



Achieving Remediation And GOVERning
Restoration of contaminated soils Now



PFAS43 in the EU Soil Law: Bridging analytical feasibility with environmental and regulatory relevance, illustrated on case studies.

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Funded by
The European Union

**More than 60% of Europe's soils
are in an unhealthy state and
need urgent actions:**



what we need is

**ACHIEVING REMEDIATION AND GOVERNING
RESTORATION OF CONTAMINATED SOILS NOW**

The Consortium



University of
Copenhagen
UCPH



Norwegian Geotechnical
Institute
NGI



ARCHE consulting



Babes-Bolyai University



City of Copenhagen



Comenius University
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Örebro University



ETH Zurich

Agenda

I. Prioritization

1. Principle
2. Scoring
3. Weight
4. “Real process”

II. PFAS-43

III. Results, occurrence

IV. Reflections

A mix between how we think it should be done,
And how we actually did it (given the constraints at the time)



I. Prioritization

1. Principle

I. Prioritization, principle

Regulatory Risk and Impact

Included in other
regulations

Natural Scientific Risk and Impact

Hazard

Human hazard

Environmental
hazard

Exposure

Persistence

Partitioning

Monitoring
occurrence*

*or volumes emitted

Socioeconomic Risk and Impact

Cost of analysis

I. Prioritization

2. Scoring

I. Prioritization, scoring

Transparent

- Show foundation/«assumptions»
- Updatable

Facilitate discussions

Parameter	Score range	Score description
A. Included in other regulations	0-1	Included (1) or not included (0) in EU regulations
B. Risk		
<u>Ba. Hazard</u>		
Ba1 Human hazard	0-3	0:has been tested and not classified,1: no information, 2: toxic effects, 3: most
Ba2 Environmental hazard	0-3	toxic (e.g. PFAS4 and precursors)
<u>Bb. Exposure</u>		
Bb1 Persistence	0-2	Degradation halflife (0: <120 days, 1:P>120 days, 2:vP>180 days),
Bb2 Partitioning	1-3	KOC (3: >49950, 2: >50 , 1: 5-50),
Bb3 Monitoring occurrence or volumes emitted	0-3	Monitoring detection frequency (0: never reported, 1: 1st percentile, 2: 2 nd percentile, 3: 3rd percentile), Volumes emitted
C. Cost of analysis	0-1	1: general LC-MS/MS method, 0: other

Normalised before weighting

I. Prioritization

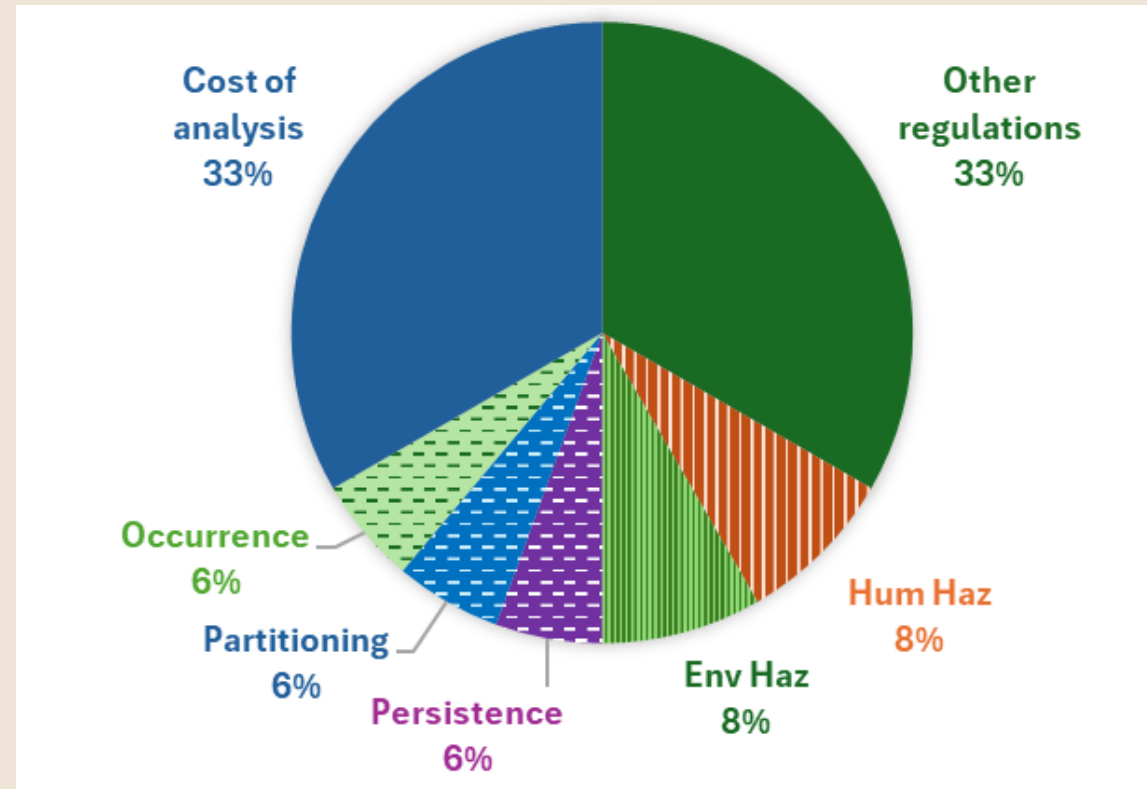
3. Weight

I. Prioritization, weight

Transparent

- Show foundation/«assumptions»
- Updatable

Facilitate discussions



The relative contribution (%) of each parameter; a) other regulations, b) risk (hazard (human and environment) and properties (persistence, partitioning, occurrence)), and c) cost of analysis, after normalisation of score ranges and applying weights.

