PFAS

Fate, toxicity and omnipresence

Tessa Pancras

Introduction to the

“forever chemicals”

… a group of thousands of man-made chemicals

… extremely persistent, bio accumulative and toxic

… used in a wide range of industrial applications and commercial and consumer products

… do not biodegrade and are highly mobile in groundwater systems

… measured in human blood

Dramatically increasing regulatory concern worldwide

… many are not detected by commercial analytical methods

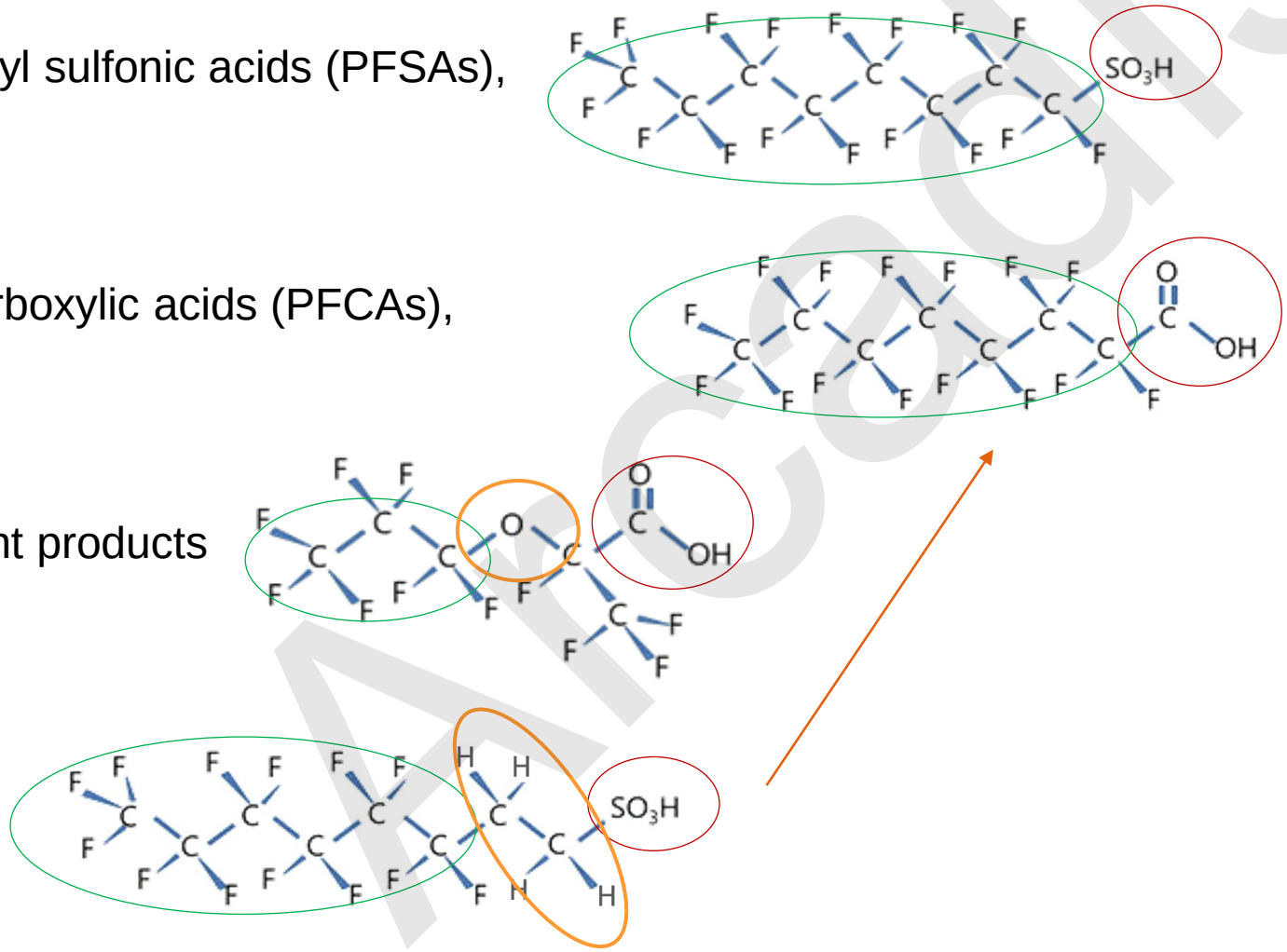
Potential threat to drinking water sources

News of today

https://www.vrt.be/vrtnws/nl/2024/04/17/pfas-vlaamse-drinkwaterstalen/#:~:text=Uit%20de%20metingen%20van%20VMM,te%20hoge%20PFAS%2Dconcentraties%20aangetroffen.

PFAS – Poly and perfluoroalkyl substances

- Perfluoroalkyl sulfonic acids (PFSAs), e.g. PFOS
- Perfluorocarboxylic acids (PFCAs), e.g. PFOA
- Replacement products
  e.g. GenX
- Precursors



PFOS

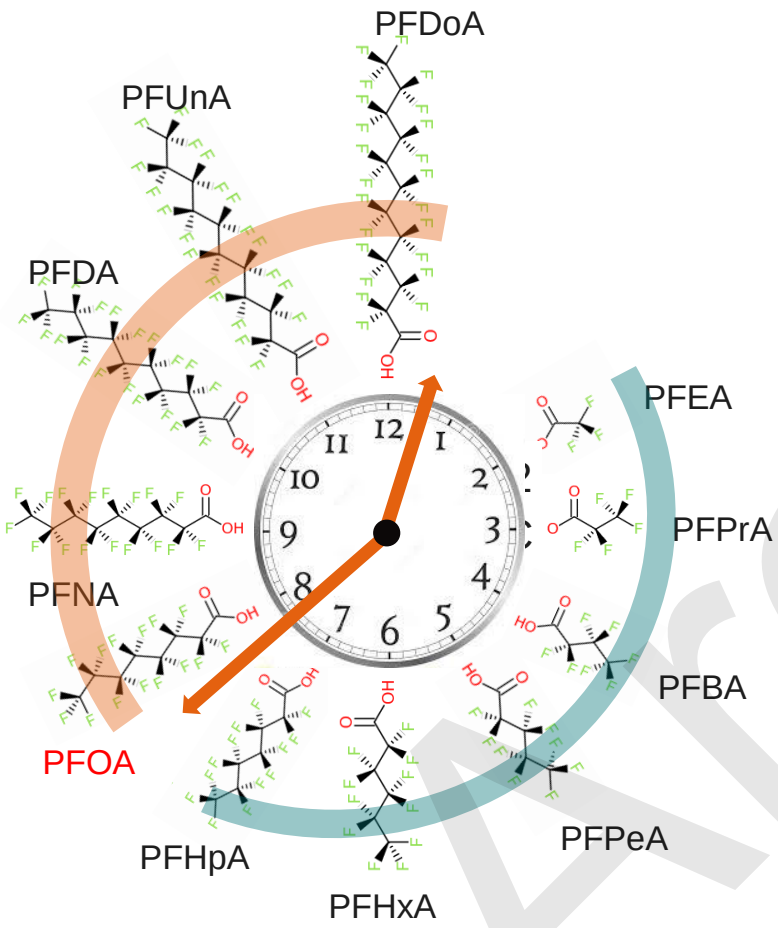
PerFluoro **Octane** Sulfonic acid

PFOA:

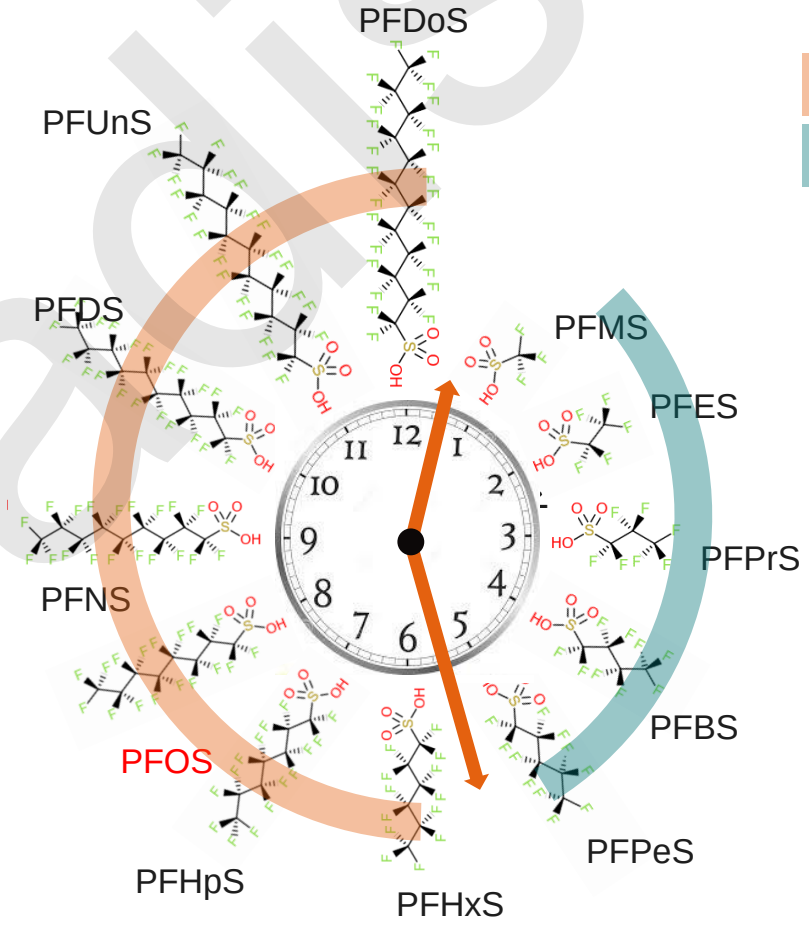
PerFluoro **Octane** Acid

Butane	C4	PFBA
Pentane	C5	PFPeA
Hexane	C6	PFHxA
Heptane	C7	PFHpA
Octane	C8	PFOA
Nonane	C9	PFNA
Decane	C10	PFDA
Undecane	C11	PFUnA
Dodecane	C12	PFDoA

Long versus Short



PFCAs

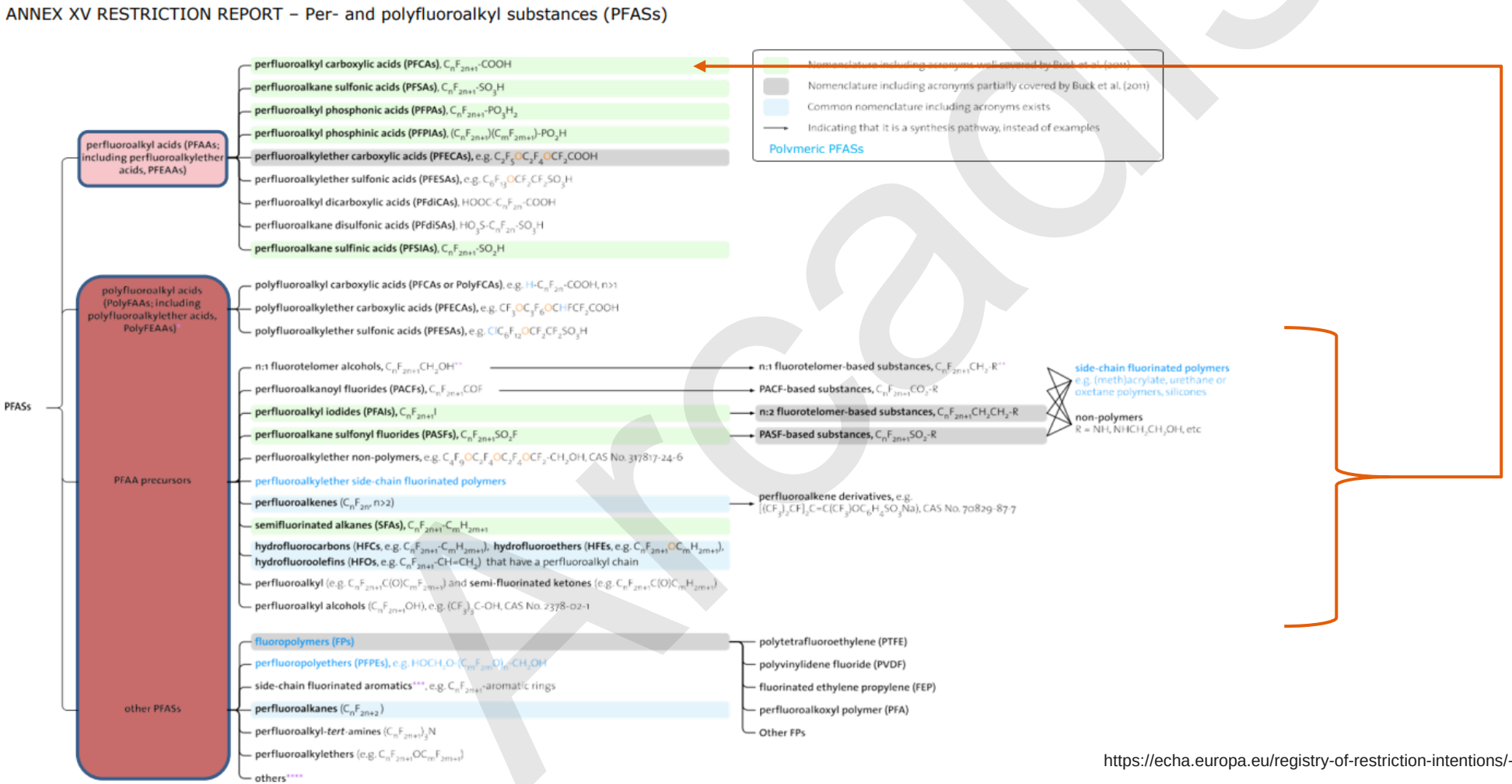


PFSAs

Long
Short

Butane	4
Pentane	5
Hexane	6
Heptane	7
Octane	8
Nonane	9
Decane	10
Undecane	11
Dodecane	12

A little bit more complicated…



https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b

What is the fuss all about?

