PFAS in Biofiltration Basin Soil, Source Apportionment, and Modified Engineered Soil

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Ingram School of Engineering

TEXAS STATE UNIVERSITY

TEXAS REGIONAL STORMWATER CONFERENCE

January 22, 2026

San Hwang, PhD, PE

Professor

- Texas State University (2020 – present)
- University of Puerto Rico at Mayagüez (2005 – 2020)

Postdoctoral Researcher

- US Environmental Protection Agency NRMRL (2003 – 2004)
- US Army Corps of Engineers ERDC (2002 – 2003)

PhD

- University of Akron, OH (2002)

San Hwang's Research Thrust

Biomass Material Development

(Civil, Environmental, and Agricultural Applications)

Green Infrastructure / Low Impact Development

(Stormwater Runoff Volume Control & Water Quality Improvement)

Environmental Remediation

(Contaminants of Environmental Concern)

TEXAS REGIONAL STORMWATER CONFERENCE

January 14, 2021
Virtual Conference

8:30 - 8:40 AM	**Introduction and Opening Remarks** | Central Texas Stormwater Coalition
8:40 -9:10 AM	**"Silt Fence is Not the Only Solution: A Discussion on Appropriate BMP Choices"** Kelsey Krueger & Matt Klaser, POWER Engineers, Inc.
	5-MINUTE BREAK
9:15 - 9:45 AM	**"Rethinking GIS Efforts to Expand MS4 Programs"** Gian C. Villarreal, Seagull PME | Matt Kitchen, Adams Environmental | Michelle Tanner, 2NDNATURE
	5-MINUTE BREAK
9:50 - 10:20 AM	**"Improvement of Walkability and Stormwater Runoff Management with Pervious Concrete Pavement"** Sangchul Hwang, Texas State University
	5-MINUTE BREAK

Synopsis

About PFAS (Per- and polyfluoroalkyl substances)

Biofiltration Basins of Interest

Occurrence of PFAS in Biofiltration Basins

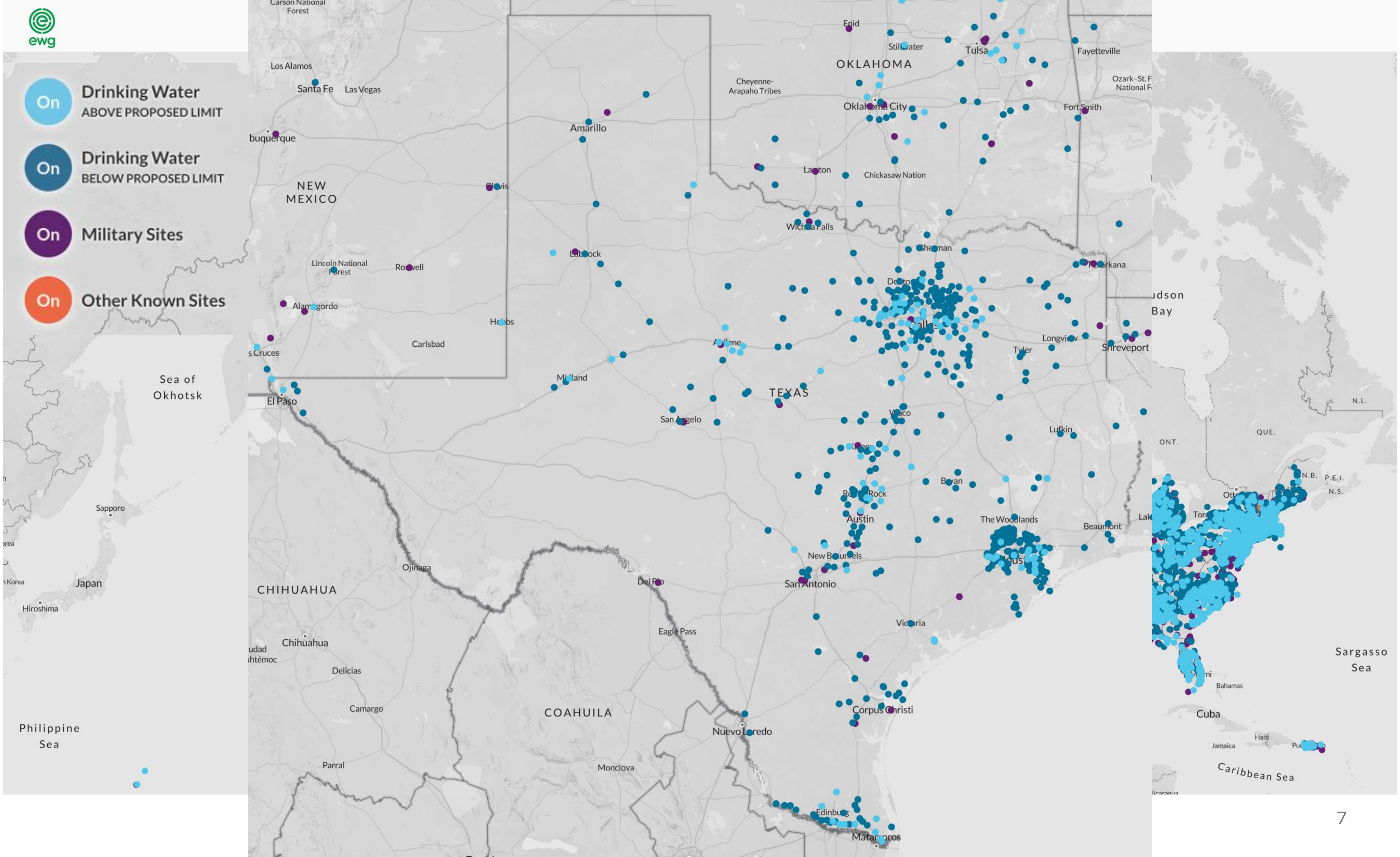
PFOA Adsorption by Biofiltration Engineered Soil

Potential Modification of Biofiltration Engineered Soil

About PFAS Source Apportionment

PFAS (Per- and polyfluoroalkyl substances)

- Human-made organic chemical compounds
- Manufactured and used since the 1940s
- Not naturally occurring and have no biologically important functions or beneficial properties to aquatic life
- Resistant to hydrolysis, photolysis, metabolism, and microbial degradation
- Toxic
- Found everywhere, forever chemicals



On
Drinking Water
ABOVE PROPOSED LIMIT
On
Drinking Water
BELOW PROPOSED LIMIT
On
Military Sites
On
Other Known Sites
Sea of
Okhotsk
Sapporo
Japan
Hiroshima
Philippine
Sea
Los Alamos
Santa Fe
Las Vegas
NEW
MEXICO
Amarillo
Lincoln National
Forest
Roswell
Carlsbad
El Paso
Midland
San Angelo
OKLAHOMA
Enid
Tulsa
Fayetteville
Cheyenne-
Arapaho Tribes
Chickasaw Nation
Fort Smith
TEXAS
Longview
Tyler
Shreveport
Lufkin
The Woodlands
Beaumont
Austin
San Antonio
Victoria
Corpus Christi
Eagle Pass
Nuevo Laredo
CHIHUAHUA
Chihuahua
Ojinaga
Delicias
Camargo
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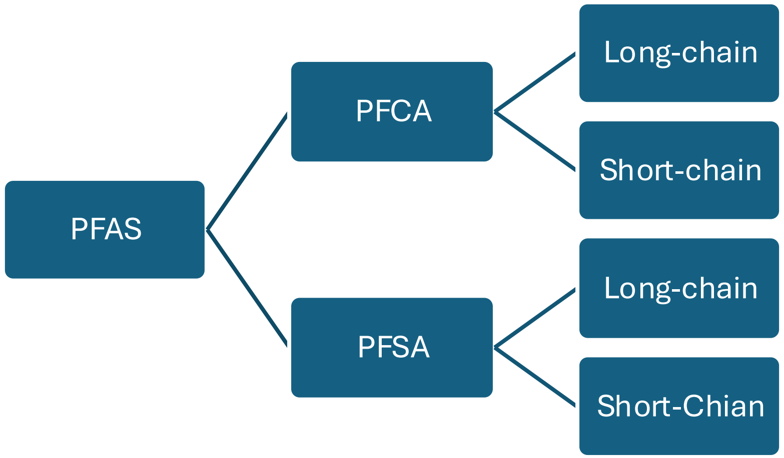
COAHUILA
Monclova
Sargasso
Sea
Cuba
Bahamas
Jamaica
Haiti
Caribbean Sea

