Will we ever have clean water again?

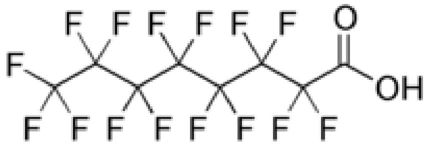
PFAS and the challenge of mobile persistent chemicals in water.

Carla Ng, University of Pittsburgh
Department of Civil & Environmental Engineering
2022 Clean Water Symposium

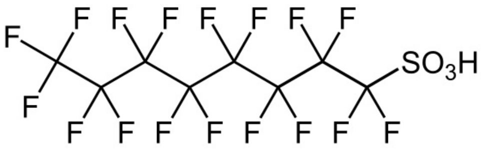
University of Pittsburgh

A quick primer on PFAS

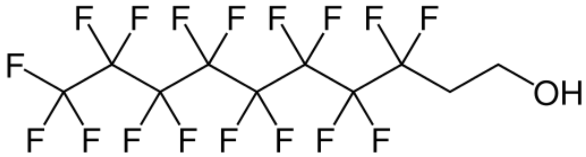
- Per and polyfluoroalkyl substances:



***PFOA**: C8 carboxylic acid*

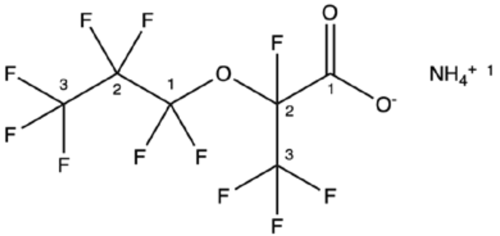


***PFOS**: C8 sulfonic acid*



***8:2 FTOH**: fluorotelomer alcohol*

- Digesting the acronym soup – key categories
  - Long-chain (CF≥6) vs. short-chain (*)
  - Transformable (“precursor” compounds)
  - Emerging/replacement trends (short-chain, ethers)

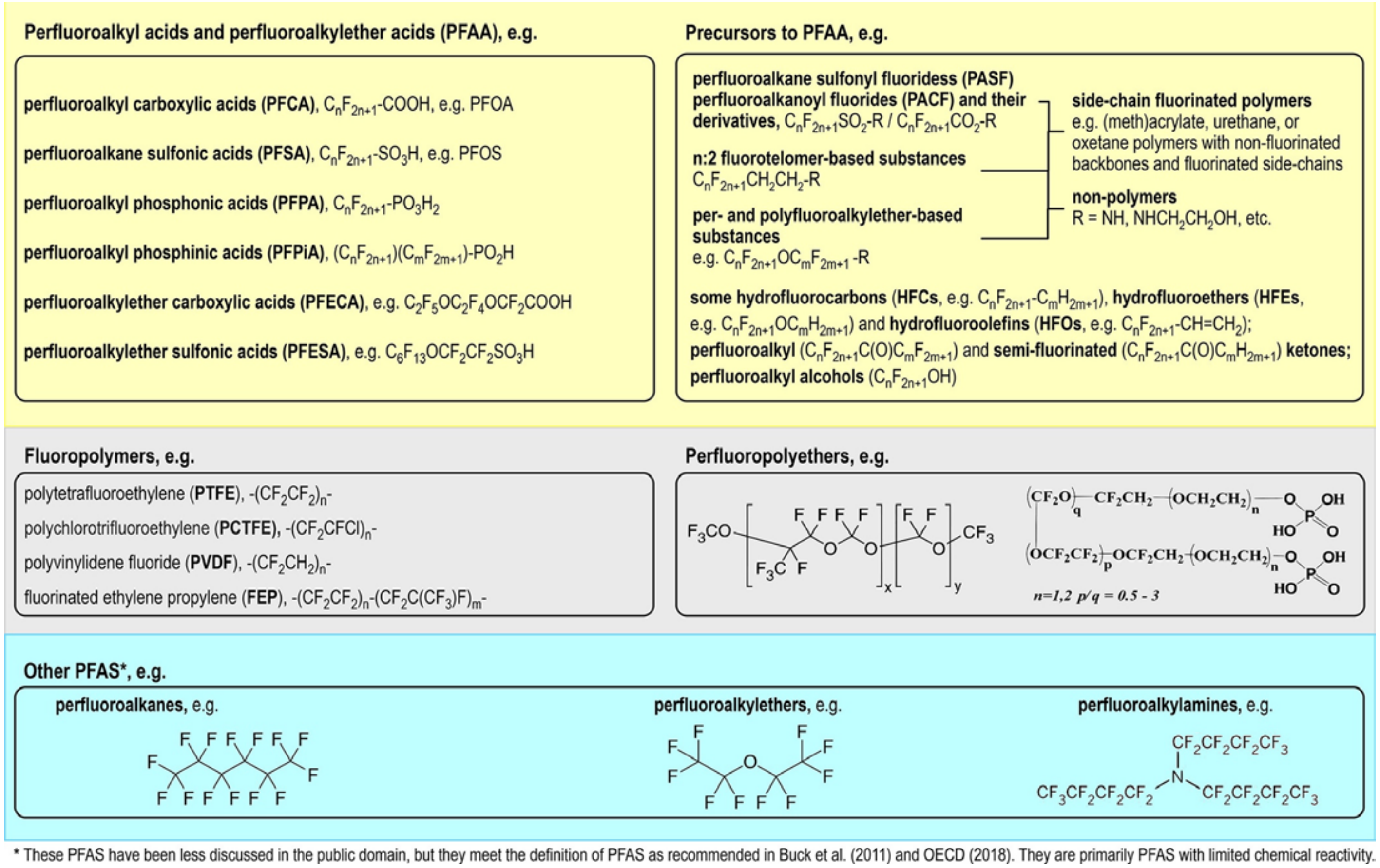


***GenX**: ammonium salt of HFPO-DA*

Beyond the usual suspects

The PFAS class is extremely diverse. Members from multiple sub-groups often used in a single products (e.g. AFFF).

Kwiatkowski et al. 2020 ESTL



Beyond the usual suspects

- We track a handful, but the PFAS universe is complex.
  - Which are used where, in what quantity?
  - Which "are" PFAS?

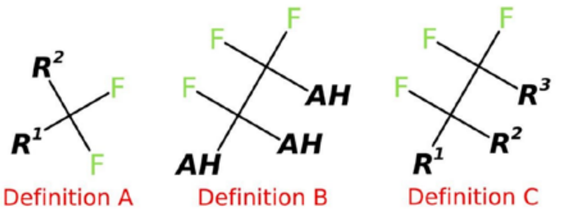


***Figure 1**: Schematic representation of the PFAS definitions A, B and C considered in this work. "AH" = hydrogen or any other atom; R^1, R^2, R^3 represent any atom other than hydrogen.*

CORE: Aggregation of open access journal papers.

