworks across jurisdictions and at the national and international level for chemical and contaminated sites management
8. integration with existing national guidelines, including the National Water Quality Management Strategy, the National Environment Protection (Assessment of Site Contamination) Measure 1999 (ASC NEPM) and the National Environment Protection (Movement of Controlled Waste between States and Territories) Measure 1998
9. where existing principles, guidelines, approaches or management options do not adequately foresee or address an identified environment risk, responses are to be 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.

General environmental obligations concerning PFAS

Environmental legislation in many jurisdictions includes obligations and duties to prevent environmental harm, nuisances and contamination. PFAS contamination can be environmentally significant due to its persistence and potential for bioaccumulation.

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

- understanding the PFAS content of products and/or 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 and determining what the water is used for. Important issues include any off-site movement, PFAS transformations and exposure pathways
- 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, and 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. Dilution is not acceptable for example in soil, compost or other products
- 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 and materials.

4 Communication and engagement

Clear and timely communication on PFAS, its impacts and its management, benefits everyone. The way in which information is conveyed is critical to building trust between those responsible, polluters, regulators and the community.

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 there are PFAS levels above the guidelines and exposure pathways, the government should communicate how the community can minimise their exposure as soon as possible.

When 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.

Effective collaboration between all levels of government is critical to successful communication and engagement with communities affected by PFAS contamination. 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 the polluter undertakes appropriate engagement activities in accordance with the environmental legislation. It may also be appropriate to involve the polluter in these discussions.

The roles and responsibilities of all government agencies, including who 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.

GUIDANCE NOTE

Communication and engagement

This Guidance note 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 *Australian Government, Per-and Poly-fluroalkyl Substances (PFAS) Information Sharing, Communication and Engagement Guidelines 2017.* and has a particular focus on the role of environmental regulators.

This Guidance note is divided into two sections. The first includes principles that should be considered when undertaking any PFAS-related communication and engagement activities. The second provides approaches for environmental regulators working with stakeholders on this issue. 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.

Clear and consistent communication is vital to increasing the community's understanding of the PFAS issue. By communicating in a way that is tailored and easy-to-understand, confusion, anxiety and distrust are reduced.

Section 1: 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. Site-specific, and where applicable, catchment-wide strategies, including the identification of key stakeholders, should be developed particularly 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.

Where the contamination crosses jurisdictional boundaries, all relevant jurisdictions should be involved in identifying stakeholders and planning engagement.

Section 2: Approaches for environmental regulators

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 the polluter with the community, to regulatory action which instructs the 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, those responsible, site owners and occupants to engage, 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 at a particular location and to provide quantitative data about concentrations and forms of PFAS at those locations. Monitoring provides data to determine whether human health and the environment are protected from PFAS exposure. Monitoring also provides the evidence for policy development, regulatory activities and site-specific management controls. Monitoring for PFAS will inform whether regulatory requirements are being met, such as whether the PFAS concentration in water meets licence discharge limits.

The two main forms of monitoring programs are: ambient (which can be done across and within catchments) and site specific. Ambient programs provide data to assess the background and/or baseline concentrations and known forms of PFAS across a range of land uses and environmental media. A site-specific program provides information on the PFAS concentrations, type, spatial extent, nature, transport means, fate, and exposure pathways and may determine whether the PFAS are changing at an impacted site (e.g. location where PFAS was used) or potentially impacted site (e.g. containment area or landfill). Monitoring programs need to consider the possibility of other PFAS sources within the same catchment, including how PFAS moves through the environment from source(s) via pathways to receptors.

GUIDANCE NOTE

PFAS monitoring

This Guidance note provides advice for the two forms of monitoring programs: ambient (which can be done across and within catchments) and site-specific.

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 spacial trends in concentration and the 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 particles (including dust), particularly where there is a high potential for airborne particles, noting options for air sampling are currently limited in Australia.

Some environmental media act as 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, 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.

CASE STUDY

PFAS assessment pilot program – ambient 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.

Site-specific monitoring programs

The ASC NEPM outlines the process for characterising site contamination (including monitoring), informed by the development of a robust conceptual site model, which takes into account the features of the surrounding land. In general, the same media and sinks should be assessed as in an ambient program (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). Food and livestock testing would be for the purpose of informing the conceptual site model.

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.

6 PFAS inventory

Local, jurisdictional and national information on the mass and volume of PFAS-containing products and PFAS-contaminated materials can be provided by collecting information on PFAS stocks from:

- facilities – including industrial and government facilities that currently hold, use, or have used or received PFAS-containing products or PFAS-contaminated materials. These may be point sources such as the site of historic or current PFAS use, storage and/or disposal, or facilities that receive diffuse PFAS inputs such as landfills and wastewater treatment plants.
- current stocks of PFAS-containing products: including surfactants used in chrome plating or firefighting
- sites contaminated by PFAS: including government and industry sites, on- and off-site contamination and catchment information.

This information will assist those with management responsibilities for PFAS contamination, inform government policy development and assist in evaluating the effectiveness of the Plan.

Appendix C provides a list of activities that may include PFAS, including a brief description about PFAS use. This list can be used to support PFAS inventory activities.

GUIDANCE NOTE

PFAS inventory

Information on the stocks of PFAS-containing products and PFAS-contaminated materials can be informed by collecting information from industrial and government facilities that hold, use, or have used or received PFAS, and by inventories evaluating major sites and industries for potential contamination.

There are a number of steps in undertaking a PFAS inventory:

- 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. Appendix C provides a list of PFAS activities in Australia.
- Define the scope of the inventory, which involves identifying the following:
  - 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.

Commonly, the objective of a PFAS inventory is to obtain data to identify areas or sites to prioritise regulatory action. Information required includes the types, locations and quantities of PFAS-containing products or PFAS-contaminated materials, management practices employed and the where available, the extent of contamination present in the environment.

The scope of a PFAS inventory should include:

- identifying major industrial and government facilities/activities that historically or currently use or store PFAS-containing products, noting that all PFAS formulations should be considered for inclusion
- identifying point sources (e.g. firefighting training facilities, foam installations, metal plating works, electricity generation and distribution facilities)
- identifying secondary sources (such as landfills, wastewater treatment facilities, biosolids use sites)
- liaising with other agencies to obtain government-held information on PFAS stocks or legacy issues

- surveying major historical or current users of PFAS-containing products to assess the types, volumes, storage, disposal, spills, suppliers and products in the jurisdiction
- reviewing government and public records on known and potential site contamination.

PFAS stocks data can be obtained using a staged approach:

- an initial desktop study, where potential sources of PFAS data and key industry and government facilities/activities of concern are identified
- qualitative and/or quantitative assessment using stakeholder questionnaires or surveys, which can provide evaluations of stocks, use, contamination and waste management
- gathering of internal information, where publicly available records and the lead agency's own information sources are reviewed
- gathering of external information, where information requests are sent to other government bodies, industries or industry associations.

In addition to the above activities which seek to identify potential point sources of PFAS contamination and current stocks of PFAS-containing product, priority should also be given to the identification of inputs to the environmental burden of PFAS (particularly PFOS, PFOA and PFHxS) that are contributing to overall PFAS background levels. There is a need to acknowledge ambient environmental concentrations in catchments and that diffuse sources may also be contributing to these ambient concentrations.

CASE STUDY

Firefighting foam survey

The Queensland Department of Environment and Heritage Protection effected the Operational Policy – *Environmental Management of Firefighting Foam* in response to growing concern regarding PFAS. The policy bans the use of certain foams and provides for the use of some PFAS-containing foams under certain requirements. Full compliance is to be achieved by July 2019. 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 those responsible for 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 was sent to over 900 participants, with 468 responses received. Approximately 425,000 kg of foam containing at least 80% PFAS was reported, mostly at bulk fuel and chemical storage facilities. Survey limitations include the narrow scope of participants and its voluntary nature. A lack of understanding of PFAS and limited availability of information on foams may have led to unintentionally misleading answers. As such the results were considered indicative only.