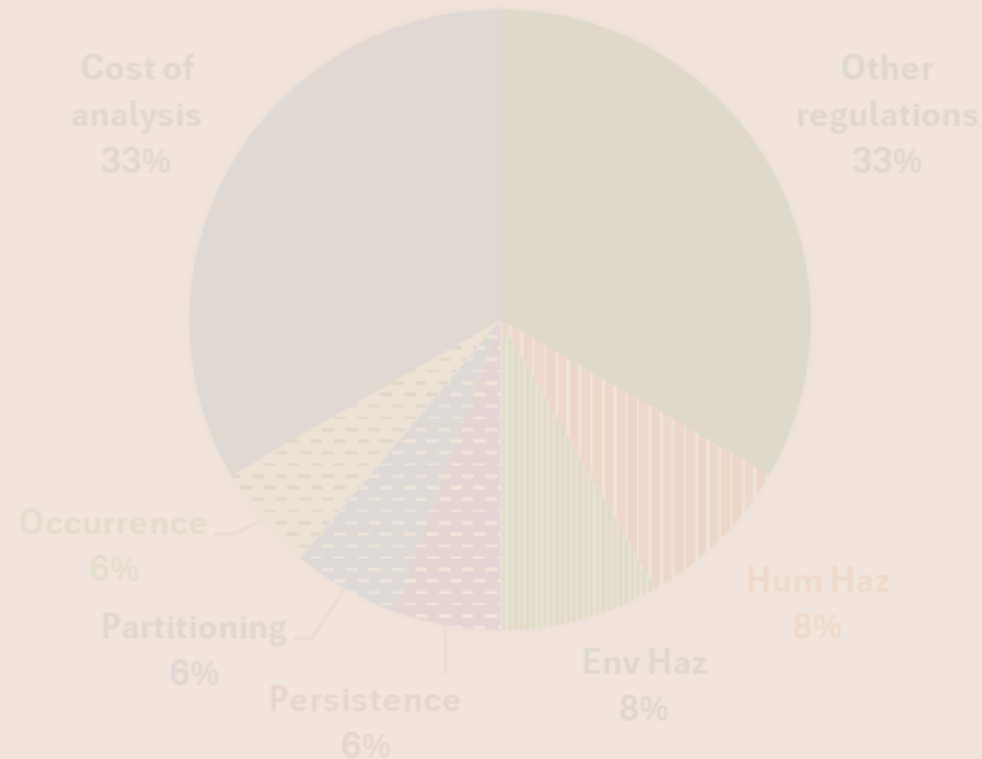
I. Prioritization, weight

Transparent

- Show foundation/«assumptions»
- Updatable

Facilitate discussions

In the end:
evaluating 57
compounds



The relative contribution (%) of each parameter; a) other regulations, b) risk (hazard (human and environment) and properties (persistence, partitioning, occurrence)), and c) cost of analysis, after normalisation of score ranges and applying weights.

I. Prioritization

4. “Real process”

I. Prioritization, “real process”

- **Pre-screening**

- Other regulations
- Increase analytical coverage
- Cost

Not time to make a thorough review of existing data,

Nor apply a systematic prioritisation scheme

Criteria, inclusion

Regulated PFAS, precursor of PFAS-4, High usage (e.g. AFFF), monitoring data, long chain vs. BCF, degradation products (indicative of neutral PFAS)

Criteria, exclusion

Not feasible to include in current anionic LC-MS/MS method, very water solvable PFAS (e.g. TFA), associated with point sources (e.g. production (GenX)),

II. PFAS-43

PFAS included in EU directives and suggestion for soil monitoring of PFAS

EU legislations that address PFAS	Surface water	Ground water	Drinking water	Food and feed	Soil
PFAS to monitor	WFD ¹ (in force /proposed)	GWD (proposed) ¹	DWD	EU	Aragorn PFAS43
PFAS-Total ²	-	-	*	-	*
PFOS derivatives ³	*/-	-	-	-	-
PFOS	*/*	*	*	*	*
PFOA	*/*	*	*	*	*
PFHxS	*/*	*	*	*	*
PFNA	*/*	*	*	*	*
PFBS	*/*	*	*	-	*
PFPeS	*/*	*	*	-	*
PFHpS	*/*	*	*	-	*
PFNS	*/-	*	*	-	*
PFDS	*/*	*	*	-	*
PFUnDS	-/-	-	*	-	*
PFDoDS	-/-	-	*	-	*
PFTrDS	-/-	-	*	-	*
PFBA	*/*	*	*	-	*
PFPeA	*/*	*	*	-	*
PFHxA	*/*	*	*	-	*
PFHpA	*/*	*	*	-	*
PFDA	*/*	*	*	-	*
PFUnDA	*/*	*	*	-	*
PFDoDA	*/*	*	*	-	*
PFTrDA	*/*	*	*	-	*
PFTeDA	*/*	*	-	-	*
PFHxDA	*/*	*	-	-	-
PFODA	*/*	*	-	-	-
HFPO-DA	-/*	*	-	-	-
ADONA	-/*	*	-	-	-
6:2 FTOH	-/*	*	-	-	-
8:2 FTOH	-/*	*	-	-	-
C6O4	-/*	*	-	-	-
PFOSA ³	-/-	-	-	-	*
N-EtFOSA ³	-/-	-	-	-	*

