

# Benefits of Surface Modified Clays in PFAS Management for Landfills: Hybrid GCL/RCM for Lining Applications

Speakers:

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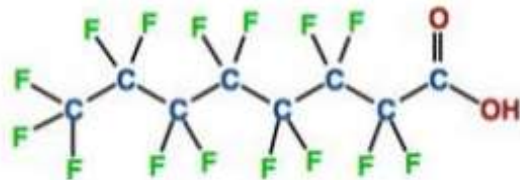


# PFAS Background & Regulations

## Perfluoroalkyl & Polyfluoroalkyl Substances (PFAS)

### Typical Compounds:

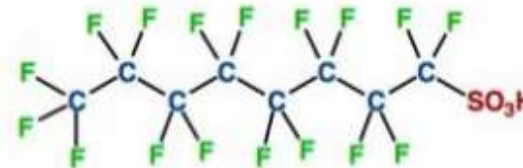
- Perfluorooctane Sulfonate (PFOS)
- Perfluorooctanoic Acid (PFOA)
- Numerous other derivatives



PFOA - perfluorooctanoic acid

PFCA = Perfluorocarboxylic acids

- Short chain  $\leq$  C6
- Long chain  $\geq$  C7



PFOS - perfluorooctanesulfonic acid

PFSA = Perfluorosulfonic acids

- Short chain  $\leq$  C5
- Long chain  $\geq$  C6

# Current Treatment Options

Granular Activated Carbon (GAC)



Chemical Oxidation



Surface Modified Clays



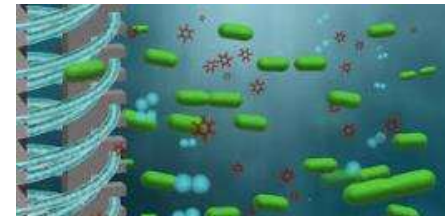
Reverse Osmosis



Ion Exchange Resin (IX)



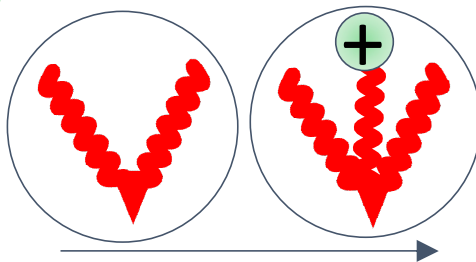
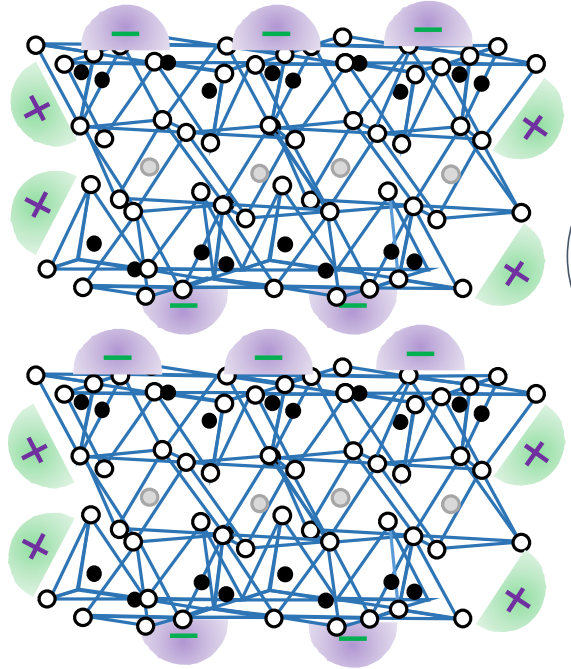
Biodegradation



- Traditional medias can be impacted by co-contaminates:
  - Competition for adsorption sites
  - Fouling by high organics, metals, bacterial growth