	Total	Not found in PFASMASTER (10,782 InChI)	Found in PFASMASTER (10,782 InChI)	Found in OECDPFAS (3,741 InChI)	Not found in PubChem*
CORE Definition A	27,058	25,446	1,612 (1686 IKFB)	944 (988 IKFB)	7,119
CORE Definition B	4,139	2,652	1,487	939	1,175
CORE Definition C	3,457	2,095	1,362	931	915
Patents Definition A	1,783,651	1,780,041	3,610	1,529	216,777
Patents Definition B	75,108	71,818	3,290	1,520	10,809
Patents Definition C	34,197	32,564	1,633	847	4,882

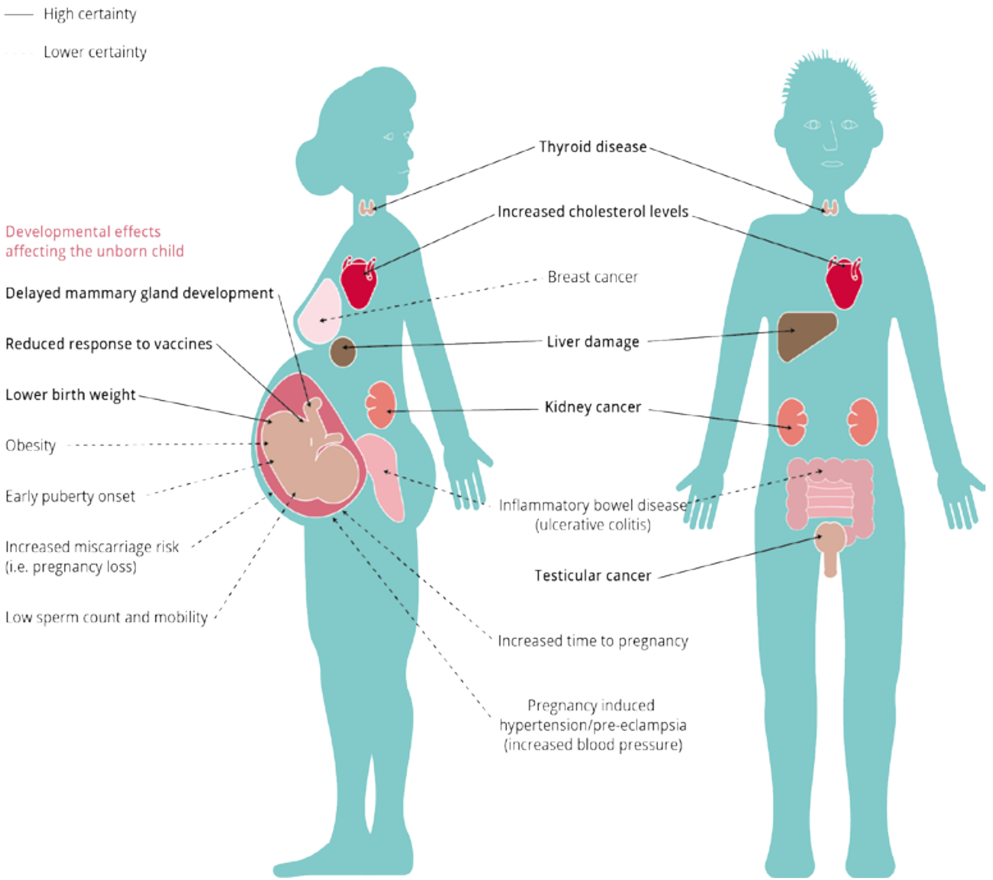
**Prior to deposition of the entire dataset to PubChem, to fill these gaps.*

Barnabas, et al. Digital Discovery, 2022, DOI: 10.1039/D2DD00019A

University of Pittsburgh

Why the concern?

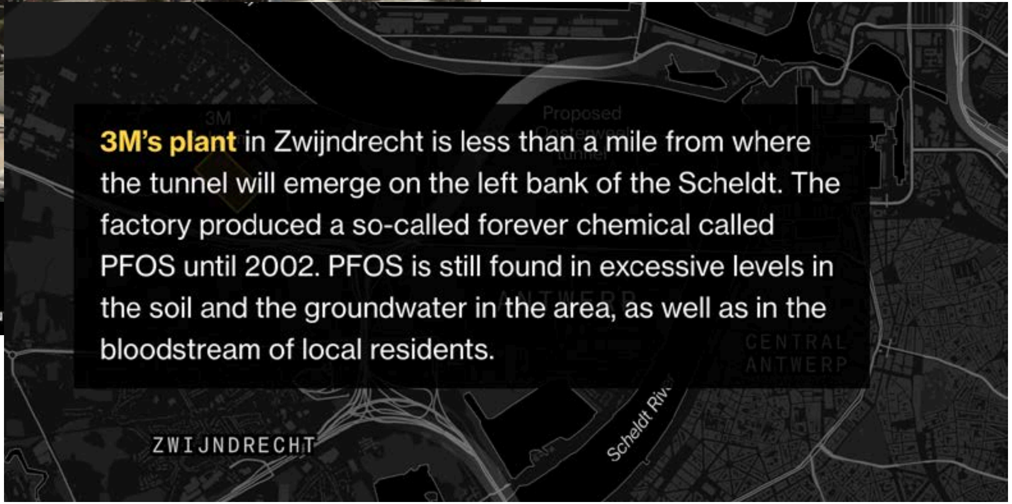
- PFOA, PFOS, PFNA, GenX, a handful of other substances with substantial basis for understanding toxicity (humans and wildlife).
- Wide variety of systems affected, concordance with animal studies.



Fenton et al. 2020 ET&C

University of Pittsburgh

How PFAS gets into our water

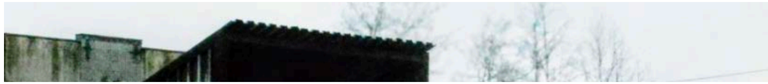


Direct releases from industrial activities.

University of Pittsburgh

https://www.bloomberg.com/graphics/2022-3m-pfas-toxic-forever-chemicals-europe/

How PFAS gets into our water



State investigating contamination at fire training center

March 30, 2022 5:33 pm

The **Fire Training Center was placed on the State's Superfund site due to water contamination from poly- and perfluoroalkyl substances, known as PFAS, which are chemicals used in firefighting applications.** The State says that the site presents a significant threat to public health and/or the environment.