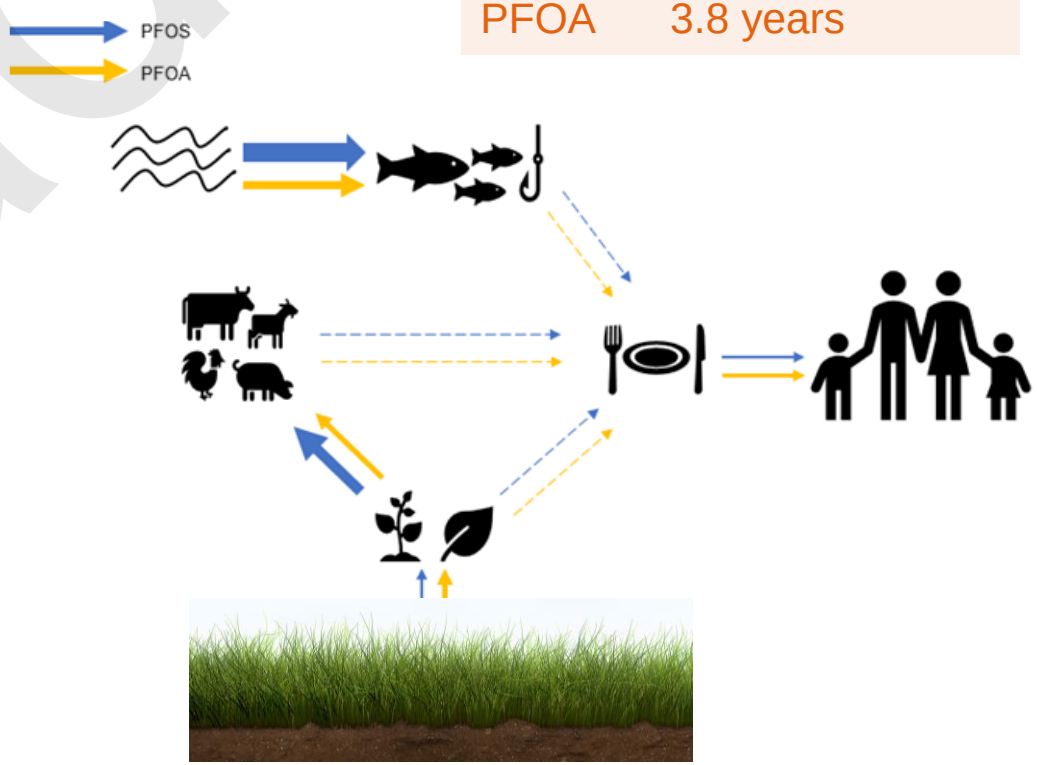
ANNEX XV RESTRICTION REPORT – Per- and polyfluoroalkyl substances (PFASs)

Properties	Concerns related to combinations of properties
Very high persistence	High potential for ubiquitous, increasing and irreversible exposures of the environment and humans;
Long-range transport potential	Difficulty to decontaminate intake water for drinking water production, low effectiveness of end-of-pipe RMMs and difficulty to treat contaminated sites;
Mobility	High potential for human exposure via food and drinking water;
Accumulation in plants	Potential for intergenerational effects and delay of effects;
Bioaccumulation potential	Potential for causing serious effects although those would not be observed in standard tests;
Ecotoxicity	Estimation of future exposure levels and safe concentration limits is highly uncertain;
Endocrine activity	Global warming potential.
Effects on human health	

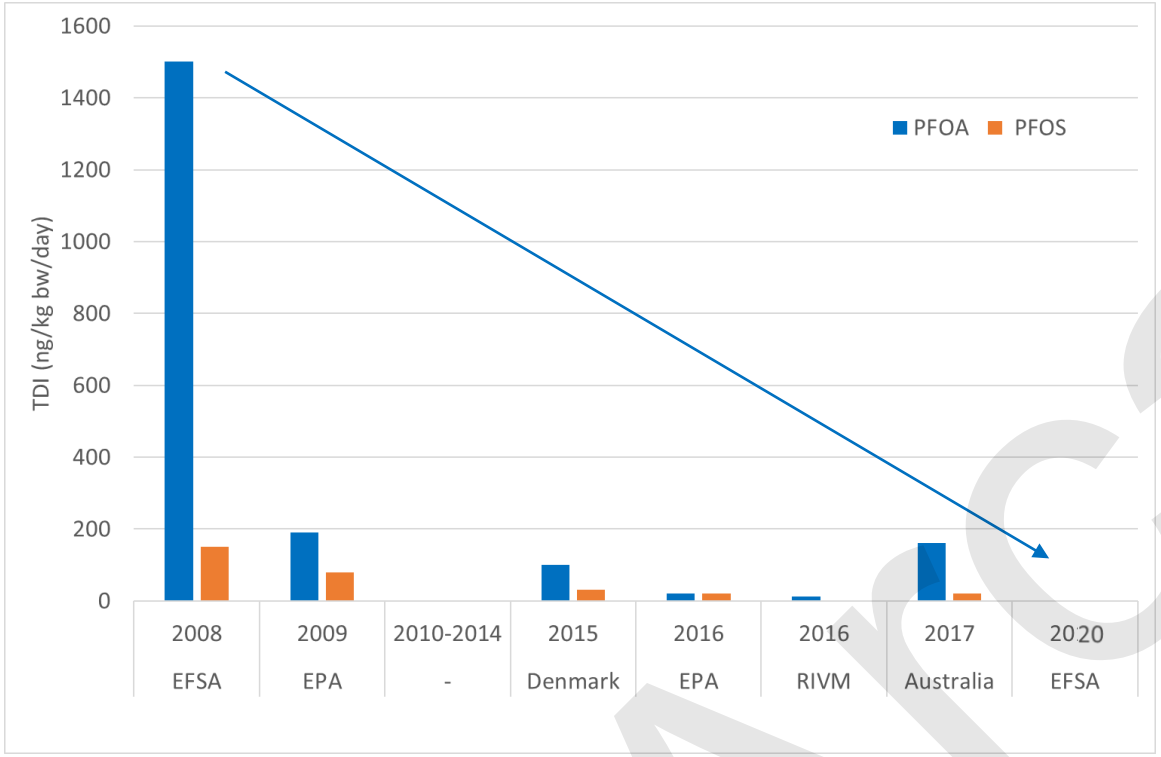
https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b

Long Chain Human Bioaccumulation Half Life:

PFHxS	8.5 years
PFOS	4.2 years
PFOA	3.8 years



Tolerable daily intake



Animal studies

↓

Epidemiological studies

JANUARY 30, 2019

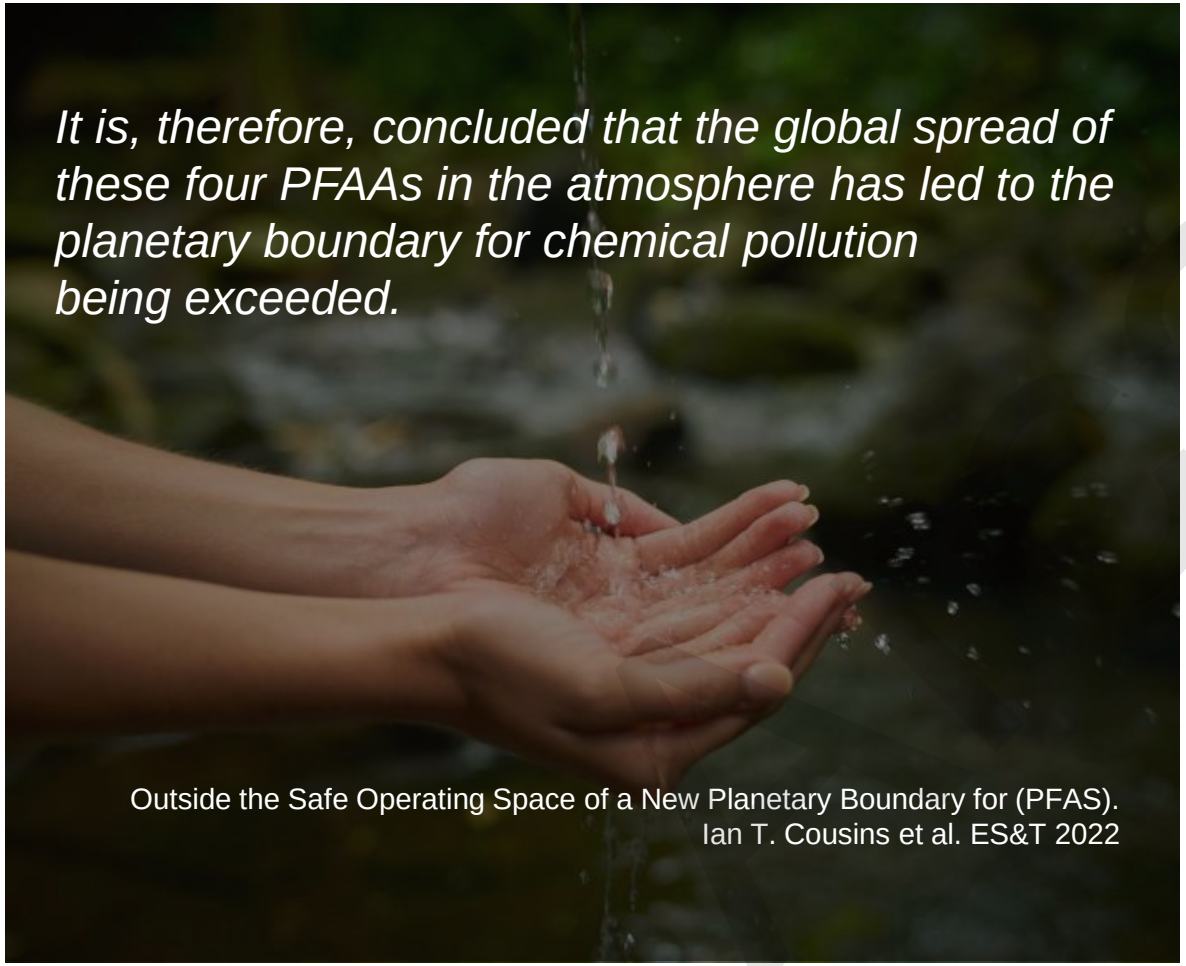
Scientists just cut the tolerable intake of PFAS by 99,9%

https://chemsec.org/scientists-just-cut-the-tolerable-intake-of-pfas-by-999/

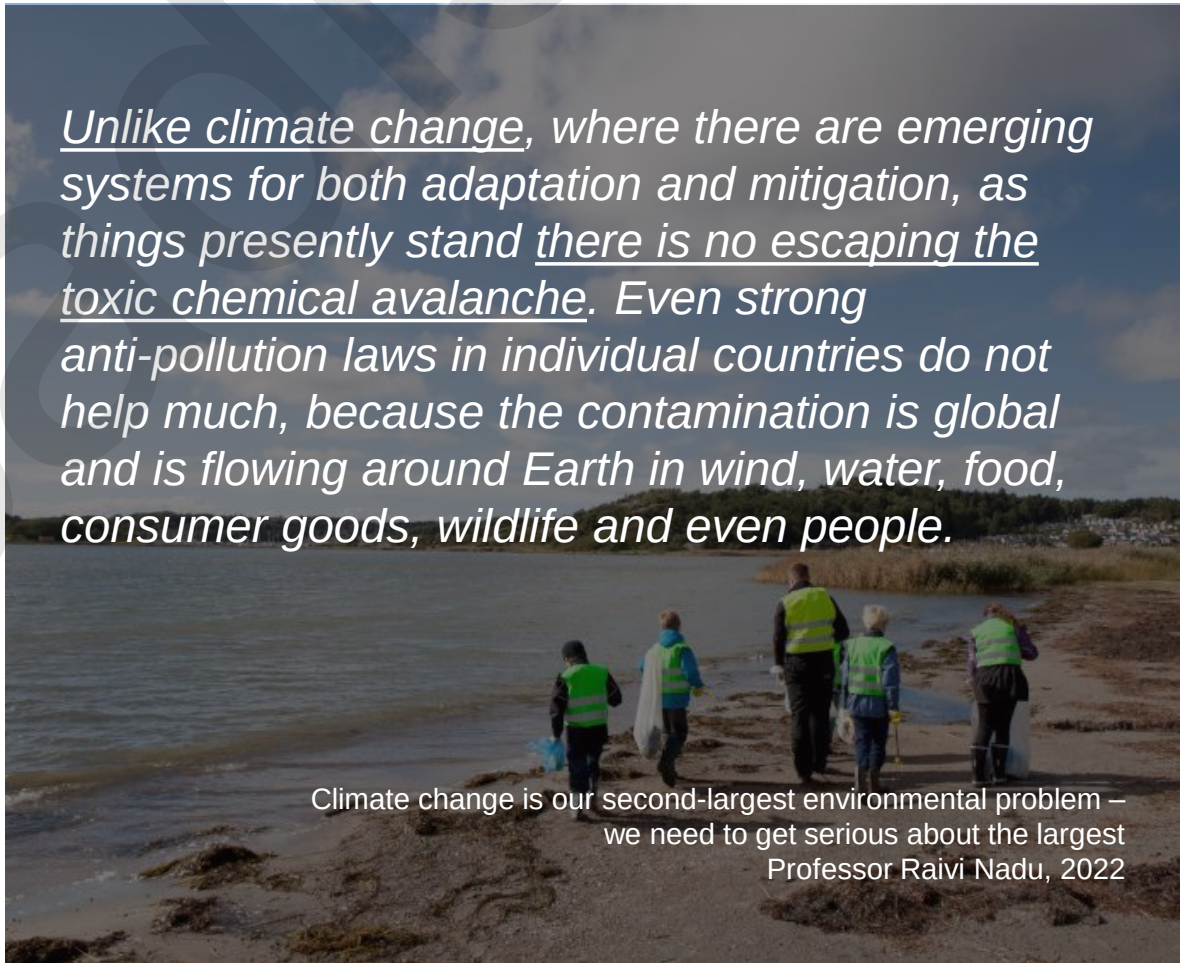
Source	TDI PFOS (ng/kg bw/day	TDI PFOA (ng/kg bw/day)
EFSA, 2008	150	1500
EPA, 2009	80	190
Denmark, 2015	30	100
EPA, 2016 (RfD)	20	20
RIVM, 2016	-	12.5
Australia, 2017	20	160
EFSA, 2018	1.9	0.9
EFSA, 2020	0.63 sum of 4 PFAS	

