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REMEDIATION OF PFAS

Allan Horneman
Arcadis – Portland, ME

Available *In Situ* Treatment Technologies for PFAS

Technology[1]	Likelihood of Success?	Rationale
Aerobic Biodegradation	Low	Biotransformation does not proceed past PFAAs
Anaerobic Biodegradation	Low	
Phytoremediation	Low	PFAAs not volatile; depth limitations
Air Sparging/Vapor Extraction	Low	PFAAs not volatile nor biodegradable
In-Situ Thermal Treatment	Low	Required temperature economically impractical; ex-situ waste management
Groundwater Extraction and Ex-Situ Treatment*	High	Presumptive remedy for PFAS to-date, focus of this discussion; ex-situ waste management
Chemical Oxidation/Reduction	Moderate	Bench-tests confirm; field evidence pending
Monitored Natural Attenuation	Low	PFAAs do not biodegrade
Permeable Reactive Barriers	High	Apply ex-situ sorption technologies with a funnel & gate; change outs required

[1]Limited to typical in-situ groundwater treatment technologies (other soil focused technologies like excavation and stabilization may be applicable for soils)

Alternative water treatment options

Compound	M.W. (g/mol)	Aeration	Coagulation Dissolved Air Floatation	Coagulation Flocculation Sedimentation Filtration	Conventional Oxidation (MnO_4, O_3, ClO_2, CLM, UV-AOP)	Anion Exchange (select resins tested)	**Granular Activated Carbon**	**Nano Filtration**	**Reverse Osmosis**
PFBA	214	assumed	assumed						
PFPeA	264								
PFHxA	314								
PFHpA	364								
PFOA	**414**								
PFNA	464					assumed	assumed		
PFDA	514					assumed	assumed		
PFBS	300								
PFHxS	400								
PFOS	**500**								
FOSA	499						assumed		assumed
N-MeFOSAA	571	assumed				assumed	assumed	assumed	
N-EtFOSAA	585					assumed	assumed	assumed	