# Surface Modified Clay

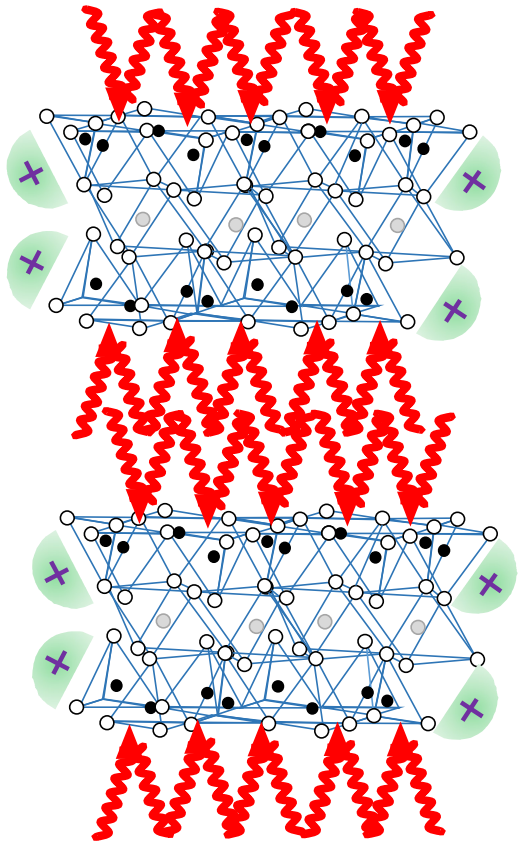
BENTONITE



Ion Exchange with Surface Active Agents

US Patent 11,000,822

FLUORO-SORB® Adsorbent



Powder



Granules

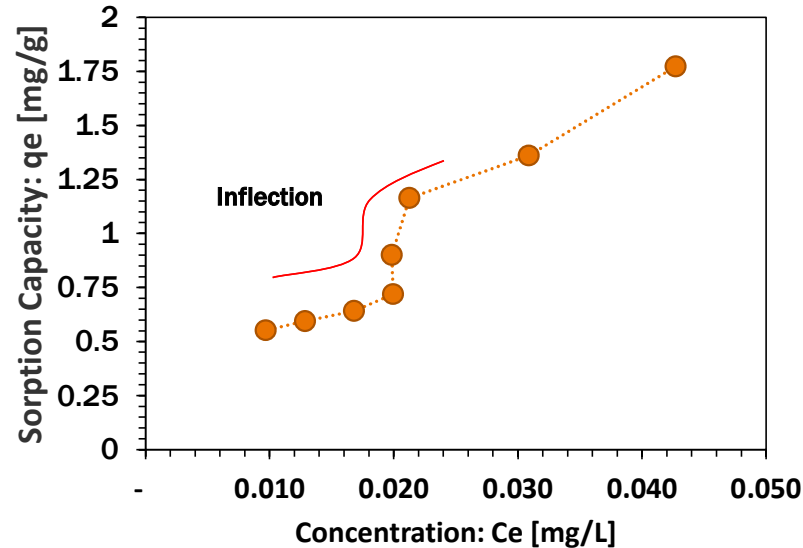
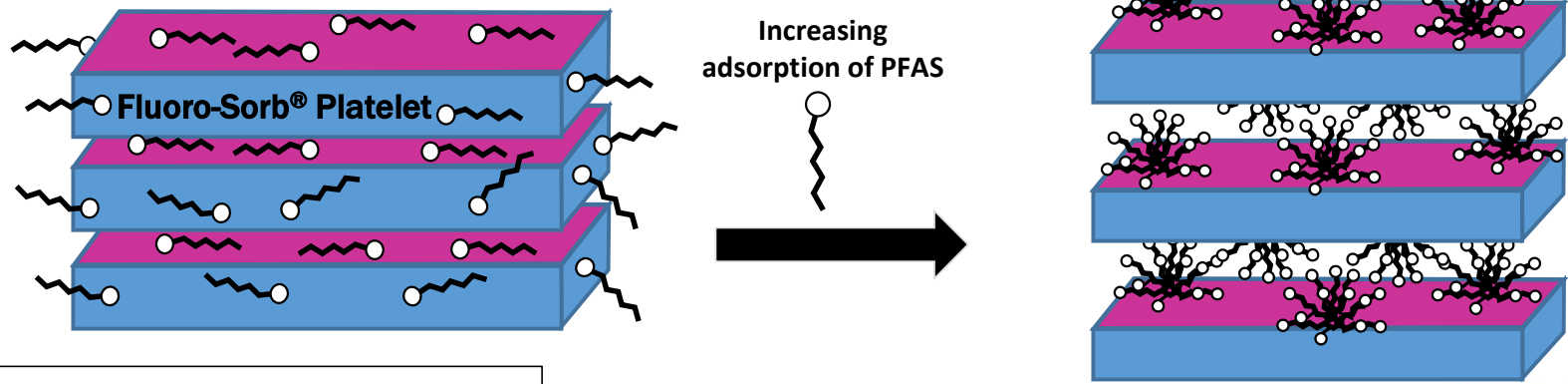


Coarse Grain

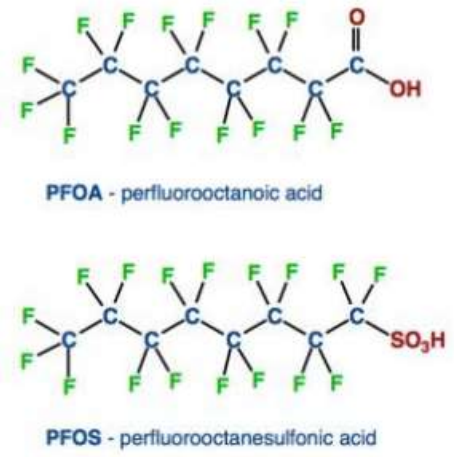


Blends 4

# PFAS Adsorption Mechanism



substance	Adsorption Capacity	d-spacing
None		2.9 nm
PFOS	31 mg/g	5.1 nm
PFOA	20 mg/g	3.6 nm
FHxSA	14 mg/g	3.8 nm
6:2 FtSA	25 mg/g	2.5 nm



Yan, B., Wang, J., Liu, J. (2021) *Water Research*, 201, 117371.