7 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.

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. The PFAS inventory will provide information on current PFAS stocks or contamination.

The consequence 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 also 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 and economic values such as the income derived from nature tourism.

Once the initial scan of risks has been determined and the prioritisation of the sites 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.

A similar prioritisation approach should be taken to determine the urgency of response when a PFAS contaminated site is identified. Initially, priority should be given 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. A site's priority may be revised as investigations proceed, for example on confirming or eliminating exposure pathways or gathering further data on PFAS present.

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 (Commonwealth)*, 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, 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 Environmental guideline values

The following guideline values represent a nationally-agreed suite that should be used to inform site investigations.

Where possible these guidance values have been derived based on, or using, existing nationally-agreed and long standing Australian processes. For guidance values that are not yet available, in particular those where there are nationally recognised processes for the review and adoption of new criteria, such as the Water Quality Guidelines, appropriate interim criteria are recommended below.

Where the above options have not been possible, internationally derived guideline values are provided with a recommendation for future work to review these within the Australian context.

A degree of conservatism has been included in the following criteria, which means that exceeding these values does not constitute a risk if other pathways are controlled. This inbuilt conservatism is necessary when deriving screening values to be protective of affected communities where multiple exposure pathways may be present. This is especially important for bioaccumulative chemicals such as PFOS, PFHxS and PFOA. The consequence of this is that an exceedance of the screening values should trigger further investigation such as site-specific risk assessment to refine the likely degree of possible risk (as opposed to the assumption that harm will have occurred).

Table 1: Health-based guidance values for use in site investigations in Australia

Health-based guidance values are used to investigate and assess potential human health risks and are to be used to inform human health risk assessments and for setting human health based guidance values.

Note: The degree of conservatism in the drinking water and recreational water guidance values (90% attributed to other exposure pathways) means that exceeding these values does not constitute a risk if other pathways are controlled.

Exposure scenario	PFOS/PFHxS	PFOA	Description	Comments and source
Health-based guidance values	0.02 $\mu g/kg_{bw}/d$	0.16 $\mu g/kg_{bw}/d$	Tolerable daily intake (TDI)	Food Standards Australia New Zealand (FSANZ) 2017a
	0.07 µg/L	0.56 µg/L	Drinking water	Australian Government Department of Health 2017
	0.7 µg/L	5.6 µg/L	Recreational water	

Note: bw = body weight, µg = micrograms

Table 2: Soil criteria for investigation – human health based guidance values

These soil guidance values should only be used to assess potential human exposure through direct soil contact. They should be applied in conjunction with other lines of investigation to account for potential leaching, off-site transport, bioaccumulation and secondary exposure.

Note: The degree of conservatism in the soil criteria for investigation – human health based guidance values (80% attributed to other exposure pathways) means that exceeding these values does not constitute a risk if other pathways are controlled. Future work is recommended to review the human health based guidance values to ensure that as new information becomes available, including further development of transfer factors, it will be used to inform updates to these values.

Exposure scenario	PFOS/PFHxS	PFOA	Land use	Comments and source
Soil – Human health screening values	0.009 mg/kg	0.1 mg/kg	Residential with garden/ accessible soil	Based on 20% of FSANZ TDI, i.e. up to 80% of exposure is assumed to come from other pathways. National Environment Protection (Assessment of Site Contamination) Measure Health Investigation Level -A assumptions with home-grown produce providing up to 10% of fruit and vegetable intake (no poultry), also includes children's day care centres, preschools and primary schools. Does not include home-grown poultry/egg.
	2 mg/kg	20 mg/kg	Residential with minimal opportunities for soil access	Based on 20% of FSANZ TDI, i.e. up to 80% of exposure is assumed to come from other pathways. National Environment Protection (Assessment of Site Contamination) Measure Health Investigation Level-B assumptions with no use for home-grown produce and poultry and includes dwellings with fully and permanent paved yard space such as high rise-buildings and flats.
	1 mg/kg	10 mg/kg	Public open space	Based on 20% of FSANZ TDI, i.e. up to 80% of exposure is assumed to come from other pathways. National Environment Protection (Assessment of Site Contamination) Measure Health Investigation Level C assumptions for public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools (except where soil used for agriculture studies) and footpaths. It does not include undeveloped public open space (such as urban bushland and reserves) which should be subject to a site-specific assessment where appropriate.
	20 mg/kg	50 mg/kg	Industrial/ commercial	Based on 20% of FSANZ TDI, i.e. up to 80% of exposure is assumed to come from other pathways. National Environment Protection (Assessment of Site Contamination) Measure Health Investigation Level-D assumptions including 8 hrs spent indoors and 1 hr spent outdoors at a site such as a shop, office, factory or industrial site. Note: the industrial commercial – Ecological Direct Exposure for PFOA has been set as 50 mg/kg in anticipation of the Stockholm Convention low content limit of 50 mg/kg.

Table 3: Soil criteria for investigation – ecological guideline values

Soil guideline values for ecological protection need to consider both direct exposure and indirect exposure. Direct exposure applies specifically to protection of organisms that live within, or are closely associated with, the soil, such as earthworms and plants. The direct exposure guidelines can be used to assess the possibility of harm to these organisms. In the absence of acceptable published guideline values for direct exposure, the Soil Criteria – Human Health are recommended as an interim position. Other factors important for assessing exposure, for example bioaccumulation and leaching/off-site transport, must be accounted for by including other lines of investigation.

The indirect exposure guideline values are intended to account for the various pathways other organisms can be exposed due to bioaccumulation and/or off-site transport. The Canadian ecological soil guideline values, adopted here as interim criteria, assessed a range of these exposure pathways scenarios, and the PFOS criteria were set based on the most sensitive of those pathways. As an interim measure, these values can be used for screening these important indirect pathways.

Exposure scenario	PFOS	PFOA	Land use	Comments and source
Interim soil – ecological direct exposure	1 mg/kg	10 mg/kg	Public open space	Future work is recommended to review available soil – ecological direct exposure criteria proposed by Australian research and industry organisations[3]. As an interim, it is proposed that the human health screening value for Public open space be used (see Table 2).
Interim soil – ecological indirect exposure	0.01 mg/kg		Residential	2017 Canadian Federal Environmental Quality Guidelines for Residential and Parkland (soil ingestion by a secondary consumer) and Commercial and Industrial – Coarse Soil (concentration in soil that is expected to protect against potential impacts on freshwater life from PFOS originating in soil that may enter the groundwater and subsequently discharge to a surface water body.) Future work is recommended to review these values for the Australian context. The Canadian Guidelines are currently being finalised.
	0.140 mg/kg		Industrial/ commercial	

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[3] For example, CRC CARE 2017, Assessment, management and remediation guidance for perfluorooctanesulfonate (PFOS) and perfluorooctanoic acid (PFOA) – Part 3: ecological screening levels, CRC CARE Technical Report no. 38, CRC for Contamination Assessment and Remediation of the Environment, Newcastle, Australia

Table 4: Terrestrial biota guideline values

The Canadian Federal Environmental Quality Guidelines (Feb 2017) state that effects have been reported at lower concentrations than the bird egg value, and should be considered in risk assessment. 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.

Exposure scenario	PFOS/PFHxS	PFOA	Description	Comments and source
Interim – ecological direct exposure for wildlife diet	4.6 µg/kg		Mammalian diet biota ww food	Canadian Federal Environment Quality Guidelines (Feb 2017)
	8.2 µg/kg		Avian diet biota ww food	
Interim – ecological exposure protective of birds	1.9 µg/kg		Bird egg ww	

Table 5: Aquatic ecosystems: freshwater and marine water guideline values

The 99th percentile species protection level may be below the ambient background concentration. Actions to incorporate background concentrations for organic chemicals with widespread (eg. global) contamination are discussed in Volume 2, section 8.3.5.5 of ANZECC and ARMCANZ (2000). The 80th percentile of background established for reference sites with low levels of human impact may be used as a default guideline values where the trigger value is less than the reliable background figure.