Beyond the planetary boundary

With Drinking Water Health Advisory levels down to 4 pg/l (USEPA), or even 4.4 ng/l (based on EFSA) it is no wonder that persistent contaminants can be found nearly everywhere above these values



Outside the Safe Operating Space of a New Planetary Boundary for (PFAS).
Ian T. Cousins et al. ES&T 2022



Climate change is our second-largest environmental problem – we need to get serious about the largest
Professor Raivi Nadu, 2022

Fate and transport

Aerobic Precursor Biotransformation to persistent PFAAs

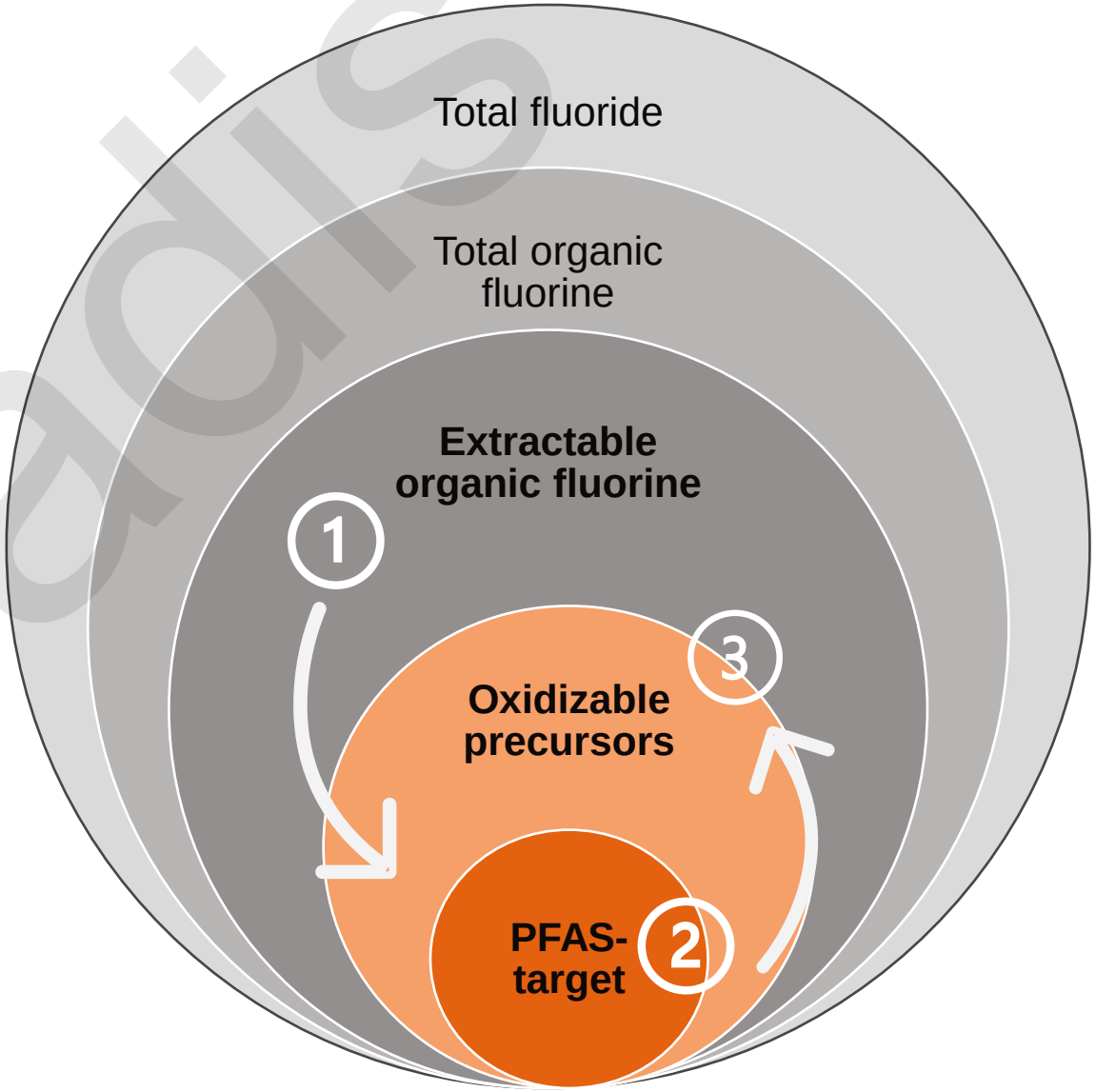
PFAS **do not biodegrade** –i.e. mineralize, **they biotransform** and many parent or intermediate compounds are not detected by conventional analytical methods

Analytical strategy

Three steps:

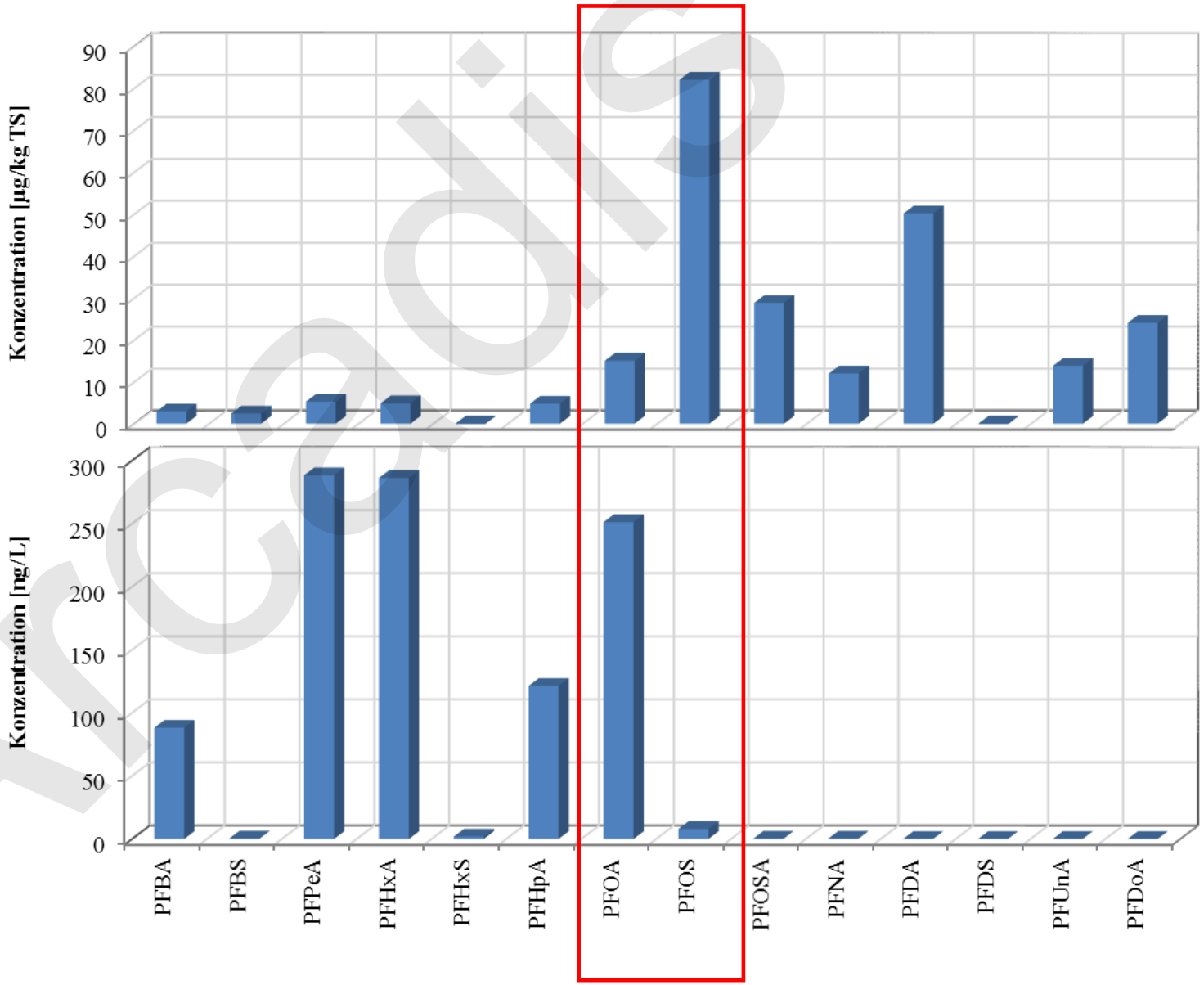
- **Extractable organic fluorine**
  - PFAS that can be extracted and thus released
  - Polymers like PTFE will not be analysed, possible contaminants in PTFE will be extracted
- **PFAS-target analysis** – up to 42 individual PFAS
- Large difference between EOF and Target:

- **TOP-oxidation** → PFAS precursors?

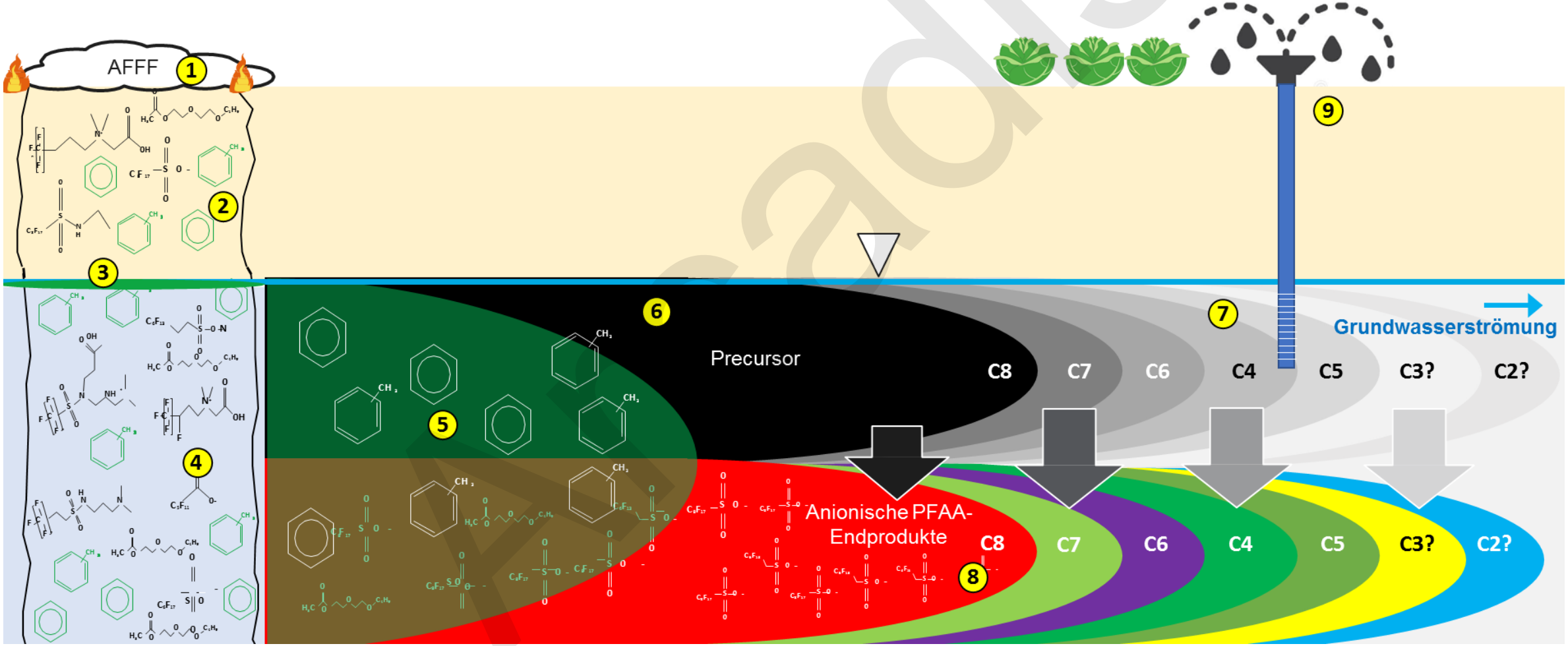


PFAS fate and transport PFCA and PFSA

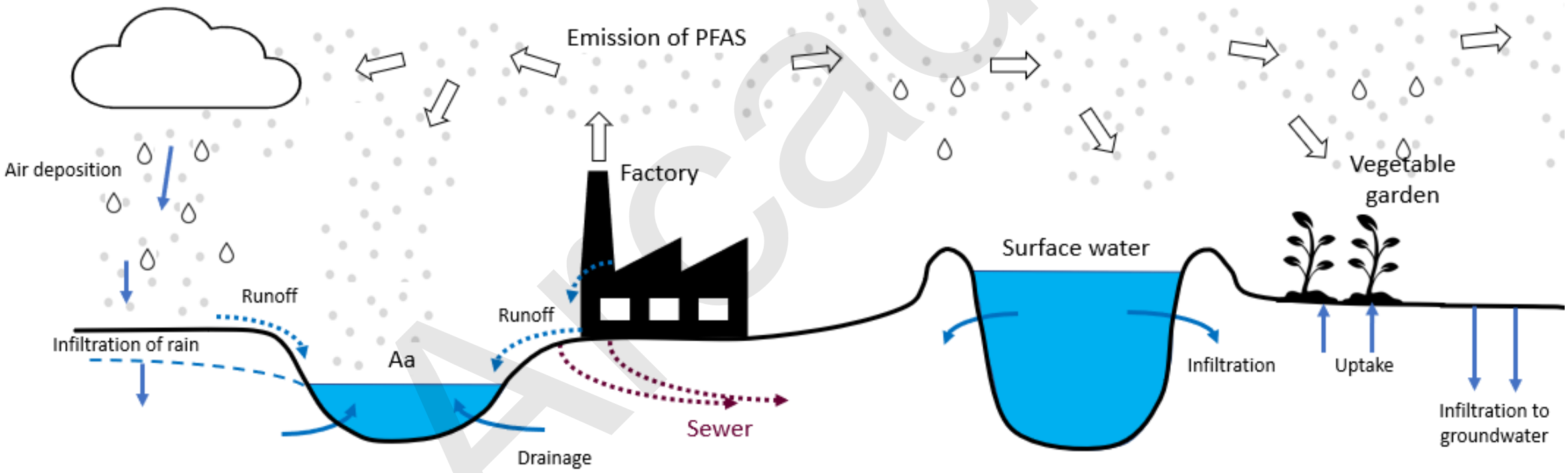
- Long plumes due to mobility and low target values
- PFSAs adsorb stronger than PFCAs
- Longer chain adsorb stronger than shorter chain
- Soil: longer chains
- Groundwater: shorter chains