In General,



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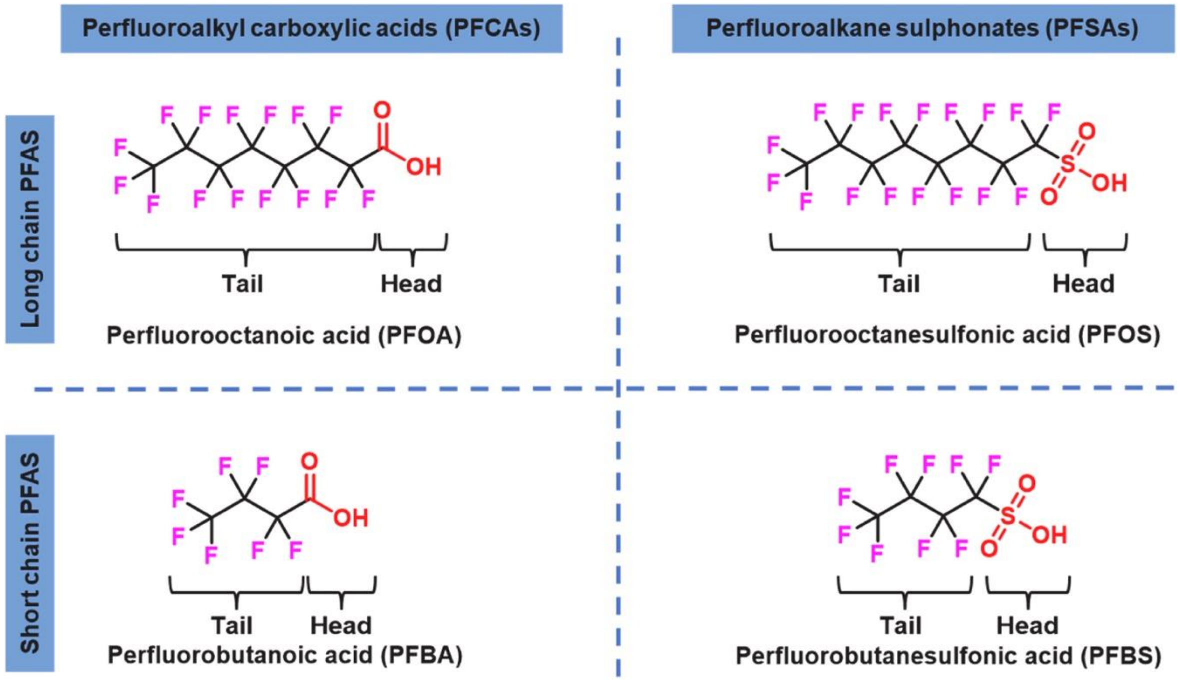

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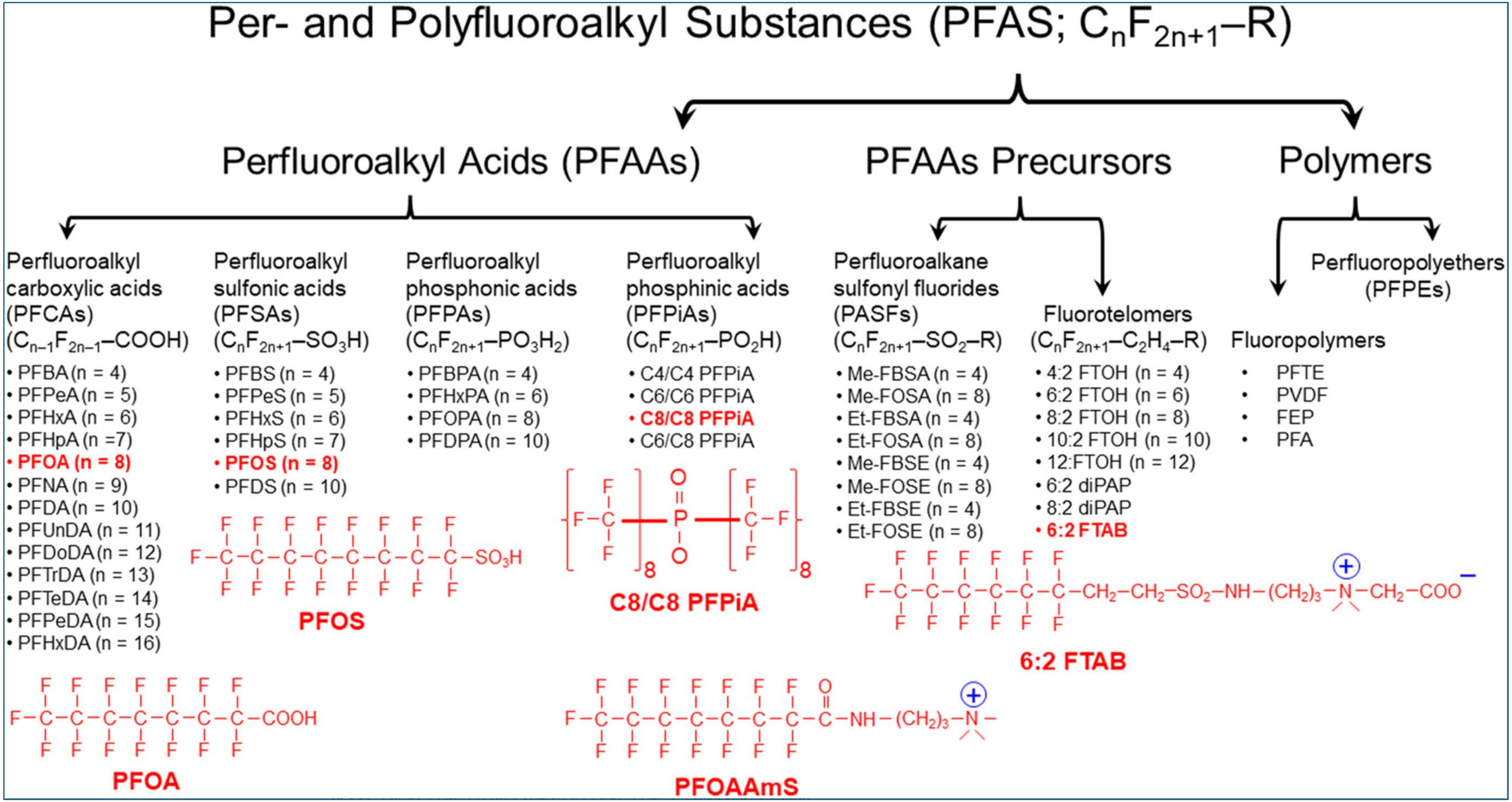
Behnami et al. (2024) https://doi.org/10.1016/j.chemosphere.2024.142088



Lyu et al. (2022) https://doi.org/10.1029/2021RG000765

Drinking Water
Drinking water contaminated by other sources of PFAS.

Waste Sites
Soil and water at or near landfills, disposal sites, and hazardous waste sites.

Fire Extinguishing Foam
Used in training and emergency response events at airports and firefighting training facilities.

Facilities
Chrome plating, electronics, and certain textile and paper manufacturers that produce or use PFAS.

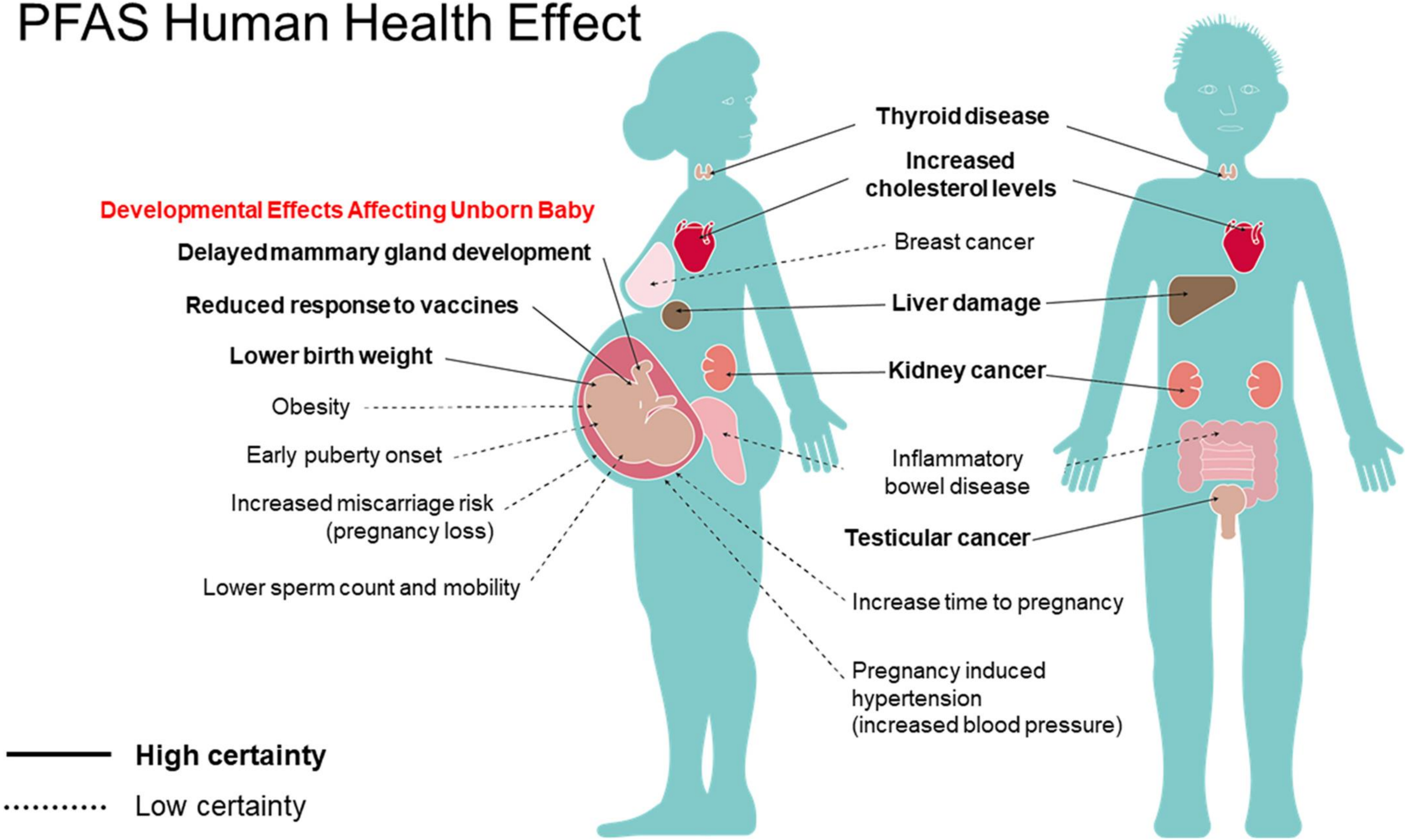
Consumer Products
Stain- or water-repellent, or non-stick products, paints, sealants, and some personal care products.