N-MeFOSA ³	-/-	-	-	-	*
FOSAA ³	-/-	-	-	-	*
N-EtFOSA ³	-/-	-	-	-	*
N-MeFOSA ³	-/-	-	-	-	*
FHxSA	-/-	-	-	-	*
N-EtFHxSA	-/-	-	-	-	*
N-MeFHxSA	-/-	-	-	-	*
FHxSAA	-/-	-	-	-	*
N-EtFHxSAA	-/-	-	-	-	*
N-MeFHxSAA	-/-	-	-	-	*
FBSA	-/-	-	-	-	*
N-EtFBSA	-/-	-	-	-	*
N-MeFBSA	-/-	-	-	-	*
FBSAA	-/-	-	-	-	*
N-EtFBSAA	-/-	-	-	-	*
N-MeFBSAA	-/-	-	-	-	*
6:2 FTS	-/-	-	-	-	*
8:2 FTS	-/-	-	-	-	*
5:3 FTCA	-/-	-	-	-	*
7:3 FTCA	-/-	-	-	-	*

1. The WFD-GWD is currently under negotiation, and the list shown here is therefore a combination of the WFD in force and the substances proposed to be included in the revised WDF.
2. Using proxy methods, e.g. EOF, TOPA, etc.
3. Precursors, salts, or functionalized analogues that can transform into PFOS through environmental or biological processes.

	Precursors to PFAS-4 (PFOS, PFOA, PFNA, PFHxS) including PFOS derivatives
	Relevant indicators for important contaminations

Excluded PFAS: 7

EU legislations that address PFAS	Surface water	Ground water	Drinking water	Food and feed	Soil
PFAS to monitor	WFD ¹ (in force /proposed)	GWD (proposed) ¹	DWD	EU	Aragorn PFAS43
PFHxDA	•/•	*	-	-	-
PFODA	•/•	*	-	-	-
HFPO-DA	-/•	*	-	-	-
ADONA	-/•	*	-	-	-
6:2 FTOH	-/•	*	-	-	-
8:2 FTOH	-/•	*	-	-	-
C6O4	-/•	*	-	-	-

New PFAS: 22

Precursors to PFAS-4

Relevant indicators for important contaminations

EU legislations that address PFAS	Surface water	Ground water	Drinking water	Food and feed	Soil
PFAS to monitor	WFD ¹ (in force /proposed)	GWD (proposed) ¹	DWD	EU	Aragorn PFAS43
PFOSA ³	-/-	-	-	-	•
N-EtFOSA ³	-/-	-	-	-	•
N-MeFOSA ³	-/-	-	-	-	•
FOSAA ³	-/-	-	-	-	•
N-EtFOSAA ³	-/-	-	-	-	•
N-MeFOSAA ³	-/-	-	-	-	•
FHxSA	-/-	-	-	-	•
N-EtFHxSA	-/-	-	-	-	•
N-MeFHxSA	-/-	-	-	-	•
FHxSAA	-/-	-	-	-	•
N-EtFHxSAA	-/-	-	-	-	•
N-MeFHxSAA	-/-	-	-	-	•

FOSE/FOSAA:
identified in 20-
40% of all samples
in the occurrence
data-set

New PFAS: 22

Precursors to PFAS-4

Relevant indicators for important contaminations

EU legislations that address PFAS	Surface water	Ground water	Drinking water	Food and feed	Soil
PFAS to monitor	WFD ¹ (in force /proposed)	GWD (proposed) ¹	DWD	EU	Aragorn PFAS43
FBSA	-/-	-	-	-	•
N-EtFBSA	-/-	-	-	-	•
N-MeFBSA	-/-	-	-	-	•
FBSAA	-/-	-	-	-	•
N-EtFBSAA	-/-	-	-	-	•
N-MeFBSAA	-/-	-	-	-	•
6:2 FTS	-/-	-	-	-	•
8:2 FTS	-/-	-	-	-	•
5:3 FTCA	-/-	-	-	-	•
7:3 FTCA	-/-	-	-	-	•