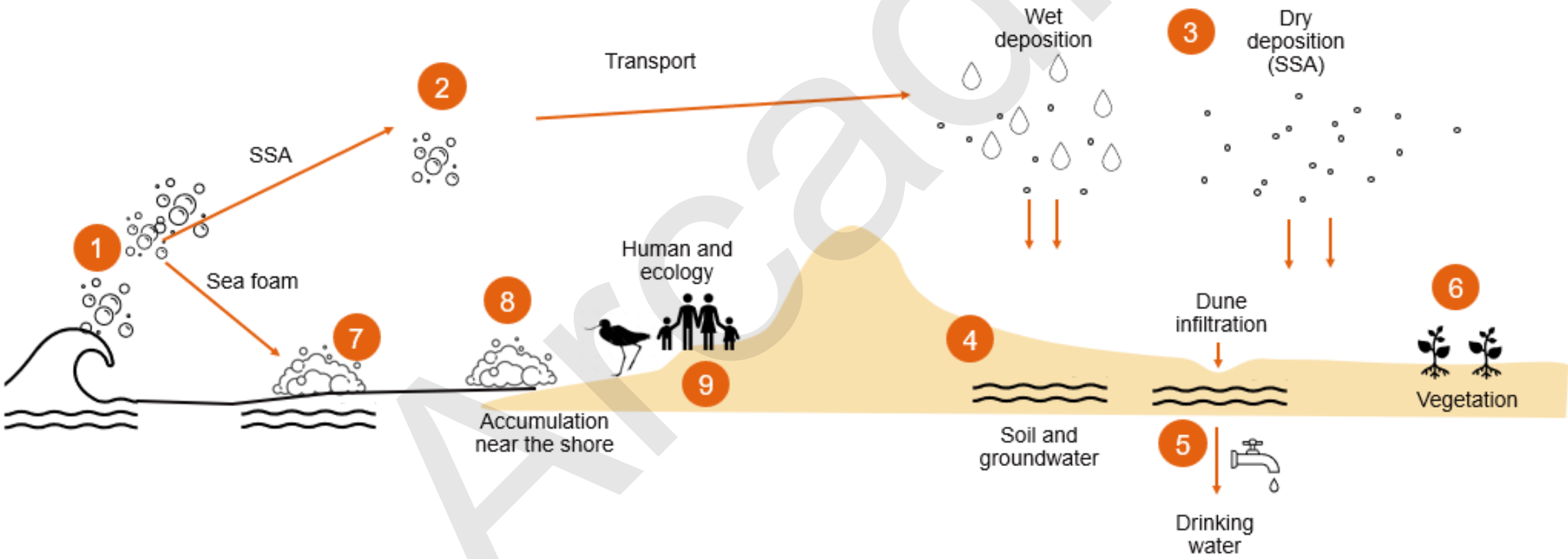
Conceptual Site Model - AFFF



CSM air deposition



CSM sea spray



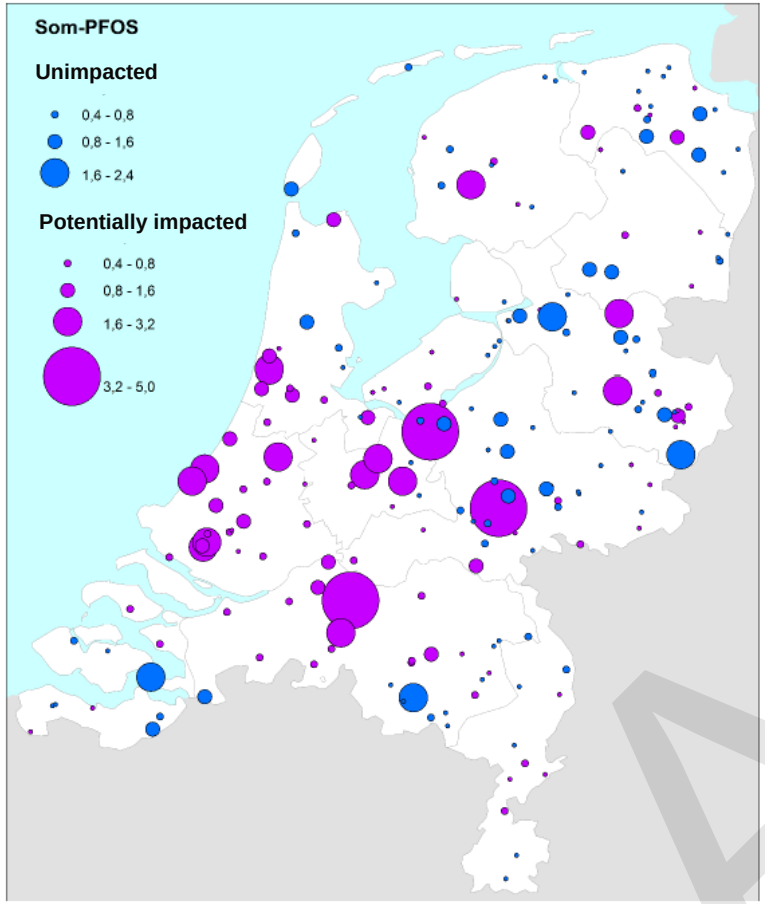
What do you think is the level of sum PFAS in your blood? (roughly)

1. 3.5 ng/l
2. 89 ng/l
3. 960 ng/l
4. 19,800 ng/l ←

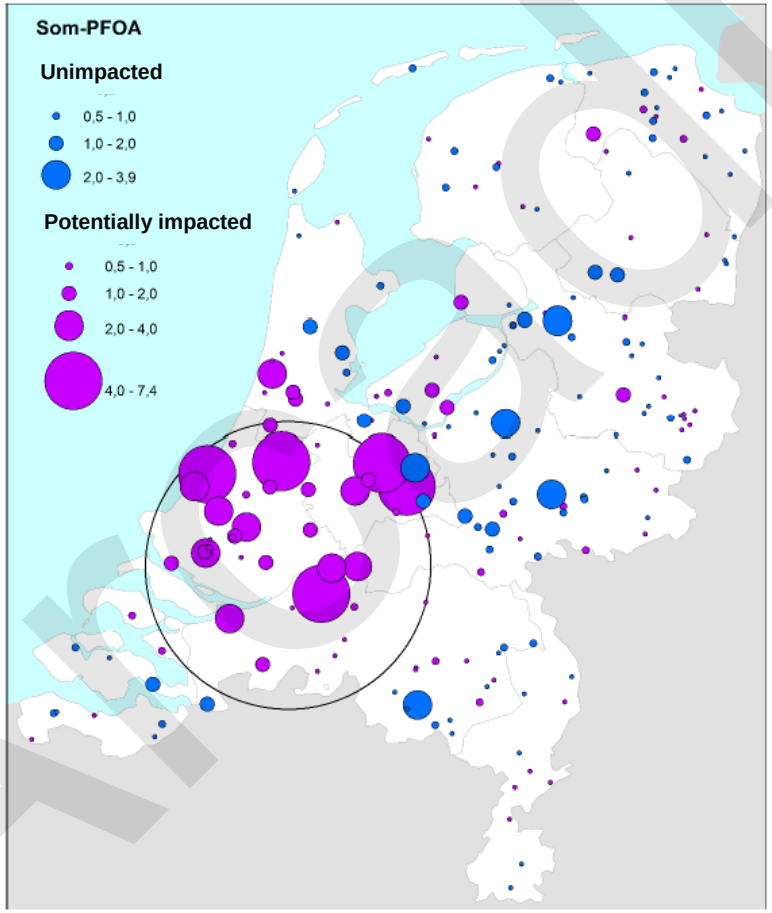
Environmental data

- Soil
- Blood

Background concentrations soil PFOS en PFOA (in NL en BE)



Figuur 4.1 Ligging meetlocaties en indicatie van de som-PFOS concentratie (toplaag). Concentraties in µg/kg droge stof.



Figuur 4.2 Ligging meetlocaties en indicatie van de som-PFOA concentratie (toplaag). Concentraties in µg/kg droge stof. De cirkel met straal van 50km is getrokken om de productielocatie in Dordrecht.

Netherlands (P95)

PFOS 1.4 µg/kg

PFOA 1.9 µg/kg

Flanders (P90)

PFOS 1.4 µg/kg

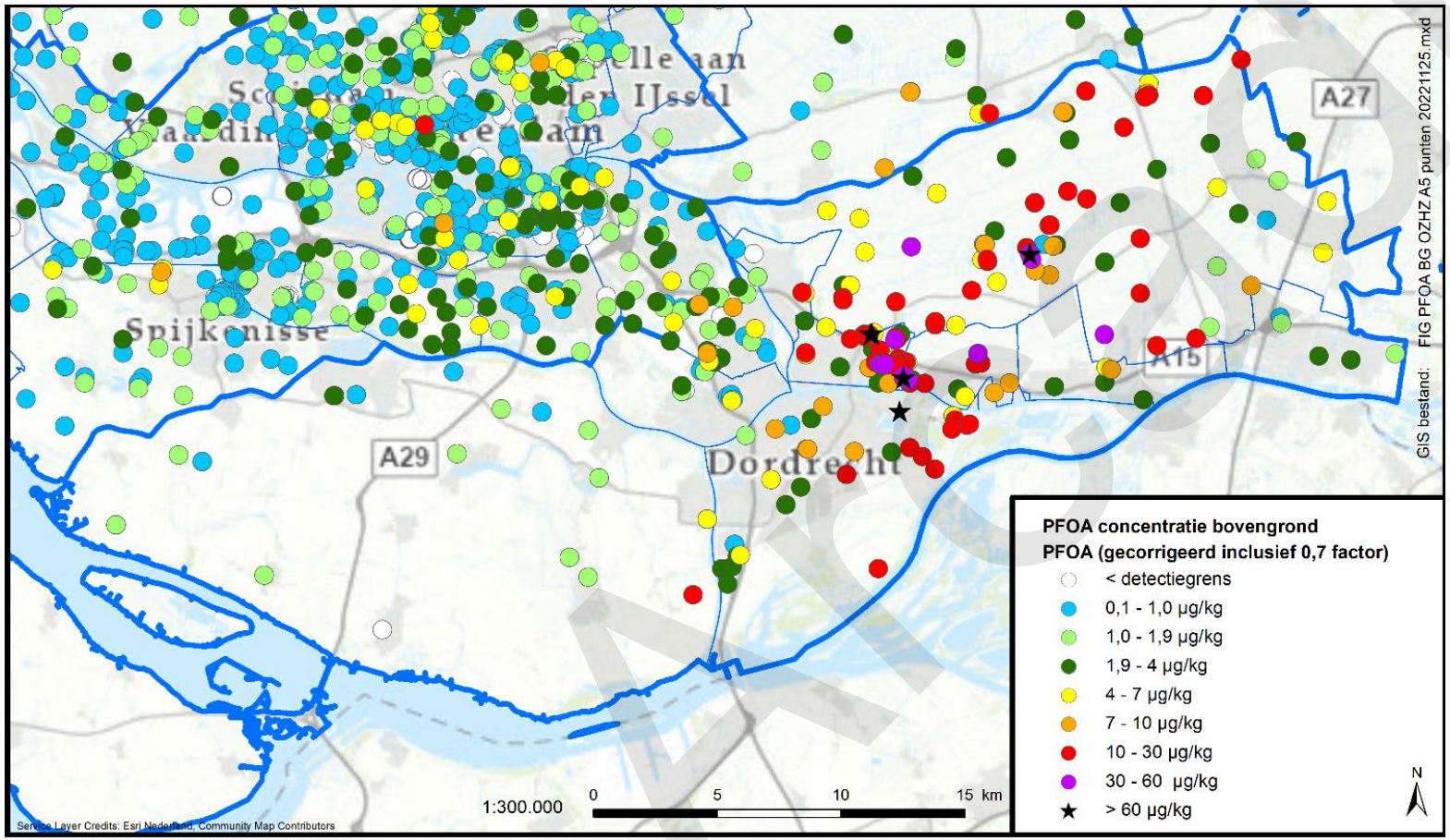
PFOA 1.0 µg/kg

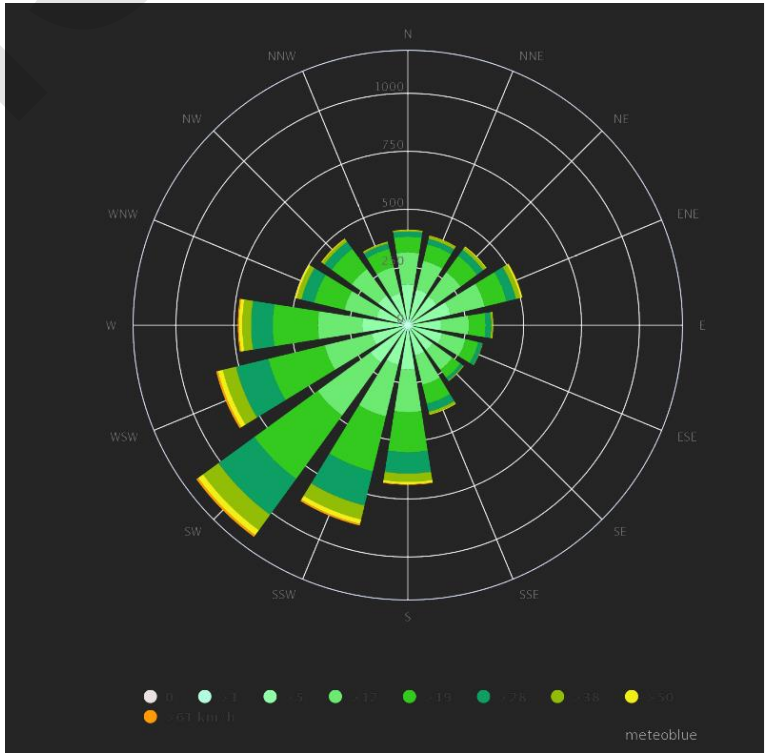
RIVM, 2020

OVAM, 2024

Why a difference between the Netherlands and Flanders, we do speak the same language?!

