Submission
No 58

INQUIRY INTO INQUIRY INTO PFAS CONTAMINATION IN WATERWAYS AND DRINKING WATER SUPPLIES THROUGHOUT NEW SOUTH WALES

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To the Select Committee on PFAS Contamination in Waterways and Drinking Water Supplies throughout New South Wales, Parliament of New South Wales

Submission

This document began as a review of the current state of affairs with respect to PFAS (per- and polyfluoroalkyl substances) to inform colleagues in the Blue Mountains, New South Wales. My search of publicly available literature has raised more and more questions as to the extent of the problem posed to humans and our fellow creatures from this huge group of synthetic substances that we have created because they have such useful properties in our industrialised society.

My chief concerns centre around **remediation of PFAS-contaminated media**, particularly the adequacy of proposed solutions **at a real-world level** – drinking water supplies, wastewater that is released to the environment, and contaminated land that can then compromise surface water and groundwater through leaching. Obvious questions surround **how robust a proposed solution might be** in terms of what substances are actually **removed and what still remain**, and to what **extent the solution has been trialled** – in the laboratory, in the field (how big an area or volume, how often and with what results), or at scale. Will a particular technique, or combination of techniques, **comprehensively remove** substances as intended? What is the **quality of the evidence** behind the testing that has been done? And then, what happens to the **any waste** after implementation – are we left with base substances of water, carbon dioxide and fluorine, or do we have a problem of separated contaminant PFAS dumped elsewhere and not completely broken down? Is "best practice" adequate in terms of what constitutes "sound" management and "safe" disposal?

These are questions that I urge your Committee to keep in mind as it considers what might work in real-world situations and how to manage any legislative plan to address this challenging problem we have created.

This submission includes points that are relevant to many of the terms of reference. I will start by providing a little background on the chemistry of PFAS to support the **recommendations** that follow.

Background: Structure and terminology

PFAS stands for per- and polyfluoroalkyl substances. They consist of chains of carbon atoms (the alkyl chain) with fluorine atoms at all or most of the available carbon bonding sites.

There are over 7 million PFAS according to the Organisation for Economic Co-operation and Development (OECD). In 2021 the OECD revised its definition of PFAS to include any chemical containing at least one saturated CF_2 or CF_3 moiety as follows, "PFAS are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group ($—CF_3$) or a perfluorinated methylene group ($—CF_2—$) is a PFAS" (OECD 2021). The number of 7 million is several orders of magnitude higher than previously established PFAS lists, typically thousands of compounds. More and more PFAS are being identified with high-resolution mass spectrometry (Schymanski et al. 2023).

In perfluoroalkyl substances, each carbon atom in the chain is fully fluorinated (carbon-fluorine bonds only), whereas the carbon chain in polyfluoroalkyl substances is partially fluorinated, with some carbon atoms containing carbon-hydrogen bonds.

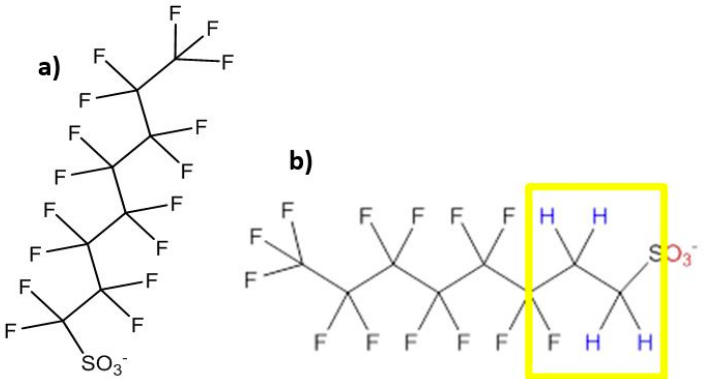


Figure 1: Structure of a perfluoroalkyl substance, PFOS, with eight carbon atoms (each at an intersection) that are fully saturated with fluorine, compared with b) the structure of a very similar polyfluoroalkyl substance, 6:2 fluorotelomer sulfonate (6:2 FTSA), in which six of the carbon atoms are fully saturated with fluorine and the other two have hydrogen attached (Debra Tabron 2016, https://www.enviro.wiki/index.php?title=File:Deeb-Article_1-Figure_1.JPG)

The subset of PFAS, perfluoroalkyl substances, was originally called perfluorinated compounds (PFC) and this term still crops up in the literature.

PFAS date from the 1930s when polytetrafluoroethylene (PTFE or Teflon) was made, well known as the non-stick lining on pots and pans. Many have been created since the 1950s because of their useful properties, such as being water-, heat- and greaseproof. They are used in a number of industries, including carpet, textile and leather production, chromium plating, photography, photolithography, semi-conductor manufacturing, coating additives, cleaning products and insecticides, and are they found in furnishings, non-stick cookware, hydrophobic (water-repelling) coating on raincoats, fire-retardant foam, lubricants, food packaging and cosmetics. Their presence in consumer products has created a measurable urban background concentration in stormwater, wastewater treatment plant influent and landfill leachate.