At least 12 military bases contaminating water supply with toxic PFAS

Testing by the Department of Defense revealed dangerous levels of the contaminants, drawing concern from public health advocates

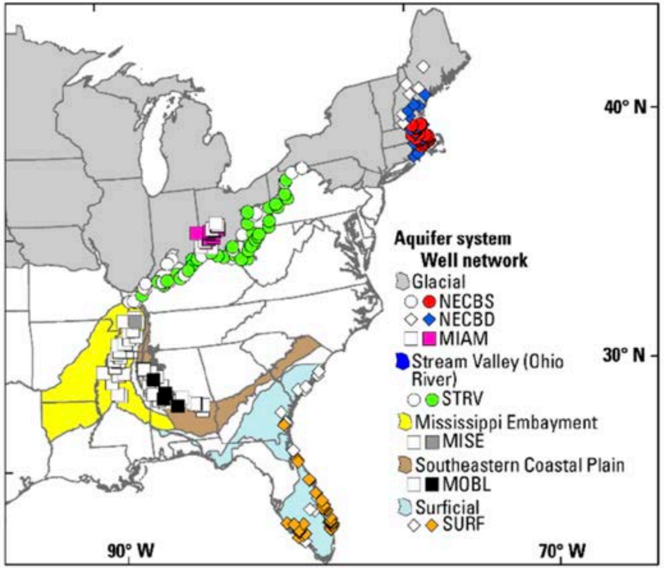
PFAS are a class of about 9,000 chemicals used to make products resistant to water, stains and eat. Photograph: Jake May/AP

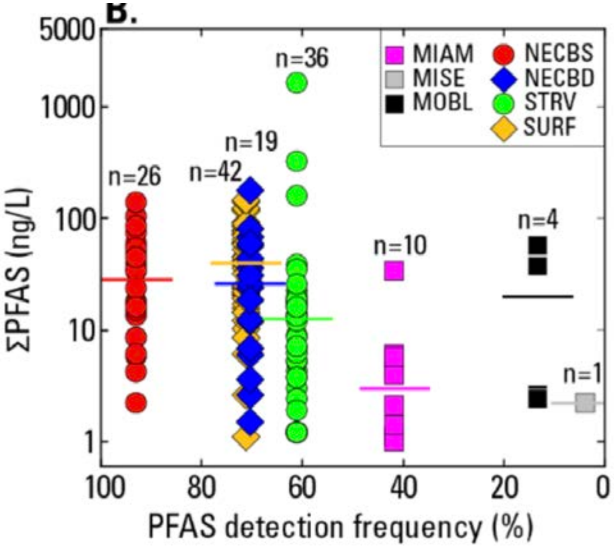
angerous levels of toxic PFAS are contaminating water supplies in areas around at least 12 military bases, new Department of Defense testing has revealed, drawing concern from public health advocates that the DoD is not doing enough to protect the public.

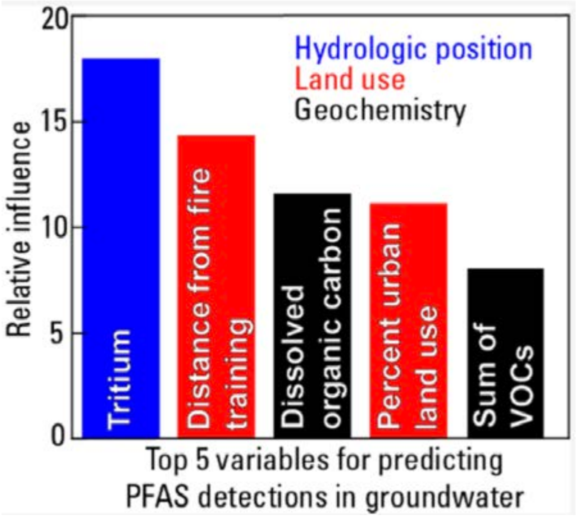
University of Pittsburgh

Groundwater contamination.

How PFAS gets into our water







McMahon et al. ES&T ***2022*** *56 (4), 2279-2288*

University of Pittsburgh

Groundwater contamination.

How PFAS gets into our water

Distribution and fate of per- and polyfluoroalkyl substances (PFAS) in wastewater treatment facilities†

Elham Tavasoli,[ab] Jenna L. Luek,[a] James P. Malley Jr[a] and Paula J. Mouser[*a]

Precursors → short-chain → effluent

Long-chain → sludge → land

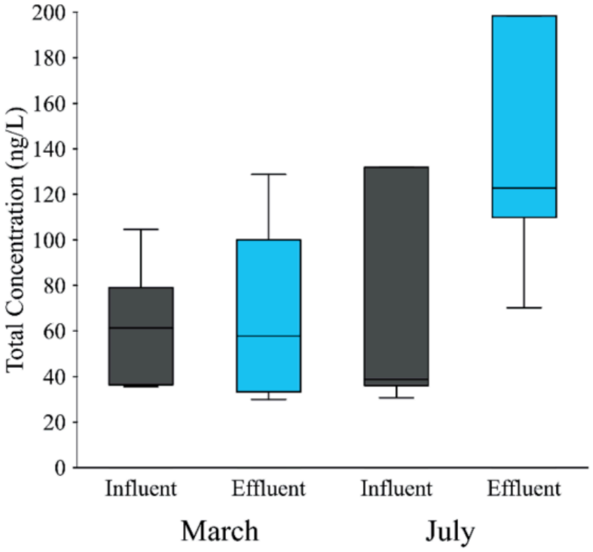


Fig. 2 Boxplot of influent and effluent ΣPFAS concentrations from all WWTFs by sampling month (March $n = 6$, July $n = 4$). Box indicates 25^{th} to 75^{th} percentile with median, whiskers indicate maximum and minimum values.

Wastewater effluent and solid waste.

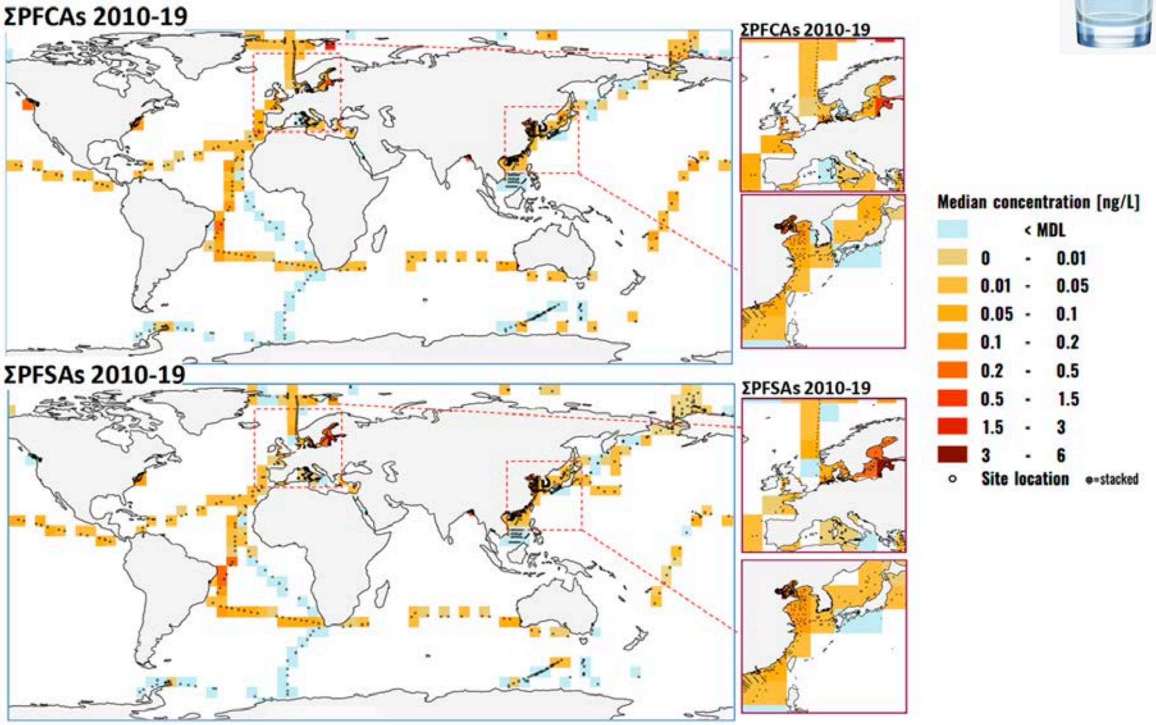
University of Pittsburgh

Tavasoli et al. 2021 DOI: 10.1039/d1em00032b

How PFAS gets into our water

Rainwater in parts of US contains high levels of PFAS chemical, says study

Levels high enough to potentially impact human health and trigger regulatory action, which only targets two of 4,700 variants