Impact Atmospheric deposition PFOA emission Dordrecht (top soil)

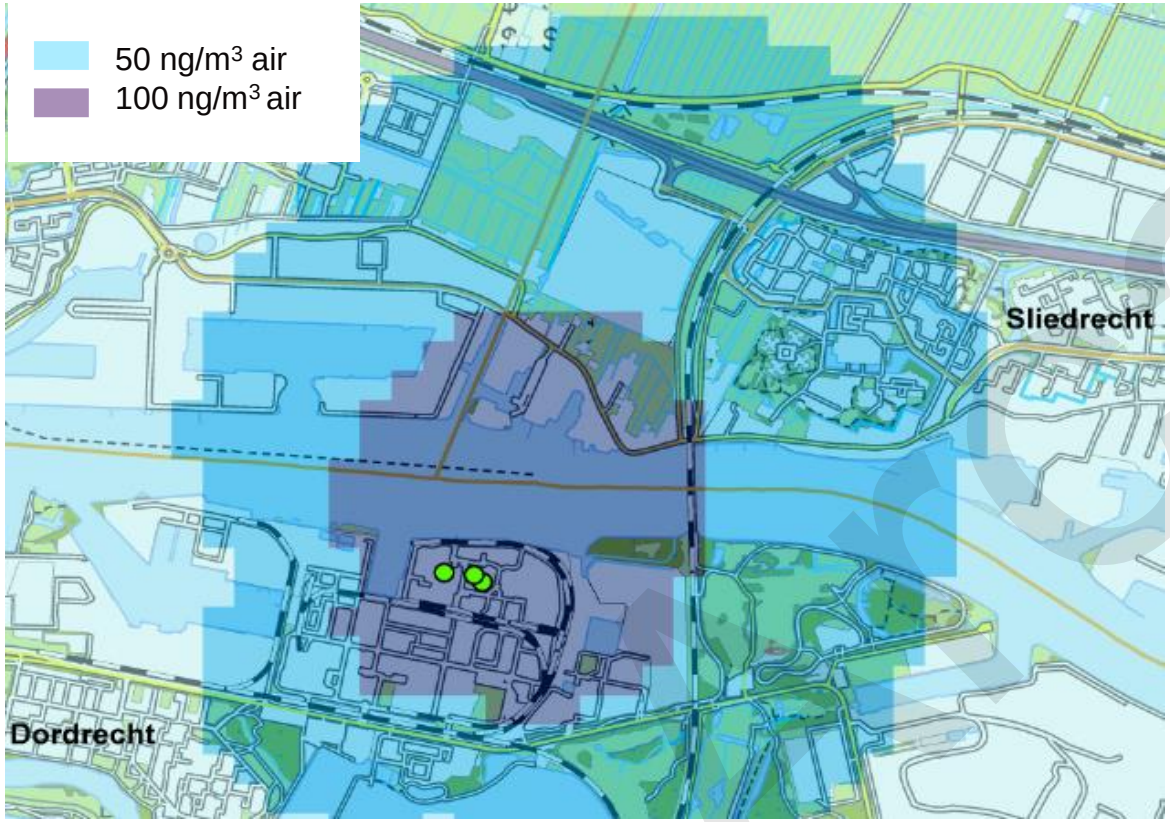




PFAS in soil and water in vegetable gardens, Arcadis, January 2023

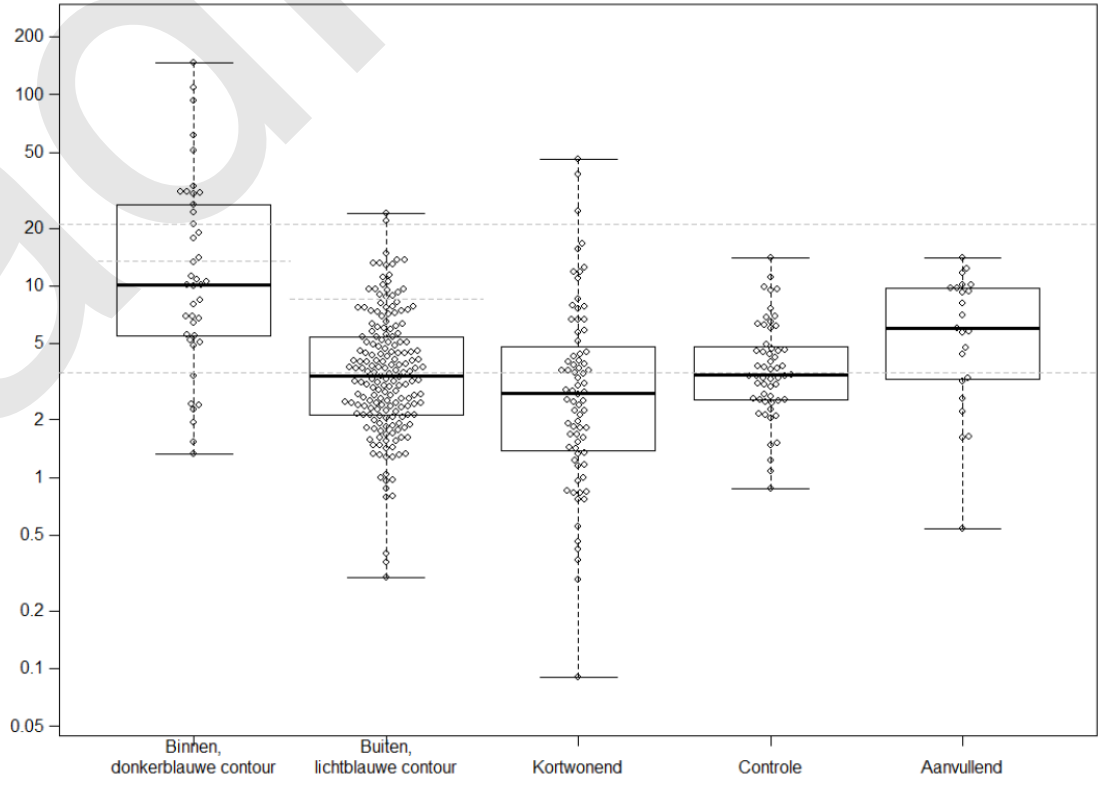
Atmospheric deposition of PFOA

Contours air emission



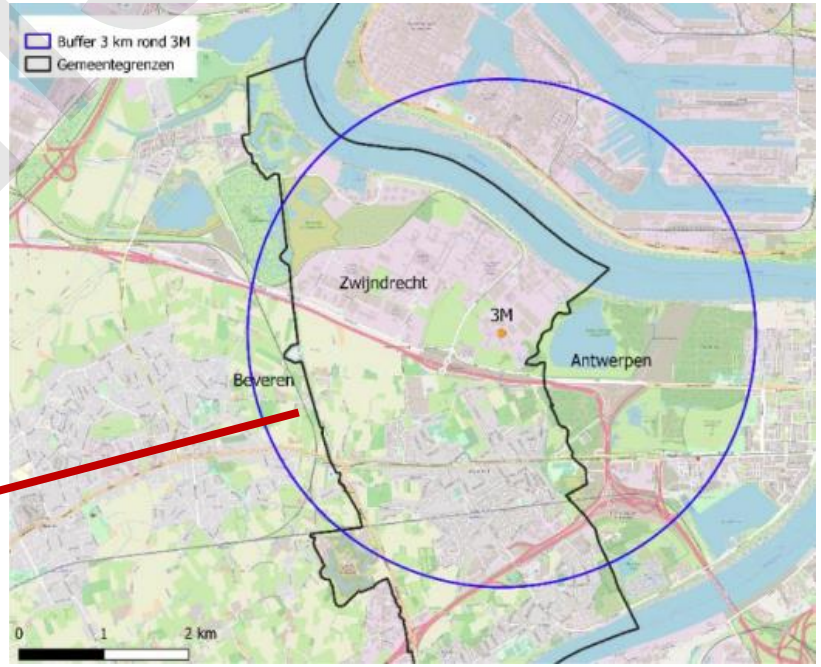
Source: Zeilmaker et al., 2016. Risicoinschatting emissie PFOA voor omwonenden. Locatie DuPont/Chemours, Dordrecht, Nederland. RIVM briefrapport 2016-0049

PFOA in blood



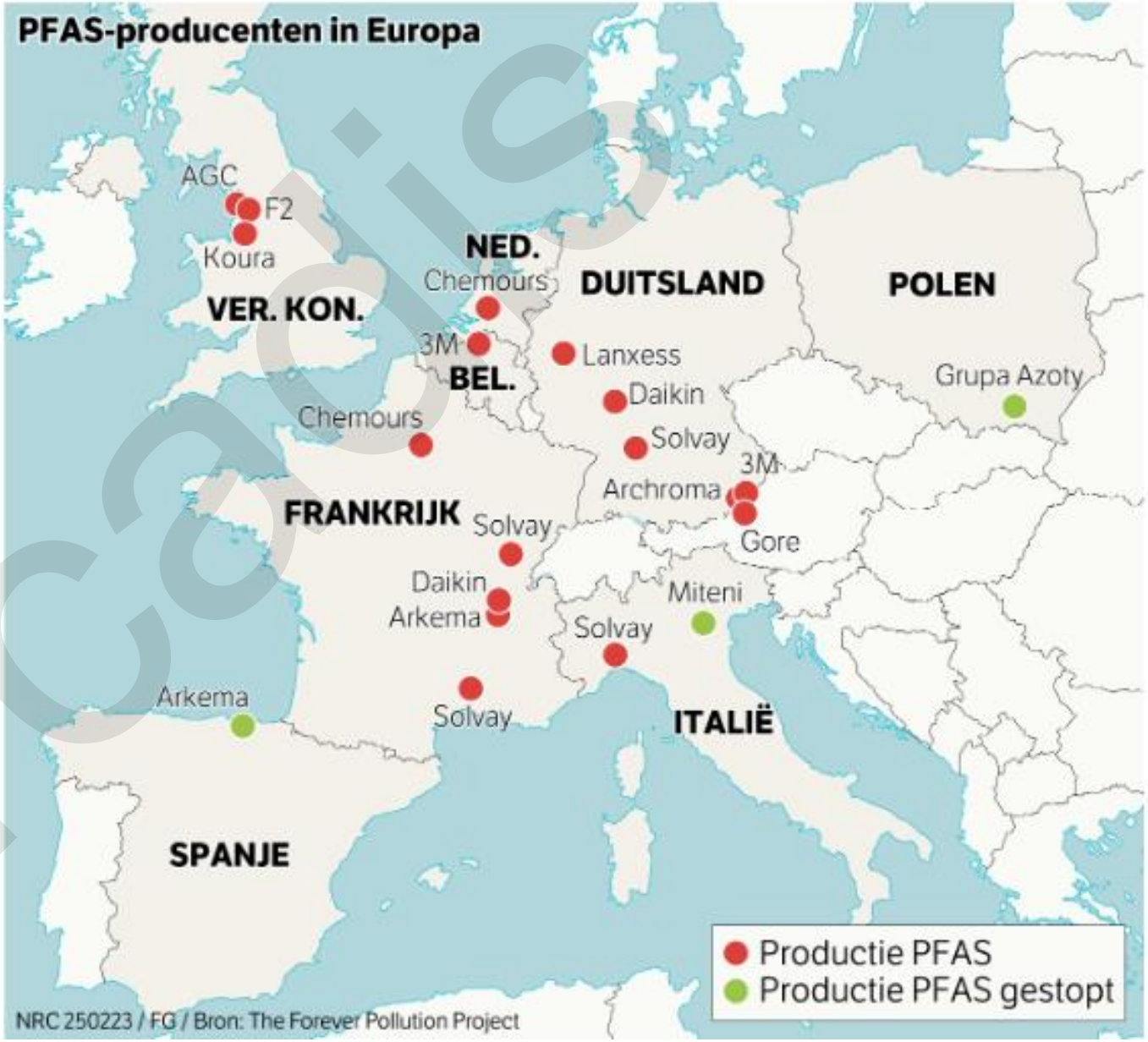
Source: Van Poll et al., 2017. PFOA metingen in bloed. Metingen in serum bij omwonenden van DuPont/Chemours in Dordrecht. RIVM rapport 2017-0077

Levels in blood of residents within 3 km of 3M site in Antwerp July 2021



Provincie Antwerpen, Vito, 2021

A few more production sites in Europe



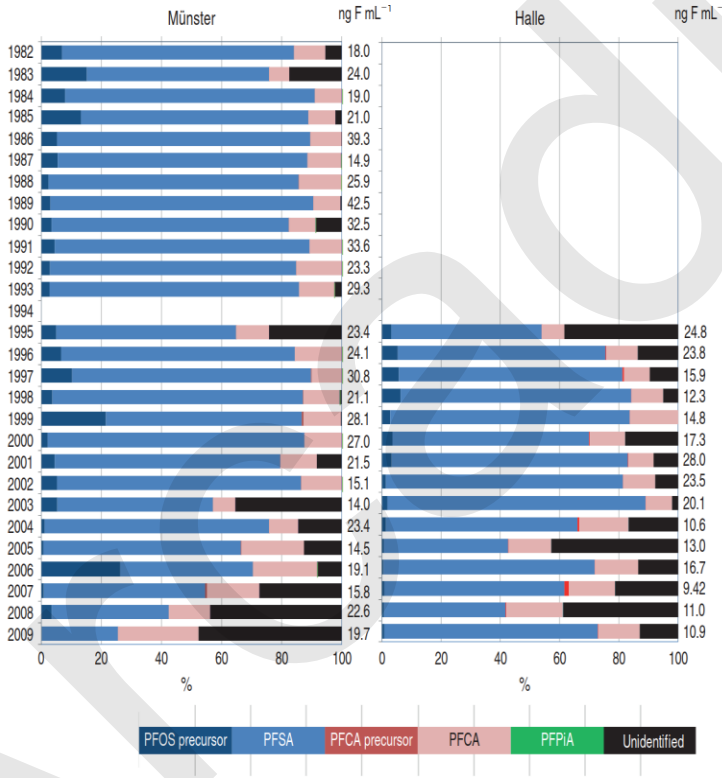
PFAS in blood serum, many studies

PFAS concentrations (μg/L) in cord plasma of newborns in Flanders and in serum of adolescents in the ir