Some chemicals in the PFAS family can exist in different ionic states – non-ionic, anion (negatively-charged), cation (positively-charged), zwitterion (with both positively-charged parts and negatively charged parts) – which, in turn, govern the chemical's properties, such as solubility, volatility, bioaccumulative potential and ecological effects.

The millions of compounds in the PFAS family can be grouped according to their structures and represented in a tree structure such as the following one with two primary classes, **polymers** and **nonpolymers**. Each class may contain many subclasses, groups and subgroups.

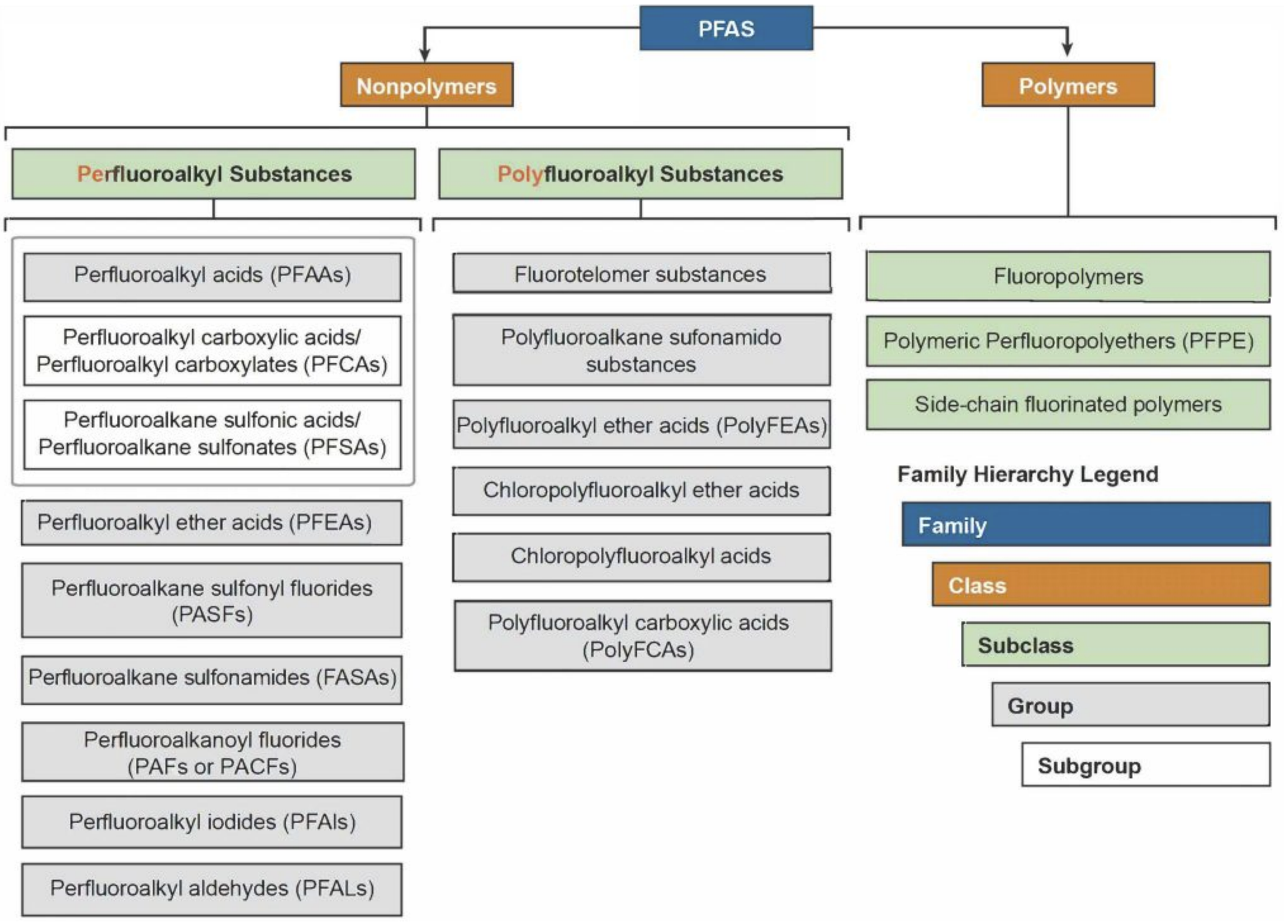


Figure 2: A PFAS family tree (Interstate Technology & Regulatory Council (ITRC) 2023, https://pfas-1.itrcweb.org/wp-content/uploads/2024/06/Fig2-4PFASFamily6-23-23-2048x1460_Corrected-1024x730.jpg)