Food Packaging
Grease-resistant paper, microwave popcorn bags, pizza boxes, and candy wrappers.

Biosolids
Fertilizer from wastewater treatment plants used on agricultural lands can affect ground and surface water.

Food
Fish caught from water contaminated by PFAS and dairy products from livestock exposed to PFAS.

PFAS Human Health Effect



Lyu et al. (2022) https://doi.org/10.1029/2021RG000765

Final PFAS National Primary Drinking Water Regulation

On April 10, 2024

Compound	Final MCLG	Final MCL (enforceable levels)[1]
PFOA	Zero	4.0 parts per trillion (ppt) (also expressed as ng/L)
PFOS	Zero	4.0 ppt

On May 14, 2025

[1] Compliance with MCLs is determined by running annual averages at the sampling point.

TABLE 1—FINAL RECOMMENDED FRESHWATER AQUATIC LIFE WATER QUALITY CRITERIA FOR PFOA AND PFOS

Criteria component	Acute water column (CMC) [1]	Chronic water column (CCC) [2]	Invertebrate whole-body	Fish whole-body	Fish muscle
PFOA Magnitude	3.1 mg/L	0.10 mg/L	1.18 mg/kg ww [4]	6.49 mg/kg ww [4]	0.133 mg/kg ww.[4]
PFOS Magnitude	0.071 mg/L	0.00025 mg/L	0.028 mg/kg ww [4]	0.201 mg/kg ww [4]	0.087 mg/kg ww.[4]
Duration	1-hour average	4-day average	Instantaneous.[3]		
Frequency	Not to be exceeded more than once in three years, on average.	Not to be exceeded more than once in three years, on average.	Not to be exceeded.[5]		

[1] Criterion Maximum Concentration.
[2] Criterion Continuous Concentration.
[3] Tissue data provide instantaneous point measurements that reflect integrative accumulation of PFOA or PFOS over time and space in aquatic life population(s) at a given site.
[4] Wet-Weight.
[5] PFOA and PFOS chronic freshwater tissue-based criteria should not be exceeded, based on measured tissue concentrations representing the central tendency of samples collected at a given site and time.

TABLE 2—ACUTE SALTWATER AQUATIC LIFE BENCHMARKS FOR PFOA AND PFOS

Chemical	PFOA	PFOA
Magnitude	7.0 mg/L	0.55 mg/L.
Duration	One hour average.	
Frequency	Not to be exceeded more than once in three years on average.	

TABLE 3—ACUTE FRESHWATER AQUATIC LIFE BENCHMARKS FOR EIGHT PFAS

Chemical	PFBA	PFHxA	PFNA	PFDA	PFBS	PFHxS	8:2 FTUCA	7:3 FTCA
Magnitude [1]	5.3	4.8	0.65	0.50	5.0	0.21	0.037	0.012
Duration	One hour average.							
Frequency	Not to be exceeded more than once in three years on average.							

[1] Values expressed as mg/L, or ppm.

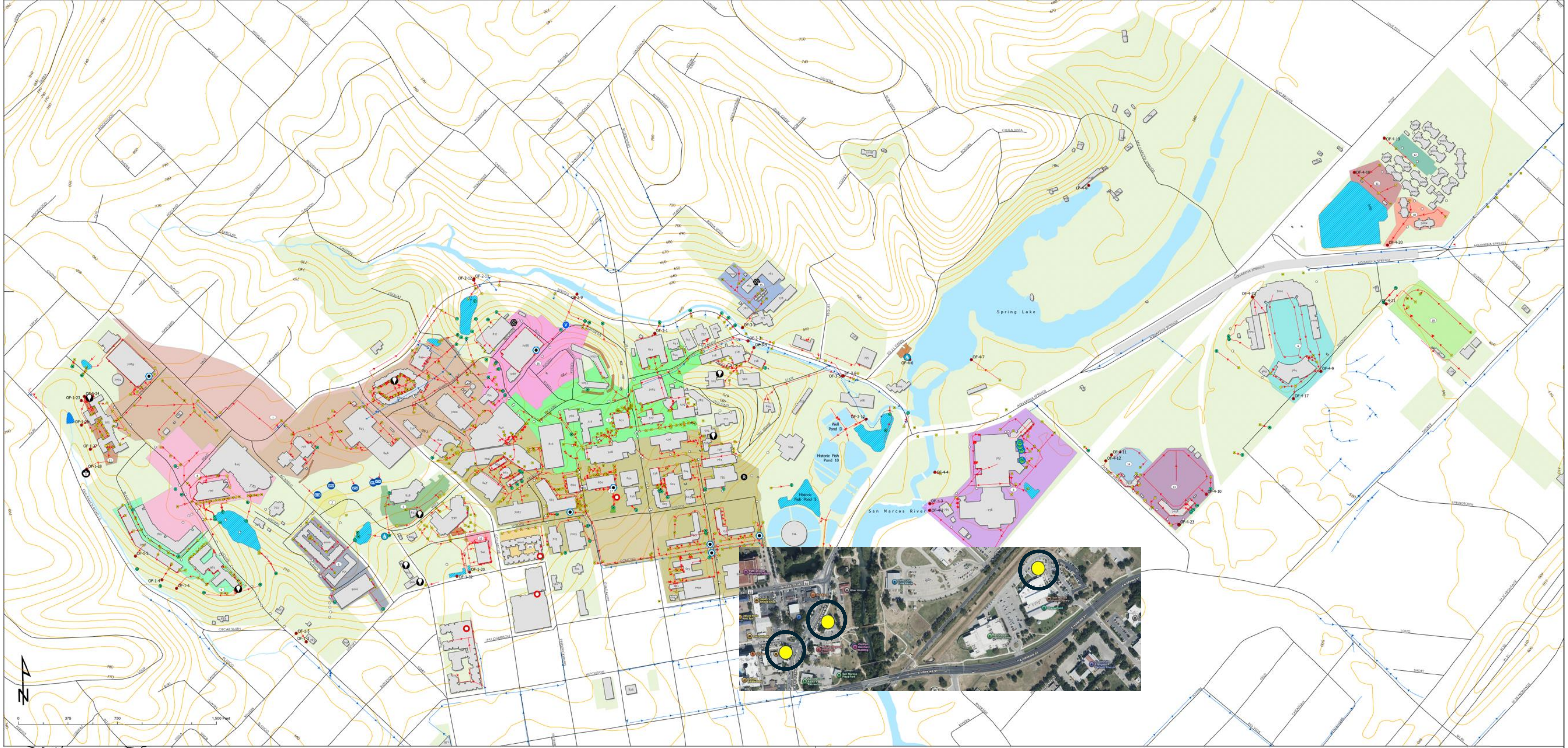
Federal Register / Vol. 89, No. 247 / Thursday, December 26, 2024 / Notices

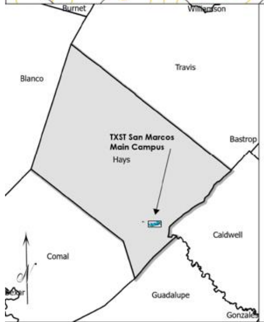
- Human Health Criteria (HHC) are designed to minimize the risk of adverse effects occurring to humans from chronic (lifetime) exposure to substances through drinking water and eating fish and shellfish from inland and nearshore waters.