# FLUORO-SORB® Adsorbent



Strategic Partner



Grade:	P	100	200	400	600
Specific Gravity <i>Test Method: ASTM C604*</i>	1.72 g/cm <sup>3</sup>	1.735 g/cm <sup>3</sup>	1.759 g/cm <sup>3</sup>	1.784 g/cm <sup>3</sup>	1.75 g/cm <sup>3</sup>
Max. Index Density <i>Test Method: ASTM D4253</i>	680 kg/m <sup>3</sup> (42.4 lb/ft <sup>3</sup> )	989.9 kg/m <sup>3</sup> (61.8 lb/ft <sup>3</sup> )	770.5 kg/m <sup>3</sup> (48.1 lb/ft <sup>3</sup> )	865.2 kg/m <sup>3</sup> (54.0 lb/ft <sup>3</sup> )	946 kg/m <sup>3</sup> (59 lb/ft <sup>3</sup> )
Min. Index Density <i>Test Method: ASTM 4254</i>	483 kg/m <sup>3</sup> (30.1 lb/ft <sup>3</sup> )	877.8 kg/m <sup>3</sup> (54.8 lb/ft <sup>3</sup> )	691.0 kg/m <sup>3</sup> (43.1 lb/ft <sup>3</sup> )	785.4 kg/m <sup>3</sup> (49.0 lb/ft <sup>3</sup> )	835 kg/m <sup>3</sup> (52 lb/ft <sup>3</sup> )
Permeability <i>Test Method: ASTM D2434</i>	Not Measured	2.2 x 10 <sup>-3</sup> cm/s	2.1 x 10 <sup>-3</sup> cm/s	8.5 x 10 <sup>-2</sup> cm/s	8.7 x 10 <sup>-2</sup> cm/s
% Passing, No. 18 (1.0 mm) Sieve <i>Test Method: ASTM C136</i>	97% through #60 mesh (0.25 mm)	100%	100%	65%	94% through #5 mesh (4.0 mm)
% Retained, No. 40 (0.42 mm) Sieve <i>Test Method: ASTM C136</i>	80% through #200 mesh (0.075 mm)	46%	8%	1%	5% through #50 mesh (0.30 mm)
Applications	Injection / ISS	ISS	Pump & Treat PRB	Pump & Treat PRB	Gravity Filtration / Surface Water



"P"