Two PFAS that have been extensively researched are perfluorooctanoic acid (**PFOA**) and perfluorooctane sulfonate (**PFOS**) in the perfluoroalkyl acid PFAA subgroup, and these have featured in toxicity studies and site evaluations over the last two decades. More attention is also being paid to perfluorohexane sulfonate (**PFHxS**) and perfluorobutane sulfonate (**PFBS**) now, as well as **GenX** chemicals. GenX chemicals, notably hexafluoropropylene oxide dimer acid (HFPO-DA) and its ammonium salt, have not been routinely measured. These "next generation" chemicals were slated as replacements for PFOA and have been used widely in the USA.

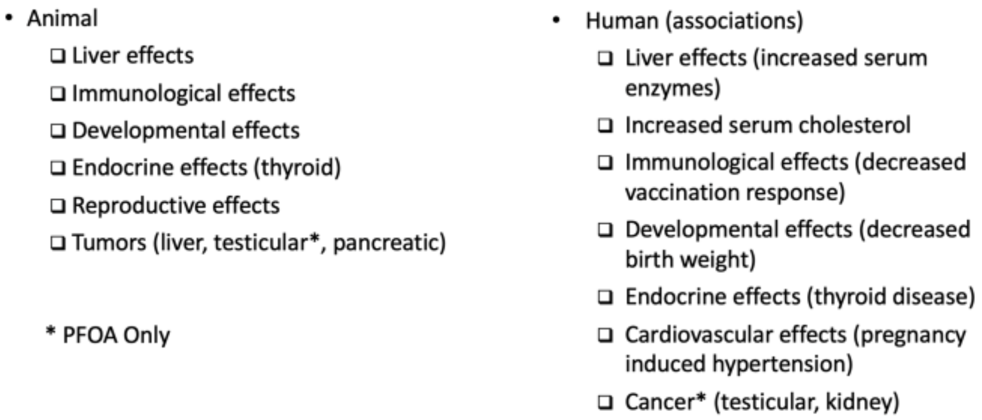
Up to 75 PFAS analytes can be tested commercially (Eurofins 2024) though the number depends on the media involved, but many kits only test for about 20.

Concerns

Some PFAS are, worryingly, **highly toxic** and linked to **developmental problems, cancer and immune-system suppression**. They are "everywhere" - in air, groundwater and surface water, and soil – and their range is global.

Occupational studies in the 1970s found PFAS in the blood of exposed workers, and in the 1990s, PFAS was detected more widely in blood in the general human population (ITRC 2023 s2.3). Several long-chain PFAAs, including PFOA and PSOS, have been measured in the low parts per billion (ppb or ng/mL) in the blood serum of almost all residents in the USA and other industrialised nations (ITRC 2023 s2.3).

PFAS have been found in blood, organs and human breast milk. The US Environmental Protection Agency (US EPA) states that the vast majority of people in industrialised countries have detectable concentrations of PFAS in their blood serum. Elevated concentrations of PFOS and PFOA in human blood have been linked to immunotoxicity, decreased sperm count, low birth weight, thyroid disease and high cholesterol (PFOA only) (US EPA 2013). Both PFOS and PFOA are suspected carcinogens (Deeb et al. n.d) Some health effects of PFOA and PFAS in animals including humans are listed in the following figure.



- Animal
  - ☐ Liver effects
  - ☐ Immunological effects
  - ☐ Developmental effects
  - ☐ Endocrine effects (thyroid)
  - ☐ Reproductive effects
  - ☐ Tumors (liver, testicular*, pancreatic)

* PFOA Only

- Human (associations)
  - ☐ Liver effects (increased serum enzymes)
  - ☐ Increased serum cholesterol
  - ☐ Immunological effects (decreased vaccination response)
  - ☐ Developmental effects (decreased birth weight)
  - ☐ Endocrine effects (thyroid disease)
  - ☐ Cardiovascular effects (pregnancy induced hypertension)
  - ☐ Cancer* (testicular, kidney)

Figure 3: Some health effects of PFOA and/or PFOS identified from published studies (ITRC 2023 2.4, https://pfas-1.itrcweb.org/7-human-and-ecological-health-effects-of-select-pfas/)

Over time, methods have been developed that can detect small amounts (e.g., parts per trillion [ppt]), and these are commensurate with levels of potential human health effects (ITRC 2023 s2.3). The number of PFAS that can be identified and quantified by analysis has also evolved, with longer lists of compounds beyond PFOA and PFOS linked to health and environmental concerns being recognised.