TABLE 1—DRAFT HUMAN HEALTH CRITERIA (HHC) FOR PFOA, PFOS, AND PFBS

PFAS	Water + Organism HHC (ng/L)	Organism Only HHC (ng/L)
PFOA	0.0009	0.00036
PFOS	0.06	0.07
PFBS	400	500

Three Biofiltration Basins of Interest in San Marcos, TX





Texas State University San Marcos

Municipal Separate Storm Sewer Systems (MS4)

~ Boundary Map ~

Storm Controls
- Cisterns
- Oil-Water Seperators
- Underground WQD
- Bioretention
- Gabion Basket
- Level Spreader
- Rip Rap Swale
- Underground Detention
- Velocity Dissipator
- Water Quality Structure
- Permeable Pavers

Storm Water Features
- Bioretention Pond
- Detention Pond
- Retention Pond
- TXST Storm Line
- Non-TXST Storm Line
- MS4 Outfall
- Non-MS4 Outfall
- Drain Inlet
- Manhole

Seperate Storm Water Catchment Areas
- 1 | To 60inch Gulch
- 2 | To Pleasant St/Sessom Creek
- 3 | Strahan to San Marcos River
- 4 | To Rail Road Drainage Ditch
- 5 | To North Street
- 6 | To Lindsey St
- 7 | To James Street
- 8 | To Glade
- 9 | To Ranch Road 12
- 10 | To Rail Road Drainage Ditch
- 11 | To Rail Road Drainage Ditch
- 12 | To Rail Road Drainage Ditch
- 13 | To Rail Road Drainage Ditch
- 14 | To Rail Road Drainage Ditch
- 15 | To Rail Road Drainage Ditch
- 16 | Mathews to Sessom Creek
- 17 | To 60 inch pipe to San Marcos River
- 18 | To Rail Road Drainage Ditch
- 19 | Res Life to Lindsey St
- 20 | Tower/San Marcos Hall To Fredericksburg St
- 21 | To Ranch Road 12

Campus Map
- Roads
- TXST Buildings
- Lakes and Ponds
- Elevation Contours
- TXST Property

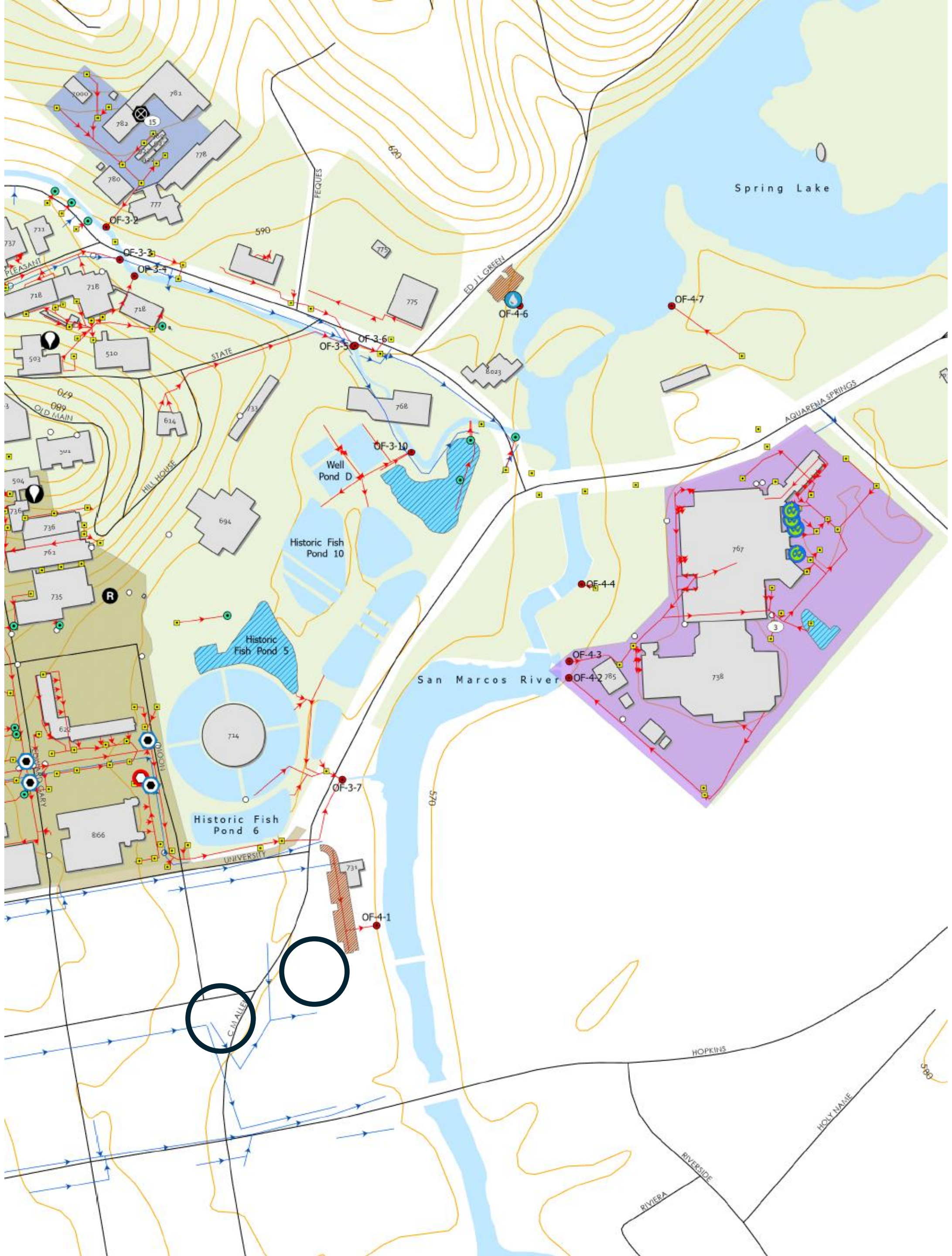
Sources:

Storm Controls, Storm Water Features, Separate Storm Water Catchment Areas, Campus Map - TXST Facilities GIS Data - 2024