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. 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 WQG advise 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.
	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.
	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	

*It is recommended that marine guidelines values developed by CRC CARE be forwarded for consideration using the nationally-agreed process.

9 Contaminated site assessment

Site assessment must take into account the characteristics of PFAS, including its high mobility in aqueous environments as well as in some soils and sediments and the ability to bioaccumulate in humans and animals, as well as biomagnify with each trophic level of a food chain. When assessing sites, consideration should be given as soon as practicable to the potential for multiple exposure pathways affecting sensitive receptors. Early stakeholder engagement and completion of water use and food surveys by people living and working in the area are critical inputs for identifying complete exposure pathways, informing decisions on precautionary measures to limit exposure and on implementing effective management controls.

Due to the complexity of PFAS contamination, 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).

GUIDANCE NOTE

Contaminated site assessment

This Guidance note provides PFAS-specific information designed to supplement that provided in the *National Environmental Protection (Assessment of Site Contamination) Measure 1999* (ASC NEPM).

Experience across Australia has demonstrated that PFAS are very mobile in some soils and aqueous environments and can bioaccumulate in human and animals, as well as biomagnify with each trophic level of a food chain. Therefore, at an early stage, site assessments need to consider the potential for multiple exposure pathways affecting receptors in order to develop a robust conceptual site model and implement effective management controls.

Site investigation

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. Therefore, if a credible source of PFAS contamination is identified (See Appendix C: Activities including PFAS), 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 (noting that in Australia and overseas, groundwater plumes tens of kilometres long have been identified).

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. The potential for complex PFAS contamination due to the use of different product formulations (for example, change in foam usage from a fluorotelomer-based AFFF to a fluoropolymer-based AFFF) should also be considered.

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.

Identification of off-site receptors

The ASC NEPM provides guidance allowing for both the classic site assessment, 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. This 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 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.

Source characterisation

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.

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

PFAS transformation

Commercially available methods based on LC-MS/MS typically will identify, depending on the analysis requested, up to about 30 PFAS compounds including the main PFAS (PFOS, PFOA, PFHxS) within scope of the Plan. However, this may only contribute a small proportion of PFAS present, as 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).

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 AFFF-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 AFFF 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.

The characterisation of pathways and receptors should consider the likely or possible presence of precursors. For example, the sampling and analysis quality plan should investigate whether precursors and their transformation products have migrated along identified pathways and to receptor sites. 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. This can be achieved by incorporating advanced analytical techniques (such as TOPA and TOFA) into the site assessment using a multiple lines of evidence approach. 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.

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.

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. Hence, using predictive models based on octanol-water partition coefficients (Kow) to predict PFAS exposure is inappropriate. Furthermore, PFAS bioconcentration factors for aquatic organisms have a high level of uncertainty.

Bioaccumulative nature of PFAS in aquatic ecosystems

PFAS bioaccumulate in aquatic organisms. In Australia, the advice when assessing bioaccumulative contaminants is to use a higher degree of species protection than would normally be used (ANZECC & ARMCANZ 2000 and Warne *et al*. 2015). 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. 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.

The recommended approach is to sample and analyse aquatic biota to account for bioaccumulation and comparison with relevant criteria (see Environmental guidelines and criteria section). A water concentration of PFAS below an LOR of 0.001 µg/L does not mean that there is minimal risk to aquatic ecosystems and does not mean that there is no need to sample aquatic biota. Environmental regulators or local catchment managers may be able to provide additional jurisdiction-specific information and guidance.

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 considerations should be given to humans and 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 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.

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.

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, 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. 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. Studies following recognised techniques for evaluating residue levels in produce are a potential source of new information.

Biomagnification

Biomagnification occurs when the concentration of a contaminant is greater in an organism than in the food it eats, resulting 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.

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 (see Environmental guidelines and criteria section). 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)
- 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 included, 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.

10 On-site storage and containment

The management of PFAS-containing products and PFAS-contaminated materials often includes on-site storage and containment. The following types of materials are expected to involve large volumes:

- PFAS-containing AFFF stocks
- PFAS-containing solid waste e.g. soil/sediment, timber, asphalt, concrete, equipment
- PFAS-contaminated water, including water generated through construction, landfill leachate, wastewater treatment plant effluent.

Storage and containment may be temporary (up to 6 months), short term (6 months to 2 years), medium term (2-5 years) or long term (greater than 5 years). On-site storage and containment is often required during the investigation, remediation or construction phase of a project or where treatment or remediation options are not available. If ongoing containment presents unacceptable risks or ongoing management requirements, it is generally expected that materials will be removed for treatment or destruction.

Storage and containment design should not create any pathways for environmental or human health exposure, thereby minimising the likelihood of environmental contamination.

Although not comprehensive, the following apply to storage PFAS-contaminated materials:

- Materials should be stored, 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, 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, including any firewater.
- 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 in a secondary containment.
- Containers should be stored 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 and handled so that they cannot fall and cause spillage outside of the containment.
- Wherever practicable, a roof or solid cover should be placed over bunded areas.

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 (including those with a base and walls) should be impervious to the materials stored, resistant to fire and managed and maintained to prevent any release of liquids and leachate to stormwater drains, waters and land. Where they are not impervious, leachate management systems should be incorporated into the design.

GUIDANCE NOTE

On-site storage and containment

This Guidance note applies to the temporary, short- and medium-term storage of PFAS-containing wastes during projects relating to investigation, remediation, and construction, as well as the medium- to long-term containment of PFAS-impacted materials where no other options exists for management.

Containment may include immobilising, capping or covering, or may require more significantly engineered containment facilities. In the medium to long-term, contained sources can be removed for destruction, particularly where ongoing containment presents unacceptable risks.

Storage

Storage should be planned and implemented in accordance with a risk-based approach designed to minimise the potential for the storage facility to release PFAS into the environment, while addressing operational requirements for differing durations of storage.

Waste concentrated liquid PFAS-containing materials should be stored in appropriate vessels such as covered intermediate bulk containers (IBCs) in bunded areas. The bunds or bunded tanks must be impermeable and sufficiently sized for a major spill, including capacity for stormwater runoff, to completely contain the movement of PFAS (i.e. as a barrier).

Storage of PFAS-contaminated materials should be undertaken in such a way that contamination must not migrate into the surrounding soil or water and all runoff should be monitored for PFAS. This can often mean storage 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 (refer to Ongoing management of containment facilities, below), the condition of storage containers 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 assessment and action should be taken.

Containment

Key considerations for on-site containment include the site assessment outcomes, the type of material that needs to be contained, the duration of storage and the volume of contaminated materials. 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. A comprehensive on-site environmental management plan must provide for ongoing monitoring and management, including quality control and an auditable monitoring and management plan.

On-site containment is only an option when:

- the source site is hydrogeologically appropriate (with consideration for depth to water table and aquifer characteristics)
- it is possible to manage risk to on- and off-site beneficial uses (direct and indirect) for soils, surface water, and groundwater
- there is capacity at the site.

Methods for on-site containment include:

- engineered stockpiles for the containment of PFAS-contaminated material (eg. 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.

When material is contained on-site, a leachate and stormwater runoff system must be implemented. Leachate and contaminated stormwater must be captured, analysed for PFAS, and if necessary, treated, removed and destroyed.

Siting and location

The following considerations are relevant for the process of site selection:

- geology and hydrogeology
- community and stakeholder concerns
- sensitive receptors, such as key flora and fauna
- matters of national environmental significance and those protected by state and territory legislation
- surface water, including risks from extreme weather events and flooding
- existing contamination
- infrastructure
- ownership of the land
- local/state or territory regulations.

Design and construction of 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 the containment facility be required, it should be built in accordance with a construction quality assurance plan approved by the environmental regulator. The construction quality assurance plan provides a means of demonstrating to the regulatory authority and the public that the construction of the facility meets design requirements.