Some of these chemicals have been detected in US tap water in the low ng/L range (Appleman et al. 2013), and higher levels (hundreds of ng/L to several µg/L) in drinking water, particularly near sites of industrial use (Appleman et al. 2013).

In Australia, NHMRC (2024) have reported typical levels of PFOA, PFOS, PFHxS and PFBS detected in drinking water supplies as listed in the table below. It will be useful to refer back to these levels when looking at guideline or threshold values (discussed in the *Regulation* section in this document).

	Raw and/or reticulated drinking water supplies (ng/L)	Contaminated residential and private bores (ng/L)
PFOA	0 – 9.7	20 – 10,500
PFOS	0 – 16.4	80 – 136,000
PFHxS	0 – 19.1	130 – 54,300
PFBS	up to 2.2	40 – 6,520

Table 1: Typical levels of PFAS in drinking water in Australia (NHMC 2024)

Note: Until recently, GenX chemicals were not routinely measured. There have *not* been authorised introductions of GenX chemicals into Australia, except for small quantities for research purposes, but it is possible that they might be present in the country as trace residues in or on imported products that may end up in landfill and then leach into water supplies.

Where there is no specific source of PFAS contamination and where PFAA concentrations in drinking water and serum are in the “typical” background range, the primary sources of these chemicals and their precursors appear to be *food and food packaging*, *consumer products* – particularly nonpolymer aftermarket treatments, such as for textiles, upholsteries, carpets and leather (“aftermarket” here being a market for treatments used to maintain or improve an existing product) – and *coatings*, and *house dust* formed from such consumer products (ITRC 2023 s7). In communities near sources of PFAS contamination, higher concentrations than those in the general population can result from ingestion of contaminated drinking water or consumption of fish from contaminated waters.

By contrast, some PFAS, including the fluoro*polymer* PTFE, are regarded by some authors to pose little environmental or health risk and so to be of ‘low concern’ because they are relatively stable, insoluble in the environment, and not bioavailable (ITRC 2023 s2). Such assessments should be viewed with caution and may reflect limitations in the extent of testing. The assessment and management of fluoropolymers should also consider the *complete* life cycle, including associated emissions during production and disposal. It would be unwise to give any class or any group a blanket exemption from regulatory review.

Some PFAS can act as **precursors** for other PFAS chemicals that are more persistent (less prone to transform) in the environment. Because of shear numbers and the cost of testing, *very little is known about many PFAS*.

We do know that many are *hard to break down* and may *last for a long time* in the environment – 1000 years or more - hence the descriptor, “forever chemicals”.

Different PFAS last for different periods of time. Their stabilities differ, for example, the presence of carbon-hydrogen groups in polyfluoroalkyl substances makes these compounds easier to partially degrade, forming shorter-chain perfluoroalkyl compounds. The medium in which they exist will affect how long they last, for example, in air, water, soil or sediment. The half-life (the length of time it takes for half of a chemical sample to degrade) of the potassium salt of PFOS is estimated to be 114 days in air, but in water more than 41 years (at 25 °C). That of PFOA is reported to be 90 days in air, but in water more than 92 years (at 25 °C) (Deeb n.d.). PFAS will last for different periods of time in females and males.

Depending on their size, constituent functional groups (e.g., acid, alcohol) and ionic state, PFAS may be water-soluble. Some water-soluble PFAAs have an affinity for proteins and tend to distribute in the liver and blood serum; some have been found in kidney, bone, lung, brain and other organs in laboratory animals and/or humans (ITRC 2023 s7). Other PFAS have an affinity for fat tissue. PFAS can build up in the body with repeated exposure – they **bioaccumulate**. Fluorosurfactants, including PFOS and PFOA, bioaccumulate. PFOA can cause several types of tumour and neonatal death in animals and have toxic effects on the immune, liver and endocrine systems.

PFAS can present a particular threat to newborns. Some PFAAs cross the placenta and are present in breast milk. In human infants, exposures from breast milk result in substantial increases in long-chain PFAA serum levels during the first months after birth (ITRC 2023 s7). Exposures to infants from formula prepared with PFAS-contaminated water are also higher than for older individuals owing to their higher rate of fluid consumption.

The toxicity of a number of PFAS has been studied *individually* but different compounds *can occur together*. The sum total of effects from a **mixture** of PFAS can be *greater than its parts*. This is an active area of research and to date has tended to centre on cell cultures, mice and fish.

Exposure to PFAS can occur **in air**, for example, from dusts from sites where PFAS are present in soil or from aerosols derived from surface water, in addition to locations close to emission sources such as manufacturing facilities, wastewater treatment plants, fire training facilities and landfills (ITRC 2023, s17).