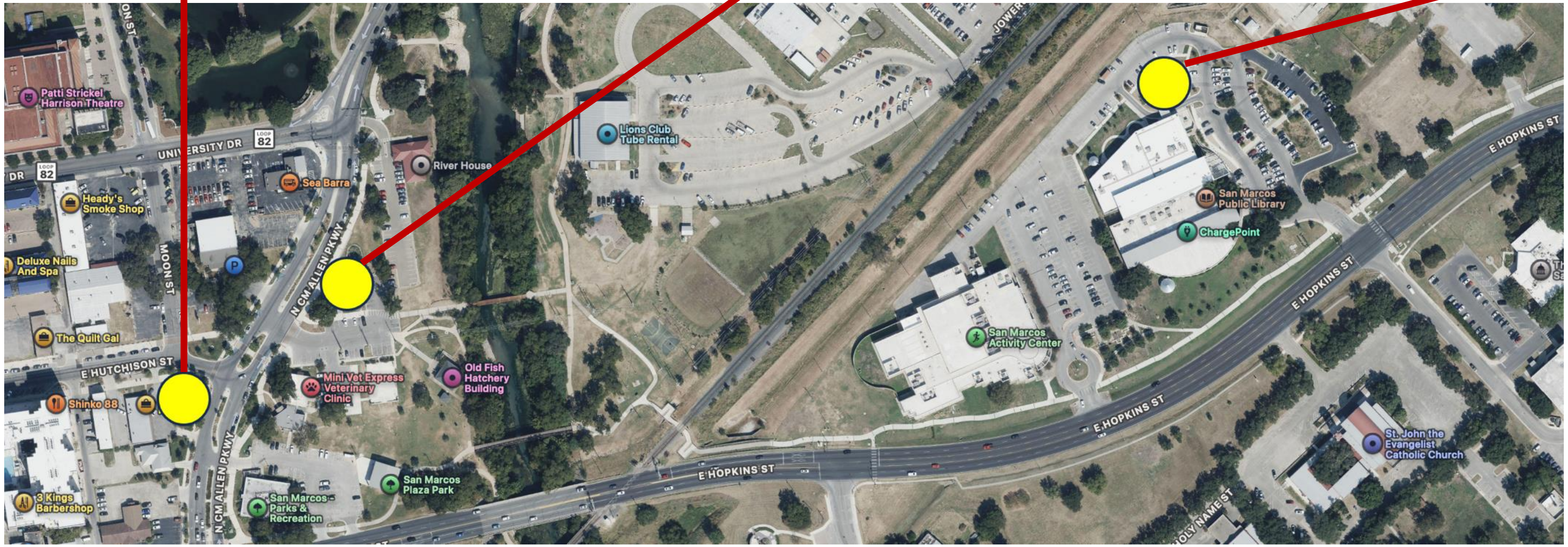
Cartography by Ben Buehler

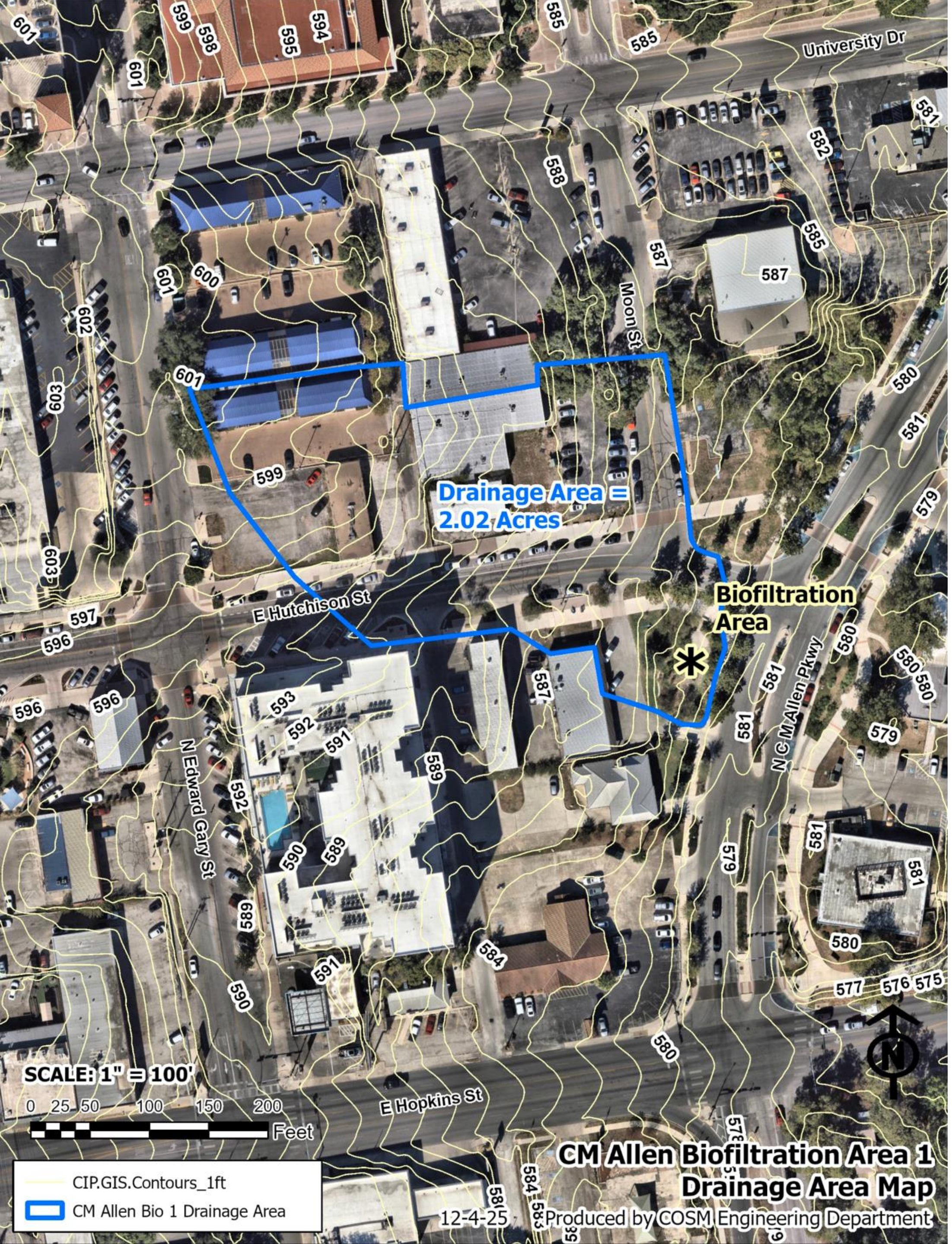
TXST

Created by Texas State Facilities GIS
1/10/2025



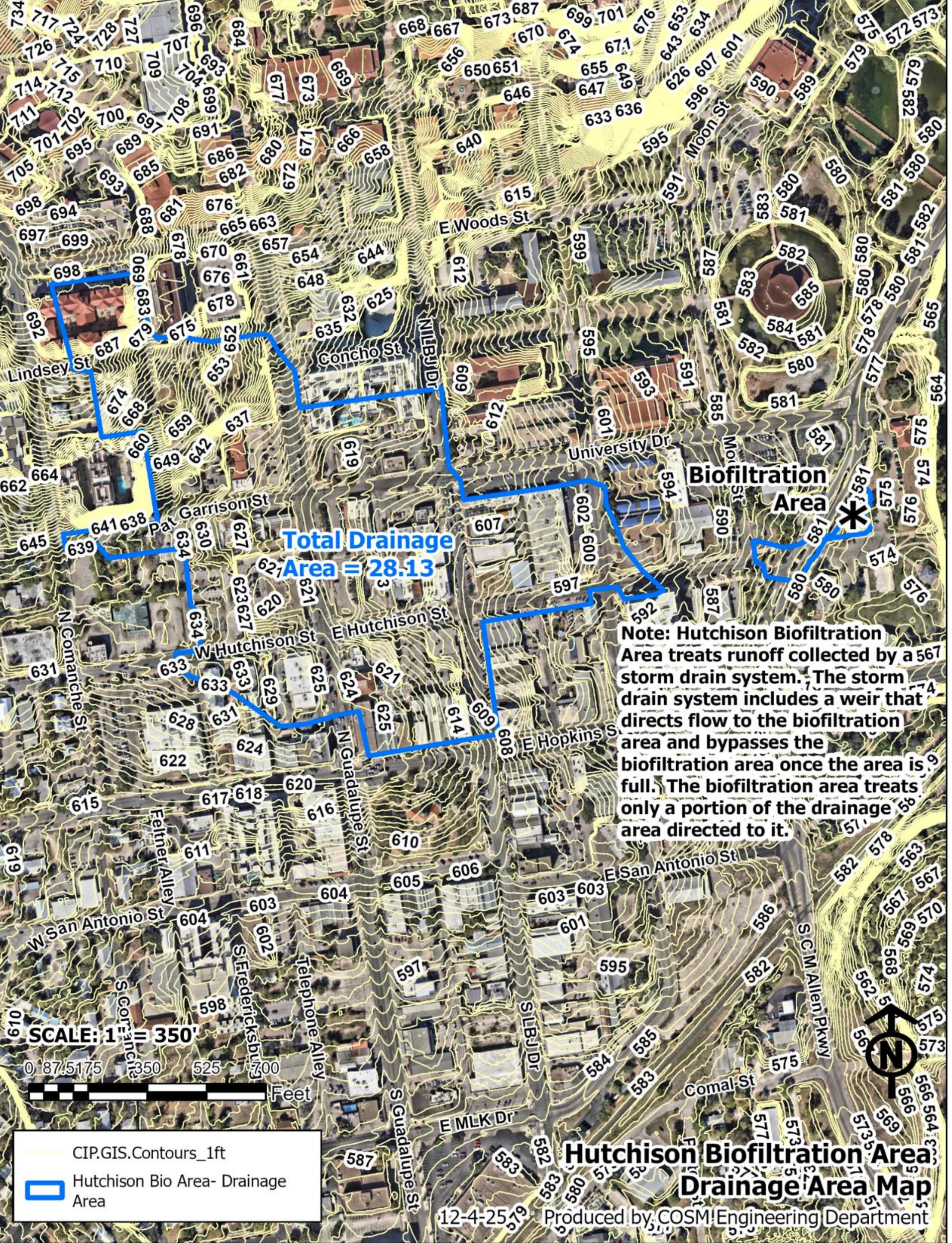
Spring Lake
San Marcos River
Historic Fish Pond 10
Historic Fish Pond 5
Historic Fish Pond 6
Well Pond D
OF-3-2
OF-3-3
OF-3-4
OF-3-5
OF-3-6
OF-3-7
OF-3-10
OF-4-1
OF-4-2
OF-4-3
OF-4-4
OF-4-6
OF-4-7
AQUARENA SPRINGS
HOPKINS
UNIVERSITY
STATE
OLD MAIN
HILL HOUSE
FEQUES
ED J.L GREEN
RIVERSIDE
RIVIERA
HOLY NAME
PLEASANT


Patti Strickel Harrison Theatre
LOOP 82
River House
Sea Barra
Heady's Smoke Shop
Lions Club Tube Rental
Deluxe Nails And Spa
MOON ST
N CM ALLEN PKWY
The Quilt Gal
E HUTCHISON ST
Shinko 88
Mini Vet Express Veterinary Clinic
Old Fish Hatchery Building
San Marcos Plaza Park
San Marcos Parks & Recreation
3 Kings Barbershop
E HOPKINS ST
San Marcos Public Library
ChargePoint
San Marcos Activity Center
St. John the Evangelist Catholic Church



