PFAS - European Benchmark Remediation activities

7th PFAS International Congress

Boris DEVIC-BASSAGET
Technical Director VEOLIA | Remediation

Hazardous Waste Europe

upds
Union des Professionnels de la Dépollution des Sites.

PFAS
PER- AND POLY-FLUOROALKYL SUBSTANCES

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Hazardous Waste Europe

Sommaire

REMEDIATION EUROPE

Reference in Soil Remediation

400+
specialists

40 years
of experience

Turnover
€150M in 2025

7
treatment facilities *

Safety
FR1 0,00 / FR2 5,26 SR
0,00 in 2025

Equipment
5 workshops & 5 laboratories

24
offices in 6 countries

Treatment & recovery
of 1,5M tonnes of soil in 2025

** plus 7 soil treatment centers in France belonging to Mineral Waste division*

PFAS “UTRA SHORT / SHORT & LONG CHAINS”…

What is the topic ?

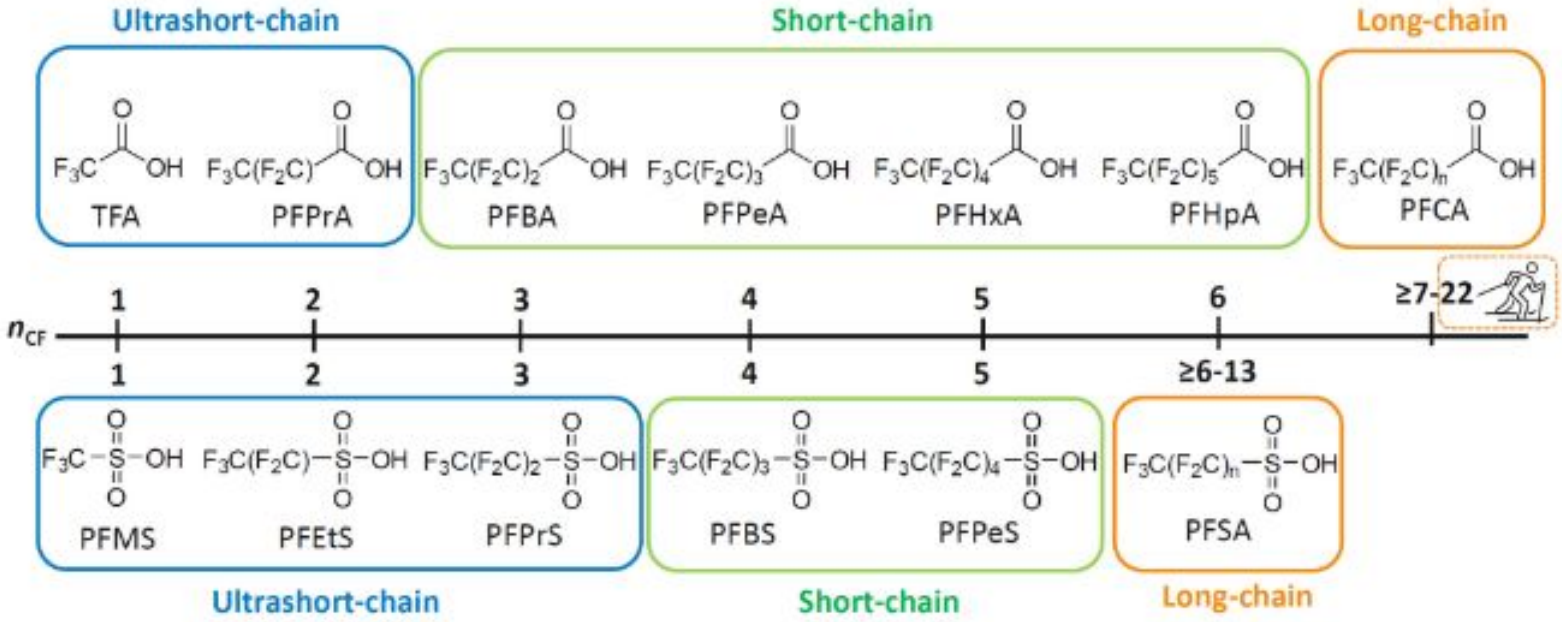
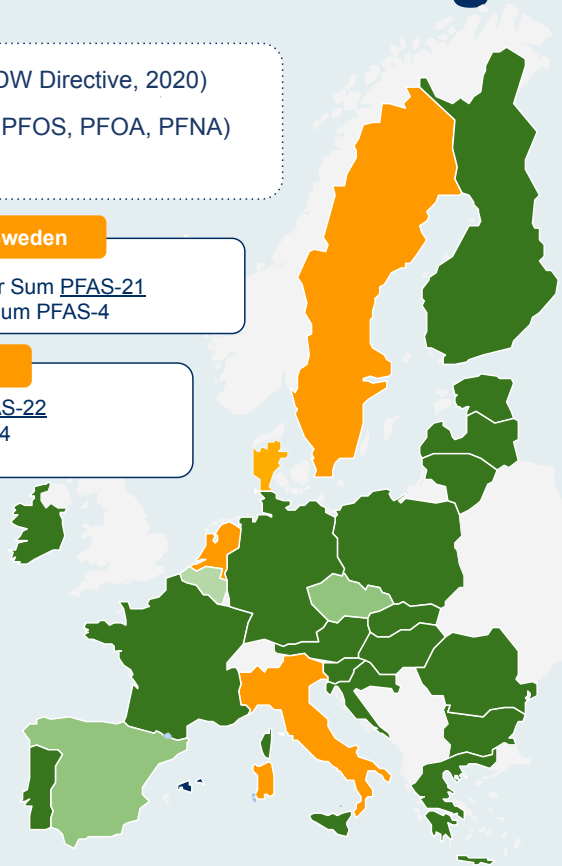


Figure 1: PFSA and PFCA categorization based on carbon chain length – ultrashort-chain, short-chain and long-chain. (Image provided courtesy of Phenomenex and SCIEX).

PFAS regulation in Drinking Water in EU

- Sum of 20 PFAS and/or Total PFAS (EU DW Directive, 2020)
- Sum of 20 PFAS + EFSA-PFAS (PFHxS, PFOS, PFOA, PFNA)
- Sum of 20 PFAS modified + EFSA-PFAS



EU

Sum of 20 PFAS: 100 ng/l and/or
Total PFAS: 500 ng/l (enforced before 01/2026)

Sweden

100 ng/l for Sum PFAS-21
4 ng/l for Sum PFAS-4

Denmark

100 ng/l for Sum PFAS-22
2 ng/l for Sum PFAS-4
9 µg/l for TFA

Netherlands

100 ng/l for Sum PFAS-22
4.4 ng/l for Sum PFAS-4 (eq. PFOA)
2.2 µg/l (reco) for TFA

Belgium

100 ng/l for Sum PFAS-20
4 ng/l for Sum PFAS-4 (target in BE regions)

Spain

100 ng/l for Sum PFAS-20
70 ng/ PFOA, PFOS, PFHxS & PFNA

Germany

100 ng/l for Sum PFAS-20 (2026)
20 ng/l for Sum PFAS-4 (2028)
60 µg/l for TFA (reco)

Czech Rep.