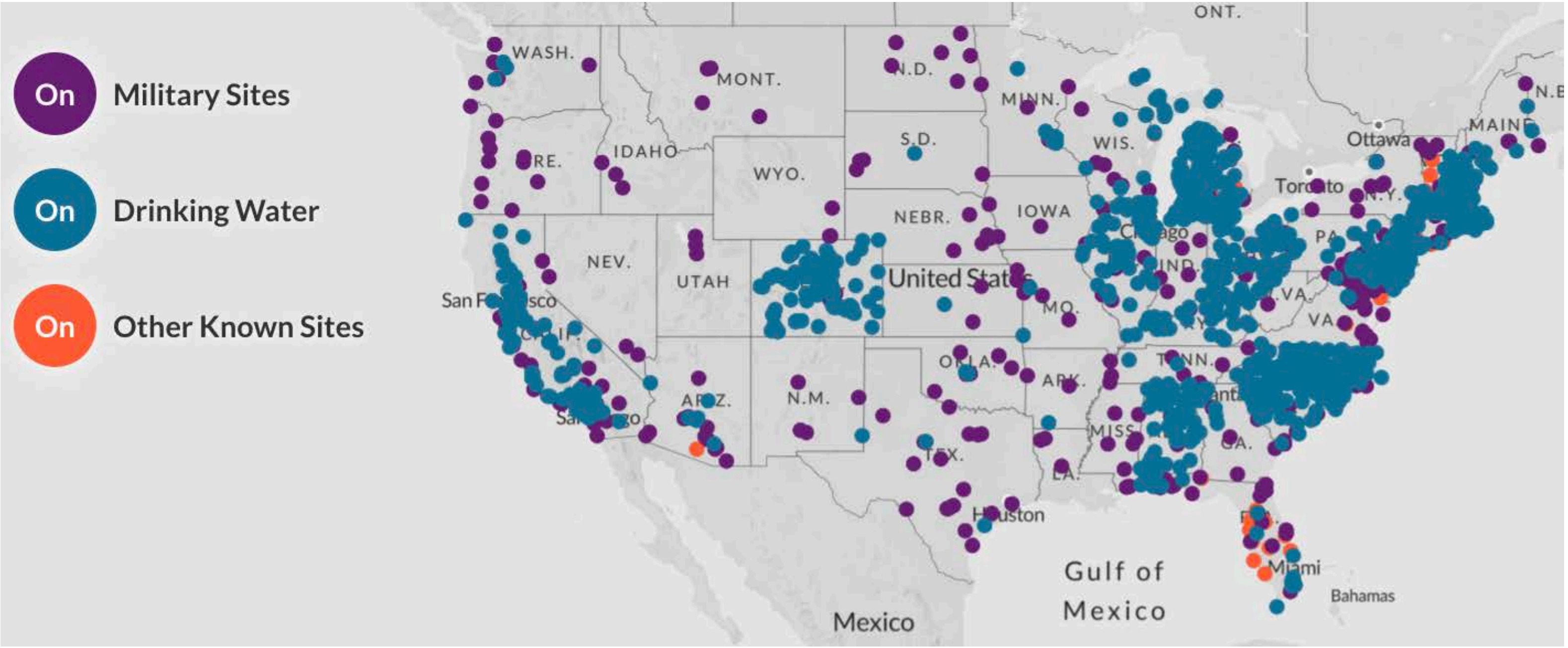


Global distribution means there is no avoiding PFAS.

Global atmospheric and oceanic cycling.

University of Pittsburgh

In other words, PFAS are everywhere.



https://www.ewg.org/interactive-maps/pfas_contamination/map/

A surprising(?) Pittsburgh example

Part of McKeesport under water advisory

July 19, 2021 | Mon Valley Independent | Latest News

Friday's fire at McKeesport Auto Body has resulted in a water advisory being issued for a portion of the city.

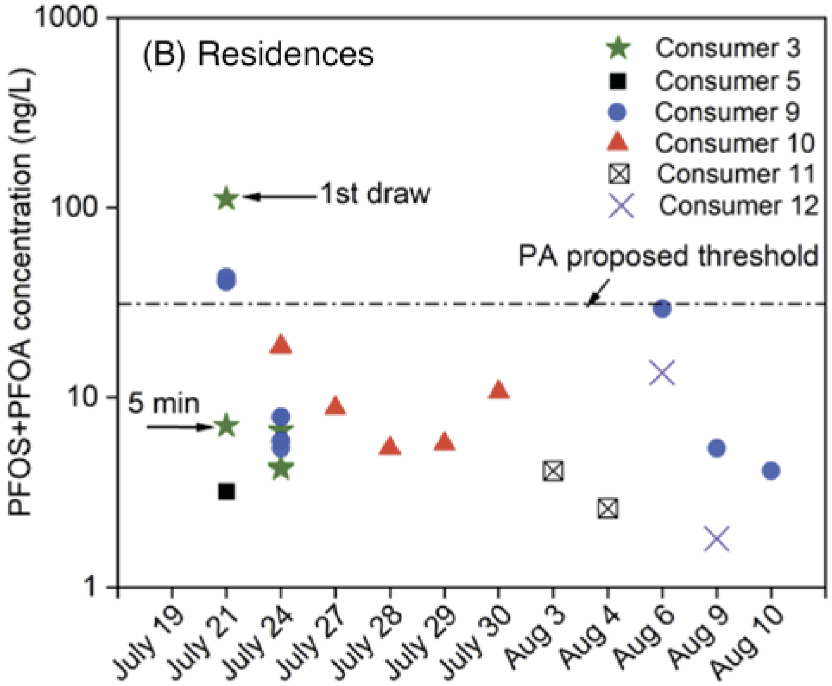
Facebook 0 | Tweet 0

By TAYLOR BROWN

tbrown@yourmvi.com

Residents of the Lower 10th Ward in McKeesport are being asked not to use their tap water as a result of a fire in the city Friday.

