Stockholm University

August 18, 2022

# Frequently Asked Questions on:

"Outside the Safe Operating Space of a New Planetary Boundary for Per- and Polyfluoroalkyl Substances (PFAS)" by Cousins et al. (**https://pubs.acs.org/doi/10.1021/acs.est.2c02765**).

***Written by: Ian T. Cousins, Jana H. Johansson, Matthew E. Salter, Bo Sha, and Martin Scheringer.***

## What are PFAS?

PFAS is a collective name for per- and polyfluoroalkyl substances or highly fluorinated substances that have a similar chemical structure. All PFAS are man-made with no natural sources and there are thousands of PFAS in use. They are extremely persistent in the environment, or break down into extremely persistent other PFAS. This property of extremely high persistence has earned them the nickname 'forever chemicals.' The four PFAS that we have covered in our paper have been investigated extensively and their toxicity has been demonstrated in many studies.

## Which PFAS are studied in the paper?

The current understanding of biological impacts is based primarily on studies of four PFAS, they are:

- PFOS (perfluorooctanesulfonic acid),
- PFOA (perfluorooctanoic acid),
- PFHxS (perfluorohexanesulfonic acid)
- PFNA (perfluorononanoic acid)

The toxicity of a few other PFAS are reasonably well characterized, but the toxicity for the vast majority of PFAS is poorly understood or unknown.

Because the human health effects are sufficiently understood for these four substances, we focused our paper on them (see this website for detailed information on human health effects for PFAS: https://www.atsdr.cdc.gov/pfas/health-effects/index.html). These four PFAS have been heavily regulated in most of the world, and the only region where any of them are still used is in Asia (primarily in China). Although the use of these PFAS has been largely phased out, their environmental levels remain stable, as discussed below.

## What effects can PFAS have on human and environmental health?

PFAS have been associated with a wide range of serious human health harms, including different forms of cancer, development toxicity, infertility and pregnancy complications, diagnosed high cholesterol, ulcerative colitis, liver hypertrophy ('enlargement'), and thyroid disease. These effects are observed at relatively higher exposure levels than the new health advisories set by the US EPA (4 pg/L for PFOA or 20 pg/L for PFOS). The effect that has driven many of the guidelines to their extremely low levels is the observation that PFAS

Stockholm University

exposure can lead to a decreased effectiveness of vaccines in children (https://www.mdpi.com/1660-4601/14/7/691/htm). At these low PFAS exposure levels (i.e. ng/L levels), it is unlikely that the other above-listed effects would be observed. It has been implicated in some news articles and social media that drinking PFAS-contaminated rainwater will cause cancer. Although there is evidence that high PFOA drinking water exposures can cause testicular and kidney cancer (http://www.c8sciencepanel.org/), there is no evidence that drinking water contaminated at ng/L levels will cause cancer.

There has been some focus on effects on plants and wildlife (called ecotoxicity), but this focus (and concern) has been relatively low compared to human toxicity. Most ecotoxicity studies focus on laboratory studies at high doses or areas heavily contaminated with PFAS. However, concern about the possible ecological impacts of PFAS is comparatively recent, so many regulatory and risk assessment programs are still in early stages of development and implementation. The ecological risks of PFAS are too detailed to be summarized here but have been reviewed by Ankley et al. (https://setac.onlinelibrary.wiley.com/doi/full/10.1002/etc.4869).

## How are PFAS used?

Glüge et al. (https://pubs.rsc.org/en/content/articlelanding/2020/em/d0em00291g) identified more than 200 use categories and subcategories for more than 1400 individual PFAS. In addition to well-known use categories such as textile impregnation for water and oil repellency, fire-fighting foams, non-stick cookware, and paper and board used in food contact materials, the identified use categories in Glüge et al. also included many categories not previously described in the scientific literature, including uses of PFAS in ammunition, climbing ropes, guitar strings, artificial turf, and soil remediation. Again, the four PFAS that are the focus of the paper are not currently used outside of Asia.