100 ng/l for Sum PFAS-20
10 ng/l for Sum PFAS-4 (indicative)

Italy

100 ng/l for Sum PFAS-30
20 ng/l for Sum PFAS-4
10 µg/l for TFA

Larger list of PFAS and lower thresholds. Awareness of potential evolution

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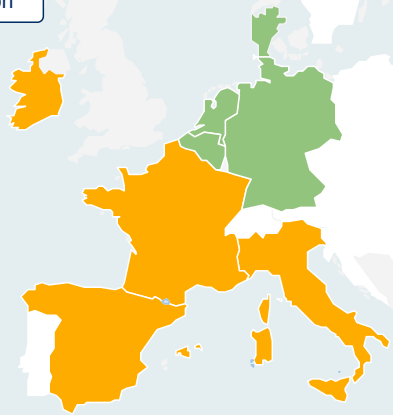
PFAS regulation in Soils in EU (µg/kg-DM)

Recovery / free reuse thresholds

No regulation / expected

Not represented



EU

Each country impose value. Main approach is drinking water level on leachates L/S =10

Denmark

Σ 4 PFAS <10 (PFOA, PFOS, PFNA or PFHxS)
22 PFAS <400

Germany

Σ ([PFAS1]/Cmax1 + ... + [PFASn]/Cmaxn) ≤ 1

Ireland

< QL today, Threshold expected soon

France

NO REGULATION

Netherlands

PFOS / PFOA / other individual PFAS:
Agro 1.4 / 1.9 / 1.4 -
Residential & Industry 3 / 7 / 3

Italy

EXPECTED

Belgium

Flanders & Brussels: PFOS < 3 ; PFOA < 2, Σ 55 PFAS < 8
Wallonia: PFOS < 0,8; PFOA < 0,5

No value = low business in remediation activities

Spain

NO REGULATION

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What levels of impact on soils and groundwater?

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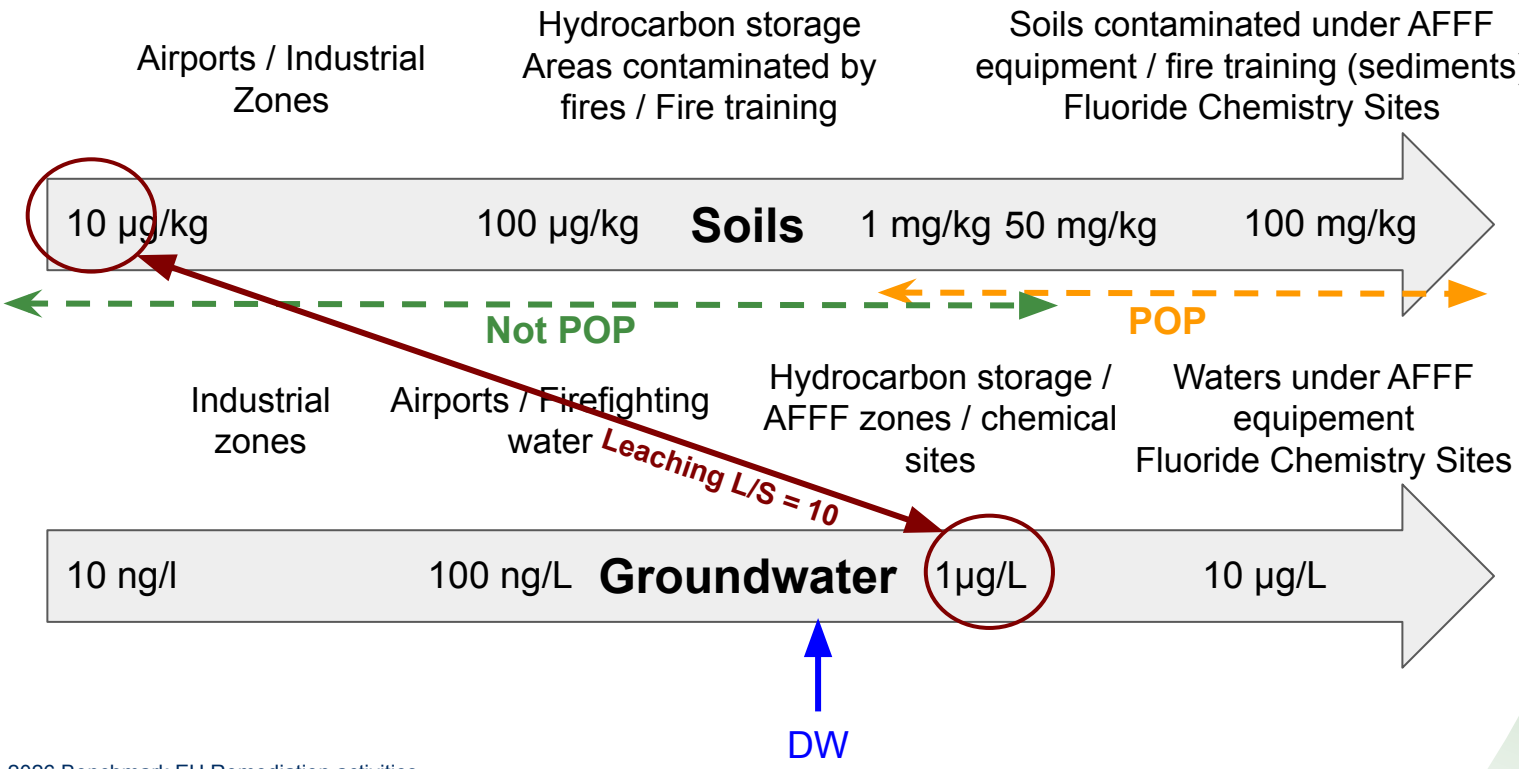
Levels of impact on soils and groundwater



What are the techniques for remediating soils and groundwater?