Once the containment facility is filled with PFAS-contaminated material, it must be capped and rehabilitated. A visual marker layer between the contaminated material and the cap will 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 a sufficiently appropriate vegetative cover to maintain the integrity of the cap.

Ongoing management of containment facilities

An environmental management plan should be prepared and implemented to manage the facility, including protocols and procedures for monitoring the effectiveness of the containment and any works in the area. The plan should include stormwater management indicating 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. Leachate and contaminated stormwater must 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 is 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 PFAS concentrations in leachate are low. Some jurisdictions require listing of waste containment facilities on contaminated land registers and regulatory approval for construction, ongoing management and monitoring.

11 Transport of PFAS-contaminated material

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.

PFAS-contaminated materials must be transported in accordance with the requirements of the environmental regulator. Decisions regarding authorisations for the interstate transport of PFAS-contaminated materials 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

PFAS-contaminated materials may be considered by environmental regulators for reuse under some circumstances, particularly for the purpose of resource recovery. 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. Regulators are considering reuse thresholds below which no further management is required.

Assessment of reuse options for PFAS-contaminated materials will be based on the principles that reuse of the material 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. 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 material irrespective of source location and can include extracted material, virgin or otherwise.

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, including soils, will not increase the risk at the destination site or lead to an unacceptable risk to the environment and/or human health.

The reuse of PFAS-contaminated materials above the Stockholm Convention low content limit of 50 mg/kg will not be considered. 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 and bioaccumulation in plants and animals, in particular, those consumed by humans and animals. Therefore, any assessment of risks associated with reuse of PFAS-contaminated material should consider the proximity and sensitivity of surface or groundwater receptors, potential for bioaccumulation and secondary or tertiary exposure to humans and animals.

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.

The following reuses 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. 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 of soil or other solid waste, and water 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.

12.1 Reuse of PFAS-contaminated water

If water containing PFAS 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.

Health- and ecological-based 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 be undertaken following consultation with the relevant regulators, as reuse activities may require specific approval. Acceptable reuse options may include:

- irrigation of non-edible crops
- dust suppression
- re-infiltration
- 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.

The reuse of biosolids is not included in this section, see the Trade waste discharge section for details on future work.

13 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; and the potential for production of other PFAS during the treatment process. Moreover, treatment can generate additional contaminated by-products and wastes if appropriate precautions are not implemented. The availability, practicability and feasibility of treatment options must be considered when considering options for PFAS treatment and remediation. Storage and/or containment may be required where treatment options are not available.

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

1. Separation, treatment and destruction: on-site or off-site treatment of the contamination so that it is destroyed, removed or the associated risk is reduced to an acceptable level.
2. Onsite encapsulation in engineered facilities with/without immobilisation: if the source site is hydrogeologically appropriate, onsite encapsulation will acceptably manage risk to the on- and off-site beneficial uses (direct and indirect) for soils, surface water and groundwater.
3. Offsite removal to a specific landfill cell: leachate should be captured, treated and the removed PFAS destroyed. 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 regulator approval.

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.

13.1 Management strategy

The implementation of a management strategy and associated environment plan for onsite mangement 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 onsite management strategy would be appropriate provided that:

- unacceptable risks to offsite 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, 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 onsite 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 Contaminated site assessment Guidance note for further information).

14 Landfill disposal

Every jurisdiction has policy and regulatory frameworks in place for waste disposal to landfill and to manage the associated environmental and human health risks. 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.

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. Presence of PFAS may preclude some leachate reuse options e.g. trade waste discharge and should be discussed with the environmental regulator and 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 "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 PFOS requirements of the Stockholm Convention[4], which require the following:

i. 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.
ii. 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.

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[5].

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 aquifer, adapted from Appleyard (1993)
- 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
- 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.

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

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

Table 6: Landfill acceptance criteria

Landfill type		**Interim landfill acceptance criteria**[6,7]		**Comments**
		PFOS + PFHxS	PFOA	
Unlined	ASLP leachable concentration (µg/L)	0.07 µg/L	0.56 µg/L	Drinking water x 1 (Australian Government Department of Health 2017)
	Total concentration (mg/kg)	20 mg/kg	50 mg/kg	Soil – Human health industrial/commercial x1 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 (Australian Government Department of Health 2017)
	Total concentration (mg/kg)	50 mg/kg	50 mg/kg	Soil – Human health industrial/commercial x10 Total concentration for PFOS + PFHxS and PFOA of 50 mg/kg (low content limit)
Double composite lined	ASLP leachable concentration (µg/L)	7 µg/L	56 µg/L	Drinking water x 100 (Australian Government Department of Health 2017)
	Total concentration (mg/kg)	50 mg/kg	50 mg/kg	Soil – Human health industrial/commercial x100 Total concentration for PFOS + PFHxS and PFOA of 50 mg/kg (low content limit)

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

[7] 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.

15 Trade waste discharge

Management of PFAS contamination in the wastewater treatment system is important. PFAS in the wastewater treatment system arise from many different sources, including domestic and industrial discharges. Further work, in collaboration with the water industry will be undertaken to establish criteria and guidance for water authorities and environmental regulators based on current science. In the interim, criteria will continue to be established by the relevant water utility or authority in partnership with the environmental regulator.

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

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 and 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 a 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

18.1 Sampling and analysis quality plans

Sampling methodology and procedures should be generally consistent with the established methods for contaminated site investigation (i.e. ASC NEPM, Schedule B2 and references therein). However, the characteristics of PFAS mean that additional steps need to be undertaken to ensure analytical results are reliable. Avoiding sample contamination is critical, particularly when analysis data is used for comparison with low environmental guideline and criteria values.

The 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.

18.2 Who should take the sample?

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. Refer to the *Australian Government, Per-and Poly-fluroalkyl Substances (PFAS) Contamination Response Protocol 2017* for further guidance about roles at government-owned sites and sites where government activities have resulted in PFAS contamination.

GUIDANCE NOTE

Sampling

This Guidance note provides additional requirements for sampling of PFAS-containing products and PFAS-contaminated materials.

Quality assurance and quality control

Environmental guideline values for PFAS for ecosystem protection are generally very low and 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. For this reason, and also due to the high risk of contamination in the field and in the laboratory, 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 and 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.

Contamination

Consideration should be given in the sampling and analysis quality plan to the type of sample to be collected, the expected PFAS concentrations and the need to take additional precautions to limit sample contamination. Attention should be given to the range of products that can cause PFAS contamination of samples, including new clothing (fabric treatments), stain and water-resistant products, sunscreen, cosmetics, fast food wrappers, Teflon©, sampling containers with Teflon©-lined lids, foil, 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.

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.

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 drinking water (USEPA, 2009), or similar sample additive specified by the 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.
- 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 Teflon® 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 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.
- 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 TOPA or TOFA analysis is to be performed on the same sample.

Soil, sediment and surface water

Conventional soil drilling and aquatic sampling techniques (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 (2014). 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 drinking water (USEPA, 2009), or similar sample additive as specified by the selected analytical laboratory. Prior to sampling drinking water for PFAS analysis, confirm the need for additive with the selected analytical laboratory.

- 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 (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 Teflon® unless the Teflon® 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 soap and rinse thoroughly in tap water before donning a clean, new pair of disposable nitrile gloves.
- Surface water must be collected by inserting a sampling container (polypropylene or HDPE) with the opening pointing down 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, including when Decon 90 is being used.
- 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 TOPA analysis is to be performed on the same sample.
- If leach testing (ASLP, toxicity characteristic leaching procedure) of soils is required, a larger sample size is required.

Biota

Where biota must be sampled to inform site assessments, 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 deheaded and deveined 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

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 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.
- 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.

19 PFAS analysis

Standard methods of analysis that are currently available in Australia, using the ASC NEPM as a guide, are listed in Table 7. The Table includes the method, the analytes typically included in the analysis, the sample type, internal standards (minimum required)[8], how the method can be used, its limitations and a reference.

Selection of a method should consider the type of sample, what needs to be analysed for (i.e. what the method can help you understand), and the quality assurance and control required. Currently, the US EPA method (or variants on it) is the most commonly used method in Australia.