CM Allen BB

- Completed in 2020
- Drainage area: 2.02 Acres

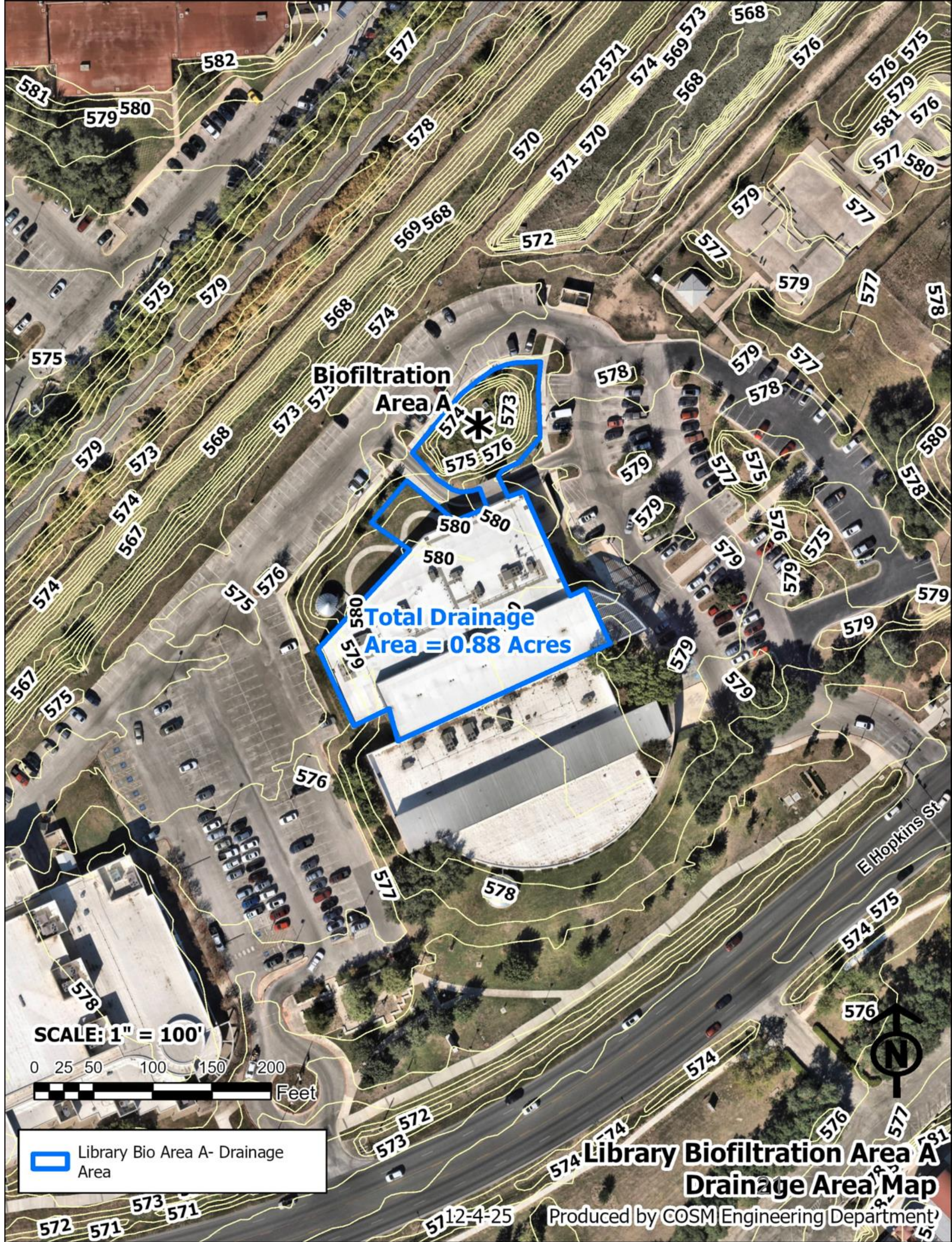


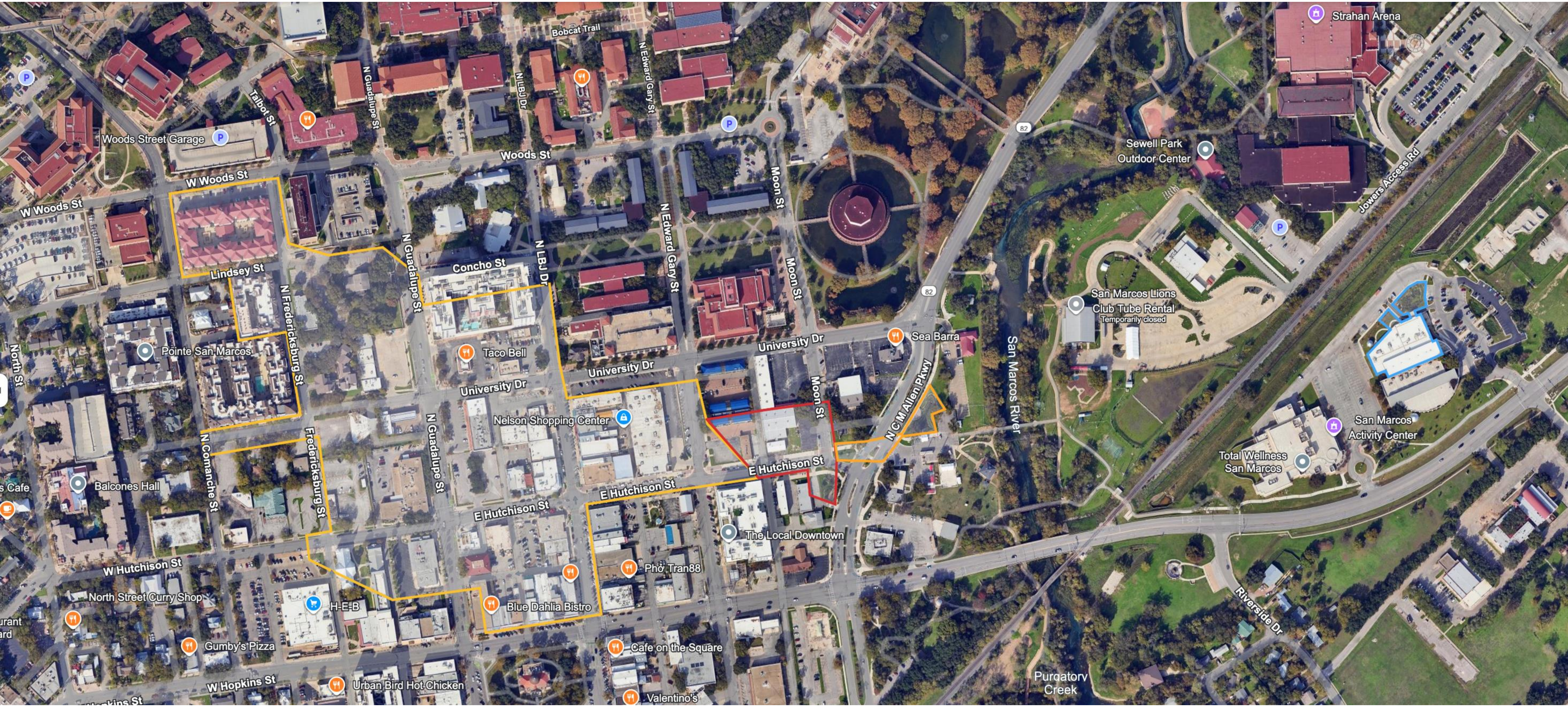
Hutchison BB

- Originally completed in 2015 and rehabilitated in 2020
- Drainage area: 28.13 Acres