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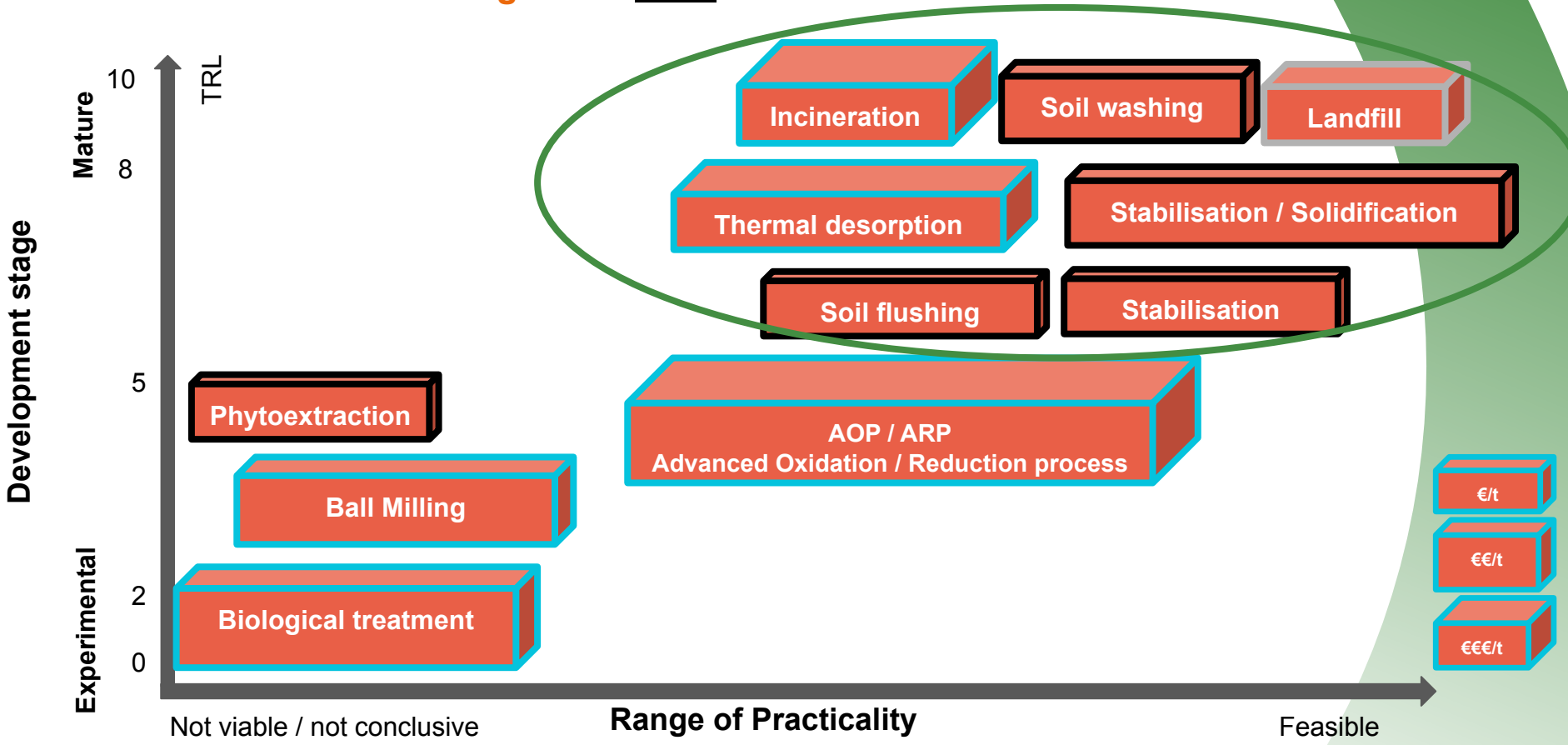
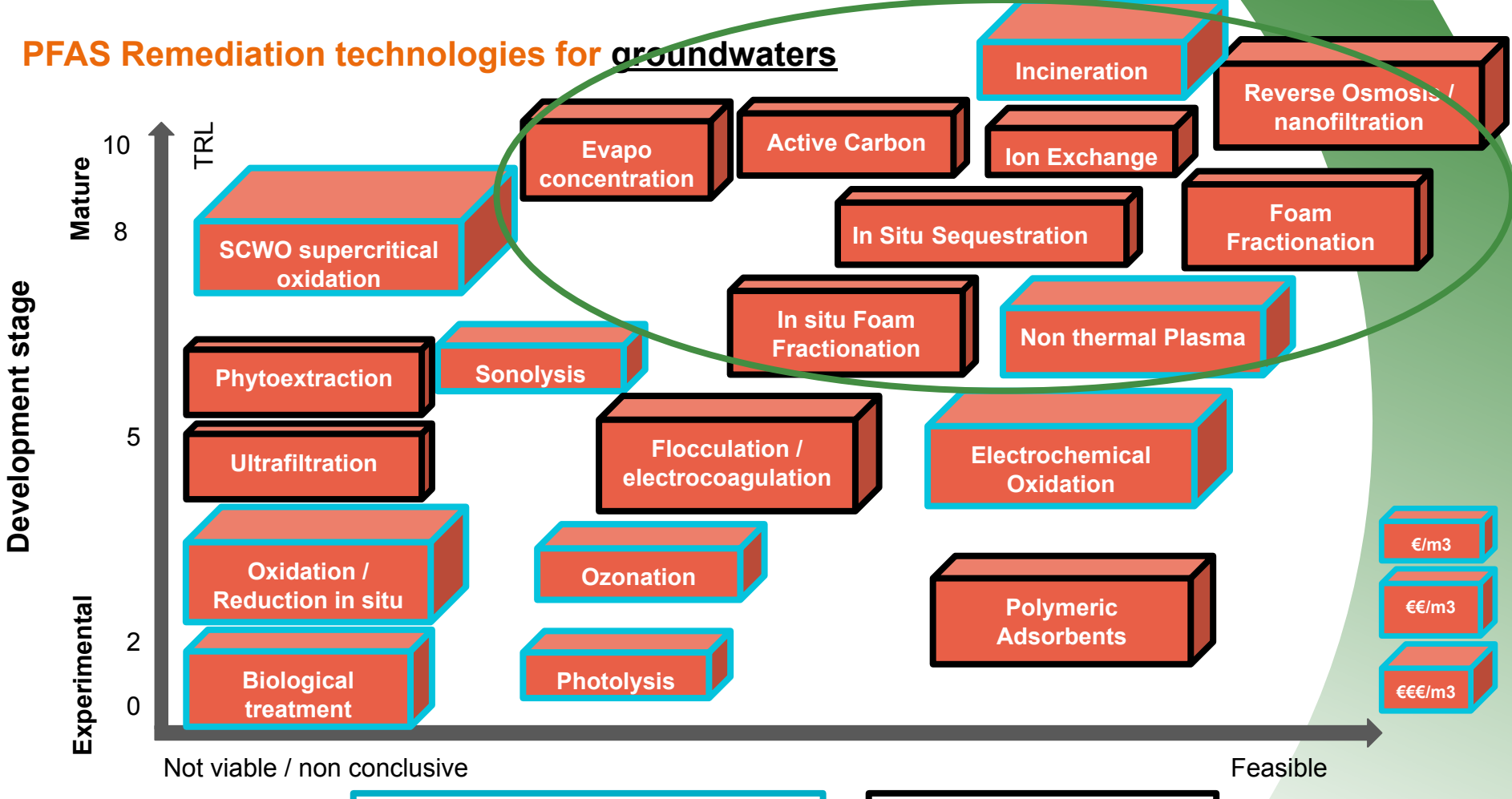
PFAS Remediation technologies for soils



PFAS Remediation technologies for groundwaters



Feasibility tests

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Lab scale pilots @ VEOLIA Remediation