8:2 FTS: identified
in 30% of all
samples in the
occurrence data-set

New PFAS: 22

Precursors to PFAS-4

Relevant indicators for important contaminations

PFAS to monitor	Precursor to	Typical sources	Aragorn PFAS43
PFOSA ³	PFOS	Textile and carpet impregnation	•
N-EtFOSA ³	PFOS	Textiles/carpet, paper and food packaging, cleaning products	•
N-MeFOSA ³	PFOS	Textiles/carpet, paper and food packaging, cleaning products	•
FOSAA ³	PFOS	Impregnation (textiles, carpets), paper coating	•
N-EtFOSAA ³	PFOS	Impregnation and surface treatment, certain plant protection products (pesticides)	•
N-MeFOSAA ³	PFOS	Impregnation and surface treatment	•
FHxSA	PFHxS	Textile and carpet impregnation, paper/cardboard, industrial surfactants	•
N-EtFHxSA	PFHxS	Textiles/carpet, specialty chemicals	•
N-MeFHxSA	PFHxS	Textiles/carpet, specialty chemicals	•
FHxSAA	PFHxS	Impregnation and surface treatment	•
N-EtFHxSAA	PFHxS	Impregnation, paper/cardboard	•
N-MeFHxSAA	PFHxS	Impregnation, paper/cardboard	•

New PFAS: 22

Precursors to PFAS-4

Relevant indicators for important contaminations

PFAS to monitor	Precursor to	Typical sources	Aragorn PFAS43
FBSA	PFBS	Short-chain impregnation products (textiles, carpets), paper/cardboard	•
N-EtFBSA	PFBS	Impregnation agents and industrial surfactants	•
N-MeFBSA	PFBS	Impregnation agents and industrial surfactants	•
FBSAA	PFBS	Impregnation (textiles/paper), specialty chemicals	•
N-EtFBSAA	PFBS	Impregnation, paper/cardboard	•
N-MeFBSAA	PFBS	Impregnation, paper/cardboard	•
6:2 FTS	Fluorotelomer-PFAA (e.g. PFHxA)	Modern AFFF firefighting foams (C6), textile and footwear impregnation, paper/food packaging, metal plating/electroplating	•
8:2 FTS	Fluorotelomer-PFAA (e.g. PFOA)	Older/certain firefighting foams, textile and paper impregnation	•
5:3 FTCA	Fluorotelomer-PFAA (e.g. PFOA)	Degradation product of 6:2 and 8:2 FTOHs used in textile, paper, and floor polish treatments, as well as firefighting foams	•
7:3 FTCA	Fluorotelomer-PFAA (e.g. PFOA)	Degradation product of fluorotelomer alcohols used in the same application areas	•

Example of PFAS sub-groups

Compound group	Examples (non-comprehensive) of individual indicators	Indicative of:
Perfluoroalkane carboxylic acids	PFBA (C4) to PFTDA (C14) PFHxDA, PFODA, and longer	Many uses and precursors Indicative for (semi-)fluorinated alkane pollution
Perfluoroalkane sulfonic acids	PFBS (C4) to PFD _o DS (C12)	Many uses and precursors
Transformation intermediates	FTCA, FTUCA	
Ultrashort acids	TFA, TFMS, TFEtS, PFPrA, PFEtA, PFPrA, PFEtA, PFPrS,	Industrial use, transformation product (e.g. from chemical- or electroremediation, pesticides), diffuse pollution
Sulfonamido alcohols	FOSE, FHxSE, FBSE and their Me/Et-derivatives	AFFF, coatings, surfactant and industrial applications (FOSE and FHxSE with respective derivatives are PFOS and PFHxS derivatives)
Fluorotelomer alcohols	6:2 FTOH, 8:2 FTOH, 10:2 FTOH, 7:2s FTOH	Production of fluoropolymer and surfactants, industrial and consumer applications
Cyclics	PFECHS	Hydraulic fluids, personal care products
Sulfonamido-based precursors	6:2 FTAB, 6:2 FTMAP, 5:3 FTB, 5:1:2 FTB, N-TAmP-FHxSA, N-AP-FHxSA, DPOSA, 6:2 FTSAS	AFFF ingredients
Perfluoroethers	ADONA, HFPO-DA, PFEESA, PF4OP, P5MeODIOXOAc, PF5OHxA, 3,6-OPFHpA, C6O4, PFMPA, PFMBA	Fluoropolymer manufacturing, industrial use
Perfluoroalkyl phosphonic and phosphinic acids	PFHxPA, PFOPA, PFDPA, 6:6 PFPiA, 6:8 PFPiA, 8:8 PFPiA	Coatings, industrial applications biomedical use
Fluorotelomer acrylates	8:2 FTAcr, 10:2 FTAcr, 6:2 FTAcr, 6:2 FTMAcr	Industrial and consumer applications e.g. coatings, co-polymers
Polyfluoroalkyl phosphate esters	6:2/6:2 diPAP, 6:2/8:2 diPAP, 8:2/8:2 diPAP, 8:2/10:2 diPAP, 10:2/10:2 diPAP, diSAmPAP	Industrial and consumer applications, primarily for coatings
Imides	Bistriflimide (NTf ₂), bis-perfluoro methanesulfonimide (Bis-FMeSI), bisperfluoroethane sulfonimide (Bis-FEtSI), bisperfluorobutane sulfonimide (Bis-FPrSI)	Ionic liquids, battery electrolytes, catalysts

III. Results, occurrence

III. Results, occurrence

Occurrence rate (% measured) PFAS compounds, from the original dataset of about 23 000 samples analyzed for PFAS-35.