Conventional Treatment

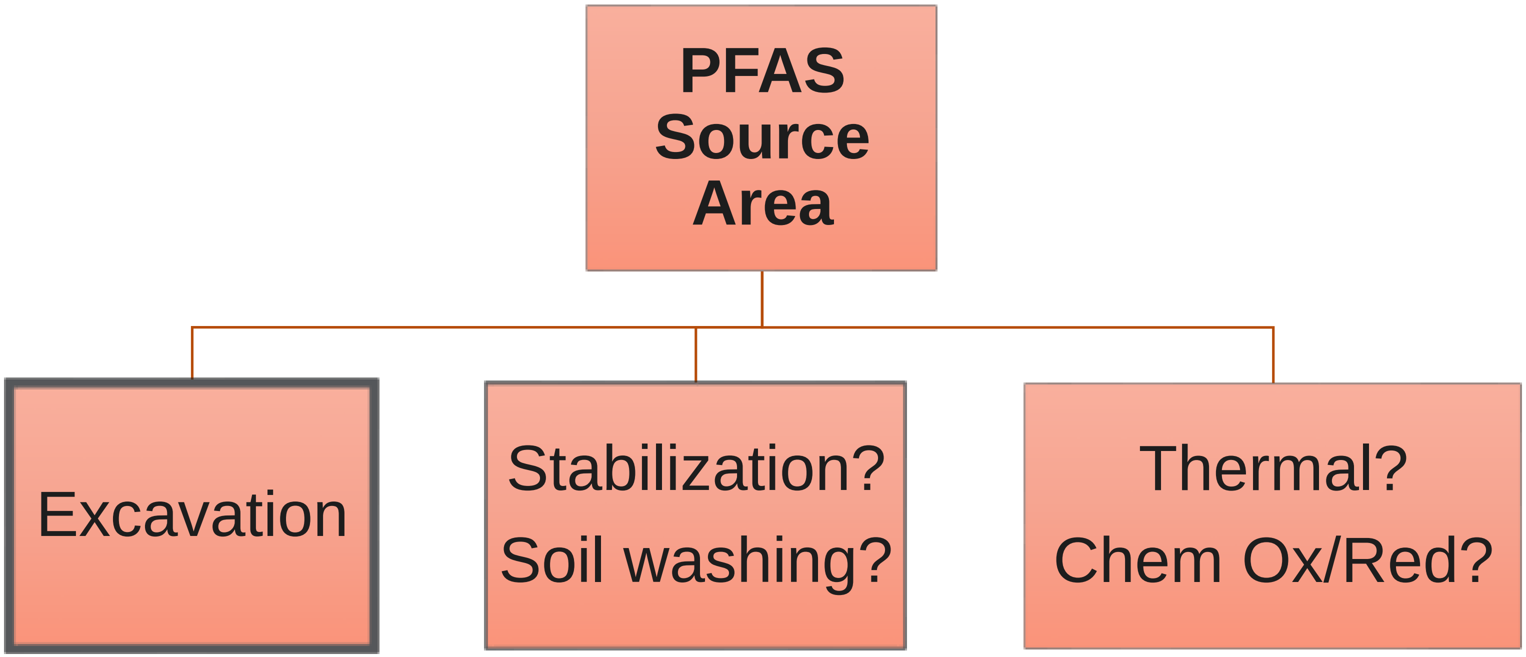
Specialized Treatment

> 90% removal
> 10%, < 90% removal
< 10% removal
unknown

Dickenson and Higgins, 2016. Treatment mitigation strategies for poly- and perfluoralkyl substances, Water Research Foundation

Alternative Source Zone Strategies

Current default strategy is excavation and P&T



Injecting Activated Carbon (AC) into Aquifers

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Claim:

- AC emplaced into the aquifer as a barrier to intercept PFAAs flux over time.
- Evenly distribute or fracture emplace AC in the subsurface to create a surface for contaminant sorption.

Product	Particle Size (µm)
Larger AC	10
Smaller AC	1-2
Emulsified vegetable oil	0.1-1

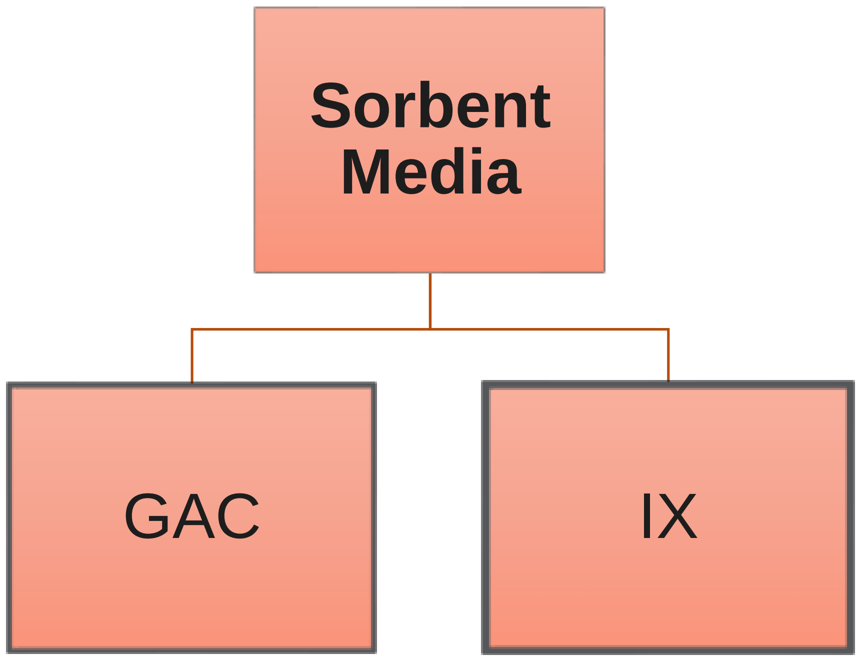
Validity:

- Uniform distribution unlikely as particle sizes are too large to distribute evenly, particles will strain in formation.
- AC has limitations for PFAAs removal, these limitations are exacerbated in-situ.
- PFAAs do not biodegrade. Once AC reaches sorption capacity, PFAAs will leach/bypass in-situ AC barrier.
- Is emplaced AC a secondary source that must be managed in-situ to perpetuity?