PFAS

Nr.	LABORATORY SCALE PILOT	REMEDIATION TECHNOLOGY
1	Aerobic BIO reactivation test - Soils - bioavailablity	Biopile® / Landfarming / Bioventing
2	BIO aero/anaerobic reactivation test - Ground Water	BIONAPPE® aerobic or anaerobic
3	Biodegradation kinetics - Soils	Biopile® / Landfarming / Bioventing
4	Kinetics of biodegradation - Groundwater	BIONAPPE® aerobic or anaerobic
5	Choice of oxidant (DSO, MOT, etc.)	Oxidation in situ / on site
6	Oxidation test (1 oxidant, 3 concentrations)	In situ oxidation
7	In situ reduction test by zero iron (T1/2…)	Permeable Reactive barrier
8	Photolysis / photo oxidation test	Water treatment with H2O2 UV
9	Study of metallic pollution of a Soil (speciation)	All treatment of metal pollution
10	Study of the distribution of a pollutant	Particle size sorting / screening / soil washing (cycloning/attrition/backwashing)
11	Characterization of water (carbonate, iron, H2S risk estimation)	Pump and Treat / Stripping / ETP® (Triple Phase Extraction)
12	Column in situ soil washing test	In situ washing - Soil flushing
13	Stripping tests	Water treatment / sparging
14	Testing a resin at a concentration (loading rate, breakthrough curves, etc.)	Water treatment on resin
15	Volatilization test for light soil pollutants	Controlled Forced soil Volatilization (MECALIS® / ROTALIS®)
16	Product sheet/Valorization: Chemistry / HCT, PAH, PCB, BTEX, COHV, Metals, agronomy / Geotechnical (particle size distribution, methylene blue index, proctor)	On-site recovery Land reuse / Renaturation
17	Stabilization	Stabilization with and without Solidification - short and long term tests
18	Thermal test	Heat treatment in oven (TDU) / capacity and thermal conductivity / column tests
19	Sludge dewatering	Jar test / Geotube or filter press
20	Neutralization	pH titration tests for all matrices (acidic sludge/tars, etc.)
21	SAFF® (surface active foam fractionation) / CFF (Continuous Foam Fractionation)	PFAS removal from waste water & foam concentration
...	Customised tests	Any thermal, biological, physical or chemical treatment.

What treatments are available at VEOLIA?

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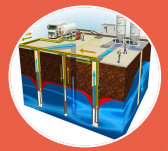
VEOLIA Hazardous Waste Europe Solutions

Site Remediation

Soils

Groundwaters



Contaminated wastes

Slightly contaminated aqueous waste

Polluted soils

Active carbon

Contaminated solid & liquid wastes

Contaminated solid waste (fly & bottom ashes, metallic hydroxide sludges)

Treatments	Contamination management	Contamination treatment	Destruction of contamination by thermal treatment	Containment of residual pollution
	In situ/ On site & Off site	VEOLIA Hazardous Waste Europe facilities		
Technics	Dig & Dump ⇒ VHWE landfills Soil Washing Stabilisation Solidification	CAG / IEX Concentration SAFF / CFF RO ⇒ VHWE	Physical treatment: Evapoconcentration Reverse osmosis	Soil Washing	Activated carbon regeneration	Incineration of hazardous waste / specific reagents	Hazardous waste landfill
Warranties	All Concentration Σ PFAS Source control of concentrated pollution Comprehensive and integrated approach up to 200 mg/kg Management of contaminated groundwater: In-situ/On-site solutions	Concentration Σ PFAS (excl. POP) (**) : Depends on post-treatment Contaminated concentrates, sludges and filtration materials ⇒ destruction by (internal) incineration	Concentration Σ PFAS (Excl. POP) (**) : 200 µg/kg Contaminated sludges ⇒ HW landfill / destruction by (internal) incineration	Concentration Σ PFAS in sued GAC (Excl. POP) (**) < 50 mg/kg Desorbed gas ⇒ post combustion incineration	Concentration Σ PFAS in Hazardous waste no limit* Treatment efficiency 99.99% 99.9999% Residual pollution in internal hazardous waste storage facilities (bottom ash and REFIDI)	Concentration Σ PFAS (Excl. POP) (**) : ✓ Direct landfilling < 1 mg/kg ✓ Stabilisation + landfill 1 mg/kg<ΣPFAS<50 mg/kg

(*) Case-by-case study
(**) PFAS POP regulation, https://eur-lex.europa.eu/legal-content/GB/ALL/?uri=CELEX%3A32019R1021

Soils landfilling (France)

Substances **PFAS classified as POPs** (persistent organic pollutant) and the associated POP thresholds are as follows:

- PFOA and its salts: 1 mg/kg
- PFHxS and its salts: 1 mg/kg
- PFOS: 50 mg/kg
- ΣPFOA-related compounds: 40 mg/kg(any substance that degrades into PFOA*)
- ΣPFHxS-related compounds: 40 mg/kg(any substance containing the fragment C6F13SO2*)

(*) : modified Total Oxidizable Precursor (m-TOP ASSAY) to assess the risk

POP ⇒ Incineration Σ [PFAS]: no limit value

NOT POP ⇒ VEOLIA HWE storage facilities if the POP thresholds are respected:

⇒ Inert (+/x3) storage: Each PFAS < QL (quantification limit in progress)
⇒ Storage Non HW landfill: Not recommended
⇒ HW landfill Direct: [PFAS] < 1 mg/kg
⇒ Stabilization + HW landfill: 1 mg/kg <Σ [PFAS]< 50 mg/kg

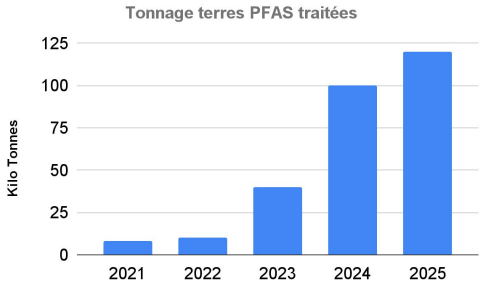
These thresholds are subject to change depending on regulations, group or Sypred directives, or feedback from experience.

List of 30 PFAS to analyze

Nom	Abréviation
Acide perfluorobutanoïque	(PFBA)
Acide perfluoropentanoïque	(PFPeA)
Acide perfluorohexanoïque	(PFHxA)
Acide perfluoroheptanoïque	(PFHpA)
Acide perfluorooctanoïque (linéaire)	(PFOA)
Acide perfluorooctanoïque (ramifié)	(B_PFOA)
Acide perfluorodecanoïque	(PFDA)
Acide perfluoro-n-nonanoïque	(PFNA)
Acide perfluoro-n-undécanoïque	(PFUnA)
Acide perfluorododecanoïque	(PFDoDA)
Acide perfluorotridecanoïque	(PFTrDA)
Acide perfluoro-1-butanesulfonique	(PFBS)
Acide perfluoropentane-1-sulfonique	(PFPeS)
Acide perfluorohexanesulfonique	(PFHxS)
Acide perfluoroheptanesulfonique	(PFHpS)
Acide perfluoro-1-octanesulfonique (linéaire)	(PFOS)
Acide perfluoro-1-octanesulfonique (ramifié)	(PFOS)
Acide perfluorononanesulfonique	(PFNS)
Acide perfluorodecanesulfonique	(PFDS)
Acide perfluoroundécanesulfonique	(PFUDaS)
Acide perfluorododécanesulfonique	(PFDoaS)
Acide perfluorotridécanesulfonique	(PFTDaS)
Acide perfluorotetradecanoïque	(PFTeDA)
Acide perfluorohexadecanoïque	(PFHxDA)
Acide perfluorooctadectanoïque	(PFODA)
Acide 2,3,3,3-Tétrafluor-2-(Heptafluoropropoxy)Propanoïque	(HFPO-DA)(Gen-X)
Acide 4,8-dioxa-3H-perfluorononanoïque	(ADONA)
C6O4/F-DIOX	
8:2 Acide sulfonique fluotélomère	(8:2 FTS)
Acide sulfonique fluotélomère 6:2	(6:2 FTS)