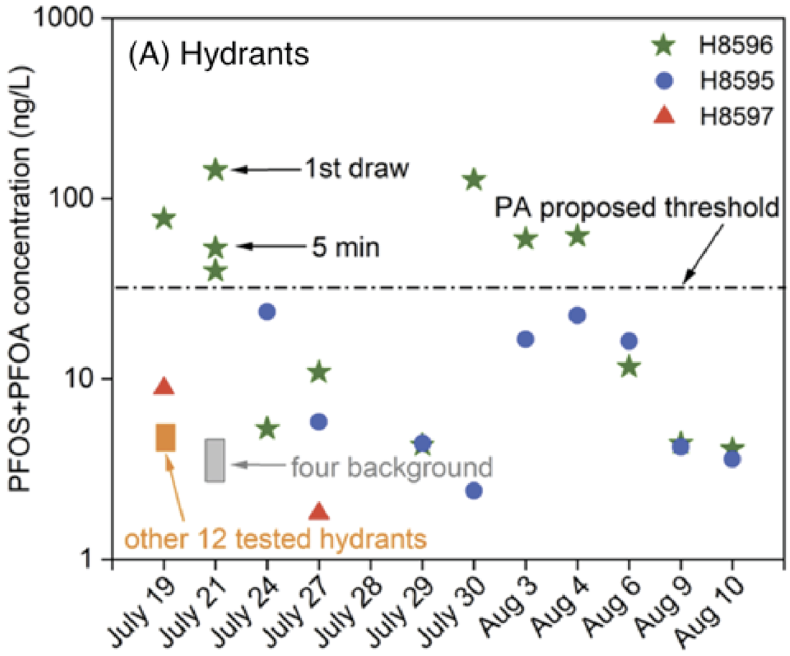
McKeesport Auto Body fire



- Testing conducted on behalf of water authority indicated varying levels, lack of consistent sampling.
- Set of targeted PFAS not necessarily appropriate for AFFF contamination.

University of Pittsburgh

McKeesport Auto Body fire

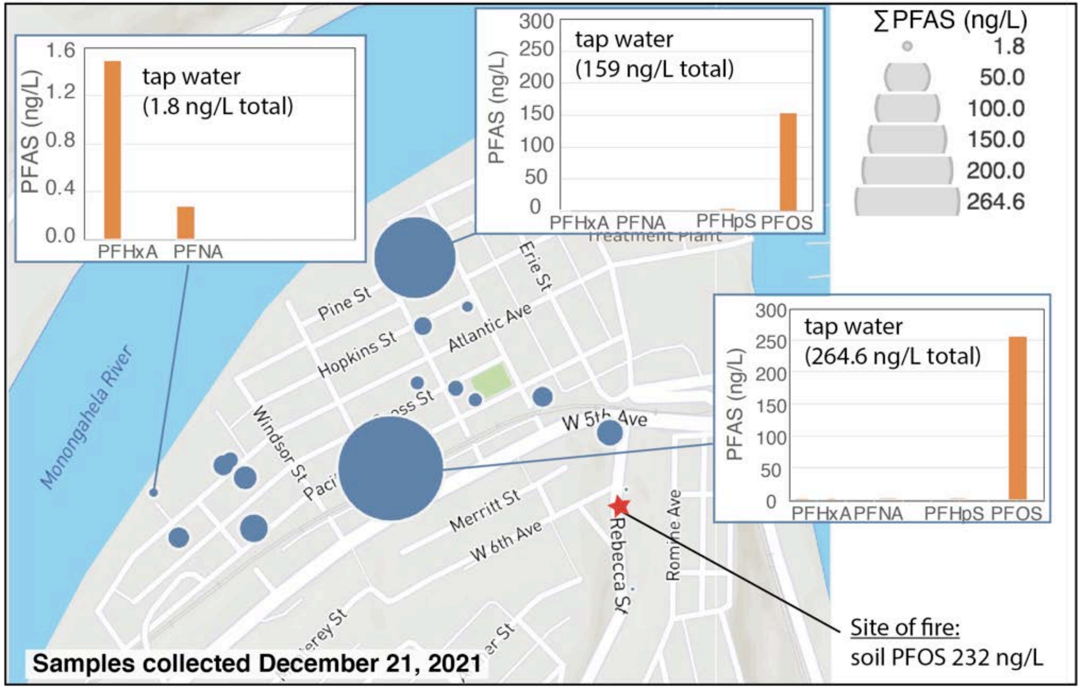


- Hydrants were a main target of sampling as they were direct reports on levels in the distribution system.
- To our knowledge, no monitoring of environmental fate was carried out.

University of Pittsburgh

Drinking water, six months later

- Working with Women for a Healthy Environment (WHE), sampled drinking water across the affected part of the community.
- Tested for long- and short-chain perfluoroalkyl acids.
- Two households had one high sample each, dominated by PFOS (>150 ng/L).
- PFOS was still high in soil around fire site (232 ng/L).



University of Pittsburgh

What can be said of the surrounding landscape?

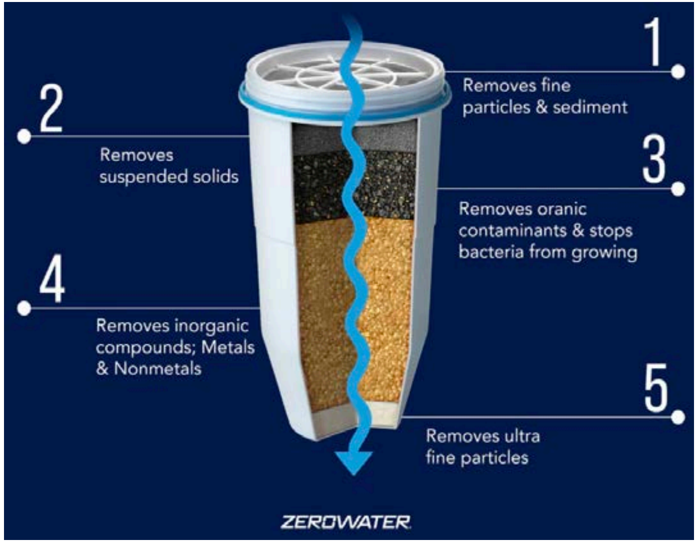
- The primary strategy to clear PFAS contamination in the distribution system was flushing of affected hydrants.
- In one case a hydrant had to be replaced because of persistent contamination.
- Where did the flushed PFAS go?

University of Pittsburgh

Treatment options …

WOMEN for a Healthy ENVIRONMENT

- At McKeesport, active community members working with WHE distributed pitcher filters to provide ongoing water treatment after the advisory was lifted.
- Filters that use a combination of activated carbon and ion exchange show better performance than carbon alone and are effective at removing long-chain PFAS like PFOS.
- Over the next two years, we will be using water, filters and soils to understand the fate and transport of this AFFF spill.