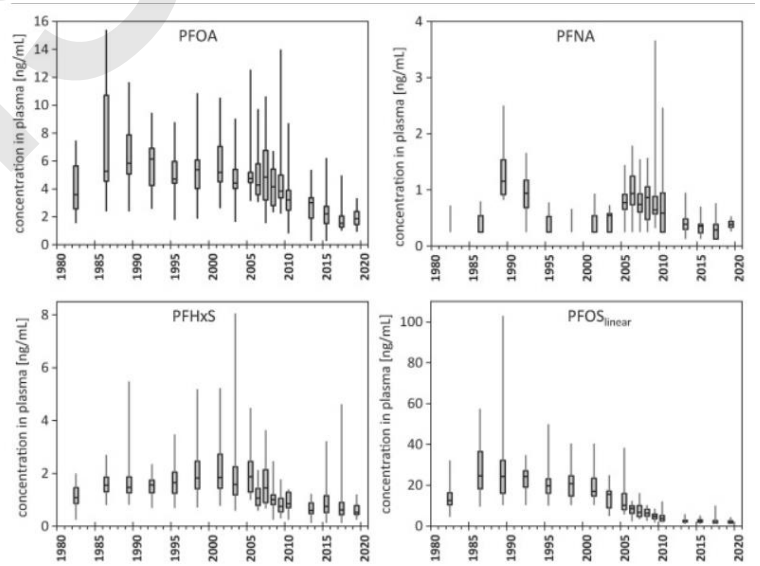
Substance	Population	Period	n	LOQ	% above LOQ	Geometric mean
PFOS	Newborns	2008–2009	220	0.3	100	2.64
PFOS	Newborns	2013–2014	269	0.2	99.6	1.12
PFOS	Adolescents aged 14-15	2010–2011	199	0.3	100	5.83
PFOS	Adults aged 20-40	2008–2009	201	0.3	100	12.54
PFOS	Adults aged 50-65	2014	205	0.2	100	7.53
PFBS	Newborns	2013–2014	269	0.2	0	<LOQ
PFBS	Adults aged 50-65	2014	205	0.2	2.9	<LOQ
PFHxS	Newborns	2013–2014	269	0.2	84.0	0.34
PFHxS	Adults aged 50-65	2014	205	0.2	99.5	1.57
PFOA	Newborns	2008–2009	220	0.3	100	1.51
PFOA	Newborns	2013–2014	269	0.2	100	1.19
PFOA	Adolescents aged 14-15	2010–2011	199	0.3	100	2.55
PFOA	Adults aged 20-40	2008–2009	201	0.3	100	3.23
PFOA	Adults aged 50-65	2014	205	0.2	100	2.82
PFNA	Newborns	2013–2014	269	0.1	89.6	0.20
PFNA	Adults aged 50-65	2014	205	0.1	100	0.86

P25/P75: 25th and 75th percentile; P90: 90th percentile; 95%CI: 95% confidence interval.

Flanders, Belgium (VITO 2020)



Germany (Yeung et al. 2016)



Germany (Göckener et al. 2020)

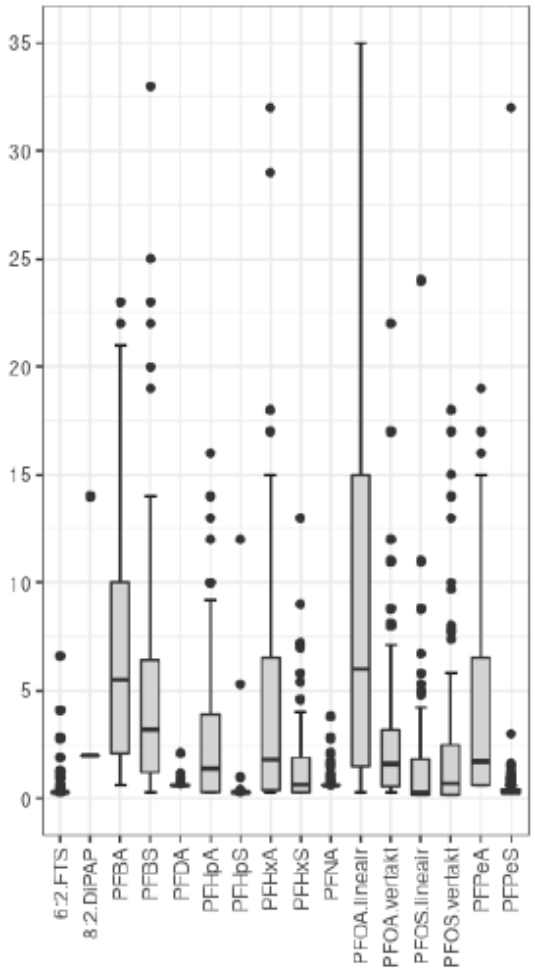
A PFAS level in blood of 15.000-20.000 ng/l is not uncommon,

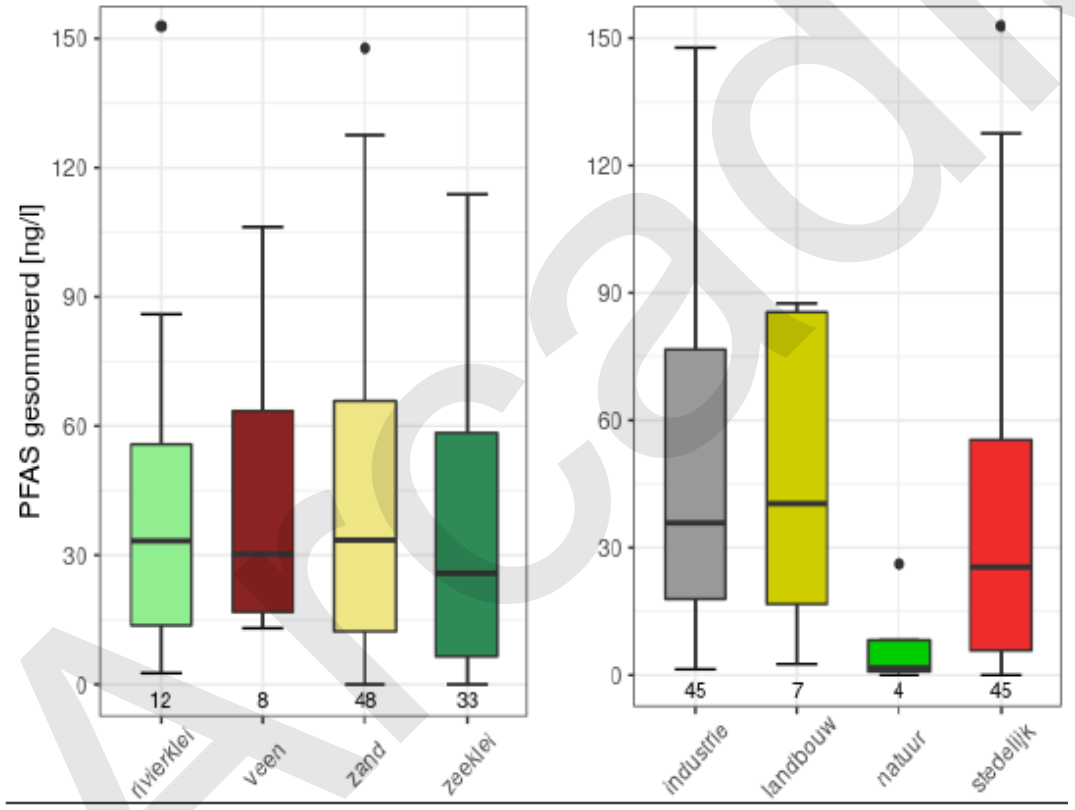
For “common” PFAS, levels are declining

Environmental data

- Water
- Vegetables

PFAS (sum) in Phreatic groundwater in the Netherlands





RIVM 2021

Phreatic groundwater:
~ 30 ng/l

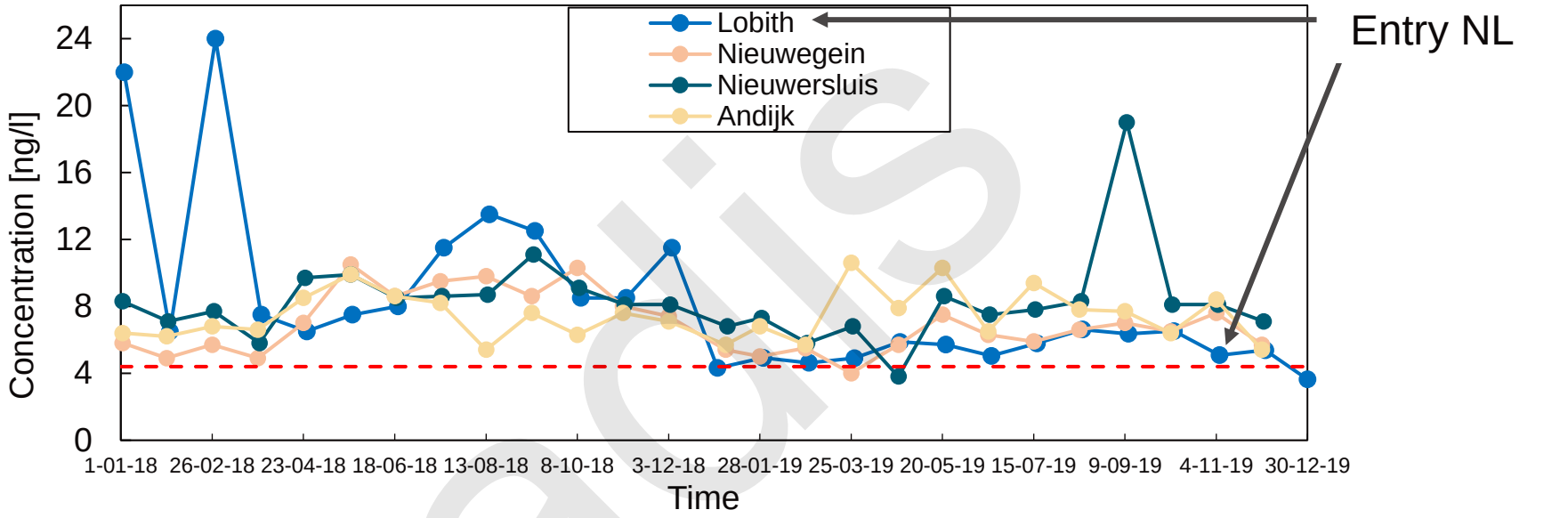
Middle deep young groundwater: ~ 6 ng/l

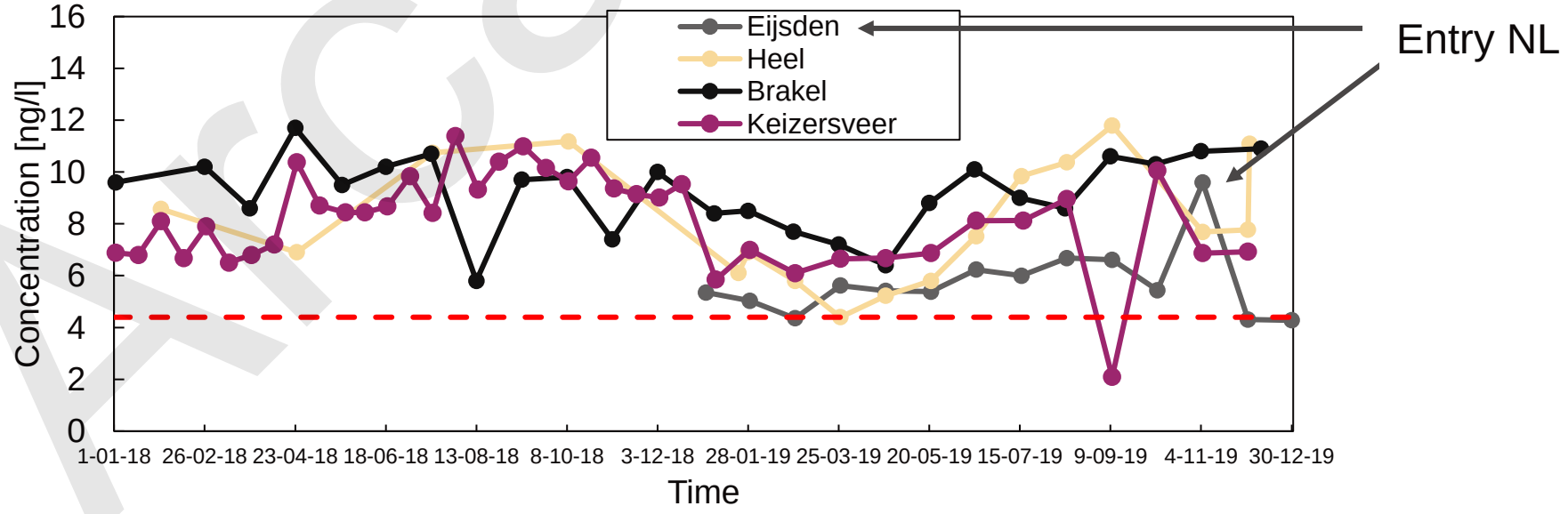
Middle deep old groundwater: 0-1 ng/l

PFAS (EFSA 4) in the main rivers of the Netherlands, source for drinking water…..