Remediation Belgium Grimbergen (soil washing)

- Acceptance criteria:
  - PFAS up to 200 µg/kg-DM in total
  - Fine particles + MO < 63 µm: 40%max
- Pricing on a case-by-case basis



Valuation	PFOSµg/kg-MS	PFOA µg/kg-MS	∑ 34 PFAS µg/kg-MS
Free reuse Flanders	3	2	8

LIST OF PFAS COMPOUNDS

Perfluor-n-butaanzuur (PFBA)	PFBA	F(CF2)3COOH
Perfluor-n-pentaanzuur (PFPeA)	PFPeA	F(CF2)4COOH
Perfluor-n-hexaanzuur (PFHxA)	PFHxA	F(CF2)5COOH
Perfluor-n-heptaanzuur (PFHpA)	PFHpA	F(CF2)6COOH
Perfluor-n-octaanzuur (PFOA)	n-PFOA	F(CF2)7COOH
Perfluor-n-nonaanzuur (PFNA)	PFNA	F(CF2)8COOH
Perfluor-n-decaanzuur (PFDA)	PFDA	F(CF2)9COOH
Perfluor-n-undecaanzuur (PFUnDA)	PFUnDA	F(CF2)10COOH
Perfluor-n-dodecaanzuur (PFDoDA)	PFDoDA	F(CF2)11COOH
Perfluor-n-tridecaanzuur (PFTrDA)	PFTrDA	F(CF2)12COOH
Perfluor-n-tetradecaanzuur (PFTeDA)	PFTeDA	F(CF2)13COOH
Perfluor-n-hexadecaanzuur (PFHxDA)	PFHxDA	F(CF2)15COOH
Perfluor-n-Butaansulfonzuur (PFBS)	PFBS	F(CF2)4SO3H
Perfluor-n-pentaansulfonzuur (PFPeS)	PFPeS	F(CF2)5SO3H
Perfluor-n-Hexansulfonzuur (PFHxS)	PFHxS	F(CF2)6SO3H
Perfluor-n-heptaansulfonzuur (PFHpS)	PFHpS	F(CF2)7SO3H
Perfluor-n-octaansulfonzuur (PFOS)	n-PFOS	F(CF2)8SO3H
Perfluor-n-Nonaansulfonzuur (PFNS)	PFNS	F(CF2)9SO3H
Perfluor-n-decaansulfonzuur (PFDS)	PFDS	F(CF2)10SO3H
Perfluoroctaansulfonamide (PFOSA)	PFOSA	F(CF2)8SO2NH2
N-Methylperfluor-n-octaansulfonamide (MeFOSA)	MeFOSA	F(CF2)8SO2NHCH3
N-Ethylperfluor-n-octaansulfonamide (EtFOSA)	EtFOSA	F(CF2)8SO2NHC2H5
N-Methylperfluor-n-octaansulfonamido-azijnzuur (MeFOSAA)	MeFOSAA	F(CF2)8SO2NHCH3(CH2)2OH
N-Ethylperfluor-n-octaansulfonamido-azijnzuur (EtFOSAA)	EtFOSAA	F(CF2)8SO2NHC2H5(CH2)2OH
4:2 fluortelomeer sulfonzuur (4:2FTS)	4:2FTS	F(CF2)4CH2CH2SO3H
Fluortelomeersulfonzuur(6:2 FTS)	6:2 FTS	F(CF2)6CH2CH2SO3H
8:2 fluortelomeer sulfonzuur (8:2FTS)	8:2FTS	F(CF2)8CH2CH2SO3H
8:2 Polyfluoralkylfosfaat diester (8:2diPAP)	8:2diPAP	(F(CF2)8CH2CH2O)2P(OH)O
(GenX) 2,3,3,3-tetrafluor-2-(heptafluorpropoxy)propionzuur	GenX	F(CF2)30CF(CF3)COOH
4,8-dioxa-3H-perfluornonaanzuur (ADONA)	ADONA	C10H11N4NaO5S
perfluor-4-ethylcyclohexaansulfonzuur (PFECHS)	PFECHS	F(CF2)(C6H10)SO3H
Perfluor-n-butaansulfonamide (PFBSA)	PFBSA	F(CF2)4SO2NH2
N-methylperfluor-n-butaansulfonamide (MePFBSA)	MePFBSA	F(CF2)4SO2NHCH3
Perfluor-n-hexaansulfonamide (PFHxSA)	PFHxSA	F(CF2)6SO2NH2

What on-site remediation techniques are available for soils?

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Thermal Desorption Unit

Principle :

Treatment of heavy contaminated soil and sludge by: thermal desorption.
Removal by transferring contaminants from solid to gas phase by heating.
Results of treatment:

- Gas phase complies with strictest emission norms.
- Solid phase meets standards for reuse.

Design:

Temperatures: rotary kiln 200-450 °C. and oxidizer 850-930 °C.
Contaminations of: TPH, BTEX, PAH, phenols and cyanides. PFAS (950°C)
Capacity of TDU: 10-20 tons/hour.

Construction:

Preparation, transport and installation.

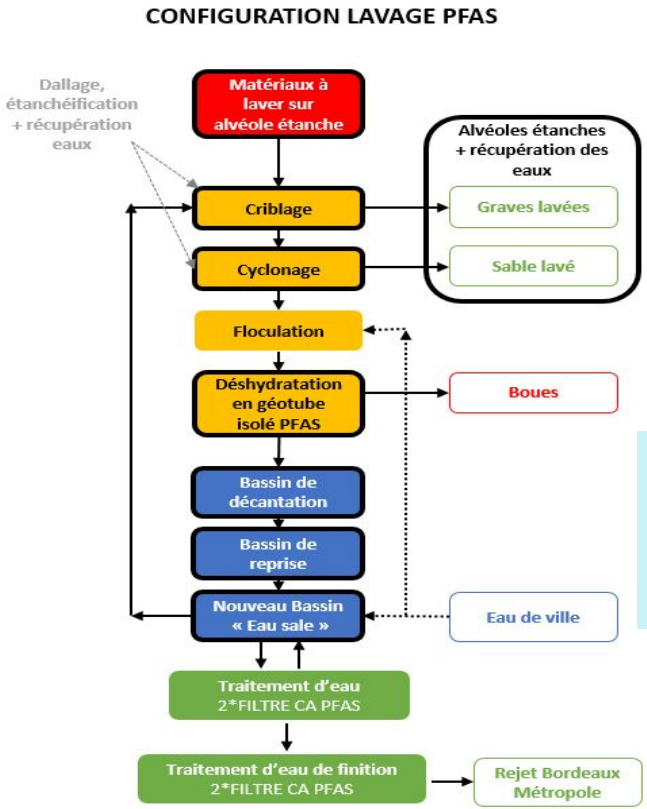
Operate:

24/7 schedule.