TOPA can be used where the US EPA method may not adequately measure all the PFAS likely to be present. Examples include contamination, where the PFAS product composition is unknown and/or where known PFAS composition extends beyond the US EPA suite. Other circumstances include transformation of PFAS or where the precursors are unknown, such as in wastewater treatment, soil, water and most environmental samples where the PFAS have been present in the environment for longer than an immediate spill. In an immediate spill, TOPA provides information on whether precursors are present and informs risk management, e.g. is the environment oxidative; and might remediation transform them.

As oxidation may be different in the environment from in the laboratory-simulated oxidation, the laboratory results may not necessarily align with the environmental end point. It is possible that in the laboratory, some PFSA precursors oxidise to PFCA, whereas in the environment, they would transform to PFSA. TOPA relies on sufficient oxidation, so an oxidation validation should be included. Absence of fluorotelomers in TOPA 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. Some laboratories have updated the TOPA method from the Houtz *et al*. (2012) original method.

TOFA can be used where there is uncertainty as to whether the US EPA method adequately measures 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 US EPA 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, e.g. is environment oxidative; and might remediation 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. TOFA 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.

Care needs to be taken in analysing the TOPA and TOFA methods. See 'Interpreting results' below.

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[8] Internal standard – An isotopically labelled version of each compound used as a reference for quantitation of native compounds. This compound is spiked into the sample prior to extraction. Use of a commercially available, isotopically labelled internal standard for each PFAS analysed is recommended where such a standard is available. If not available, a suitably scientifically justified alternative should be used.

Table 7. Standard methods of analysis

Method	Analytes included	Sample type	Internal standards (minimum required)	How can the method be used?	Limitations	Reference
US EPA Method 537[9] Determination of selected perfluorinated alkyl acids in drinking water by solid phase extraction and LC-MS/MS	PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFDoA, PFTrA, PFTeA, PFBS, PFOS, NMeFOSAA, NEtFOSAA	Drinking water, ground and surface water	^{13}C-PFOA, ^{13}C-PFOS and d3-NMeFOSAA Linear and branched isomers should be included.	To analyse for specific analytes	Only analyses for specific PFAS Does not require results to be corrected for Internal Standard recovery Limited internal standards Further details in the reference.	Shoemaker *et al*. 2009
US EPA 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	PFBA, PFPA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFDoA, PFTrA, PFTeA, PFBS, PFHxS, PFHpS, PFOS, PFOSA, NMeFOSA, NEtFOSA, NMeFOSE, N-EtFOSE	Sewage sludge and biosolids	^{13}C-PFBA, ^{13}C-PFHxA, ^{13}C-PFOA, ^{13}C-PFNA, ^{13}C-PFDA, ^{13}C-PFUnA, ^{13}C-PFDoA, ^{18}O-PFHxS, ^{13}C-PFOSA, d$_3$-NMeFOSE Linear and branched isomers should be included.	To analyse for specific analytes	Only analyses for specific PFAS Further details in the reference.	US EPA Method EPA-821-R-11-007
Total Oxidisable Precursor Assay (TOPA)	Total PFAS chains (C4-C14)	Water samples and extracts including soil, biota, AFFF products and wastes	Linear and branched isomers should be included.	Can be used in conjunction with a US EPA method to estimate the total PFAS in a sample, and in some circumstances, the approximate end point PFAS. Can help inform risk assessments.	Cannot be used to target exact PFAS precursors, as it is a semi-quantitative[10] method. Allows for some inferences as to precursor chain length.	Houtz *et al*. 2012
Total Organic Fluorine Assay (TOFA) as combustion ion chromatography (the most common available)	Total fluoride in organic and inorganic forms	Water samples and extracts including soil, biota, AFFF products and wastes	Linear and branched isomers should be included.	Can be used in conjunction with a US EPA method to understand the total presence of organic fluorine in a sample and compare this to the organic fluorine equivalent detected by the US EPA method.	Cannot be used to target exact PFAS precursor compounds.	Laboratory reported methods only

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[9] Some laboratories are using a modified US EPA Method 537 to obtain a recommended suite of analytes, such as the inclusion of the 6:2 and 8:2 fluorotelomers and PFHxS.

[10] 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.

19.1 Interpreting results

The fate and behaviour of PFAS need to be considered in choosing a method and interpreting results. The following environmental indicators may give some indication: pH, electrical conductivity, redox potential, metals (iron etc.), soil particle size, and biological activity. These factors potentially affect mobility of PFAS and the degradation of precursors.

TOPA and TOFA 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 TOPA provides further additional insights about the nature of the precursors not available with TOFA.

GUIDANCE NOTE

Analysis of precursors and relevance to site assessment

This Guidance note provides guidance on the use of techniques to analyse PFAS precursors.

Several techniques exist and are available in Australia to determine the presence of PFAS precursors. TOFA considers the total mass of fluorine while TOPA considers PFAS with perfluorinated carbon chain lengths from C4 to C14.

Other analyses used internationally may be available in some Australian research institutions or by sending samples overseas for analysis. These include liquid chromatography quadrupole time of flight mass spectroscopy and particle-induced gamma emission (PIGE) spectroscopy.

TOFA 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 TOFA 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.

TOFA has a significantly higher limit of reporting (LOR) when compared to that usually available with TOPA 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.

TOFA can also be used to check the degree to which TOPA 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 TOPA or standard LC-MS/MS analysis.

TOPA 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, AFFF 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 TOFA, 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 AFFF foam samples, the LOR achieved by TOPA is generally similar to standard analysis.

Below are some important points concerning the use of total PFAS measurements methods like TOPA and TOFA:

- Oxidation via TOPA 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 TOPA 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 and new spills are not equivalent. A new spill may benefit from TOPA 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.

For PFCA precursors, the TOPA oxidation generally follows what happens in the environment. It converts precursors to PFCA with some partial defluorination, which creates a result that includes some slightly shorter chain PFAS products. In contrast, some PFSA precursors oxidise to an equivalent carbon

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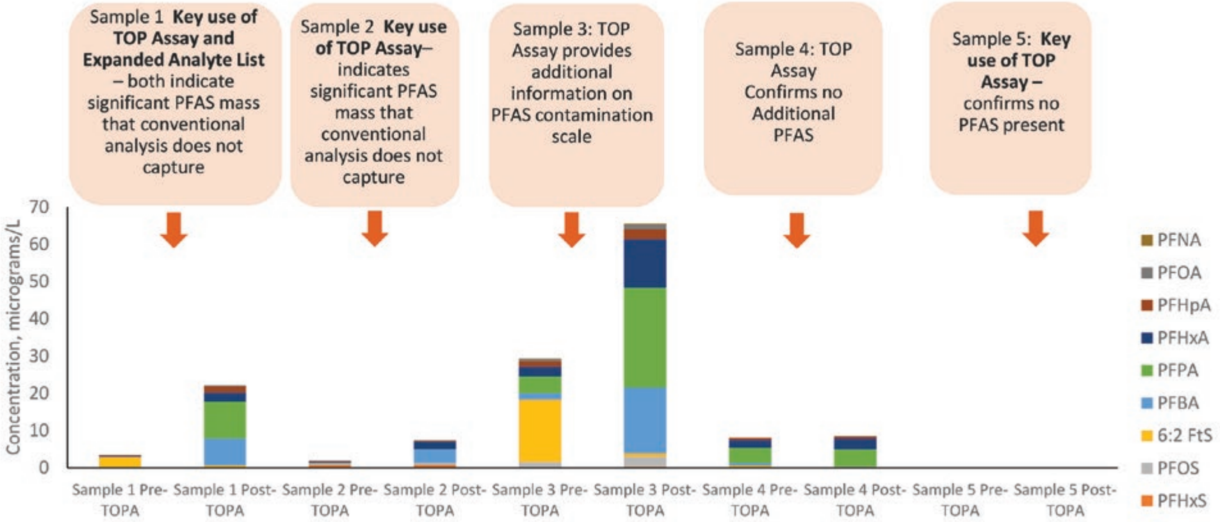
TOP Assay Applied to Groundwater



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).

chain length PFCA in the digestion, which differs from oxidation in the environment where they would transform to the equivalent PFSA. For example, a PFHxS precursor in the TOPA digestion would oxidise into PFHxA and PFPeA rather than PFHxS, as would occur in the environment. 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.