Low boiling point PFAS are **potent greenhouse gases**. Their global warming potentials typically ranging from thousands to tens of thousands, which means that they trap far more heat than carbon dioxide (Greenhouse Gas Protocol 2024). Smaller quantities tend to be emitted into the atmosphere than other greenhouse gases but they last for a long time. The environmental concerns of PFAS in the atmosphere are similar to other halogenated compounds (e.g., chlorofluorocarbons (CFC)).

Nonpolymer PFAS that include the *per*fluoroalkyl and *poly*fluoroalkyl substance subclasses have received more attention than polymer PFAS. They are most commonly detected (to date) in humans, biota and environmental media (soil, water, air), more abundant in investigation sites and have more data available about their human health and ecological effects from environmental exposure (ITRC 2023).

Remediation

The C-F bond is very strong and so is very hard to break. Breaking the C-F bond usually requires a huge amount of energy. Remediation schemes are expensive and have relied on the use of strong reducing agents, high temperatures or pressures.

Soil and groundwater remediation is challenging and costly because of the thermal and chemical stability of PFAS and the complexity of PFAS mixtures.

Cleanup of **soil** will depend on the properties of the site. Products are available to “stabilise” PFAS and to decrease leaching. Soil might also be washed (which does not remove the PFAS from the environment, only from the soil) and incinerated (Deeb et al. n.d.).

Some PFAS chemicals are water-soluble and one major pathway for human exposure is consumption of contaminated drinking water. One option to decontaminate **water** has been to filter out PFAS with **granulated activated carbon** (GAC), which is then either thermally reactivated and reused, or disposed of in landfill or incinerated. Sources of GAC include bituminous coal, lignite coal and even coconut shells (ITRC 2023 s12). GAC does **not** capture all PFAS chemicals, particularly shorter chain compounds, and incineration can be incomplete (Service 2024). This approach has been used for years at scale. The efficiency of capturing a specific PFAS depends on pH, ionic strength and the concentrations of organic co-contaminants and competing inorganic anions present.

Ion-exchange technologies (IX) have met with some success removing several different PFAS in pilot studies at least (ITRC 2023 s12).

Other sorbents, which either absorb or adsorb species of interest, such as mixtures of clay, have also been tried. In a major study, techniques employing high-pressure **membrane treatment** using **nanofiltration** or **reverse osmosis** were reported to effectively remove PFAS in full-scale water treatment facilities, including a small PFAS, perfluorobutanoic acid (Appleman et al. 2013; Deeb et al. n.d.).

Foam fractionation is an adsorptive separation technique that uses air and turbulence to generate bubbles rising through a water column to strip amphiphilic substances (having both hydrophilic or water-loving and hydrophobic or water-repelling parts) like PFAS from the bulk liquid. PFAS adsorb to the surface of the bubbles as they rise upwards and accumulate at the top of the column as a concentrated foamate that is then removed for further treatment or disposal. PFOS and PFOA have been successfully removed to low parts per trillion but short-chain PFAS (with four or fewer carbons) have **not** been effectively removed. The technique has been implemented at the pilot- and full-scale level ex-situ to remove PFAS in groundwater, leachate and industrial water. It is effective at removing a wide range of PFAS concentrations (for example, from low nanograms per litre to high milligrams per litre) but removal of PFAS at high concentrations require longer hydraulic retention times and/or additional stages of treatment. Foam fractionation is not significantly impacted by total organic carbon (TOC), dissolved metals and hardness that foul adsorpive media and membranes, unlike PFAS treatment with GAC, anion exchange resin and reverse osmosis. Site-specific water chemistry can affect performance (ITRC 2023 s12) and air bubbles are cheap, mobile, and “sustainable,” and do not require disposal after use (Burns et al. 2021).

The Australian Department of Defence contracted a groundwater treatment field trial at Oakey using surface-active foam fractionation (SAFF) and downstream “polisher” anion exchange resin (AIX), which after a three-year field trial was expanded and continued. The groundwater had been contaminated by Class B aqueous film-forming foams (AFFFs) used for firefighting and training purposes. The SAFF process was highly effective removing three “priority” species, PFOS, PFOA and PFHxS to levels below those specified in Australian and US standards, and remaining trace amounts were removed by the subsequent AIX resin, as were most of another eight “ancillary” species (Burns et al. 2021). The highly enriched PFAS foamate was to be incinerated.

Conventional water treatment techniques such as ferric or alum coagulation, granular/micro-/ultra- filtration, aeration, oxidation (i.e., permanganate, ultraviolet/hydrogen peroxide), and disinfection (i.e., ozonation, chlorine dioxide, chlorination, and chloramination) were mostly *ineffective* in removing PFAS (Appleman et al. 2013).