100



200



400



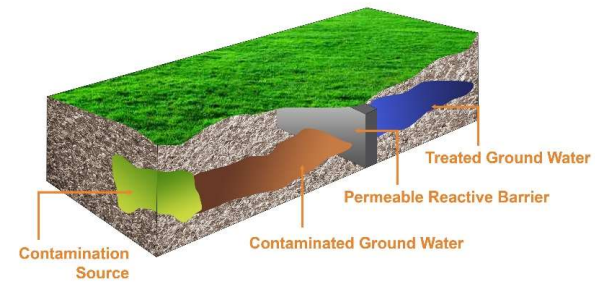
600

# Media Deployment

## Groundwater/Drinking Water / Waste Water Filtration Standalone or Pre- or Post-Treatment



## Passive Groundwater Permeable Reactive Barrier



## Source Zone Treatment In Situ Stabilization/Solidification



## Sediment Capping CETCO REACTIVE CORE MAT®

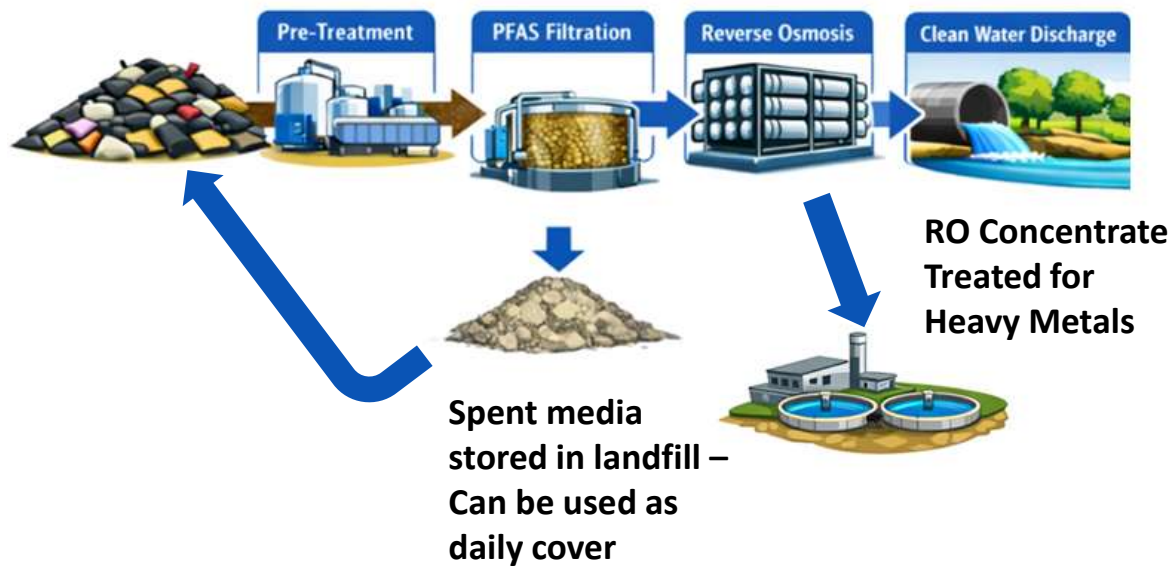


# Use in Landfills

Leachate Analysis	Units	Result
Chloride	(mg/L)	4,800
D-As	(mg/L)	0.9654
COD	(mg/L)	1,100
TOC	(mg/L)	261
NH <sub>3</sub> -N	(mg/L)	0.661
TKN	(mg/L)	ND<0.300
TON	(mg/L)	ND<0.300
Perfluorobutanoic acid (PFBA)	ng/L	4,390
Perfluoropentanoic acid (PFPeA)	ng/L	5,860
Perfluorohexanoic acid (PFHxA)	ng/L	8,420
Perfluoroheptanoic acid (PFHpA)	ng/L	1,680
<b>Perfluorooctanoic acid (PFOA)</b>	ng/L	5,370
Perfluorononanoic acid (PFNA)	ng/L	569
Perfluorodecanoic acid (PFDA)	ng/L	651
Perfluorobutanesulfonic acid (PFBS)	ng/L	6,450
Perfluoropentanesulfonic acid (PFPeS)	ng/L	126
Perfluorohexanesulfonic acid (PFHxS)	ng/L	704
Perfluoroheptanesulfonic acid (PFHpS)	ng/L	22.1
<b>Perfluorooctanesulfonic acid (PFOS)</b>	ng/L	557
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	ng/L	23.6
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	ng/L	679
<b>PFAS - Total</b>	ng/L	35,502
<b>PFAS - MADEP-6</b>	ng/L	8,827
<b>PFAS - NHDES-4</b>	ng/L	7,200
<b>PFAS - EPA-2 (PFOA + PFOS)</b>	ng/L	5,927



## Landfill Leachate Treatment Process



- Currently being used in 6 leachate treatment systems globally
- New England Leachate treatment system in operation since 2020



# RCM Application



- RCM was placed on the streambed and covered by a layer of riprap to anchor the mat in place near an active Airforce base
- Initial pore water concentration ranged from 8,000 to 1,000,000 ng/L
- Initial surface water concentrations ranged from 28,000 to 54,000 ng/L
- RCM PFAS treatment rate: 80-95%

# Hybrid RCM / GCL Applications



Landfill Liners / Waste Encapsulation



Retention Ponds / Storm Water Collection

## Design Objectives:

- Low permeability  $< 1 \times 10^{-9}$  cm/sec
- Chemical resistance to aggressive leachates: chlorides, high divalent salts etc.
- High PFAS adsorption capacity