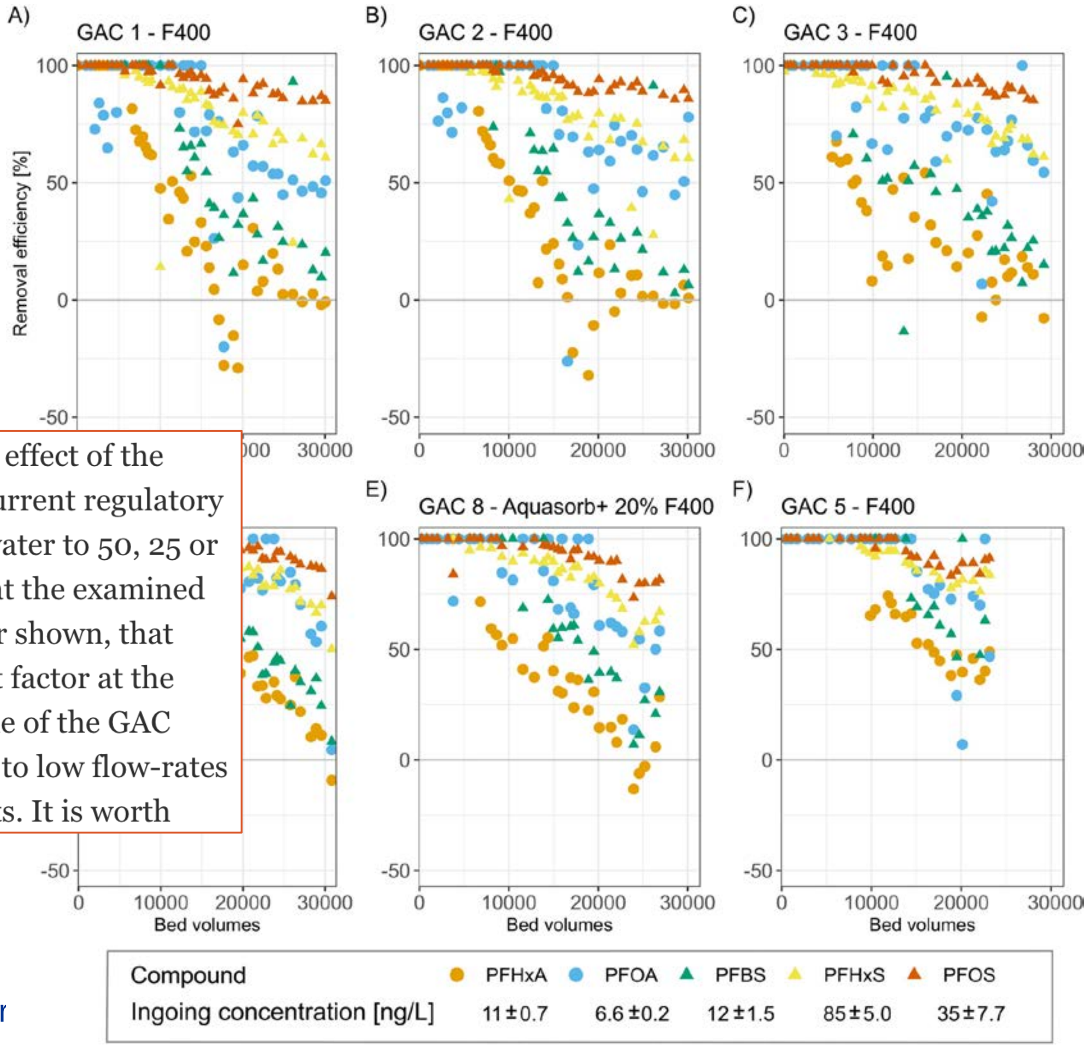


University of Pittsburgh

NIH NIEHSSRP

Stay Tuned!

Treatment options …and limitations



A subsequent cost analysis indicated an overwhelming effect of the treatment goals on unit cost. A decrease of Sweden's current regulatory guidelines of accepted 90 ng L^{-1} in finished drinking water to 50, 25 or even 10 ng L^{-1} would increase annual operations cost at the examined DWTP by 21, 135 and 314%, respectively. It was further shown, that regeneration cost is the dominant PFAS treatment cost factor at the Bäcklösa DWTP. Prolonging the overall service life time of the GAC filters by adopting a operations strategy of adjustment to low flow-rates at the end of service life could decrease operations costs. It is worth

University of Pittsburgh

Belkouteb et al. 2020 Water Resear

Where the policy landscape is taking us

Environmental Toxicology and Chemistry—Volume 40, Number 3—pp. 550–563, 2021
Received: 31 May 2020 | Revised: 19 August 2020 | Accepted: 20 August 2020 550

Critical Review

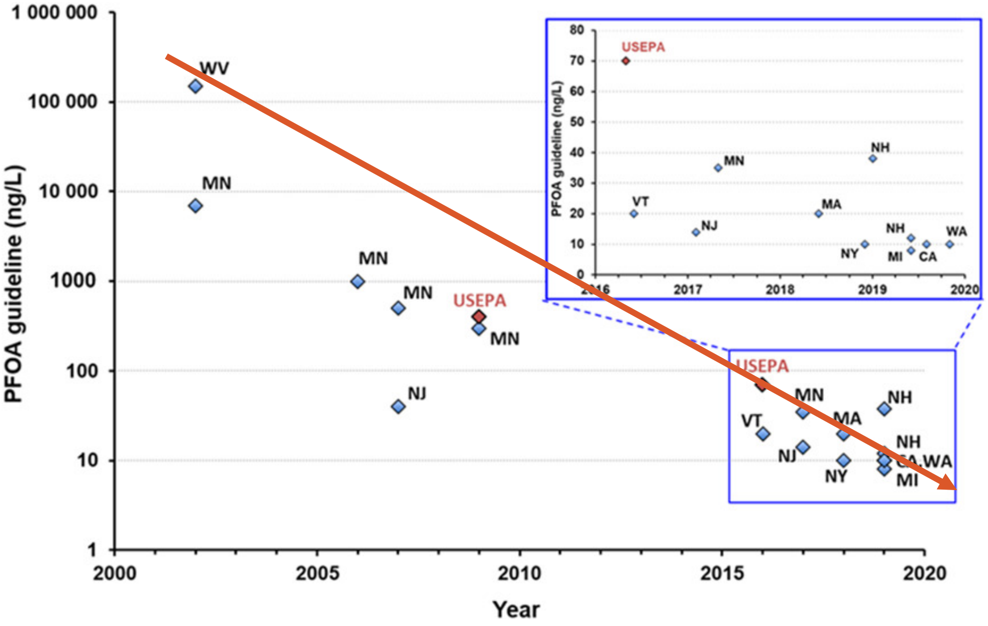
Recent US State and Federal Drinking Water Guidelines for Per- and Polyfluoroalkyl Substances