Compound	% Measured
PFOS	88
PFOA	64
PFHxS	59
PFPeA	55
PFHxA	52
PFNA	49
PFHpA	46
PFUnDA	31
6:2 FTS	31
PFBA	30
PFHpS	30
FOSA	28
PFDA	27
8:2 FTS	23
PFDS	20
PFTTrDA	19
PFBS	16
PFDoDA	15
PFPeS	15
PFNS	13
PFTeDA	12
FOSAA	8.1
N-MeFOSAA	7.3
N-EtFOSAA	5.6
PFHxDA	4.2
PFDoDS	3.8
N-MeFOSA	3.8
N-EtFOSE	2.7
PFUnDS	2.4
N-MeFOSE	1.9
PFTTrDS	1.6
N-EtFOSA	0.55
HPFHpA	0.51
4:2 FTS	0.20
PF-3,7-DMOA	0.029

Occurrence rate (% measured) of PFAS compounds measured in the validation dataset (Eurofins NL, n = 1000 - 5000)

Compound	% Measured
PFOS	77
PFOA	66
PFBA	41%
PFPeA	32%
PFHxA	25%
PFHpA	22%
PFDA	20%
PFNA	16%
PFHxS	12%
6:2 FTS	12%
FBSA	10%
PFDoDA	10%
PFUnDA	8.1%
PFBS	7.1%
FOSA	6.1%
N-EtFOSA	6.1%
N-EtFOSAA	5.7%
N-MeFOSAA	4.8%
PFHpS	4.4%
PFTeDA	4.1%
N-MeFBSAA	4.0%
PFTTrDA	3.5%
8:2 FTS	3.4%
PFPeS	3.3%
10:2 FTS	2.7%
PFDS	2.4%
PFHxDA	2.2%
HPFHpA	2.2%
HFPO-DA (GenX)	2.0%
8:2 FTUCA	1.8%
8:2 diPAP	1.5%
PFODA	1.3%
N-MeFOSA	1.2%
N-MeFBSA	0.78%
9CI-PF3ONS	0.52%
DONA	0.39%
4:2 FTS	0.27%

Legend:

Present in both PFAS-21 and PFAS-43

Only present in PFAS-43 (not PFAS-21)

Present in dataset, not part of either PFAS-43 (nor PFAS-21)

Only present in validation dataset, not part of either PFAS-43 (nor PFAS-21)

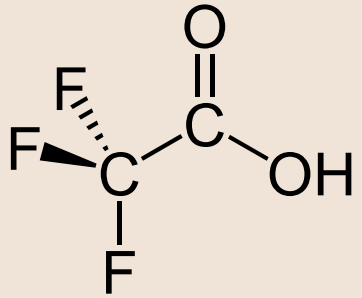
Most frequently occurring compounds are covered by both PFAS-21 and PFAS-43

PFAS-43 does not exclude any frequently occurring compounds (validation dataset confirmed initial expert opinions)

PFAS-21 underestimates PFAS in approx. 35% of the samples in the data sets.

IV. Reflections

TFA



Let us say:

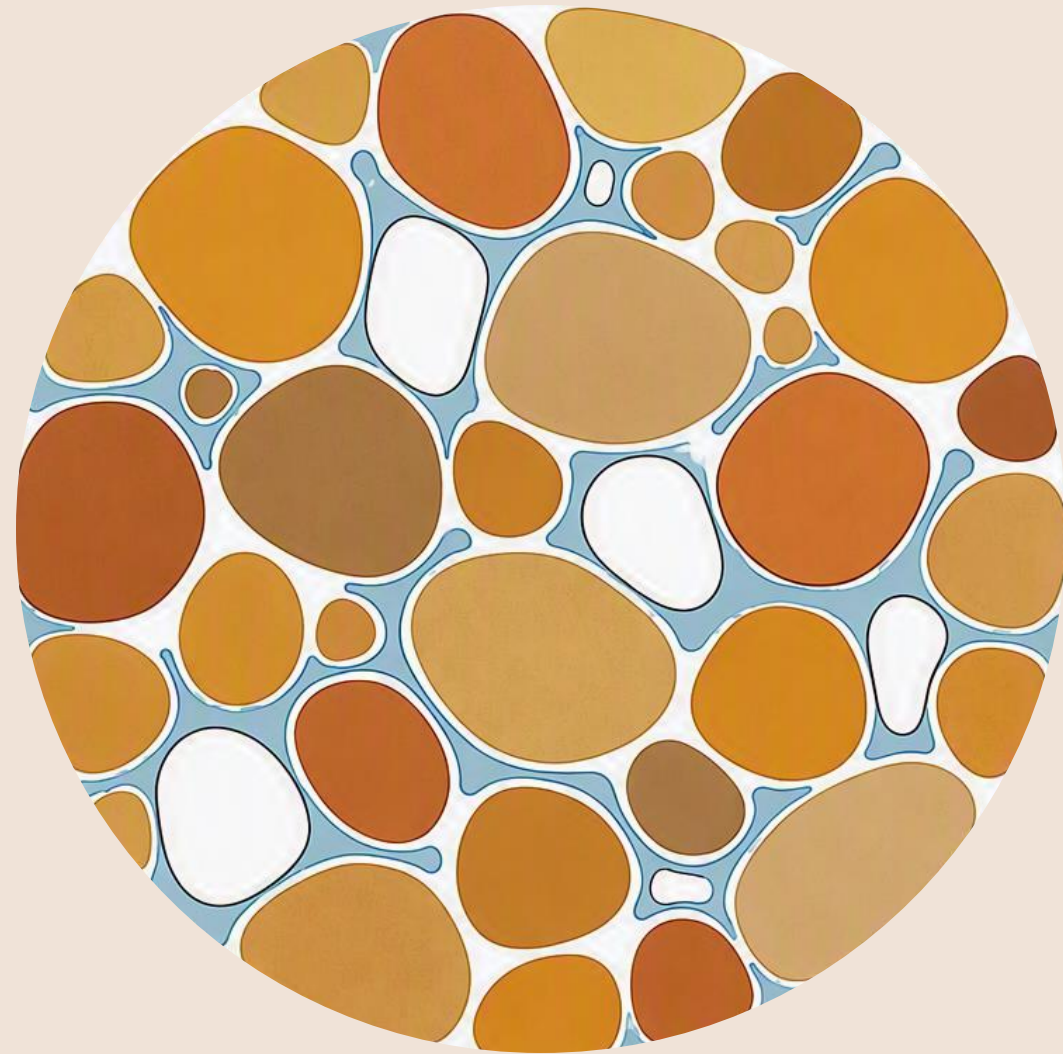
80%

20%

Soil particles

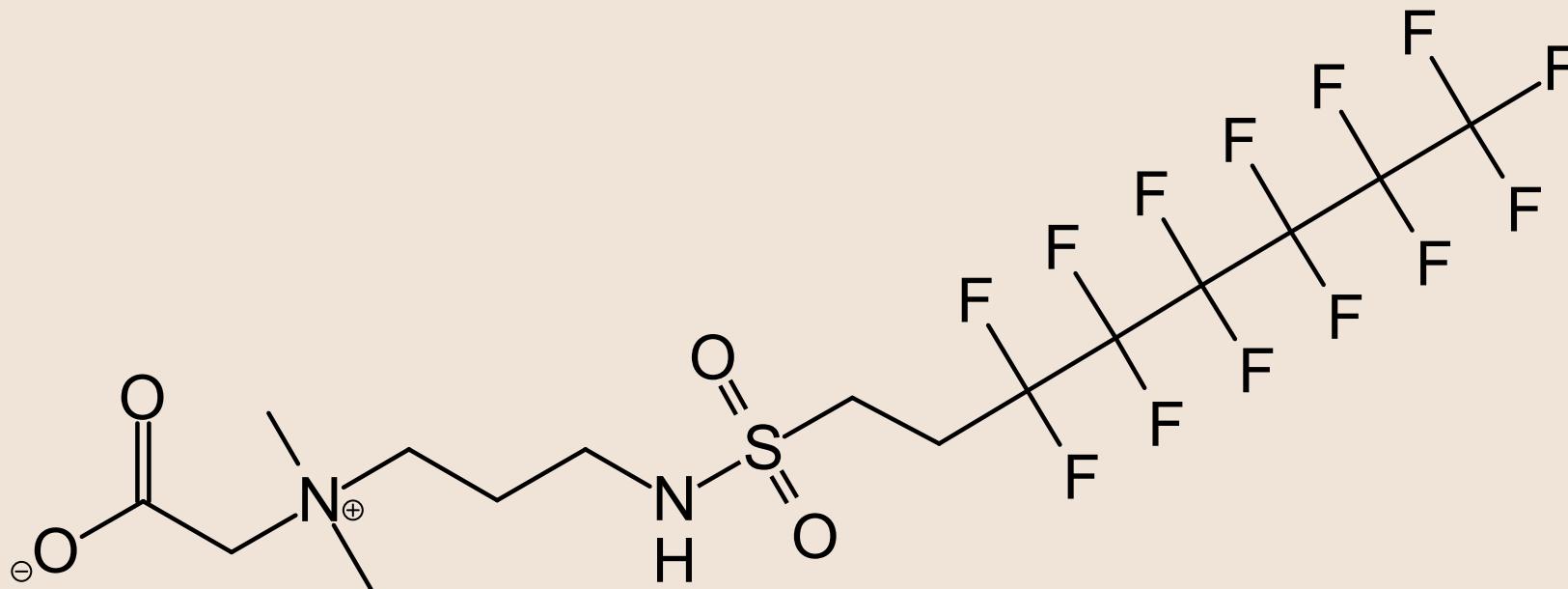
Water

Air

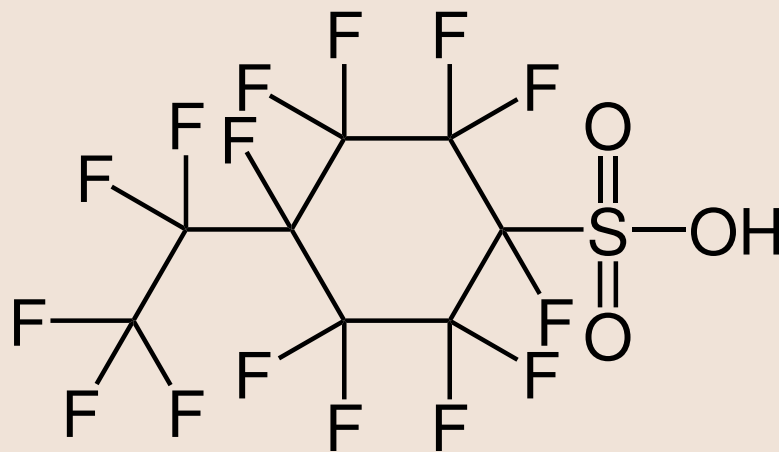


- Very water soluble (mobile) PFAS
- Lack robustness of sampling/results
 - e.g. after rain events
 - detection levels