## What are the main messages of the paper?

The article points out that the due to the increase in knowledge of toxicity in the last 20 years of the four well-studied PFAS mentioned above, what is considered a safe exposure level for humans for these PFAS has continuously declined (this is also discussed in: https://setac.onlinelibrary.wiley.com/doi/full/10.1002/etc.4863).

The result of this increased knowledge of toxicity is that the recommended guideline levels for these four PFAS have also been reduced to the point that ambient environmental levels are above or close to the guideline levels. These ambient environmental levels have been stable since they were first measured in the environment in the early 2000s, and there is no evidence of an increasing or decreasing temporal trend in these levels (https://environmentalevidencejournal.biomedcentral.com/articles/10.1186/s13750-017-0114-y). We expect therefore that the ambient environmental levels will ubiquitously remain above or close to the guideline levels for the foreseeable future (on the order of decades, but the exact recovery time is uncertain).

## What are the planetary boundaries and why has a new planetary boundary for PFAS been exceeded?

In the planetary boundary concept, an attempt is made to estimate the boundaries for ‘a safe operating space for humanity’. Chemical pollution was one of the original nine anthropogenic

Stockholm University

impacts for which planetary boundaries were postulated. The boundary of 'chemical pollution' was recently renamed the boundary of 'new entities'. As emissions of PFAS have **globally** and **irreversibly** contaminated the planet so that environmental resources are no longer safe to use, we argue that humanity is outside the safe operating space of a new planetary boundary for PFAS. This means that the 'novel entities' boundary is also exceeded. We suggest in the paper that multiple separate planetary boundaries can emerge from within the novel-entities boundary and that the PFAS planetary boundary is the first to be identified and exceeded.

Being outside the safe operating space for humanity is not a good place to be. It doesn't mean that humanity is necessarily in imminent danger, but it means that we have made the planet rather inhospitable for human life given that basic environmental resources (drinking water sources, surface waters, and soils) are irreversibly contaminated with PFAS and considered as unsafe to utilize in order to support human life.

## How are PFAS measured in rainwater and other environmental media?

In our paper, we collect data from previously published studies. Some of those measurements for PFAS in previously-published studies were made by some of the authors, but no new data are presented in the paper. There are often questions on how PFAS are measured in environmental media, so a brief plain language description is provided below. If you want more details on the analysis of PFAS in rainwater then please see the work of Johansson et al. (https://pubs.rsc.org/en/content/articlelanding/2018/em/c8em00102b).

Precipitation samples (rain or snow) are often collected using an open funnel that drains into a collection bottle. Soils are often sampled with a sampling device called an 'auger' which collects a profile (core) of the top organic layer (top 5-20 cm) of the soil. Surface waters are often simply sampled by taking "grab" samples (simply filling containers with water), but they can also be sampled in more complex ways (e.g. rivers can be sampled using flow-proportional samplers). From all of these environmental samples, PFAS are then extracted and concentrated before being analyzed on an advanced analytical instrument.

It is critically important to check that the samples are not contaminated during handling, which could lead to an overestimation of levels. To ensure this does not happen, multiple so-called blank samples are analyzed alongside the environmental samples.

As mentioned in the paper, it is an extreme analytical challenge to measure pg/L (parts per quadrillion levels) in water, so it is probably not possible to practically determine if levels are above or below the guideline set at pg/L levels by the US EPA (e.g. 4 pg/L PFOA or 20 pg/L PFOS).

## What treatment methods are available for PFAS and can they clean the water and soil so that PFAS levels are below the new low guidelines?

A wide range of methods are emerging for the treatment of soils and water contaminated with PFAS. Common methods for cleaning contaminated water include granular activated carbon, anion-exchange resins, chemical oxidation, electrochemical oxidation, reverse osmosis, and sonolysis. Soil stabilization, washing, and thermal treatment approaches are also being

developed for treating PFAS-contaminated soils. Importantly, these treatment methods focus only on 'hotspot' contaminated areas and often require a high energy input to be effective.