Interesting research has been published very recently involving **photo-catalysts**. Some low-energy ways are being investigated to break the C-F bond and these involve a catalyst that absorbs energy from visible light and then triggers a reaction. The catalysts break down a wide range of PFAS compounds at ambient pressure and temperatures (Service 2024). Use of these catalysts is still at the experimental stage and they have not been tested in the field.

Yan-Biao Kang and colleagues report targeting an organic catalyst, a carbazole-cored super-photoreductant KQGZ, with violet light at 40-60 °C, breaking down a range of large and small PFAS compounds. The catalyst takes electrons from a chemical added to PFAS compounds in solution and boosts the electrons’ energy, which enables them to react with and break apart the PFAS compounds giving fluorine-free carbonate, formate, oxalate and trifluoroacetate products. The separated fluorine atoms are sequestered by reacting them with potassium hydride in solution to form potassium fluoride, a nontoxic ingredient used, for example, in toothpaste. This fluoride can be recycled (Service 2024, Zhang et al. 2024).

In a second study, Garret Miyake and colleagues report the development of a related organic catalyst that’s more selective. Energised with blue light, it too takes electrons from an additive in solution and transfers them into PFAS compounds. Rather than just ripping the PFAS molecules apart, it removes the fluorine atoms and replaces them with hydrogens (hydrodefluorination), creating a hydrocarbon (Liu 2024, Service 2024). This technique either did not work with, or was not applied to, Teflon. (An “accelerated article preview” was only available at the time of writing this document and limited information was available.)

As argued in a *Nature* editorial (20 Nov 2024), these ideas need to be tested in real-world settings with catalysts that work in wastewater and which clean up contaminated soils.

The irony is that some PFAS we are now trying to remove were introduced to replace other harmful chemicals, for example, ozone-destroying chlorofluorocarbon (CFC) refrigerants.

Research is also needed into safer alternatives to PFAS that do similar things without harming health and the environment.

Regulation

The **Stockholm Convention on Persistent Organic Pollutants** is a multilateral environmental agreement that sets globally accepted standards for the use and management of persistent organic pollutants (POPs). It aims to reduce or eliminate the production, use and release of key POPs, synthetic compounds that, to varying degrees, resist photolytic, biological and chemical treatments. *Three* large groups of PFAS compounds are currently listed as persistent organic pollutants under the Stockholm Convention: **PFOS**, its salts and related compounds, and perfluorooctane sulfonyl fluoride (PFOSF); **PFOA**, its salts, and PFOA-related compounds; and **PFHxS**, its salts and PFHxS-related compounds. The Review Committee of the Stockholm Convention is currently looking at long-chain perfluorocarboxylic acids (LC_PFCAs), their salts and related compounds (Stockholm Convention 2024 and ITRC 2023 s2.4). Other PFAS may be nominated in the future (NEMP 2022).

Australia is a party to this Convention. When a chemical is listed under the Stockholm Convention, Australia is required to *ratify and implement* a range of actions (NEMP 2020). A number of countries have imposed restrictions on PFAS though others like China and Russia are reported to still produce PFOS and PFOA (ITRC 2023 s2.4).

The Heads of Environmental Protection Agencies Australia and New Zealand (HEPA) agreed to a PFAS National Environmental Management Plan (NEMP) in 2020. The current NEMP, Version 2.0, describes standards, such a guidance values for specified PFAS groups in a variety of media (water, soil, air) and protocols for testing for them. It is a “living document designed to reflect the current state of knowledge” and is to be formally reviewed every five years (NEMP 2020). HEPA expanded on Version 2.0 and issued a *draft for consultation* of NEMP, Version 3.0, in 2022 (NEMP 2022).

There are several ways to express concentrations for PFAS that are in common usage in, for example, water: micrograms per litre (µg/L) equivalent to parts per billion (ppb); nanograms per litre (ng/L), equivalent to parts per trillion (ppt). For drinking water, countries set **limits** or **threshold values**, above which they accept evidence that the compound has toxic effects. The limit may reflect the limit of detection at the current time and it should not be interpreted that below the value, the concentration is “safe”. In some jurisdictions, a limit may be “enforceable” and in others merely a “guidance value”.

In **Australia**, the **current drinking water guideline values** are 70 ng/L (equivalent to 0.07 µg/L or 70 ppt) for the *sum* of PFOS and PFHxS (which could be PFOS alone, PFHxS alone, or the sum of the two), and 560 ng/L (or 0.56 µg/L or 560 ppt) for PFOA (NEMP 2020, NEMP 2022).

However, the NHMRC, whose recommendations inform the NEMP, has recently released **draft guidelines** for drinking water in Australia that include revised regulations for *four* main PFAS chemicals in drinking water **reducing the limit** for PFOA from 560 ng/L to 200 ng/L and for PFOS from 70 ng/L to 4 ng/L. New limits are proposed for PFHxS of 30 ng/L and PFBS (perfluorobutane sulfonate) of 1000 ng/L (NHMRC 2024, Trager 2024). NHMRC did not see a guidance value for GenX chemicals as necessary at this time.