6:2 FTAB

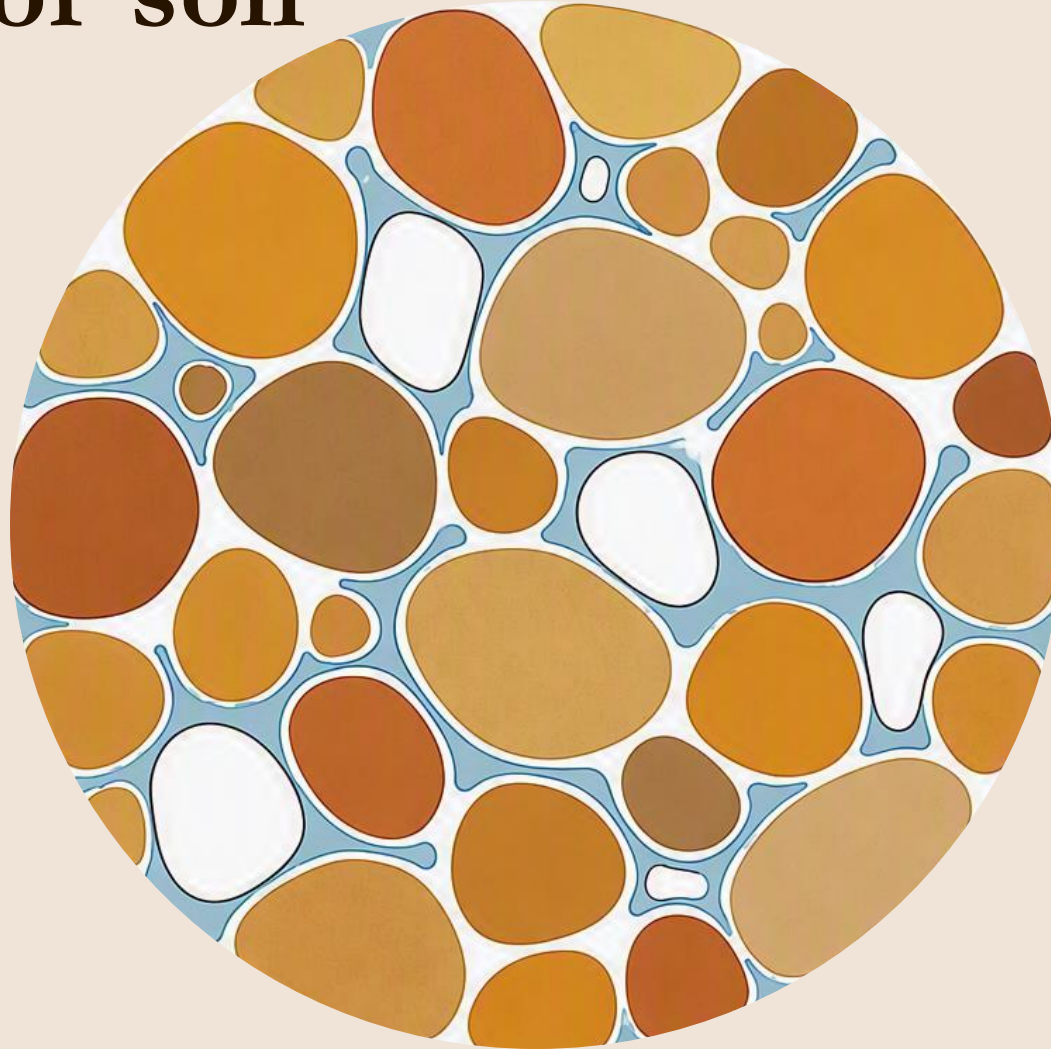


PFECHS (“peaches”)