# PFAS Impacted Leachate Chemistry

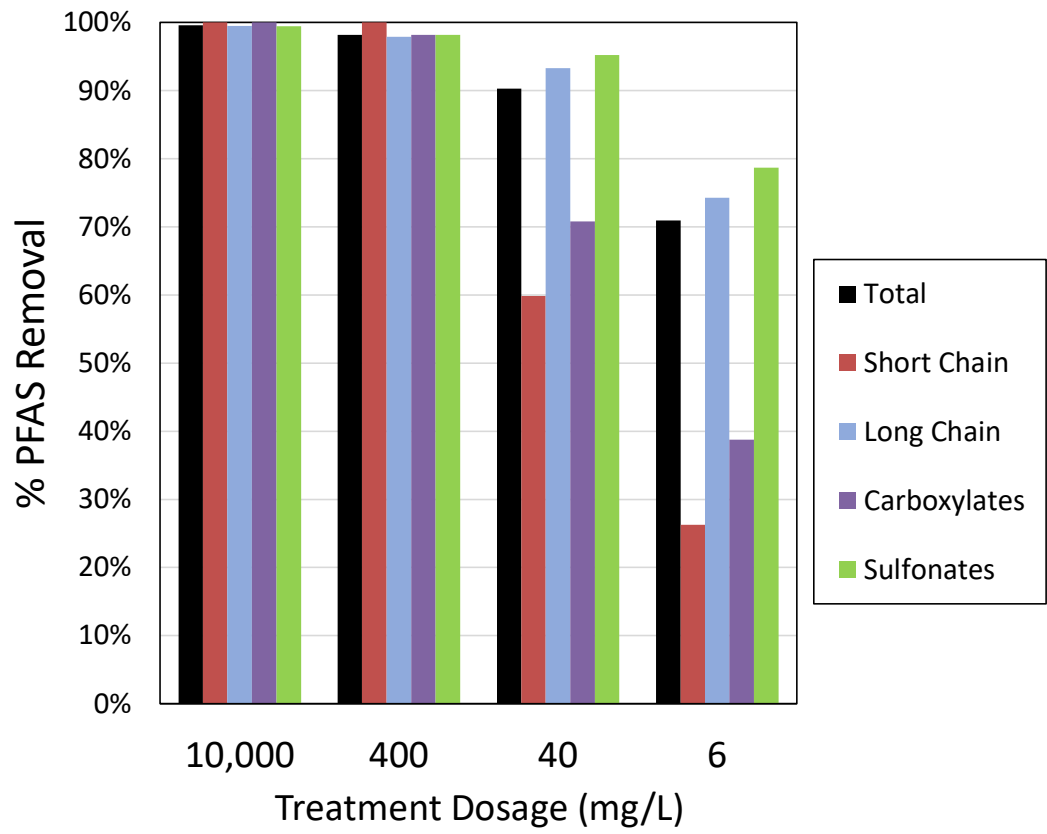
Airforce Base Water	Result
pH	7.29
Conductivity (µS/cm)	206
TOC (mg/L)	2.4
BOD (mg/L)	<2.0
COD (mg/L)	7.9
Acetone (µg/L)	8.3
Diesel (µg/L)	0.43
Ca (mg/L)	50
Na (mg/L)	2.6
NO <sub>3</sub> <sup>-</sup> (mg/L)	0.32

PFAS in Leachate	Concentration (ng/L)
PFPeA (C5)	694
PFHxA (C6)	2,407
PFHpA (C7)	393
<b>PFOA (C8)</b>	<b>4,024</b>
PFPrS (C3)	19
PFBS (C4)	100
PFPeS (C5)	186
<b>PFHxS (C6)</b>	<b>7,044</b>
PFHpS (C7)	263
<b>PFOS (C8)</b>	<b>20,770</b>
4:2 FTS (C6 telomer)	24
6:2 FTS (C8 telomer)	2,928
8:2 FTS (C10 telomer)	387