Références en remediation :

- EARTHSURE®, Melbourne (Australia) up to 80 000 ton/yr
- 2012 VHWE Saint-Pierre de Chandieu (Total le Pontet - FR)

Soil washing on site



16 References on industrial contaminated sites or leachate

5 Soil decontamination sites

<u>Laboratory pilots:</u> Necessary

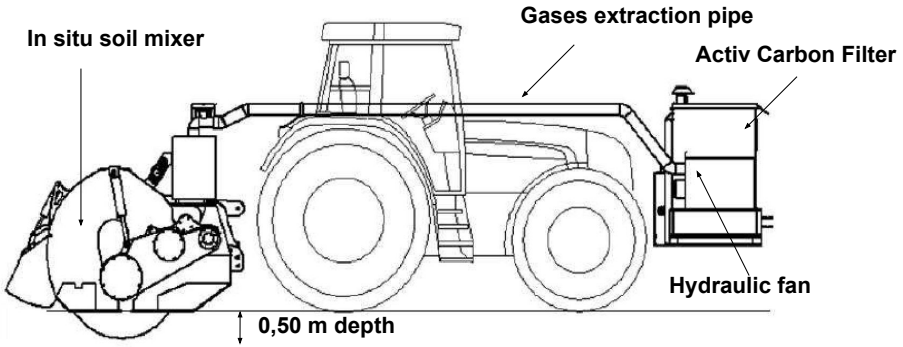
- fines ratio (<63µm),
- Clay content "clayiness"
- Efficiency

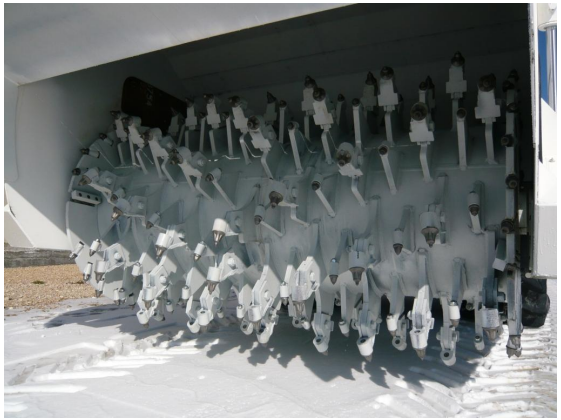
<u>Soil treatment objective</u>:

- % mass (mass balance)
- Residual values
- Example (Rex Ford): 200 µg/kg ⇒ 8µg/kg

Stabilization on site (dry way Soil Mixing)

UNIT WITH GAS TREATMENT CA (Patent FR2975088)





References in remediation:

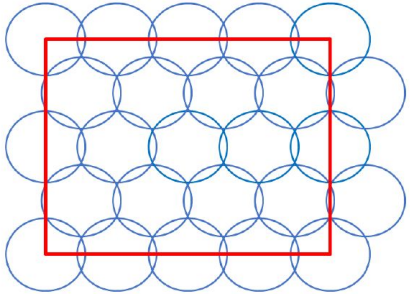
- BP courchelettes Acid tars(FR 2014-16)
- Orano (Hg) (FR 2020-22)

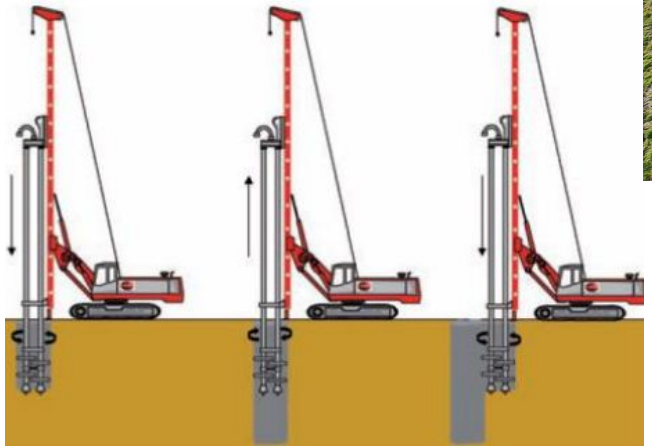
LEACHABLE PFAS (depending on formulation)

- **95-99% PFAS leaching reduction on long chains**
- **10-50% on short chains**

<u>No action on total PFAS. Only for GW protection</u>

Stabilization - Solidification in situ (Soil Mixing)

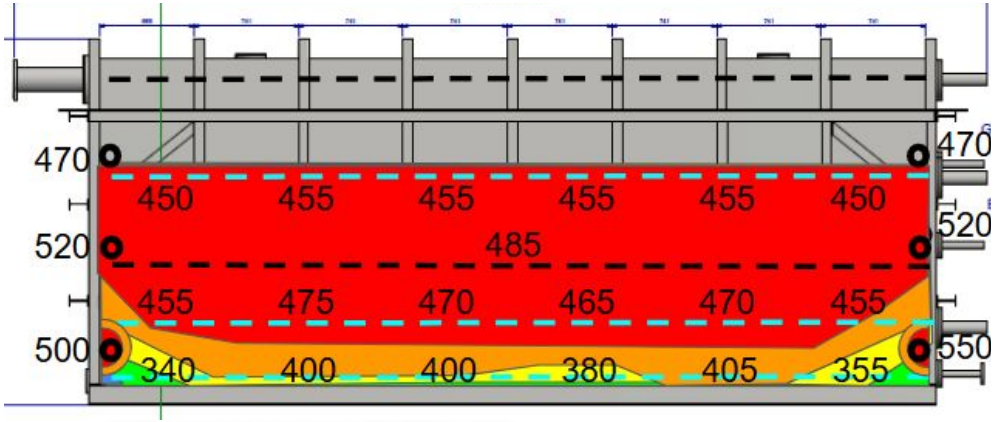




References in Remediation (Chlorinated):
- Themeroil (FR 2020-23)
- SEM VR (FR 2022-26)

LEACHABLE PFAS (depending on formulation)
- **95-99% PFAS removal on long chains**
- **20-90% on short channels**

Destructive: conductive thermal heating on-site or in-situ (Krüger)



DeFluorinator

PFAS thermal destruction mechanisms:

- Degassing of volatile HF and PFAS
- In situ **mineralization**
- **Defluorinator®** at 600 °C increases the mineralization of volatile PFAS.