In April 2024, the US EPA announced the National Primary Drinking Water Regulation listing enforceable (by 2029) maximum contaminant levels (MLC) for *six* PFAS: 4 ppt (or 4 ng/L) for each of PFOS and PFOA, 10 ppt (or 10 ng/L) for each of PFHxS, PFNA and HFPO-DA (commonly known as GenX Chemicals) and 1 (unitless) for PFAS mixtures containing at least two or more of PFHxS, PFNA, HFPO-DA, and PFBS using a Hazard Index MCL to account for the combined and co-occurring levels of these PFAS in drinking water. It also published non-enforceable *goals* (MLCG) of zero ppt for PFOS and PFOA, an MLCG being “the level in a contaminant in drinking water below which there is no known or expected risk to health”. A goal of zero suggests admission that *no level of PFOA or PFOS is safe*.

Europe has issued drinking water directive thresholds, enforceable by 2026: a “sum of PFAS” of 0.1 µg/L for a group of 20 PFAS and a “PFAS total” of 0.5 µg/L. (The 20 specified PFAS are PFBA, PFPA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFBS, PFPS, PFHxS, PFHpS, PFOS, PFNS, PFDS, perfluoroundecane sulfonic acid, perfluorododecane sulfonic acid, perfluorotridecane sulfonic acid.) The “PFAS total” refers to the total amount of all PFAS that might be present, not just to the 20 named substances (Chem Trust 2024).

In the UK, England and Wales currently have a non-binding “wholesomeness” guideline value of 0.1 µg/L for the *cumulative* total of 48 PFAS. Water companies will be required to enforce this limit in 2025. Scotland adheres to the EU guidelines (DWI 2024, Trager 2024).

Scientists at the European Chemicals Agency (ECHA) are considering a proposal from authorities in Denmark, Germany the Netherlands, Norway and Sweden to **ban** 10,000 PFAS compounds in common use (*Nature* editorial 2024). Once an opinion is formed as to whether the proposed restriction is appropriate to reducing the risks to people’s health and the environment, and on its socio-economic impacts and enforceability, it will be sent to the European Commission who, together with EU Member States, will decide on the potential restriction (ECHA 2023). At this stage, aspects of the proposal are being considered by ECHA’s Committees for Risk Assessment (RAC) and for Socio-Economic Analysis

(SEAC) on a sector basis (to date: petroleum and mining; textiles, upholstery, leather, apparel and carpets; food contact material and packaging; and later: applications of fluorinated gases; transport; energy) (ECHA 2024). They are concentrating on the waste stage, for example, emissions from waste disposal and incineration, and are distinguishing between solid PFAS particle emissions and those that leach from materials as there are different environmental concerns for fluoropolymer particles and non-polymeric PFAS.

Recommendations

Treat PFAS as a class

- Treat PFAS as a **class** for regulatory purposes due to their high persistence, accumulation potential and/or hazards of the PFAS studied to date (Kwiatkowski et al 2020). Traditional toxicity analysis methods on mammals are time-, cost- and labour-intensive, and even then those conducted with non-humans do not always reflect the level of toxicity that humans may suffer. Toxicity data is available for a relatively small number of PFAS with PFOS and PFOA having the most extensive data sets. Under various risk assessment guidelines used around the world, in vivo mammalian laboratory animal or human data are required for development of chemical-specific toxicity factors, like reference doses, used to set standards for PFAS in drinking water and environmental media. With seven million PFAS in existence, but only some thousands being used commercially (4700 estimated by Cousins et al. 2020, cited by ITRC 2023 s7) and then toxicity data being gathered about only a very small number, it is neither feasible nor health-protective to follow a "chemical-by-chemical" paradigm for PFAS. In addition, exposure to multiple PFAS can occur at once.

  This class approach was advocated by Thornton (2000) in relation to the related class, organochlorines (chlorine and fluorine being closely related electronically and sharing many properties) and is supported by a number of scientists for PFAS (ITRC 2023 s7).

- **Limit ongoing uses of PFAS to those PFAS deemed "essential"**, that is, "uses considered essential because they are necessary for health and safety or other highly important purposes and for which alternatives have not been established" (ITRC 2023 citing, for example, Cousins et al. 2019).

  There is complexity here. What is "essential" and what is not? What period of time might be allowed to find alternatives before use of a substance is banned, and hence any phase-out period?

Managing PFAS as a class reduces the chance of replacing well studied hazardous substances with poorly studied but structurally similar PFAS that have the potential to be similarly hazardous, which has been described as "regrettable substitution" (Kwiatkowski et al. 2020).