Complexity of soil

- See a “higher” amount of different PFAS
- (hidden) pool of PFAS compounds



Analytical strategies

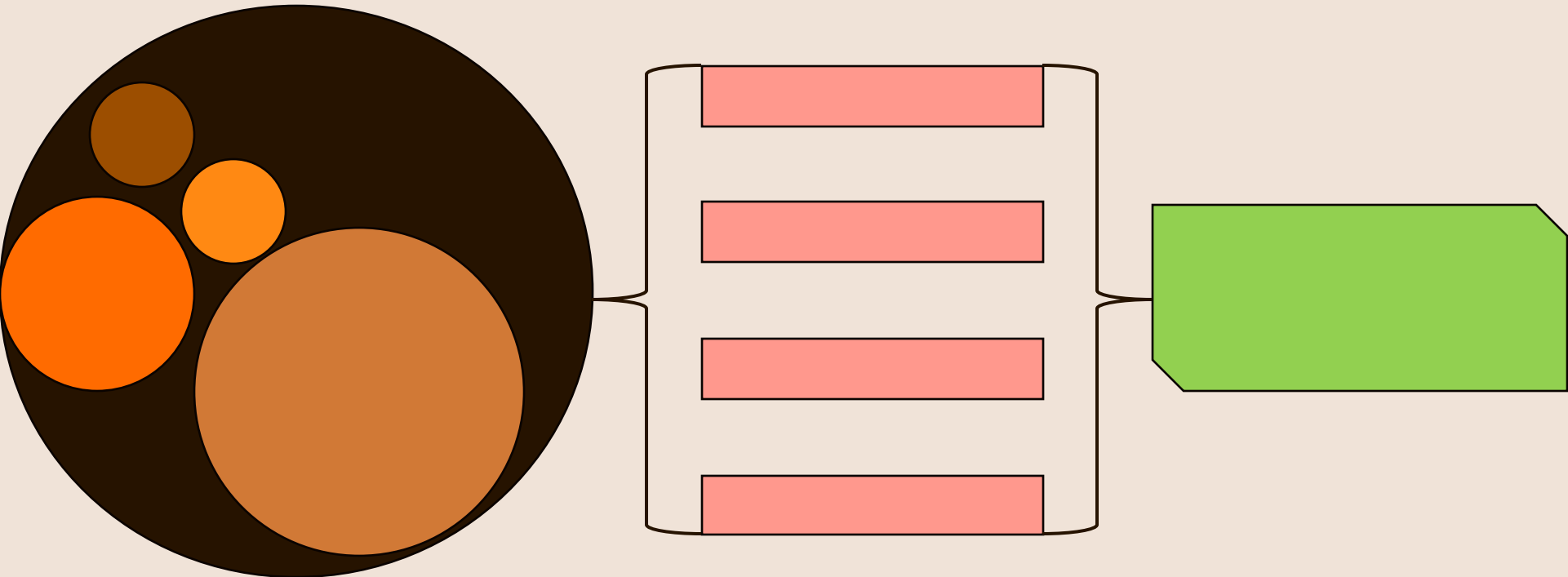
Source composition

Pathways

Receptor(s)

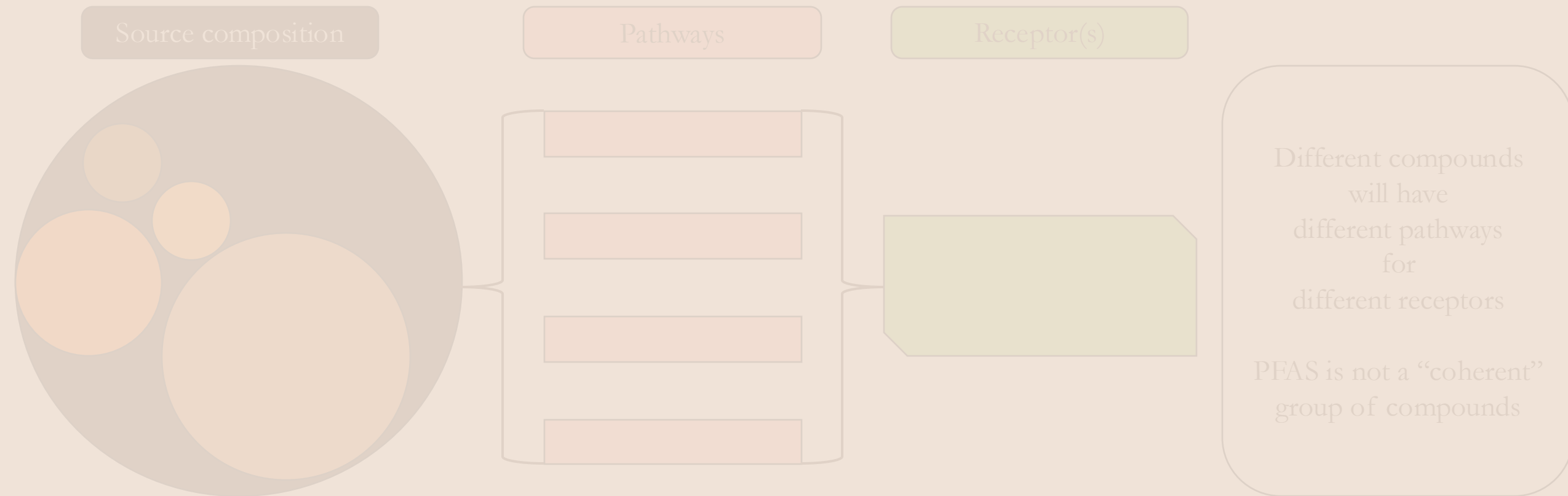
Different compounds
will have
different pathways
for
different receptors

PFAS is not a “coherent”
group of compounds



Analytical strategies

- Monitoring
 - “total” + indicator compounds
 - “Low cost”
- Site characterization
 - Conceptual understanding
 - Minimize data gaps
- Source tracking
 - Pathways
 - Unique markers





Achieving Remediation And GOVERning Restoration of contaminated soils Now



Thank you!

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