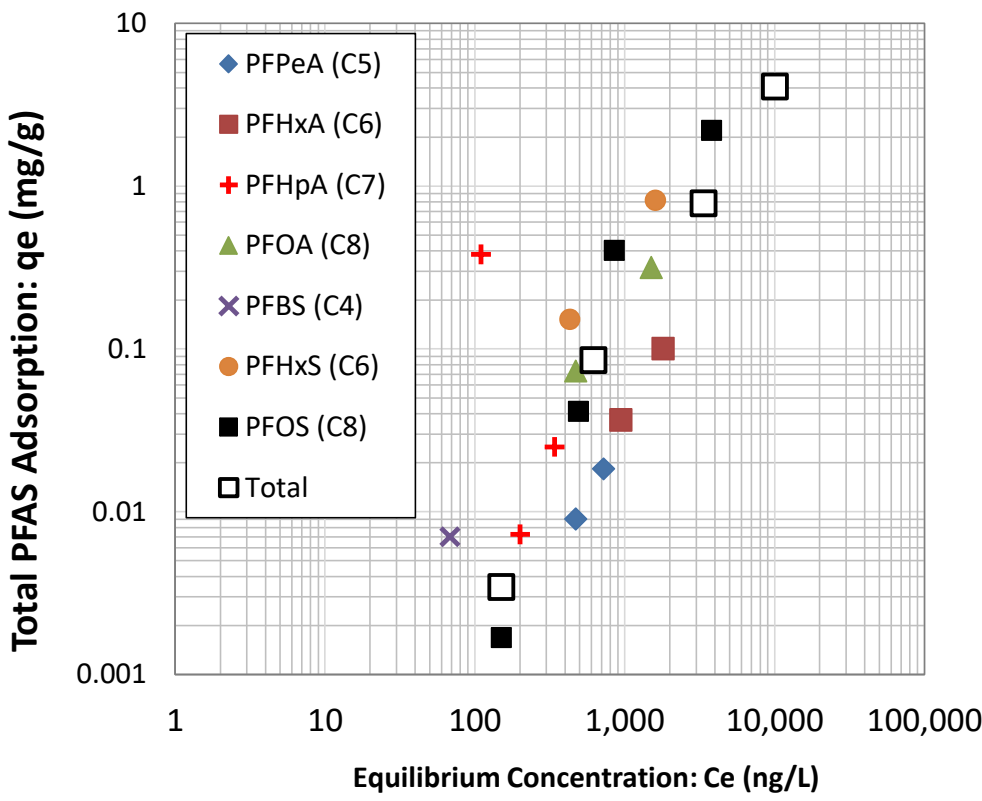
# PFAS ADSORPTION ISOTHERM



PFAS Adsorption by Class

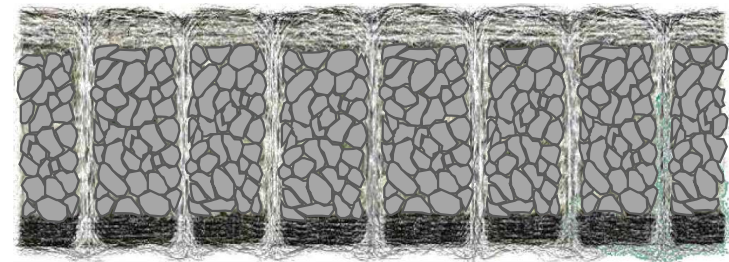


PFAS Adsorption by Compound



# Hybrid GCL Design and Testing

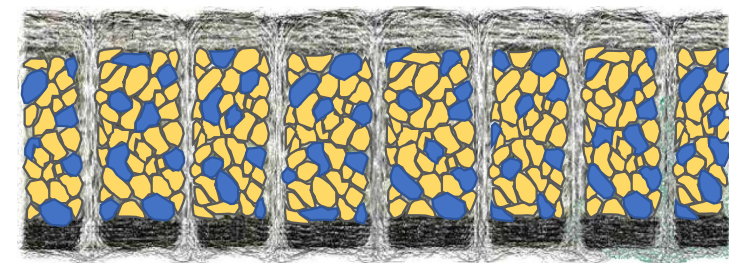
**System 1:**  
Bentonite Only (Control) @ 1 lb/ft<sup>2</sup>



## Hydraulic Conductivity Testing (k):

- ASTM D6766:Falling head/Constant tail
- Pre-hydration with site leachate
- Hydraulic gradient of 150
- Effective confining stress of 20 kPa