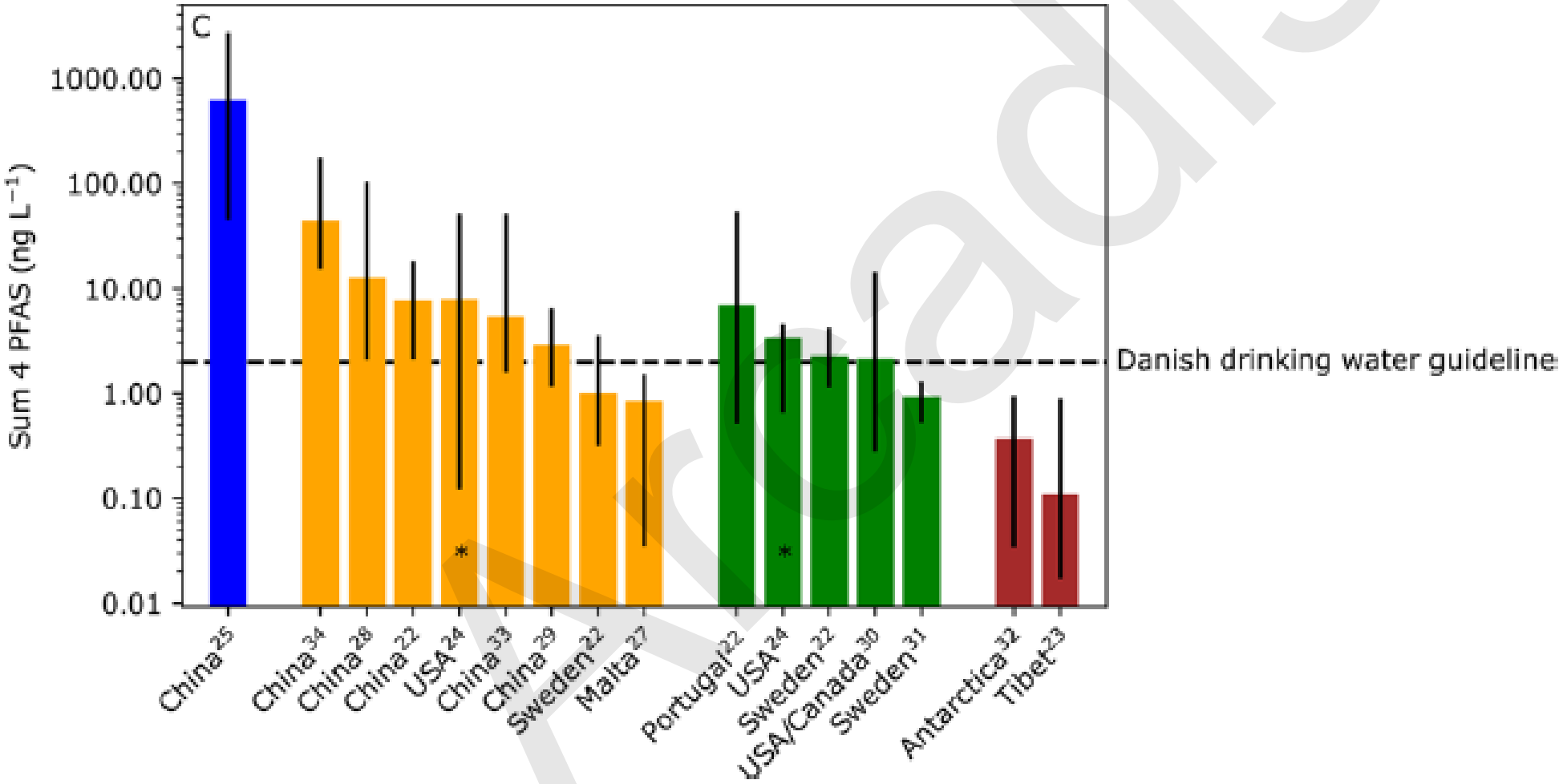
- Concentrations above 4,4 ng/l enter NL
- Concentrations seem to increase further in NL
- Sources: WWTP, Paper industry, landfills,

Sources:
-Vewin / RIWA-Rijn
- Expertisecentrum PFAS

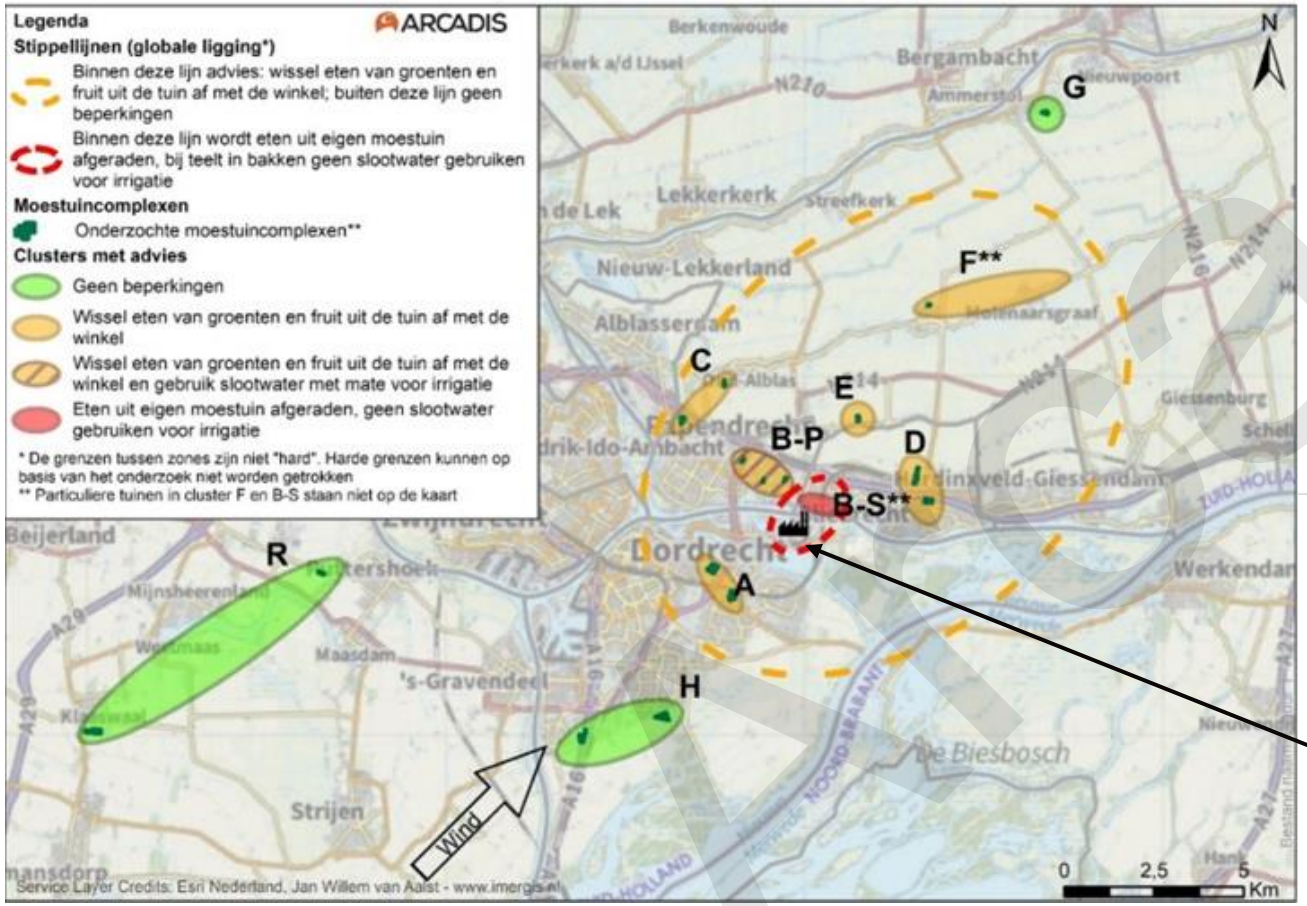


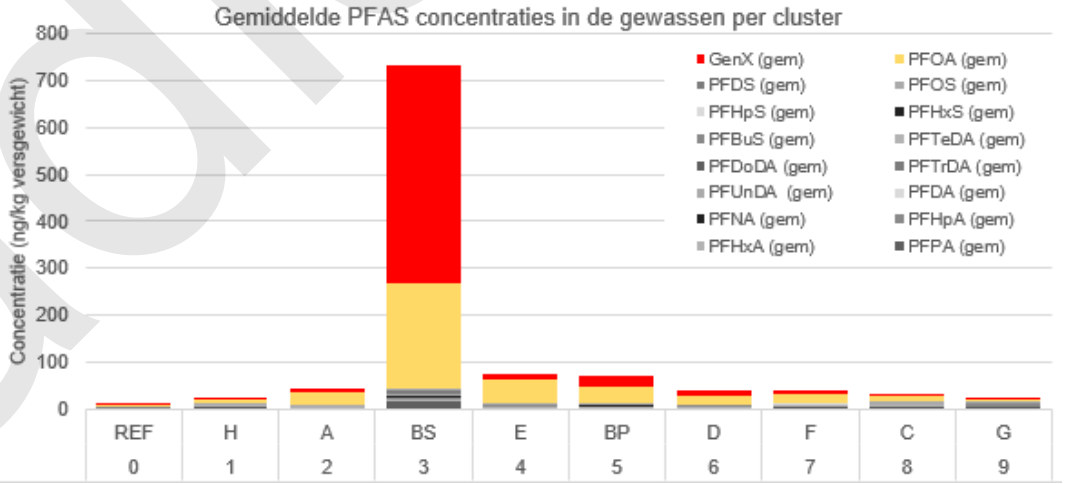


Sum 4 PFAS in rain (wet deposition)



Concentrations in vegetables around Chemours





Chemours

Contribution of food and water to Total Weekly Intake in the NL

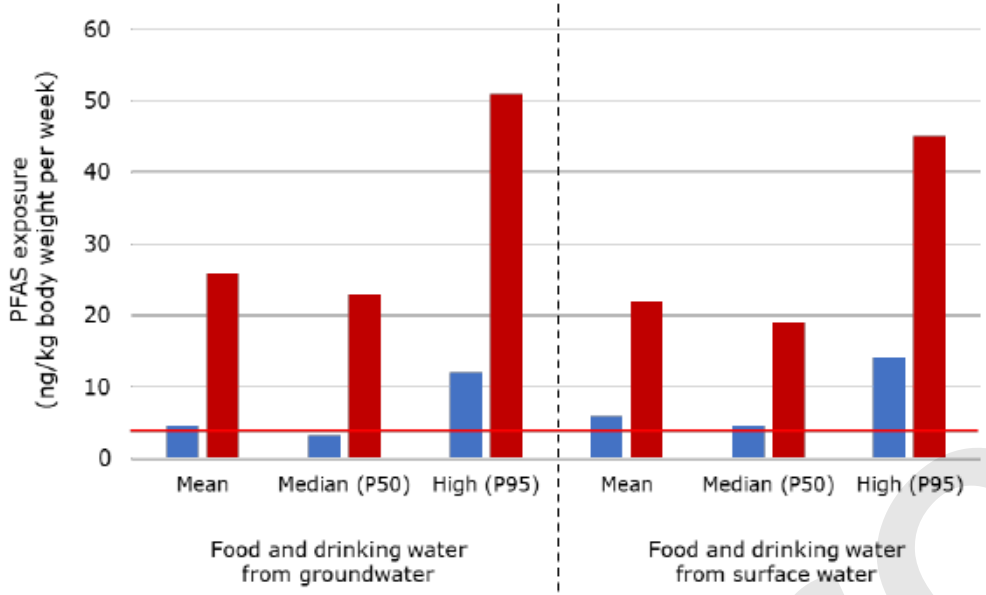
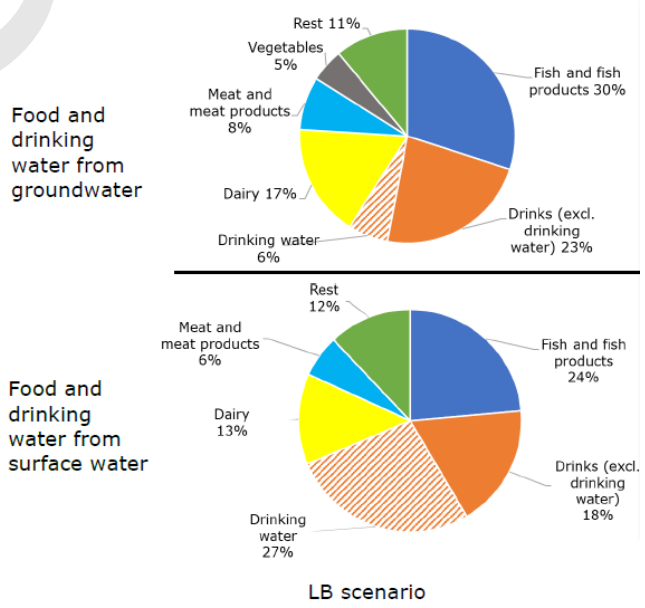


Figure 3 Mean, median (P50) and high (P95) lower bound (LB; blue bars) and upper bound (UB; red bars) long-term exposure to PFAS, expressed as PEQ, through food and two drinking water types for the Dutch consumer aged 1-79 years and compared with the TWI (red line; 4.4 ng/kg body weight) [a]

The total weekly intake of PFAS through food and water in the NL is 1-3 (mean – P95) times above the EFSA TWI

Contribution of drinking water is 6%-27% dependent upon source and scenario.



PFAS in eggs

Don't eat the eggs, hobby chicken keepers in Dordrecht are told

December 21, 2023

Photo: DutchNews.nl

People living near the Chemours factory in Dordrecht and who keep chickens as a hobby are being warned not to eat their eggs because they contain high concentrations of PFAS, a complex group of chemicals linked to cancer and other health issues.