The following chart illustrates possible different outcomes of TOPA analysis for three 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.

Managing uncertainty

Commercially available analytical techniques generally measure fewer than 30 of the thousands of known PFAS. 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, 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 PFAS-contaminated materials and sites.

TOPA and TOFA 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.

19.2 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 accreditation or validation of the method[11]
- whether the method reporting limits can be achieved for the specific guidelines and criteria being applied (e.g. for the US EPA Method 537)
- 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. Typical recoveries are between 50-150% (± 50%) depending on media and the specific analyte.
- if undertaking TOPA, that validation of the methods oxidation using detectable oxidisable precursors (eg. labelled internal standards) is undertaken and reported, and that dilutions are also recorded and reported
- additional quality assurance measures for TOPA include
  - the total PFAS concentration post-TOPA should be greater or equal to the total PFAS concentration pre-TOPA, 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-TOPA should be equal to or greater than the sum of PFCA pre-TOPA, which signifies any precursors being converted to PFCA products
  - the sum of PFSA post-TOPA should approximate the sum of PFSA pre-TOPA, 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%
    - noting greater leniency may be applied for samples where PFAS were detected ≤ 10 times LOR.

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 Limit of reporting

In general, the limit of reporting (LOR) for PFAS is 0.01-0.05 ug/L for water, 5 ug/kg solids, and 0.5-5 ug/kg for biota. Trace and ultra-trace analyses are also available 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.

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

20 Future work

The Plan will continue to be updated as new information becomes available. Table 8 outlines further work that will confirm interim guideline values and criteria and approaches in the Plan as well as address gaps that have been identified through its development, including through the public consultation process.

The recommended future work includes actions that are expected to be completed by the HEPA Working Groups as well as the development of a small number of priority research proposals that would be expected to be delivered in collaboration with leading research groups. The NCWG will establish the plan for future work, which will include more consultation and peer review, consideration of practicability and the development of further case studies, further review of international standards, options for alignment with industry risk assessments (for example, the oil and gas industry) and include the review of the Water Quality Guidelines.

Table 8: Future work for completion to inform the mid-2018 Plan update

Future work	Description	Expected completion
Ecological guideline values	1. Review the indirect exposure guideline values from Canada and their relevance in the Australian context and make recommendations to HEPA (e.g. adopt/modify/revoke). 2. Review available direct exposure guideline values to determine suitability for inclusion in the Plan.	June 2018
Criteria for soil and waste reuse criteria	Establish soil and waste reuse criteria, with consideration of both total and leachable values.	June 2018
Criteria for water authorities and utilities	Work with water authorities/utilities to develop criteria or approaches for the derivation of criteria, including trade waste acceptance criteria, wastewater treatment effluent and biosolids criteria.	June 2018
Guidance note – Treatment and remediation trials	Develop a Guidance note on requirements for undertaking preliminary treatment and remediation trials.	June 2018
Guidance note – Response to uncertainty	Develop a Guidance note responding to uncertainty arising from the analysis of other PFAS, considering various national and international resources.	June 2018
Revision of the Guidance note on Monitoring	Development of protocols / guidance for sampling the less common materials especially if we are to identify low level PFAS contamination for example in concrete timber etc.	June 2018
Guidance Note – Site prioritisation	Develop a Guidance note to provide the process for site prioritisation.	June 2018
Revision of the Guidance note on Containment	Develop further guidance / protocols for on-site containment of PFAS-contaminated materials, including considerations for design criteria.	June 2018
Guidance note – application of environmental guidelines and criteria	Develop a Guidance note on the application of environmental criteria including extrapolating from investigation to intervention to remediation.	June 2018
Revision of the Guidance note on Sampling	To provide further guidance on options for cost-effective analyses.	June 2018
Protocol for data sharing	Develop a protocol for data sharing to establish a structured way of sharing data and information.	June 2018

RESEARCH ACTIVITIES

Future work	Description	Expected completion
PFAS sources entering and emitted from wastewater treatment plants	Develop a research proposal to characterise PFAS in trade waste/sewer systems entering wastewater treatment plants to help identify the relative contributions of industrial sources discharging to trade waste, including landfills, in the total PFAS load.	Out of sessions March 2018, to consider funding options
Ambient concentrations	Develop a research proposal to investigate, through monitoring, ambient concentrations of PFAS across Australia to inform decisions relating to site assessment, management options and the practicality of adopted guideline values and other criteria.	Out of sessions March 2018, to consider funding options
Analytical method validation	Develop a project proposal with a suitable partner for analytical method validation, including inter-laboratory and/or proficiency trials	Out of sessions March 2018, to consider funding options
Toxicity equivalence factors for short and long chain PFAS	Development of toxicity equivalence factors for short and long chain PFSA and PFCA to allow for risk assessment of a broader suite of PFAS	Out of sessions March 2018, to consider funding options
Bioaccumulation in the Australian context	Understanding bioaccumulation in the Australian context, to assist development of Australian guideline values for wildlife food and water quality	Longer term
Development of ecotoxicological guideline values	Further development of ecotoxicological guideline values, that consider multigenerational effects	Longer term
PFAS sediment concentration impact on ecotoxicity and bioaccumulation	Understanding the importance of PFAS sediment concentrations on ecotoxicity and bioaccumulation in aquatic biota	Longer term
PFAS behaviour	Understanding the behaviour (sorption/desorption; transport; transformation) of PFAS of concern (targeting factors such as water characteristics; organic matter characteristics; salinity; pH; microbial composition)	Longer term
PFAS precursors	Fate, behaviour, transport of precursors and the kinetics of their degradation to form PFAS end products	Longer term

21 Review

Through HEPA, environmental regulators and policy makers in collaboration with the Australian Government Department of Environment and Energy will undertake a formal review of the Plan and its implementation every five years. There will be more frequent informal reviews as needed. The working groups appointed by HEPA, including the National Chemicals Working Group, the National Contaminated Environments Network and the National Waste Working Group, will monitor PFAS research and information, consider the outcomes of the future work activities associated with this Plan and provide recommendations to HEPA on findings and proposed updates to the Plan. These recommendations will be informed by ongoing stakeholder engagement and consultation. The Plan is expected to be updated in mid-2018 with the first formal review expected five years later.

References

Appleyard, 1993. Explanatory notes for the groundwater vulnerability to contamination maps of the Perth Basin, Record 1993/6 Geological Survey of Western Australia, Department of Minerals and Energy.

ANZECC and ARMCANZ, 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, National Water Quality Management Strategy Paper No. 4.

Australian Government Department of Health, 2017. Health based guidance values for PFAS for use in site investigations in Australia. http://www.health.gov.au/internet/main/publishing.nsf/Content/2200FE086D480353CA2580C900817CDC/$File/fs-Health-Based-Guidance-Values.pdf

Australian Government Department of Industry, Innovation and Science, National Measurement Institute, 2016. *Proficiency Test Report AQA 16-06 PFOS/PFOA in Fish, Soil and Water*, November 2016.

Australian Government, Per-and Poly-fluroalkyl Substances (PFAS) Information Sharing, Communication and Engagement Guidelines 2017.

Backe, W.J., Day, T.C. and Field, J.A., 2013. Zwitterionic, cationic, and anionic fluorinated chemicals in aqueous film-forming foam formulations and groundwater from US military bases by nonaqueous large-volume injection HPLC-MS/MS. *Environmental science & technology*, 47(10), pp.5226-5234.