⇒ **LAB scale** : The ground (**4800 µg/kg**) **T°C> 350°C**

for 4 weeks

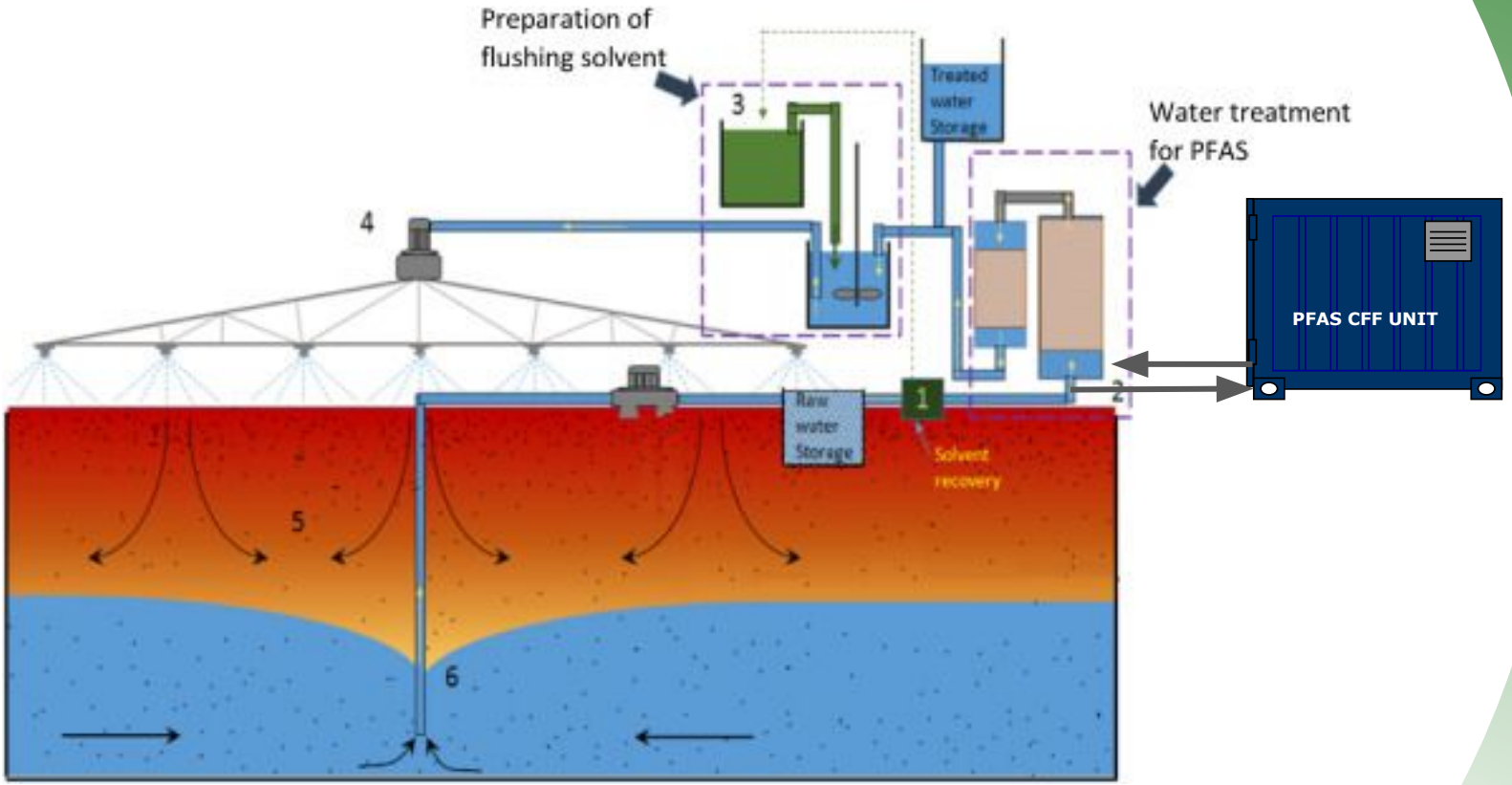
- **PFAS 35 / 35 TOP < LQ (2 samples)**
- **PFAS 22 < LQ (1 sample per tonne)**
- **PFAS 22 leaching (L/S = 2) < LQ**

⇒ **Site pilot scale** : INBOX 20t in container soils

(**PFAS = 200 µg/kg**) treated at**~ 250°C for 4 weeks**:

- **PFOS = 0.5 µg/kg** And **PFHxS = 0.1 µg/kg**
- others PFAS **35 and PFAS 35 TOP remaining < QL**

In situ Soil flushing



What in-situ treatments are available for groundwater?

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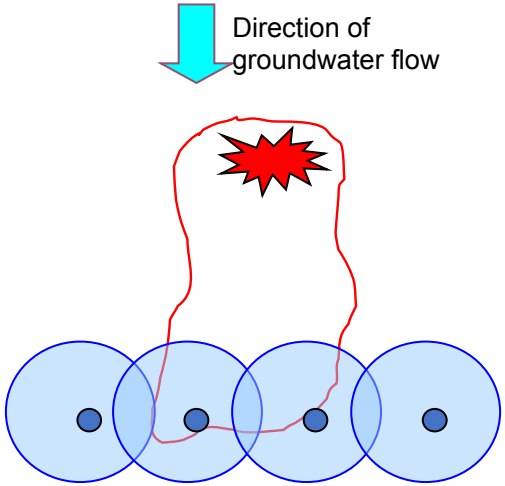
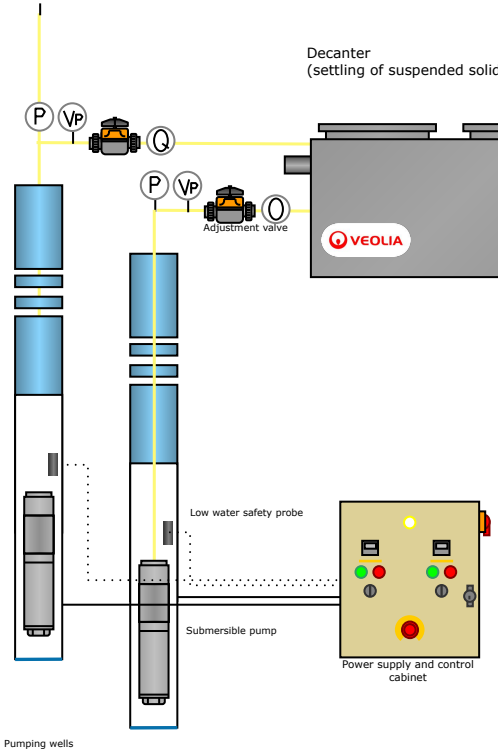
Pump & Treat / hydraulic barriers
Activated carbon + Resin: The baseline

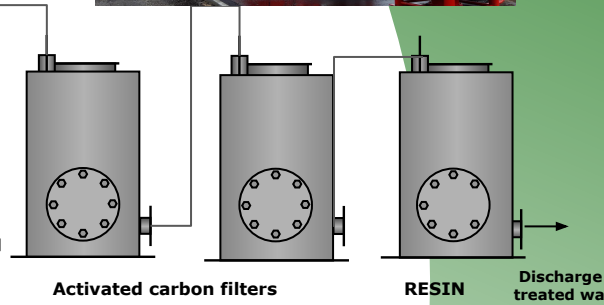


Hydraulic barrier

Stop the spread of pollution

Reduce plume pollution





GAC :
- 95-99% PFAS removal on long chains
- Ineffective on short chains
- Sensitive to TOC