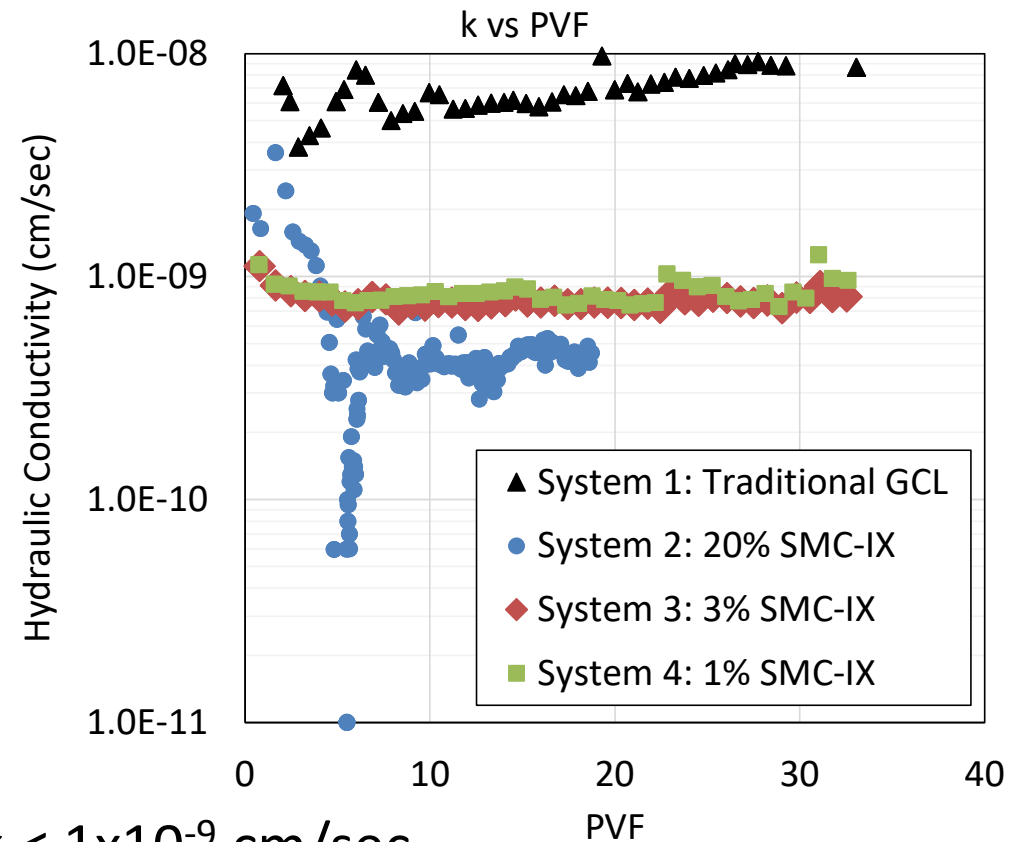
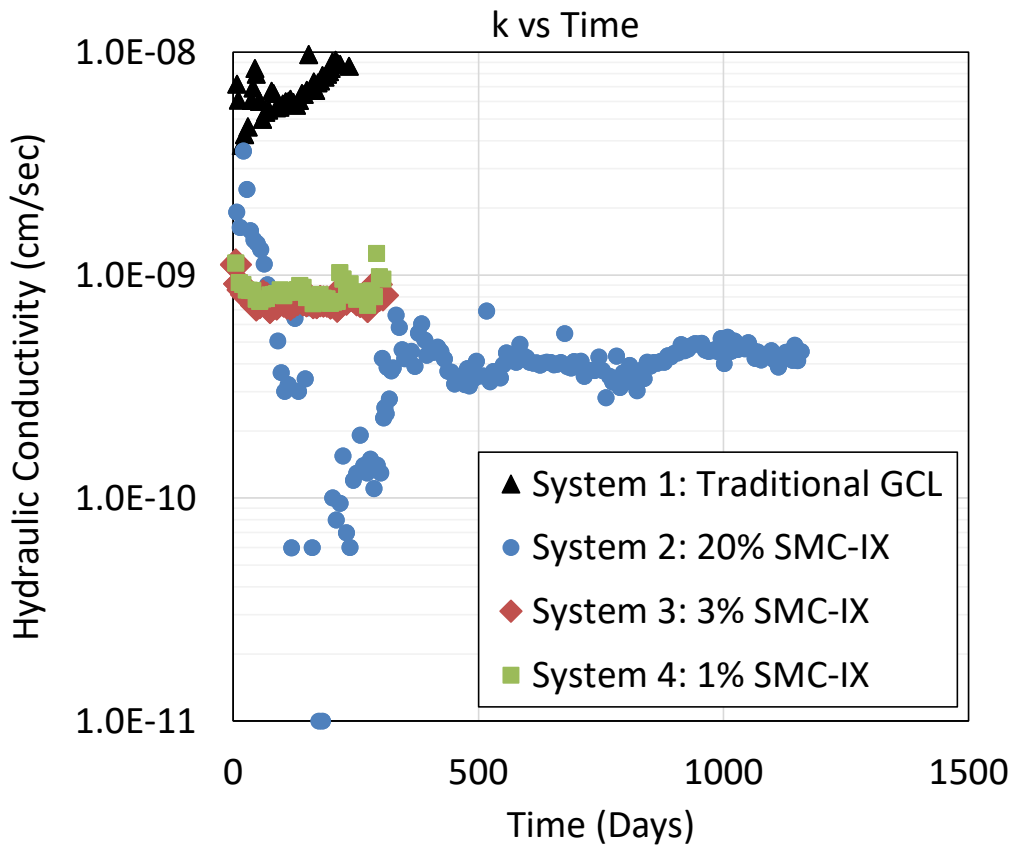
**Systems 2, 3, 4:**  
Polymer Modified Bentonite + SMC @ 1 lb/ft<sup>2</sup>