Barzen-Hanson, K.A. Roberts, S.C. Choyke, S. Oetjen, K. McAlees, A. Riddell, N. McCrindle, R. Lee Ferguson, P. Higgins, C.P. and Field J.A., 2017. Discovery of 40 Classes of Per- and Polyfluoroalkyl Substances in Historical Aqueous Film-Forming Foams (AFFFs) and AFFF-Impacted Groundwater. *Environ. Sci. Technol.*, 51 (4), pp 2047–2057.

Blaine, A.C., Rich, C.D., Sedlacko, E.M., Hundal, L.S., Kumar, K., Lau, C., Mills, M.A., Harris, K.M. and Higgins, C.P., 2014. Perfluoroalkyl acid distribution in various plant compartments of edible crops grown in biosolids-amended soils. *Environmental science & technology*, 48(14), pp.7858-7865.

Canadian Government, 2017. *Canadian Environmental Protection Act, 1999. Federal Environmental Quality Guidelines, Perfluorooctane Sulfonate (PFOS), February 2017.* Environment and Climate Change Canada.

Commonwealth Environmental Management Guidance on Perfluorooctane Sulfonic Acid (PFOS) and Perfluorooctanoic Acid (PFOA), Draft dated October 2016 and published December 2016: http://www.environment.gov.au/protection/chemicals-management/pfas.

D'Agostino, L.A. and Mabury, S.A., 2013. Identification of novel fluorinated surfactants in aqueous film-forming foams and commercial surfactant concentrates. *Environmental science & technology*, 48(1), pp.121-129.

Department of Defense (DoD) and Department of Energy (DOE), 2017. *Consolidated Quality Systems Manual (QSM) for Environmental Laboratories,* Based on ISO/IEC 17025:2005(E) and The NELAC Institute (TNI) Standards, Volume 1, (September 2009), DoD Quality Systems Manual Version 5.1, DOE Quality Systems for Analytical Services Version 3.1.

Government of Western Australia, Department of Environment Regulation, 2017. *Interim Guideline on the Assessment and Management of Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS), Contaminated Sites Guideline*, v.2.1, January 2017.

Houtz, E.F. and Sedlak, D.L., 2012. Oxidative conversion as a means of detecting precursors to perfluoroalkyl acids in urban runoff. *Environmental science & technology*, 46(17), pp.9342-9349.

Houtz, E.F., Higgins, C.P., Field, J.A. and Sedlak, D.L., 2013. Persistence of perfluoroalkyl acid precursors in AFFF-impacted groundwater and soil. *Environmental science & technology*, 47(15), pp.8187-8195.

Martin, J.W., Mabury, S.A., Solomon, K.R. and Muir, D.C., 2003. Bioconcentration and tissue distribution of perfluorinated acids in rainbow trout (Oncorhynchus mykiss). *Environmental Toxicology and Chemistry*, 22(1), pp.196-204.

McGuire, M.E., Schaefer, C., Richards, T., Backe, W.J., Field, J.A., Houtz, E., Sedlak, D.L., Guelfo, J.L., Wunsch, A. and Higgins, C.P., 2014. Evidence of remediation-induced alteration of subsurface poly-and perfluoroalkyl substance distribution at a former firefighter training area. *Environmental science & technology*, 48(12), pp.6644-6652.

National Environment Protection (Assessment of Site Contamination) Measure, 1999. (ASC NEPM).

NSW EPA, 2016. Designing sampling programs for sites potentially contaminated by PFAS. Available at http://www.epa.nsw.gov.au/resources/community/Sampling-Programs-PFAS-contaminated-sites-160718.pdf.

OECD, 2013. OECD/UNEP Global PFC Group, Synthesis paper on per- and polyfluorinated chemicals (PFCs), Environment, Health and Safety, Environment Directorate, OECD.

OECD Chemicals Safety, Portal on Per and Poly Fluorinated Chemicals: http;//www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals.

Shoemaker, J.A., Grimmett, P.E. and Boutin, B.K., 2009. Determination of selected perfluorinated alkyl acids in drinking water by solid-phase extraction and liquid chromatography/tandem mass spectrometry (LC/MS/MS). *Tandem Mass Spectrometry (LC/MS/MS), in, US Environmental Protection Agency, Washington, DC*.

UNEP, 2017, Guidance for the inventory of perfluorooctane sulfonic acid (PFOS) and related chemicals listed under the Stockholm Convention on Persistent Organic Pollutants ('UNEP Guidance').

US EPA, 2011, *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.

Warne, MStJ, Batley, G.E., van Dam, R.A., Chapman, J.C., Fox, D.R., Hickey, C.W. and Stauber, J.L., 2015. Revised Method for Deriving Australian and New Zealand Water Quality Guideline Values for Toxicants. Prepared for the Council of Australian Government's Standing Council on Environment and Water (SCEW). Department of Science. *Information Technology and Innovation, Brisbane, Queensland*.

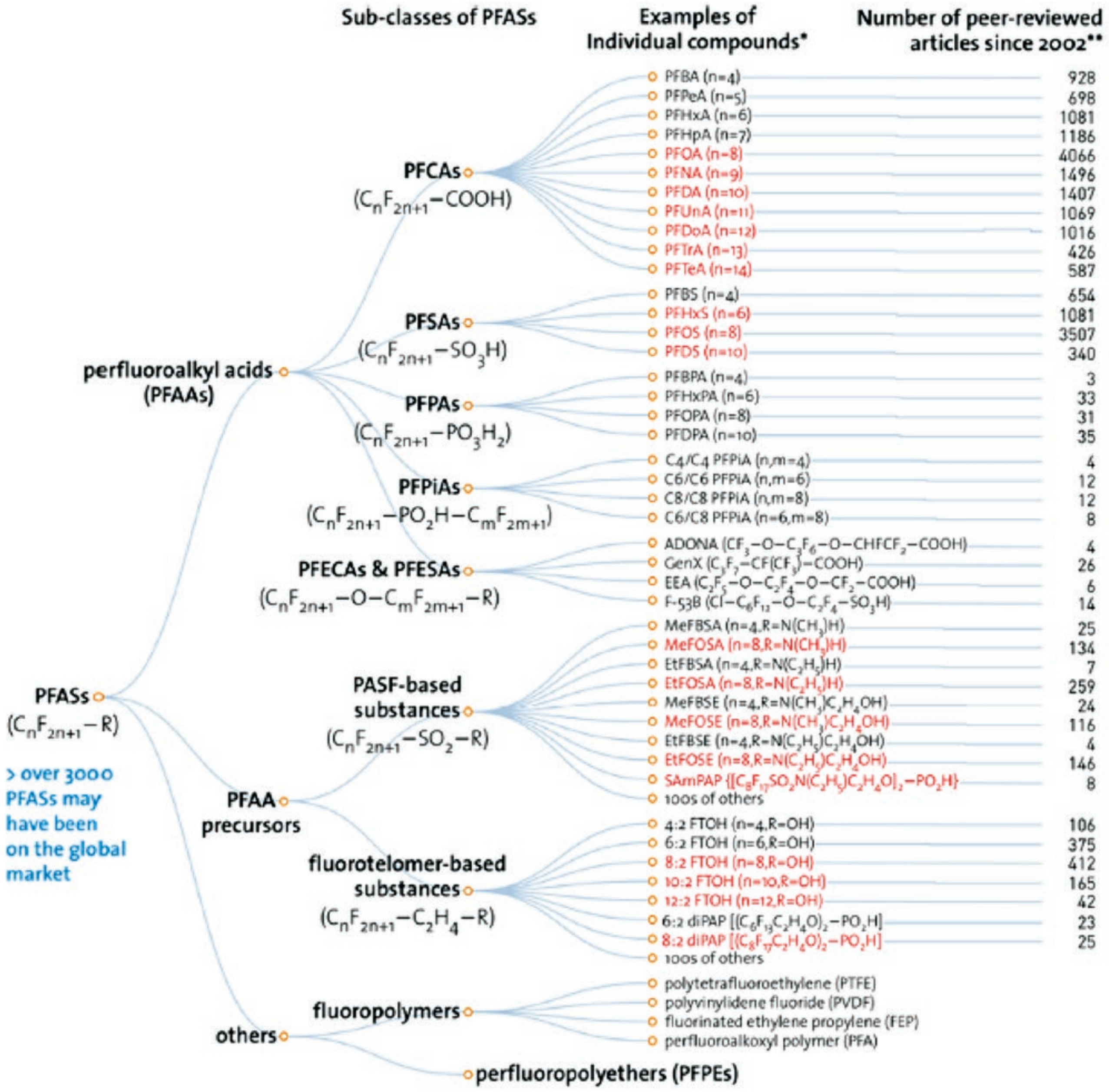
Washington, J.W., Jenkins, T.M. and Weber, E.J., 2015. Identification of Unsaturated and 2H Polyfluorocarboxylate Homologous Series and Their Detection in Environmental Samples and as Polymer Degradation Products. *Environmental science & technology*, 49(22), pp.13256-13263.