Resins:
- For short chains polishing

References in PFAS remediation:
- EPP Le Pontet (FR 2012)
- Schiphol Airport (NL 2022)
- Trissino barrier (IT 2024-26)
- Brooklyn Victoria (Australia)
- New South Wales (Australia)
- FORD Blanquefort (Soil washing water loop)
- Grimbergen BE (Soil washing water loop)

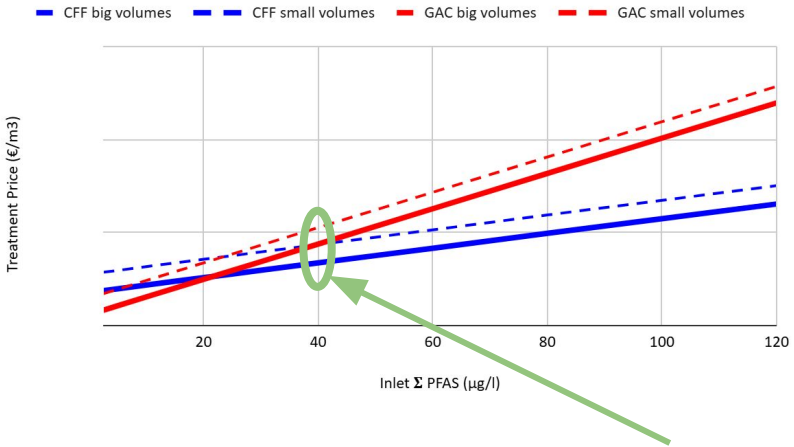
WT unit CFF (Continuous Foam Fractionation)

New concept (Pending Patent)

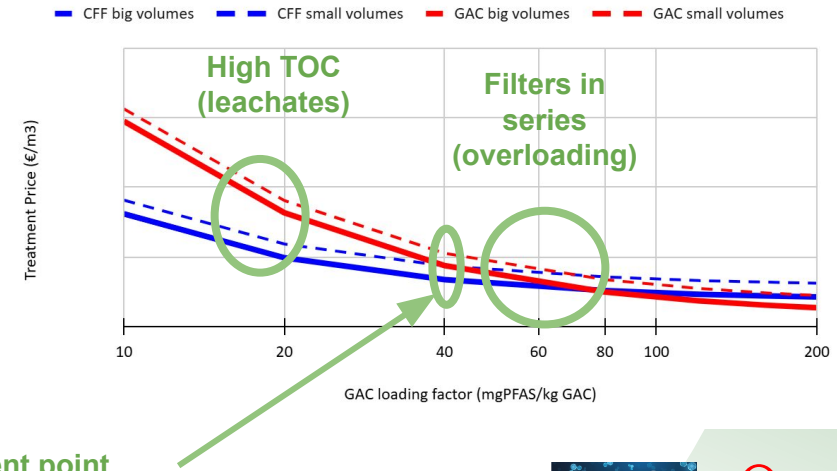
CFF with GAC air / water post treatment compared to 100% GAC treatment. Same volume treated

Hypothesis / DATA	Unit	PFBA	PFOA	PFHxS	PFOS	Somme PFAS
POP regulation	mg/kg-DM		1	1	50	
Concentration INLET	µg/L	3	6	2	20	40
AC loading ratio (breakthrough)	mg PFAS /kg GAC	3	12	4	13	40
Treatment flow	m3/h	10				

KPI : Inlet ΣPFAS concentration, Flow 10 m3/h , mob demob non included

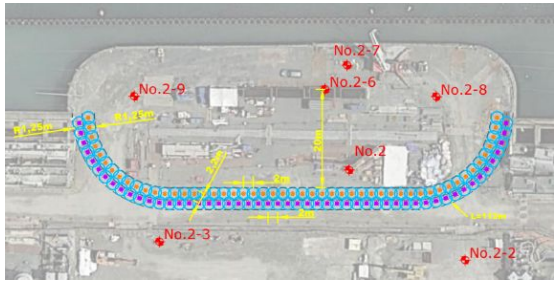


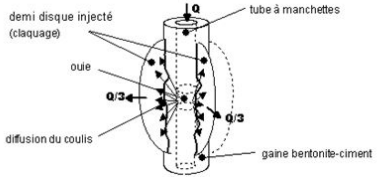
KPI : GAC loading factor, Inlet ΣPFAS concentration = 40µg/l , Flow 10 m3/h , mob demob not included

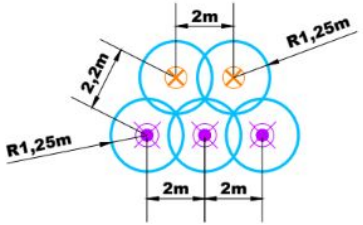


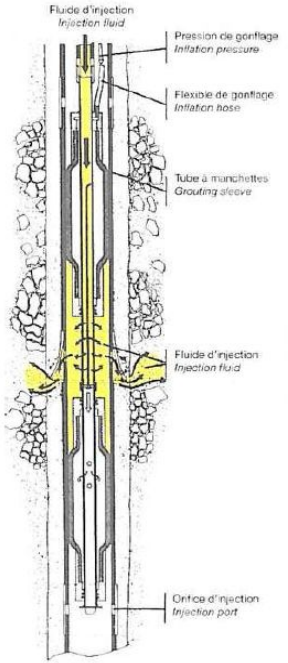
i-PRB : injected permeable reactive barriers / Source

IMPREGNATION: Low-pressure injection of reactive suspensions Sleeved pipes / Direct Push
HYDRAULIC FRACTURING (fine soils)









Advantages of sleeved pipes:

- In situ = Non-destructive (no geotechnical degradation)
- Reusable equipment (reinjection) or preventive TAM drilling
- deep workings possible (40-50 m)
- No/light permeability modification
- long-term sizing ("one shot" operation for sources)
- Mix of reagent = mix of pollutants (PFAS / Metals / Chlorinated / Energetics)

Disadvantages:

- Minimum permeability K > 10^{-5}m/s to allow impregnation / otherwise hydraulic fracturing
- Limited range of action 1-2 m for particle impregnation injection (filtration effects, etc.)
- pollution remains fixed in the ground (no destruction for PFAS)

Conclusions

⇒ No regulation for soils = difficulties to appreciate the level of contamination
- no action
- no remediation

⇒ No regulation ≠ authorization (ex: inert landfills / platforms)

⇒ Innovations are everywhere / site applications are only just beginning

⇒ Technologies exist. Need to be validated under realistic conditions, considering not just PFAS concentration, but also competing ions, natural organic matter, and the specific water/soil matrix involved.

More information:

http://remediation.veolia.com/

boris.devic-bassaget@veolia.com