- System 2: 20% SMC**
- System 3: 3% SMC**
- System 4: 1% SMC**

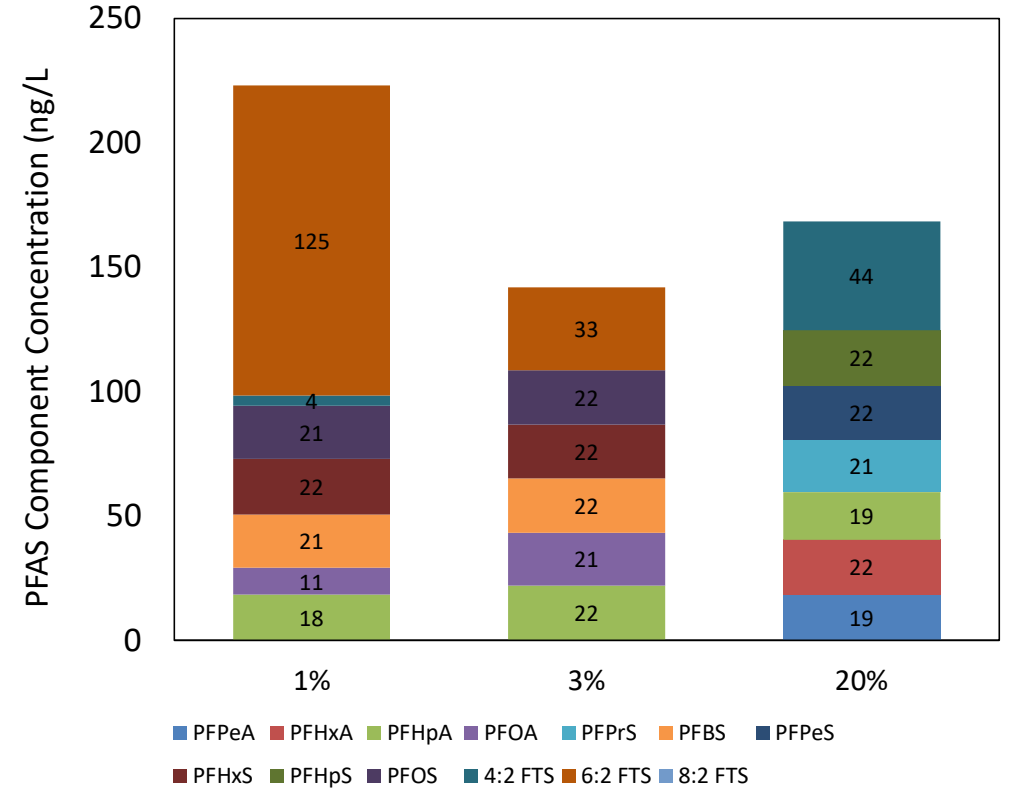
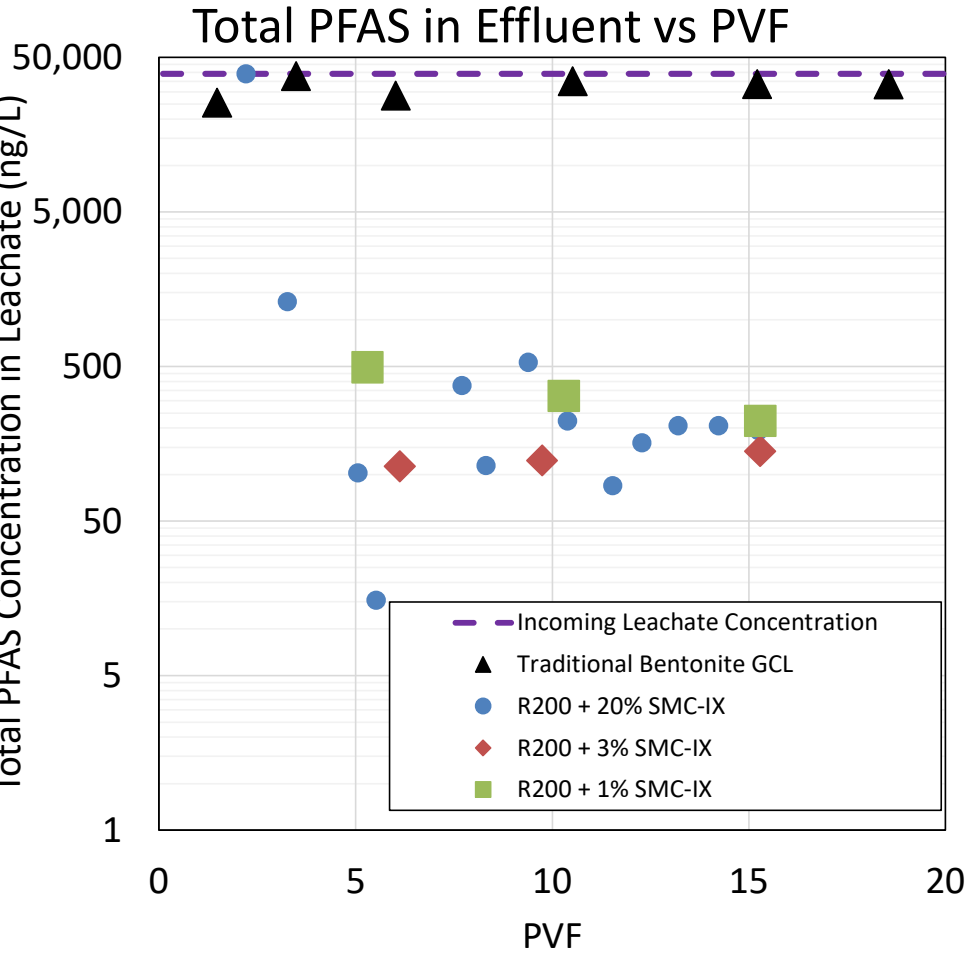


# HYDRAULIC CONDUCTIVITY



Hybrid GCL/ RCM  $k < 1 \times 10^{-9}$  cm/sec  
 20% system tested for > 3 years

# EFFLUENT PFAS CONCENTRATION



# SUMMARY & CONCLUSIONS



- New surface modified clay developed for efficient PFAS remediation
- Incorporated into geosynthetic design to combine both hydraulic barrier properties and PFAS remediation
- Combination RCM+GCL: PFAS Concentration reduce from 39,000 ng/L to < 250 ng/L (99.3% reduction)
- Traditional bentonite geosynthetic clay liner: No PFAS removal observed
- Combination RCM + GCL is a “sorptive” hydraulic barrier to retard PFAS migration into the environment
- New GCLs can be customized to the engineering design life requirements and type of contaminants present at the site



# *Thank You For Your Attention!*

## *Questions?*

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