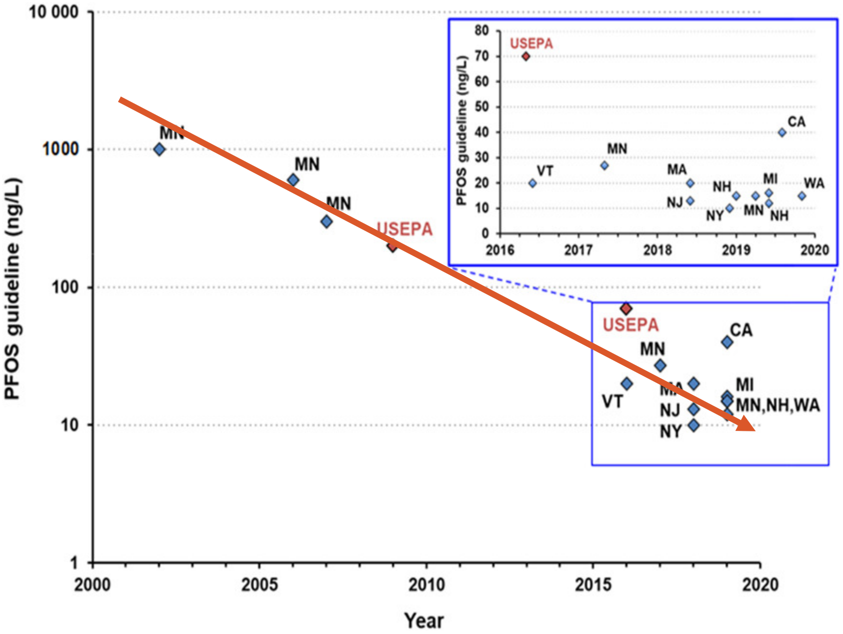
Gloria B. Post*

New Jersey Department of Environmental Protection, Trenton, New Jersey, USA

University of Pittsburgh

Where the policy landscape is taking us





Other PFAS are added (state-by-state basis) including short-chain PFAS.

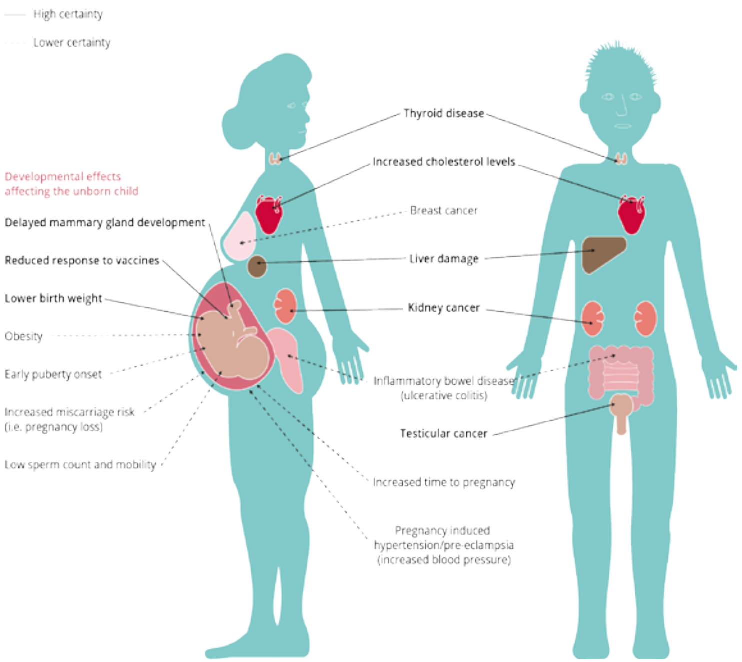
Post, 2021 ES&T

University of Pittsburgh

The search for novel sorbents

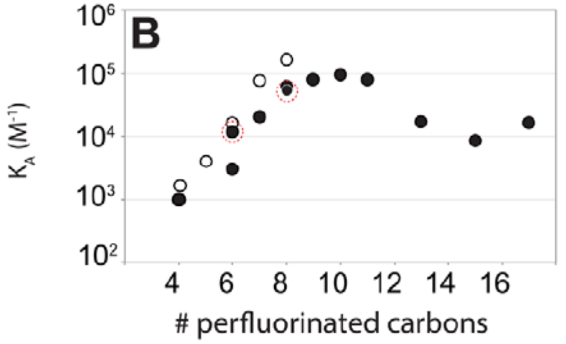
- What can be done about short-chain PFAS?
- Reverse osmosis is effective but expensive and energy intensive.
- GAC/IX are less effective and require regeneration/disposal of large volumes.

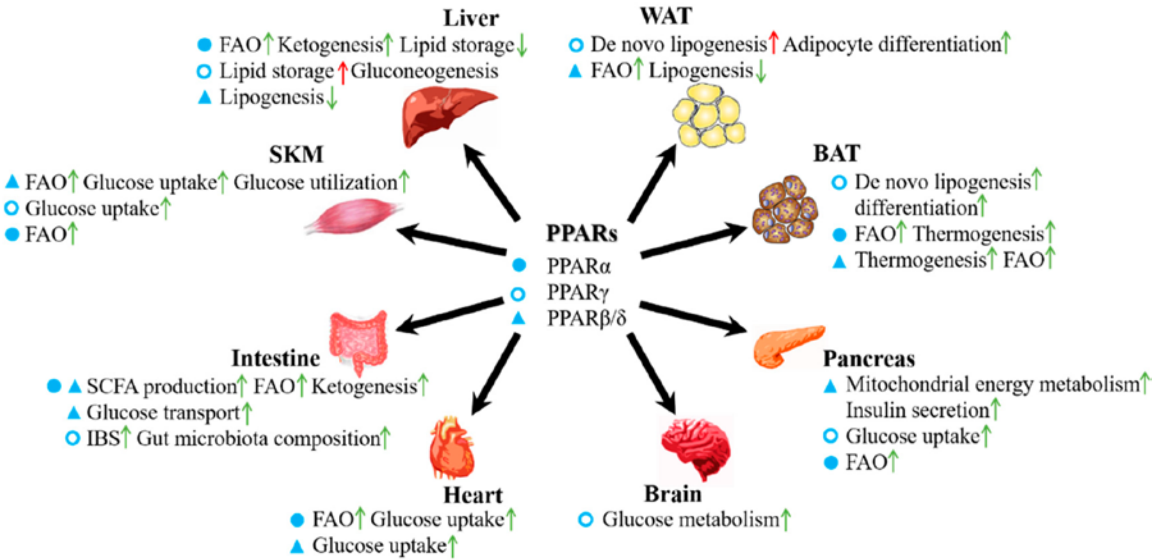
Toxicology: Problem… and clue to solution?



University of Pittsburgh

Proteins as biological sorbents





Some PFAS bioaccumulate due to binding to proteins like FABP and serum albumin.