As mentioned above, although these methods are reasonably effective for the four PFAS discussed in our paper, it would be challenging analytically to determine if the treated water would be below the guidelines. Ross et al. have written a review of treatment methods (https://onlinelibrary.wiley.com/doi/full/10.1002/rem.21553). It is uncertain if low pg/L levels can be achieved by water treatment processes.

## Is the environmental contamination really irreversible?

Although there are treatment methods for PFAS, these cannot be applied to globally contaminated soil and water (it is impossible to clean up the entire planet!). We can only wait for the levels of the four PFAS to slowly decline to levels below the low guideline levels. PFAS will not be degraded, but they will slowly be diluted into the deep oceans on a timescale of decades, and this will result in slowly declining global levels.

The continual cycling of PFAS between the surface and the atmosphere (e.g. the PFAS moving from land to oceans and then back from oceans to land) will likely slow the decline in global levels. PFAS that end up in the ocean may boomerang back to shore after they are re-emitted into air with the crashing of waves. Research carried out at Stockholm University suggests that sea-to-air transport of PFAS on sea spray aerosols is a significant contributor to PFAS air pollution (https://www.su.se/english/news/harmful-boomerang-pfas-pollution-in-ocean-comes-back-to-land-1.587927).

## How are humans exposed to PFAS?

For the larger class of PFAS, human exposure pathways will vary enormously. For the four PFAS that we focused on in the paper, humans are exposed primarily through ingestion of food, drinking water, and household dust. Food is contaminated with PFAS primarily from the environment, so exposure to low-level PFAS through food intake is also expected to continue long into the future. It should also be noted that humans in developed countries have been exposed to the four PFAS for several decades already and that exposure (e.g. human blood levels) peaked at around the turn of the millennium in most developed countries (https://environmentalevidencejournal.biomedcentral.com/articles/10.1186/s13750-017-0114-y). At the time of the highest ambient human exposures, around 20 years ago, there was a relatively poor knowledge of human toxicity for the four PFAS.

While the levels of the four PFAS in our study peaked in human blood about 20 years ago, there are many thousands of other PFAS that should also be considered. The concentrations of some these other PFAS are not decreasing in human blood (https://environmentalevidencejournal.biomedcentral.com/articles/10.1186/s13750-017-0114-y), and some novel and emerging PFAS may be increasing, although there is currently a lack of data to corroborate this. Many PFAS are not monitored, or studied at all, so we know nothing about their exposure levels or their toxicities, which is concerning.

## How can humans avoid exposure to PFAS?

It is not possible to avoid some future long-term low-level exposure to the four PFAS in our paper. Some potential but unproven options to lower exposure are provided here. In homes

Stockholm University

and offices, vacuuming will reduce dust exposure, but there are no methods to remove PFAS from food. Vegetarians will have relatively lower exposures compared to those on an omnivorous diet given that PFOS, PFOA, PFHxS and PFNA are in particularly high concentrations in meat and fish. Other options to reduce human exposure are cleaning up all contaminated hotspots to stop future emissions from these areas and to put more pressure on China to stop emitting certain problematic PFAS. Efforts to clean up contaminated areas are anyway needed to reduce local high levels of human exposure to PFAS.

## Do people really drink rainwater?

Yes, in many parts of the developing world it is common to drink untreated rainwater. Although in most developed countries, it is common to drink treated water from a local supplier, it has come to our attention during media work that direct consumption of rainwater is common even in some developed countries. For example, in Western Australia it is common to collect rainwater and drink it without any treatment.

## Is it safe to drink rainwater?

We are uncertain. The guidelines are set so low because the authorities want to be close to certain that no effects will occur at those levels. Therefore, precautionary assumptions are often used to ensure that the public is protected. We have to hope that effects will not occur, but we cannot be certain if they have already occurred or will occur in the future on the large scale.