Weiner, B., Yeung, L.W., Marchington, E.B., D'Agostino, L.A. and Mabury, S.A., 2013. Organic fluorine content in aqueous film-forming foams (AFFFs) and biodegradation of the foam component 6: 2 fluorotelomermercaptoalkylamido sulfonate (6: 2 FTSAS). *Environmental Chemistry*, 10(6), pp.486-493.

Appendices

Appendix A: PFAS sub-classes and common PFAS abbreviations

Taken from: Wang, Z., DeWitt, J.C., Higgins, C.P. and Cousins, I.T., 2017. A never-ending story of per-and poly-fluoroalkyl substances (PFASs)?, Environ. Sci. Technol., 51(5): 2508–2518.



Common PFAS abbreviations

FTS	fluorotelomer sulfonate
PFAA	perfluoroalkyl acid
PFCA	perfluorocarboxylic acid
PFDA	perfluorodecanoic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexane sulfonate, or perfluorohexane sulfonic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoate, or perfluorooctanoic acid
PFOS	perfluorooctane sulfonate, or perfluorooctane sulfonic acid
PFOSA	perfluorooctane sulfonamide
PFSA	perflurosulfonic acid

Appendix B: Activities including PFAS

The following table summarises a range of activities that may be associated with PFAS contaminants.

Activity[12]	Description
Activities with a risk of fire	
Aluminium production	Onsite firefighting
Battery production	Onsite firefighting
Bitumen production	Kerosene use and storage
Brewing and distilling	Ethanol production
Coal works	Onsite firefighting
Dangerous goods production	Risk of fire – likely to use a range of hydrocarbons, polar solvents etc.
Explosives production	Risk of fire – explosions
General chemical storage	Risk of fire – likely to use a range of hydrocarbons, polar solvents etc.
Generation of electrical power from coal	Onsite firefighting
Generation of electrical power otherwise from coal, diesel or gas	
Generation of electrical power from diesel	
Hardware retailers	AFFF deluge systems
Mining for coal	Onsite firefighting; used in drilling fluids
Mining for minerals	
Paints, polishes, adhesives production	Risk of fire; historically used in sealants, adhesive products, coatings, paint and varnishes
Petrochemical production	Onsite firefighting used; as a surfactant for gas well stimulation
Petroleum exploration, assessment and production	
Petroleum products and fuel production	
Petroleum products storage	
Underground car parks and tunnels	AFFF deluge systems
Other activities	
Automotive industry	Stain and water protection, fire retardant and metal plating applications
Aviation	Hydraulic fluids, fire-fighting, potentially in paints and surface treatments
Battery use	Used in batteries, particularly for high end use such as lithium style batteries.
Chrome / metal plating industry	High concentration PFOS mist suppressants used to reduce chromium exposure to workers.
Electricity and telecommunications	Flame-resistant devices, fittings, coatings and wrappings; semiconductor etching; fire-fighting 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 foam refurbishers/ deluge system service	Storage and disposal of large volumes of firefighting foams.
Fertiliser production	Used as an adjuvant in fertilisers
Healthcare	Small quantities in X-ray film, charged-coupled devices (CCDs), artificial blood, flexible tubing, denture cleaners

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[12] For further information, refer to https://www.oecd.org/env/ehs/risk-management/PFC_FINAL-Web.pdf

Activity	Description
Manufacturers of building products	Tile coatings, stone coatings, paints, varnishes, sealants
Manufacturers of food, food packaging and food preparation products	Baking paper, aluminium foil, fast food wrappers and non-stick equipment
Manufacturers of household appliances	Heaters, heat lamps, irons, stoves, refrigerators and high-end (lithium) batteries
Manufacturers of personal care products	Cosmetics, shampoo, shaving cream, dental floss, sunscreen, nail polish
Manufacturers of textiles, leather, upholstery, carpets, clothing, shoes	Widespread use of fluorinated compounds to provide stain and water protection.
Paper or pulp production	Used in internal and surface sizing agents for paper manufacturing
Paper/pulp waste	
Printing, packaging and visual waste generation	Used to apply grease, oil and water resistance to packaging products
Recovery of waste oil	Collection of PFAS-containing waste
Recovery of hazardous and other waste	
Retailing, wholesaling and storage of fire-fighting and fire protection supplies	Rural supply stores, council depots, outstation service centres
Sewage treatment (small and large plants)	Inputs from residential and industrial sources
Soap and detergents production	Household goods such as shampoos and cosmetics
Sporting goods suppliers and sports facilities	Ski wax, outdoor clothing, water-resistant treatments
Waste disposal by application to land	PFAS-containing waste in the landfill
Waste storage – hazardous, restricted solid, liquid, clinical, asbestos waste	Collection of waste PFAS-containing products.

Appendix C: Treatment technologies potentially available in Australia

The table provides a summary of PFAS treatment technologies which may be available in Australia, adapted from the following documents:

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

The listing of a PFAS treatment technology has not taken into account commercial availability or feasibility.

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

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
beneficial uses	environmental values and human activities that need protection from the effect of pollution and waste
bioaccumulate	to accumulate in organisms from water, soil/sediment and/or food
biomagnify	to increase in concentration in organisms with each trophic level of a food chain
biosolid	nutrient-rich organic materials resulting from the treatment of domestic sewage in a wastewater treatment facility
biota	living organisms in a given area
bund	wall built to retain water or to hold waste
conceptual site model	description of a site including the environmental setting, geological, hydrogeological and soil characteristics together with the nature and distribution of contaminants. Potentially exposed populations and exposure pathways are identified.
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 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	widespread without a single identifiable source
ecological	referring to ecology
ecology	the study of the relationships among organisms as well as the relationships between them and their physical environment
environmental regulator	a HEPA member agency
environmental risk 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.
groundwater	the water beneath the surface that moves through geologic formations (aquifers)
infiltration	the passing of water into the soil or into a drainage system
landfill	a facility for the disposal of waste
leachate	a liquid that collects at the bottom of a site, for example at a landfill site
likelihood	probability that something might happen
long term	greater than 5 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)
PFAS-contaminated material	PFAS-contaminated soil, sediment, timber, asphalt, concrete, containers etc.
precursor	a substance from which another substance is transformed
receptor	living organisms including humans, the habitat which supports such organisms, or natural resources that could be adversely affected by environmental contaminations resulting from a release at, or migration from, a site.
risk	the probability that, in a certain timeframe, an adverse outcome will occur in a person, group of people, plants, animals and/or the ecology of a specified area that is exposed to a particular dose or concentration of a hazardous compound
risk management	evaluating alternative actions, selecting options and implementing them in response to risk assessment. The decision making will incorporate scientific, technological, social, economic and political information.
screening	process of comparison of site data to screening criteria to obtain a rapid assessment of contaminants of potential concern.
short term	6 months to 2 years
temporary	up to 6 months
toxicity	the degree to which a substance is toxic (i.e. a biochemical effect)
vulnerable aquifer	A very high vulnerability 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. A high vulnerability 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.

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