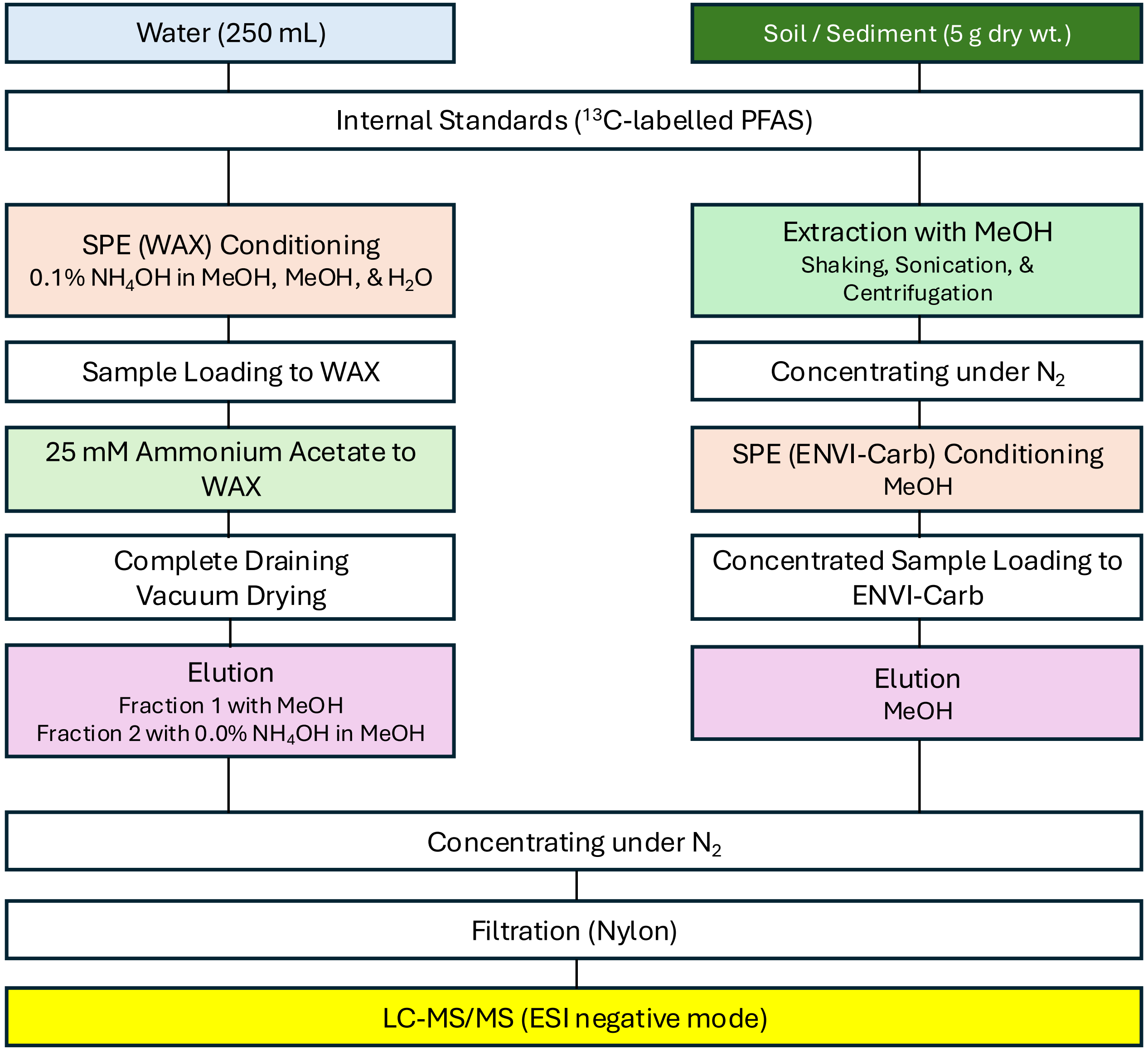
Library BB

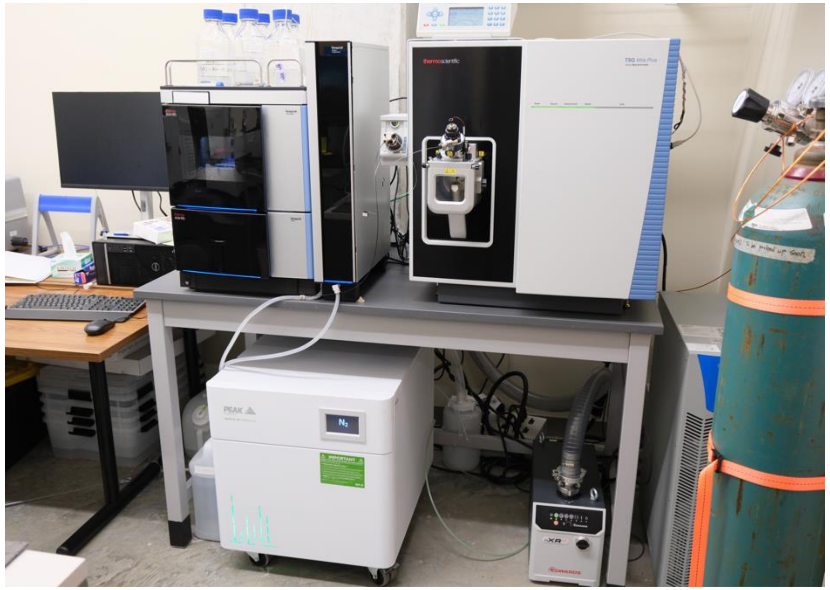
- Completed in 2021
- Drainage area: 0.88 Acres

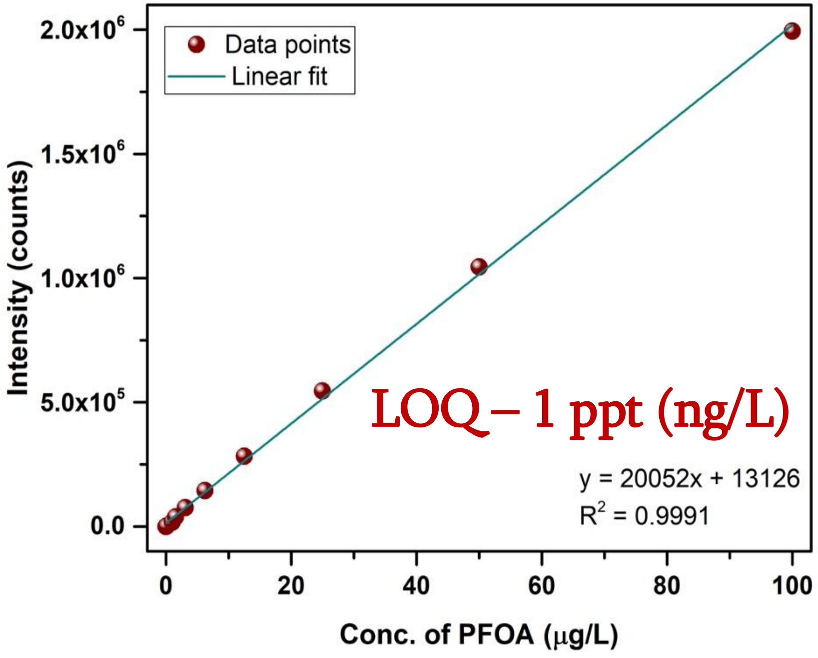



Strahan Arena
Bobcat Trail
Woods Street Garage
W Woods St
Woods St
Sewell Park
Outdoor Center
Jowers Access Rd
Concho St
Lindsey St
San Marcos Lions
Club Tube Rental
Temporarily closed
Pointe San Marcos
Taco Bell
University Dr
Sea Barra
Nelson Shopping Center
N C M Allen Pkwy
San Marcos River
San Marcos
Activity Center
Total Wellness
San Marcos
Balcones Hall
E Hutchison St
The Local Downtown
W Hutchison St
Phở Tran88
North Street Curry Shop
H-E-B
Blue Dahlia Bistro
Gumby's Pizza
Cafe on the Square
W Hopkins St
Urban Bird Hot Chicken
Valentino's
Purgatory
Creek
Riverside Dr
N Guadalupe St
N LBJ Dr
N Edward Gary St
Moon St
N Fredericksburg St
Fredericksburg St
N Comanche St
North St
Talbot St