If rainwater is consumed directly, then it could be cleaned, for example, by filtering through activated carbon, but we doubt whether it can be cleaned to pg/L levels, and it would anyway be challenging to determine if cleaning had been effective due to the lack of analytical methods able to measure to those levels. Research labs can measure down to pg/L levels as we discussed in the paper, but these labs are not available for the routine testing for large number of water samples.

As discussed above, humans are anyway exposed to PFAS via food and dust ingestion in their homes, and these exposure pathways cannot be easily avoided. It is not possible to completely avoid low-level PFAS exposure so humans will have to live with long-term low-level exposure for the foreseeable future. We will have to live with the uncertainty of whether effects are occurring or not. This is a terrible situation to be in and we must learn an important lesson from this.

## How are PFAS emitted to, and cycled through, the atmosphere?

This is complex and not fully understood. The four PFAS included in our paper have three main atmospheric sources. These three sources are discussed in turn below.

1) Other volatile PFASs that were historically used in consumer products were emitted into the environment. In the atmosphere, some of these volatile PFAS can degrade into the four PFAS, which do not degrade further. The four PFAS are involatile and will be deposited on the Earth's surface after they have formed in the atmosphere, for example, when they are washed out of the atmosphere by rain. These volatile PFAS have also been phased out, but their levels in the atmosphere do not appear to be declining (https://environmentalevidencejournal.biomedcentral.com/articles/10.1186/s13750-017-0114-

Stockholm University

y). There could be a continuous source of volatile PFAS in the atmosphere from old landfills and surface soils that have been contaminated in the past. It remains an important research question.

2) The four PFAS can be remobilized from the ocean to the atmosphere in sea spray aerosols (see the work of some of the authors here: https://www.su.se/english/news/harmful-boomerang-pfas-pollution-in-ocean-comes-back-to-land-1.587927). Bubbles formed by wave action rise to the surface and burst, emitting sea spray aerosols, and these small droplets are highly enriched with the four PFAS. Once emitted, these small aerosols transport the PFAS over long distances in the atmosphere before eventually depositing on the surface. There is growing evidence that sea spray aerosols are an important source of PFAS to the atmosphere. More evidence will be published soon.

3) PFOA and PFNA are still used in the manufacture of fluoropolymers (e.g. polytetrafluoroethylene, PTFE) in Asia (especially China), and there are large direct releases of these PFAS into the atmosphere there. This is the reason why there are high levels of PFOA in Chinese rainwater measurements near a fluoropolymer plant included in Figure 1 of our article. The PFAS emitted in China will not remain in China and will be transported worldwide.

Understanding the relative contribution of these sources of PFAS to the atmosphere is the focus of ongoing research.

## Will PFAS ever eventually return to safe levels?

As explained above, it is impossible to avoid long-term low-level exposure to the four PFAS that we focus on in the paper. These four PFAS are already heavily regulated in most parts of the world and we are just going to have to wait decades for them to slowly dilute into the deep oceans.

## What lessons can be learned?

Although we cannot do anything to eliminate our long-term low-level exposure to the four PFAS discussed in the paper, we can all do a lot to re-evaluate our ongoing use of the wider class of PFAS. There are many thousands of PFAS currently in use. All PFAS are man-made, therefore they have no place in the environment, and will never degrade. Due to this problematic extreme persistence, scientists (including some of the coauthors of the present study) have suggested that PFAS should only be used where they are essential and that the essentiality of every use of PFAS should be evaluated (https://pubs.rsc.org/en/content/articlelanding/2019/em/c9em00163h). As pointed out in the paper, persistence is generally seen as a less immediate hazardous property than toxicity, but it is actually the key factor that lets pollution problems spiral out of control (https://pubs.rsc.org/en/content/articlelanding/2019/em/c8em00515j).