Apply a precautionary paradigm in regulation

- **Emphasise the precautionary paradigm** that focuses on *preventing exposure rather than managing exposure*.

  Many PFASs that have been studied are **toxic even in very small amounts** so it cannot be assumed that *any dose is safe*. The risk posed by persistent PFAS poses long-term hazard to human and environmental health. It is insidious.

  The PFAS NEMP 2.0 acknowledges the precautionary principle, which it interprets as "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" (NEMP 2.0 2020). As mentioned earlier the NHMRC has recommended much lower guidance values for certain PFAS in various media (NHMRC 2024). It should never be interpreted, though, that below these levels the supply is "safe" and that organisms can accommodate some degree of chemical exposure with no or negligible effects (Thornton 2000). That interpretation is characteristic of the risk approach and biology does not work like that.

- **Put the onus needs on the producer** to demonstrate with comprehensive longer term testing that any PFAS to be used for a process is safe throughout its life cycle. Therefore, any companies proposing to produce PFAS compounds in Australia need to furnish evidence of comprehensive testing of their potential product as well as their plans for safety regimes and management plans, before any approval is given. Producers of PFAS compounds in Australia need to be subject to strict reporting guidelines and inspections by regulatory authorities.

- **Require users** of a PFAS substance in industry **to show** to regulators that the substance is currently **critical to their operations** and that they are moving towards employing safer alternatives. Regular reports documenting progress towards elimination of use of the particular PFAS need to be mandatory for the organisations in such fields. The dangers to health posed by PFAS are too great to allow arguments about onerous "red tape" with respect to reporting to hold any sway.

- **Give notice of phase-out periods** on various substances to allow for suitable alternatives to be adopted, after which use would not be permitted.
- Introduce a ban on all PFAS not deemed to be "essential".

Monitor PFAS in drinking water

The NHMRC (2024) reported that water quality data for PFAS has to date been collected on an *ad hoc basis* in areas with contaminated PFAS sites. Some water utilities conduct regular monitoring where their water is close to PFAS contamination sites whilst others monitor water even when there is no identified source of contamination.

- Due to their widespread occurrence, and as new information is becoming available all the time (Connick 2024 and Landow 2024), **require all water utilities to carry out tests on a regular and frequent basis** for as wide a variety of PFAS as possible, not just PFOA, PFOS, PFHxS, PFBS, certain GenX chemicals and any other substances when they are officially listed.

Review treatment techniques

A number of techniques to remove PFAS from various media are listed in the NEMP (NEMP 2020, 2022). Many critical details are absent, however, nor are these readily available in the references listed, some of which are Australian Government websites dating back to 2016 and 2017 (NEMP 2022). So, it cannot be assumed that the information published in the NEMP was up-to-date.

Different techniques can be used on different media of course – soil, sediment or water. Some remove PFAS, for example, soil washing, but the effluent still remains to be treated or destroyed. Some techniques may be useful only in combination with others, such as foam fractionalisation (FF) and granular activated carbon (GAC), and then the foam concentrate and filters need to be destroyed. Some cannot be employed directly on site (in situ) and need to be removed and treated some distance away (ex situ), for example FF, reverse osmosis. Others are said to be at a "laboratory" stage, for example, ultrasonication of water/wastewater.

Questions that arise include the following.

> *To what extent has each technique been tested? How much of a medium was treated in terms of mass or volume?*
>
> *How robust was the testing in terms of its methodology?*
>
> *Which PFAS were tested?*
>
> *How efficient was the technique – what were the concentrations of each PFAS compound tested before and after treatment, and thus the percentage reduction?*
>
> *Which PFAS were removed, long- or short- chain compounds, or both, bearing in mind that some techniques are ineffective with short-chain PFAS, which can be quite toxic?*

- **Gather and amalgamate into to an accessible and readily readable public register**, information about techniques have been used **at a practical scale in real-world settings**, for example, at the level of a contaminated reservoir or soil at an airfield, and what their energy consumption, financial costs and possible ecological effects might be. **Update** this register as new information becomes available.
- **Invest in robust field trials** of practical methods, and **implement** those that stand up to scrutiny at contaminated sites and then report regularly on the results of treatment.
- **Provide the detail to the public.** It is all too easy to claim success or say that a solution to a PFAS contamination problem exists and will be implemented, but to what extent and a solution to what precisely? Answers often lie in the detail. A case in point is the recent press announcement that a filtration system will be installed at the Cascade Water Filtration Plant in Katoomba, NSW after PFAS was detected at 300 times that of Sydney's main water source (EDO 2024). Neither the identity of the filtration method (reverse osmosis?) nor the particular PFAS compounds to be removed was supplied, so the public might be lulled into thinking that the problem is going away when that might not be the case.

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