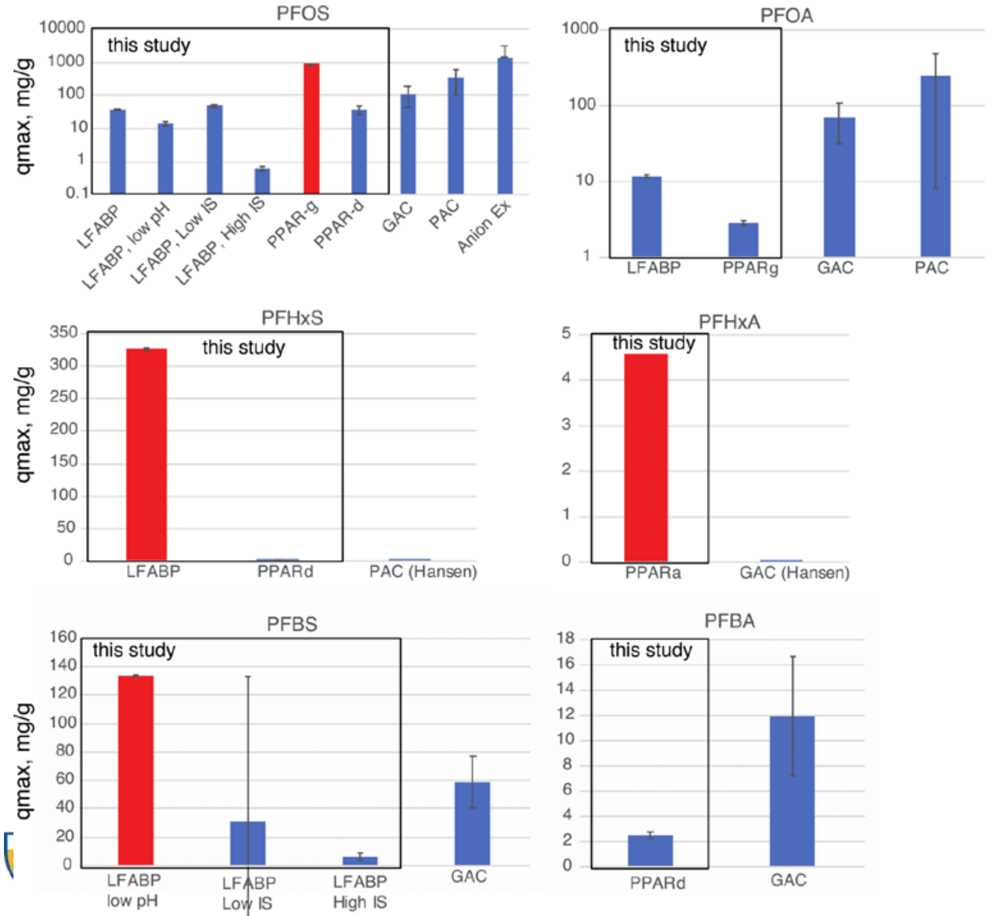
Short-chain PFAS are less bioaccumulative, but their toxic impacts indicate they may still have strong interactions with specific receptors.

University of Pittsburgh

Ng et al. 2014 ES&T 4637-4648

Hong et al. *Molecules* **2019**, *24*(14), 2545

Proteins as biological sorbents



Proteins evaluated by dialysis compare favorably with activated carbon, particularly for short-chain PFAS.

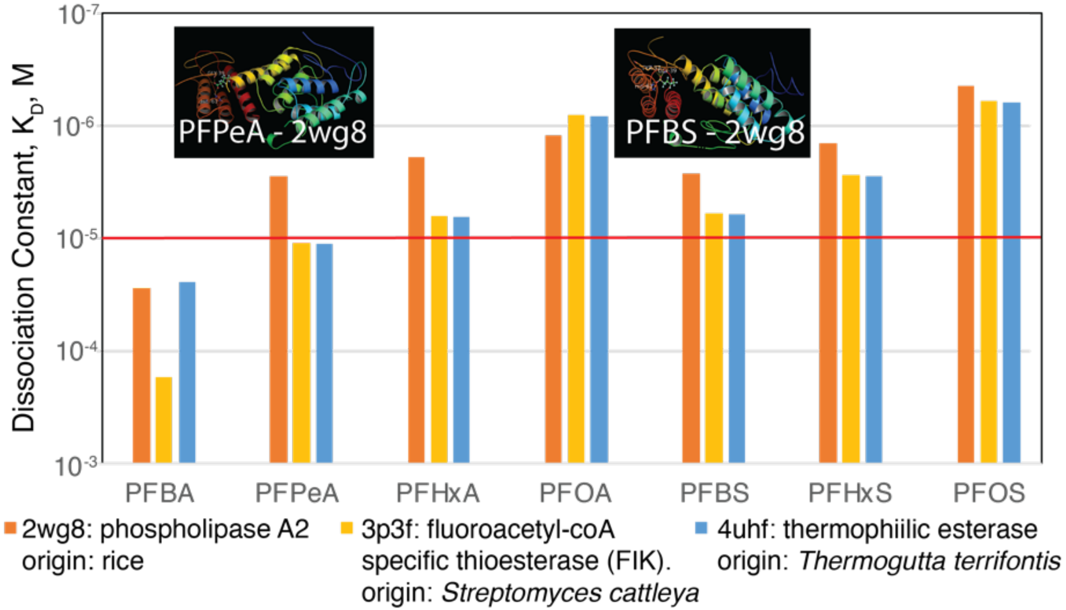
We found better performance for PFHxS, PFHxA and PFBS.

PPAR-γ at least as good as anion exchange, better than activated carbon for PFOS.

The bad news: Implications for toxicity?

Khazaee et al. 2021 Toxics

Using molecular modeling to screen for potential sorbents



Next phase: Complementary in vitro methos for evaluation of binding affinity, column studies.

We use a combination of protein database screening with molecular docking simulations to identify potential sorbents.

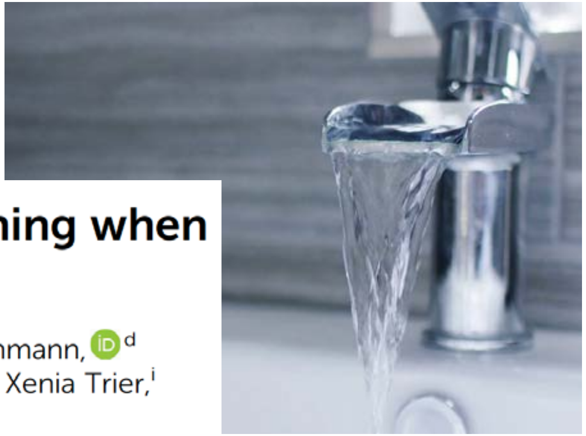
Screening criteria are relevant endogenous ligands, small size, and potential for ease of extraction or production.

University of Pittsburgh

SERDP DOD · EPA · DOE

First, do no harm: the need to turn off the PFAS tap.

Even with these strategies, we will not solve the major issue with these chemicals: their ***extreme persistence***.



Check for updates

Cite this: DOI: 10.1039/c9em00163h

The concept of essential use for determining when uses of PFASs can be phased out

Ian T. Cousins,[†*a] Gretta Goldenman,[b] Dorte Herzke,[c] Rainer Lohmann,[d] Mark Miller,[e] Carla A. Ng,[f] Sharyle Patton,[g] Martin Scheringer,[h] Xenia Trier,[i] Lena Vierke,[j] Zhanyun Wang[k] and Jamie C. DeWitt[l]

Check for updates

Cite this: *Environ. Sci.: Processes Impacts*, 2019, **21**, 781

Why is high persistence alone a major cause of concern?

Ian T. Cousins,[a] Carla A. Ng,[b] Zhanyun Wang[c] and Martin Scheringer[*d]

University of Pittsburgh

Questions?

carla.ng@pitt.edu

@Ng_lab

University of Pittsburgh