Considerable questions/doubt remain for this application.

Sorbent Media Alternatives

GAC is the current go-to, but alternatives emerging.



Granular Activated Carbon (GAC)

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POE Systems	Surface Water	Ground Water
✓	✓	✓

Applicability:

- GAC can effectively remove PFOS/PFOA from water (>90%).

Benefits:

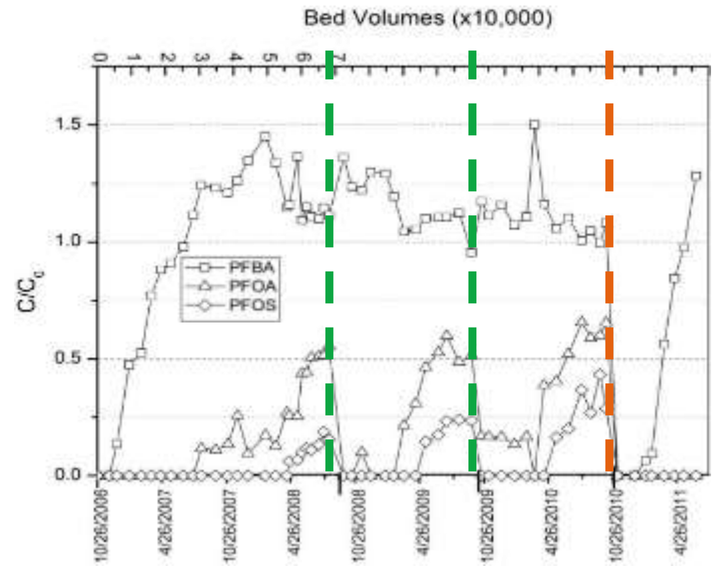
- Manages low concentrations; low flow rates; compatible geochemistry (low natural organics, low hardness, low PFAS, etc.).
- Easily saleable, rapid deployment.

Limitations:

- 80x less sorptive capacity for PFOS vs. BTEX.
- Effectiveness decreases as PFAA chain length decreases, C4 poor.
- Long term O&M cost.
- Little know about effectiveness at removing precoursors

Deployment:

- Competition with natural organics, precursors, and other contaminants will effect performance.
- Reactivated GAC can remove PFOS/PFOA.



Dickenson and Higgins, 2016

Anion/Non-Ion Exchange (AIX)

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	Surface Water	Ground Water
	✓	✓

Applicability:

- AIX can remove PFAAs from water (10-90% effectiveness).

Benefits:

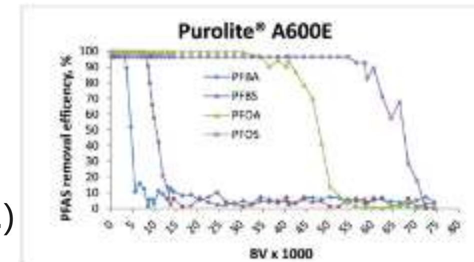
- Engineered resins to focus on long chain versus short chain; low flow rates; compatible geochemistry (low hardness, low salinity, low TDS, low precursors, etc.)
- GAC followed by AIX may be more comprehensive for overall PFAAs removal.
- AIX resins targeted at short chain PFAAs are available.
- Some AIX resins may actually outperform GAC (resin and site specific).

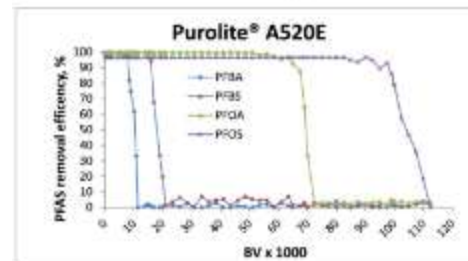
Limitations:

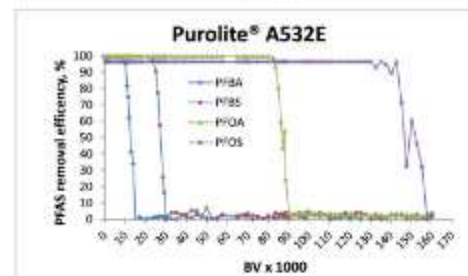
- Resin unit cost may exceed that of GAC.
- No testing against precursors completed
- Regeneration for long chain PFAAs requires methanol in addition to brine.