▲ Kippen achter gaas. © Rob Voss

Hobbykip-ei kan te veel pfas bevatten: 'Wissel af met supermarkt-ei'

Mensen die ervoor kiezen om eieren van eigen kippen te eten, krijgen het advies deze af te wisselen met eieren uit de supermarkt. Nederlandse hobbykipeieren kunnen namelijk hoge concentraties van het schadelijke pfas bevatten. Dat blijkt uit een risicobeoordeling door de Nederlandse Voedsel- en Warenautoriteit (NVWA).

Edwin van der Aa 13-03-24, 10:54 **Laatste update:** 13-03-24, 11:41

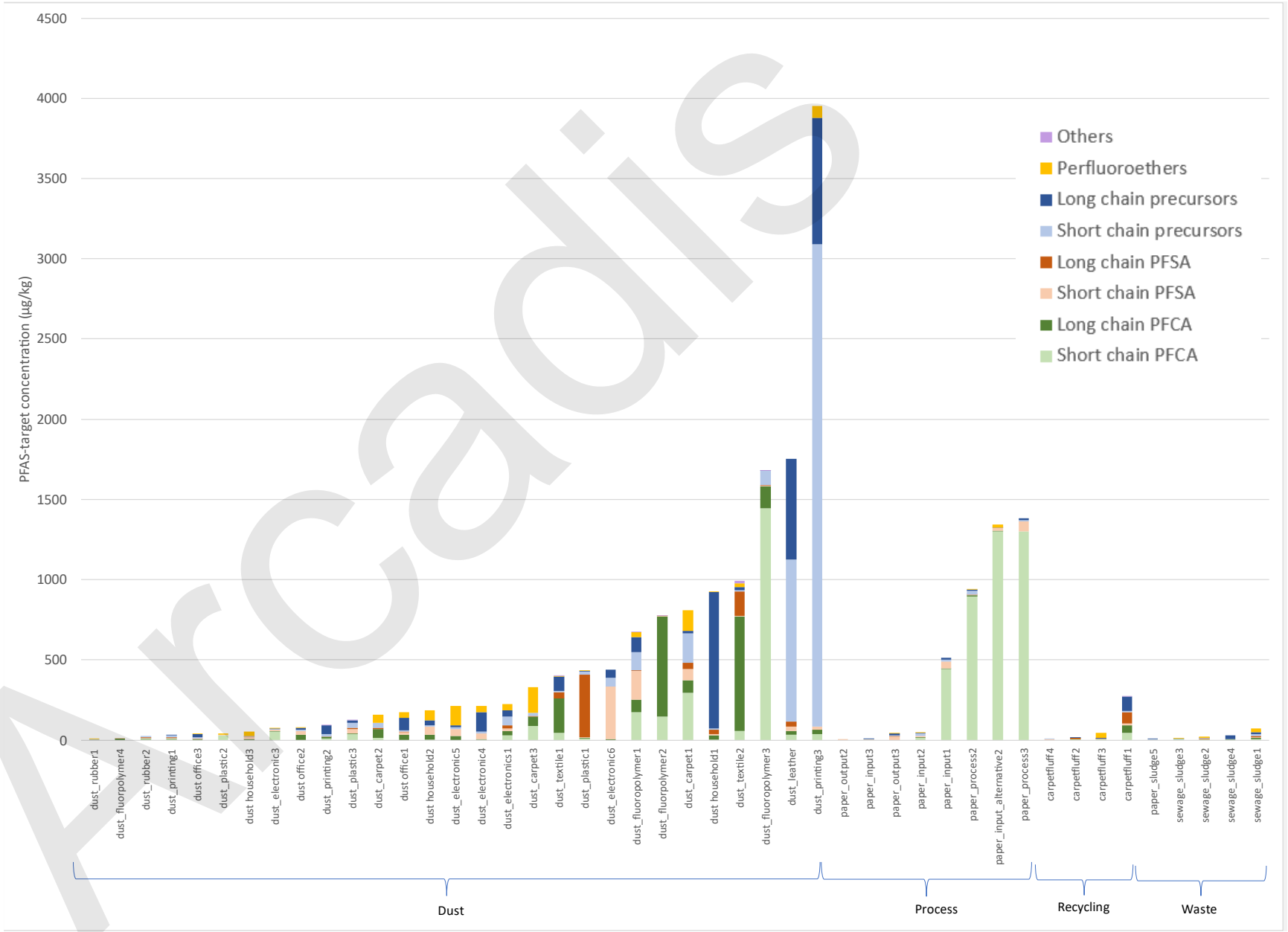
Environmental data

- Dust
- Consumer goods

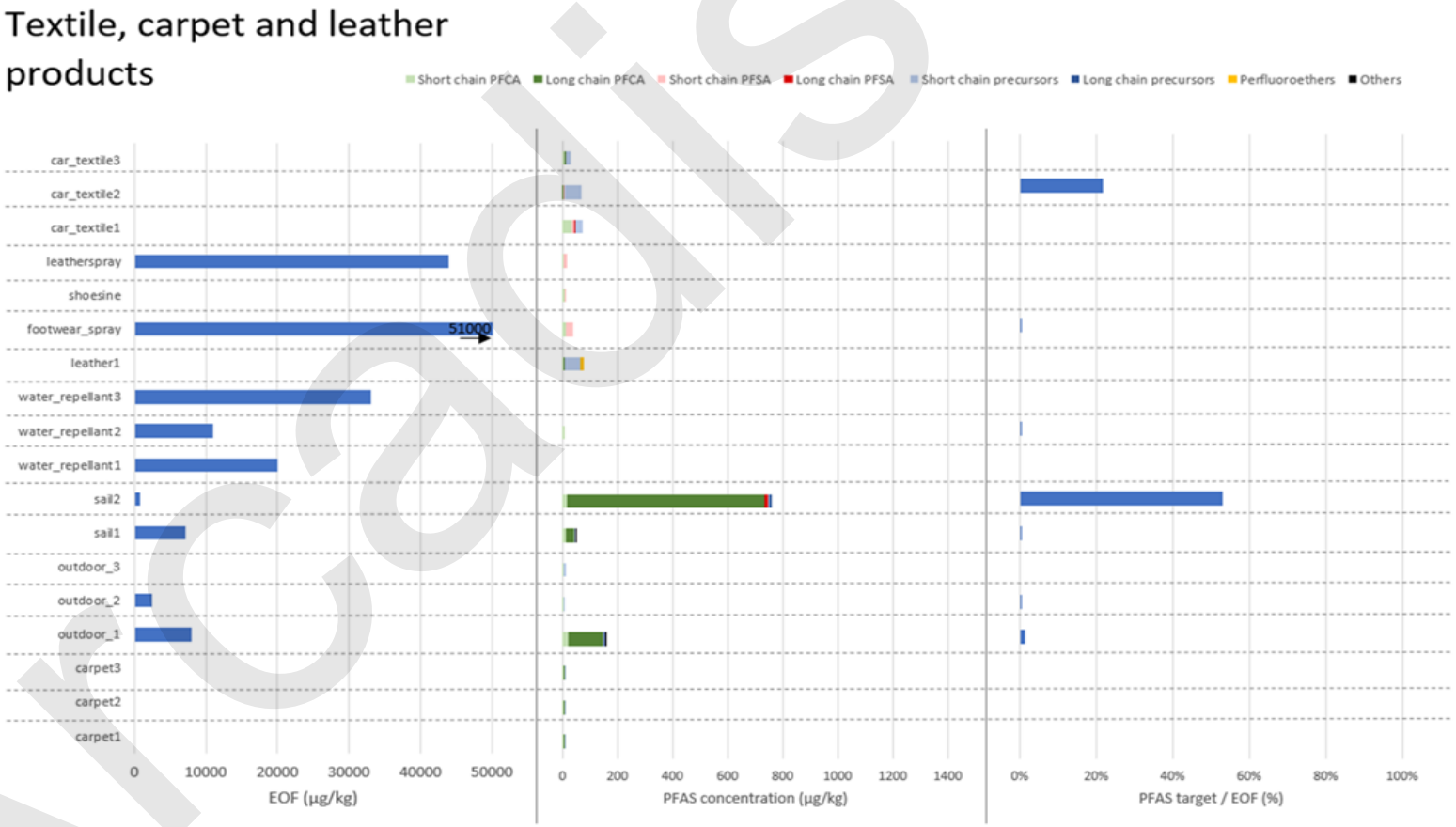
PFAS-target analysis, dust, recycling, processes, waste

Target-analysis 42 PFAS

- High concentrations in dust
- Various PFAS
- PFAS in recycling processes paper
- Recycling of tapestry

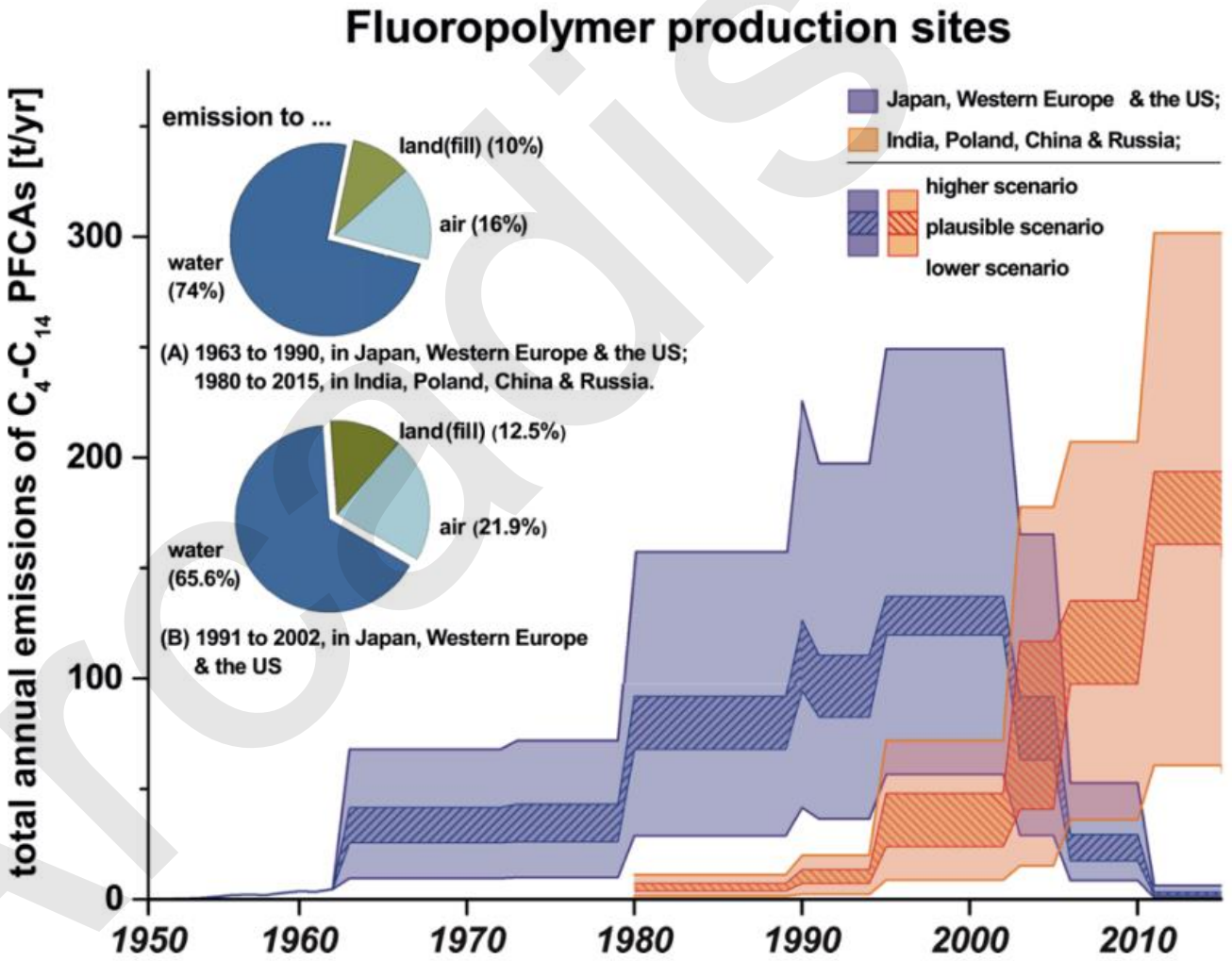


DARK MATTER!
A huge amount of unidentifyable PFAS in consumer goods



Concluding

Prevention and restriction is key, but:



Wang et al. (2014a).

Recap

• Soil background NL/BE	PFOS/PFOA	~ 1 500 ng/kg
• Ground water Phreatic	sum PFAS	~ 30 ng/l
• Surface water Rhine/Meuse	EFSA 4	~ 10 ng/l
• Rain	EFSA 4	~ 1-2 ng/l
• Vegetables	sum PFAS	~ 10 ng/kg
• Dust households and offices	sum PFAS	~ 1 000 000 ng/kg
• Bloodserum EU	sum PFAS	~ 20 000 ng/l
• Consumergoods	sum PFAS	~ 100 000 ng/l

Target levels:

• Drinking water (EU)	sum PFAS	100 ng/l / 500 ng/l
• Drinking water (NL)	sum PFAS (PEQ)	4.4 ng/l
• Surface water AA-EQS (EU)	sum PFAS (PEQ)	4.4 ng/l
• Surface water (NL)	PFOS	0.007 ng/l
• Soil vegetable garden (NL)	PFOS/PFOA	2 400 ng/kg / 2300 ng/kg
• Intervention level soil (NL)	PFOS/PFOA	60 000 ng/kg

Practically all these concentrations exceed the latest advisory levels for drinking water in Denmark, the Netherlands and US-EPA, and most probably EU to follow

Reflection

- Obvious, any level of PFAS has risk
- Prevention, restriction, and only dilution can mitigate our diffuse issues
- Monitoring of (background) levels becomes more important than improving target levels
- Advisory levels are not remediation levels; think about sustainability of remediation
- Relative toxicity and dark matter
- Awareness and responsibility
- Tackle sources! Improve technologies

Above all we need to raise the awareness of citizens and consumers worldwide so that they begin to demand products that are not toxic and do not leave poisonous pollution behind them.

Raivi Nadu, 2022

Additional PFAS information

https://www.arcadis.com/campaigns/pfas/index.html

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