Deployment:

- Geochemical screening and column tests with site-specific water







Treatment Train Development

Applicability

- Pretreatment reducing PFAS concentrations by orders of magnitude prior to GAC

Benefits:

- Expand GAC lifetime and reduce cost associated with frequent GAC change.
- Address co-contaminants, e.g. petroleum hydrocarbons.
- Reduce disposal/destruction cost by creating high concentration waste.

Limitations:

- Still in testing phase.
- May not be stand alone treatment options.
- Economy vs flow.

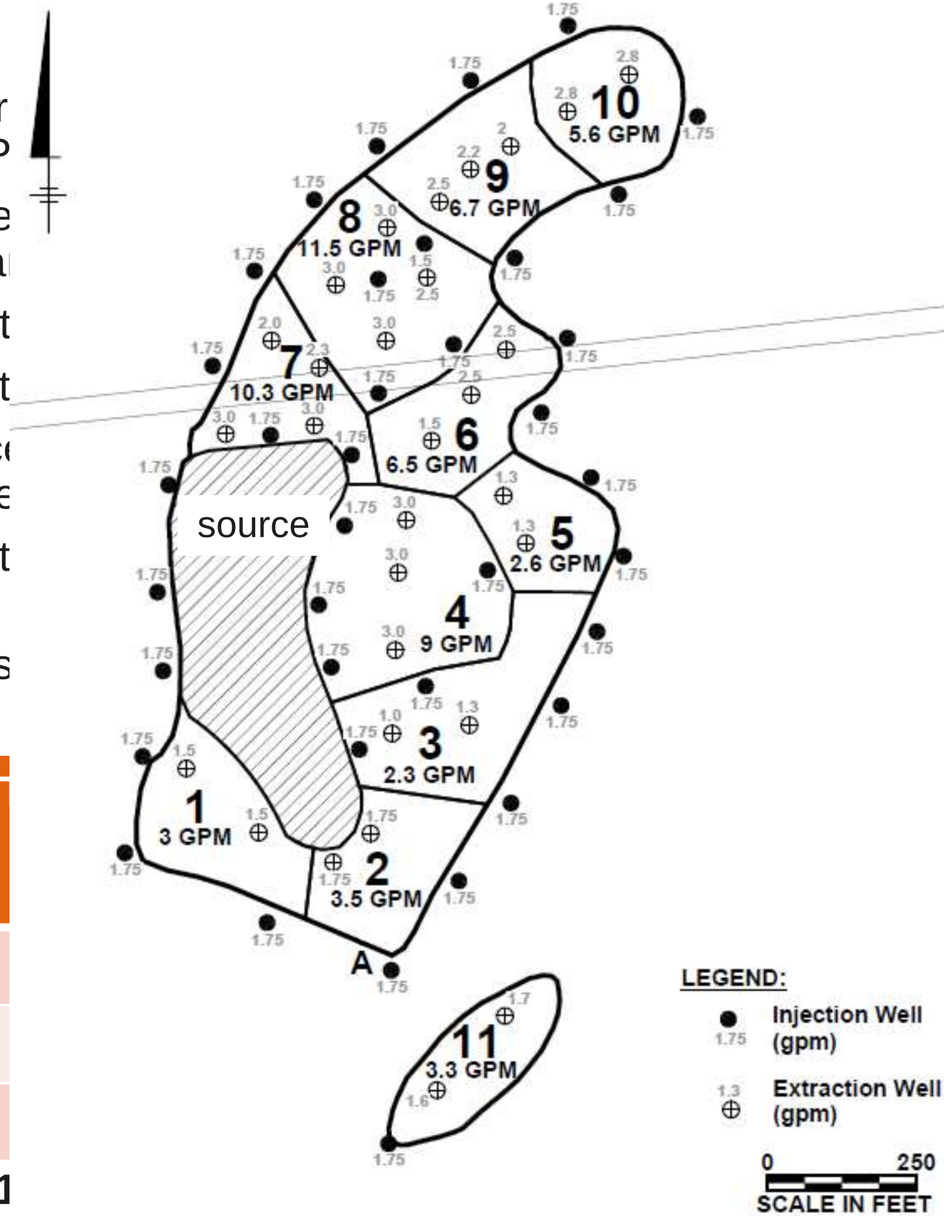
Deployment:

- High concentration source zones
- Still in development/testing phase.

Deployment Variations

Dynamic Groundwater Recirculation (DGR)

- Groundwater ... current presumptive solution for P
- Municipal fee ... ncreasingly scrutinized (public demai
- DGR present
  - Eliminat ... der a NPDES permit)
  - Enhance ... ation hydrogelogic principle
  - Applicat
- Caution with ... ts – but DGR can be designed in s

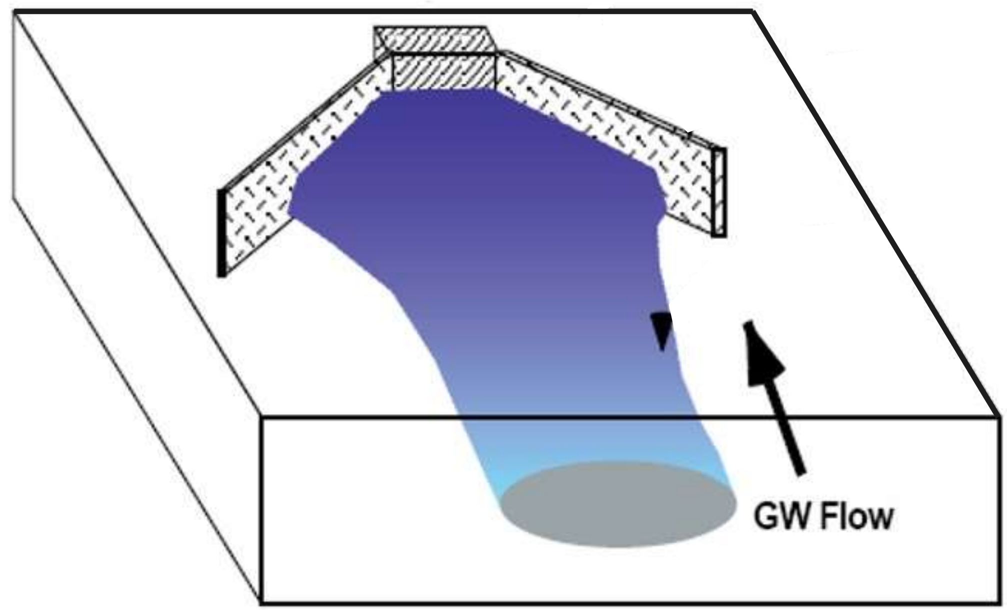


GET	d s*

*Assumes $4/1 ... ment Works (POTW)

Permeable Reactive Barriers (PRBs)

- Many of the aforementioned treatment technologies may be applied in-situ in a PRB
- A funnel and gate (F&G) PRB is most appropriate as future change out of reactive media will likely be necessary
- Hydraulics can be designed to achieve proper contact conditions (i.e., minimize channeling through GAC).



Summary

- PFAS treatment of municipal water and groundwater presents a difficult challenge, and available commercial treatment alternatives represent likely interim measures.
- Few destructive PFAS treatment technologies exist, and no destructive mechanisms have been proven at the field-scale.
- The current state of the practice is physical removal and disposal (incineration or landfill).
- Groundwater extraction and treatment presents a current default solution (with various and developing ex-situ treatment technologies). Site-specific applications may benefit from DGR or PRBs.

Contacts

Allan Horneman Ph.D.
New England PFAS Lead
Arcadis US
Allan.horneman@arcadis.com

Jeff Burdick
North America PFAS Lead
Arcadis US
jeff.burdick@arcadis.com

Ian Ross Ph.D.
Global PFAS Lead
Arcadis UK
ian.ross@arcadis.com

Download at:
https://www.concawe.eu/publications/558/40/Environmental-fate-and-effects-of-poly-and-perfluoroalkyl-substances-PFAS-report-no-8-16