Sample Preparation before Analysis

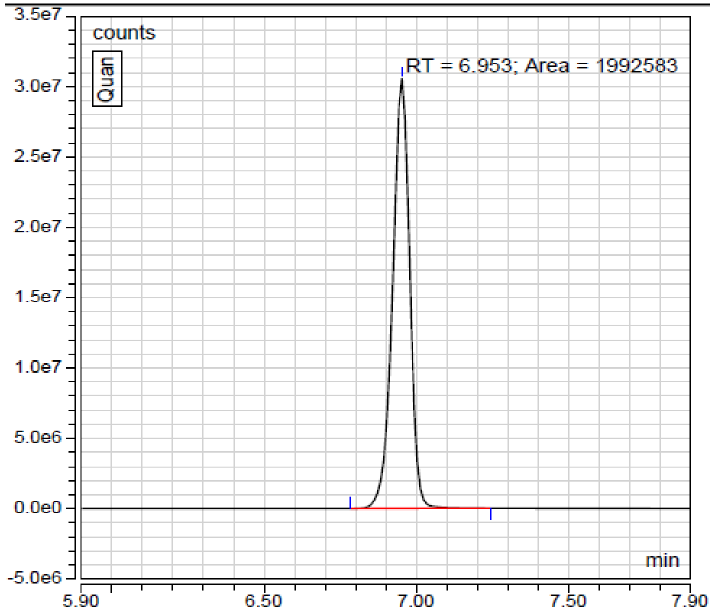


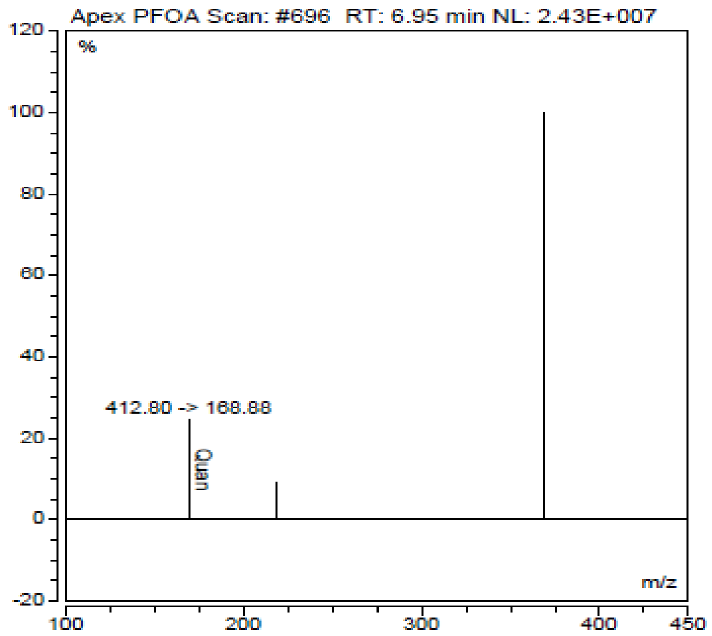


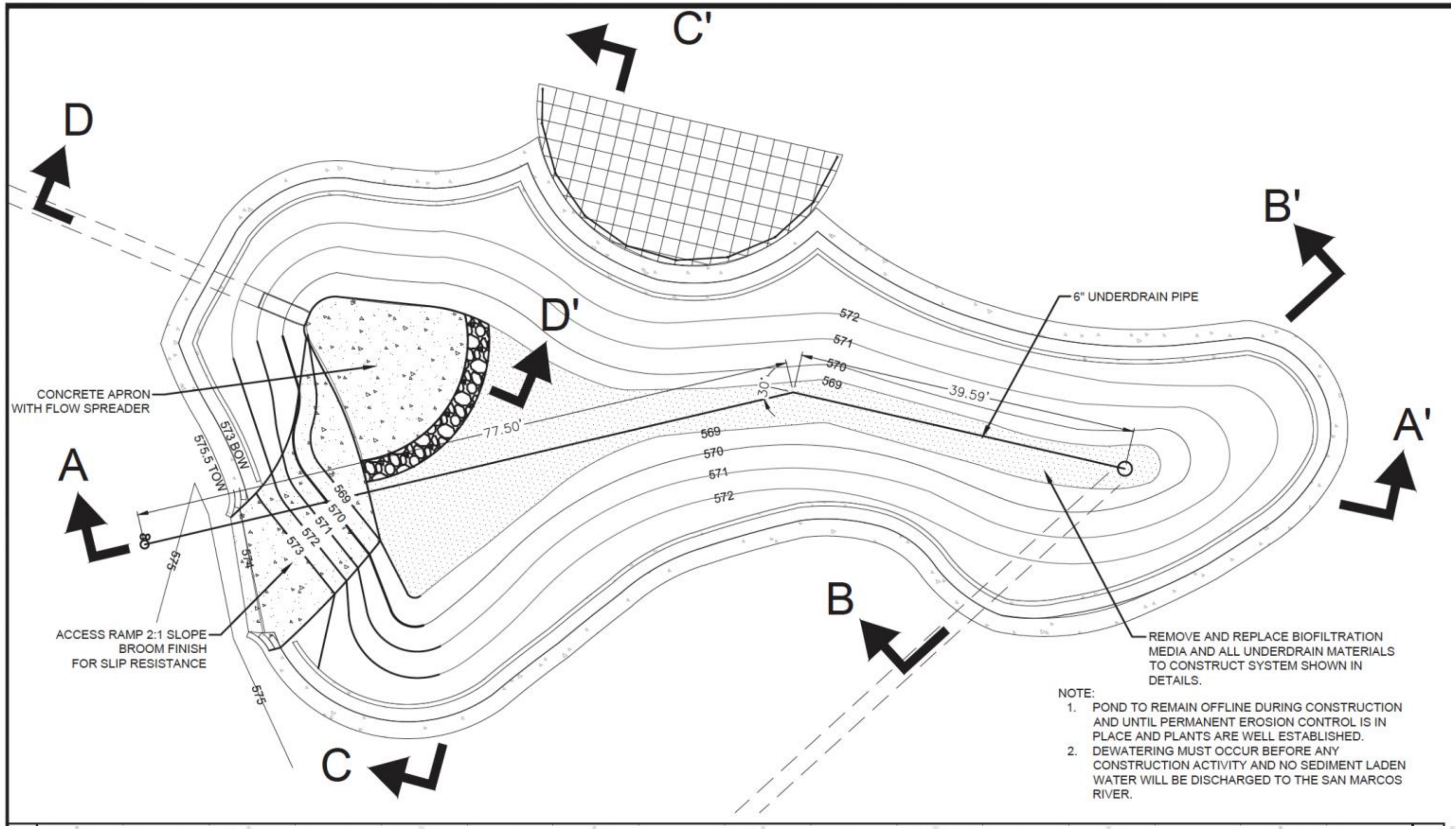


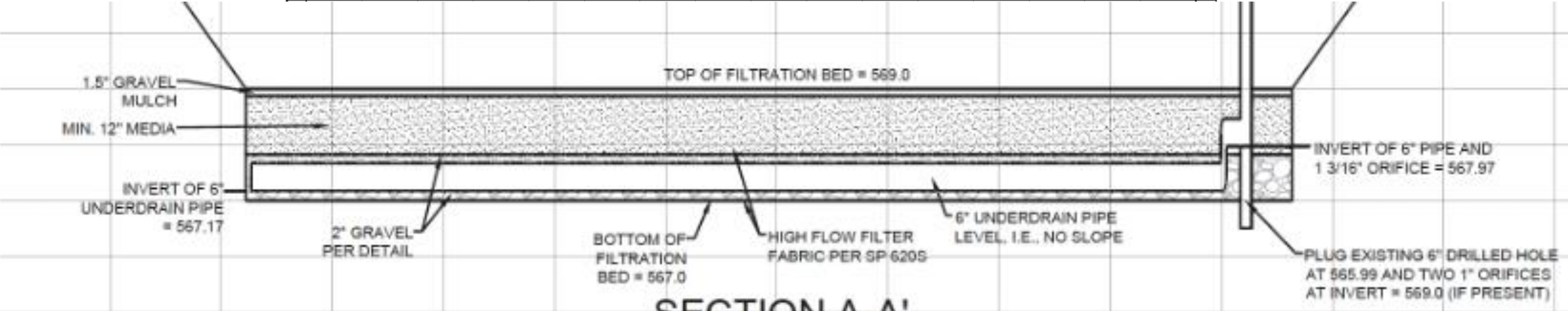
17 PFAS

PFBA
PFPeA
PFBS
PFHxA
PFHpA
PFHxS
PFOA
PFNA
PFOS
PFDA
PFDS
PFUdA
PFDoA
PFTrDA
PFTeDA
PFHxDA
PFODA



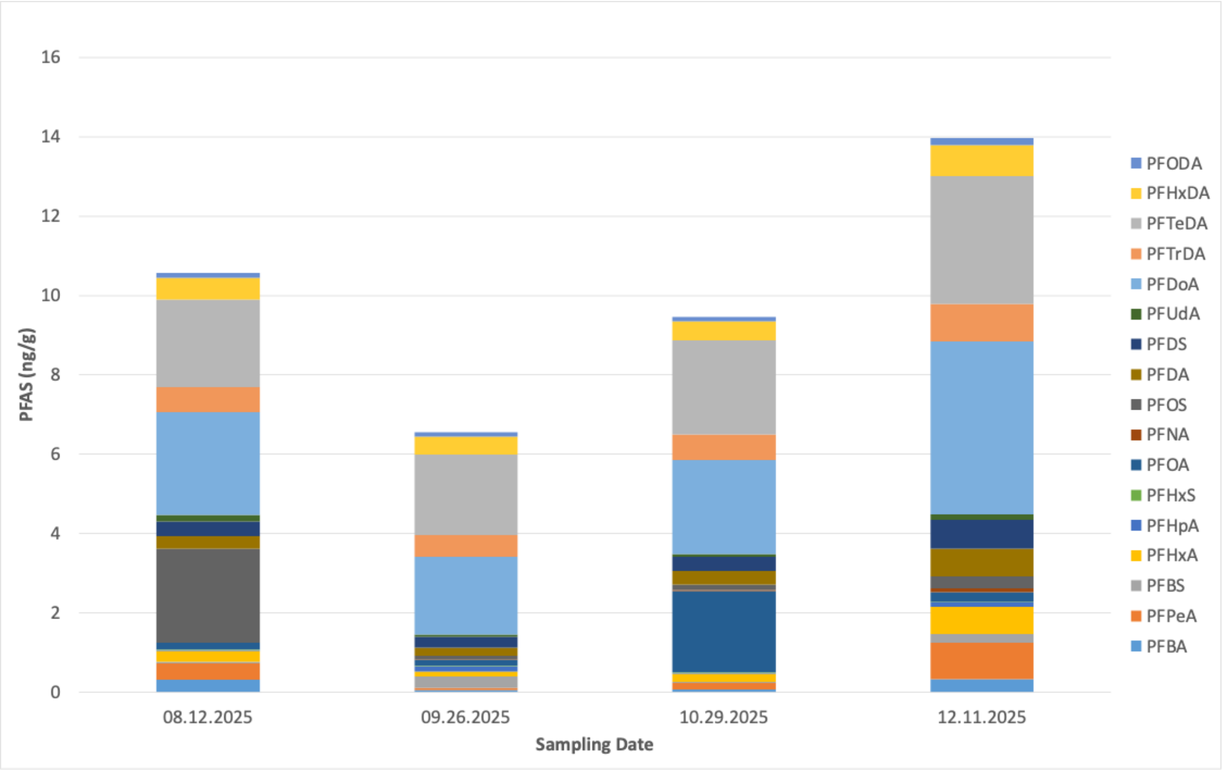


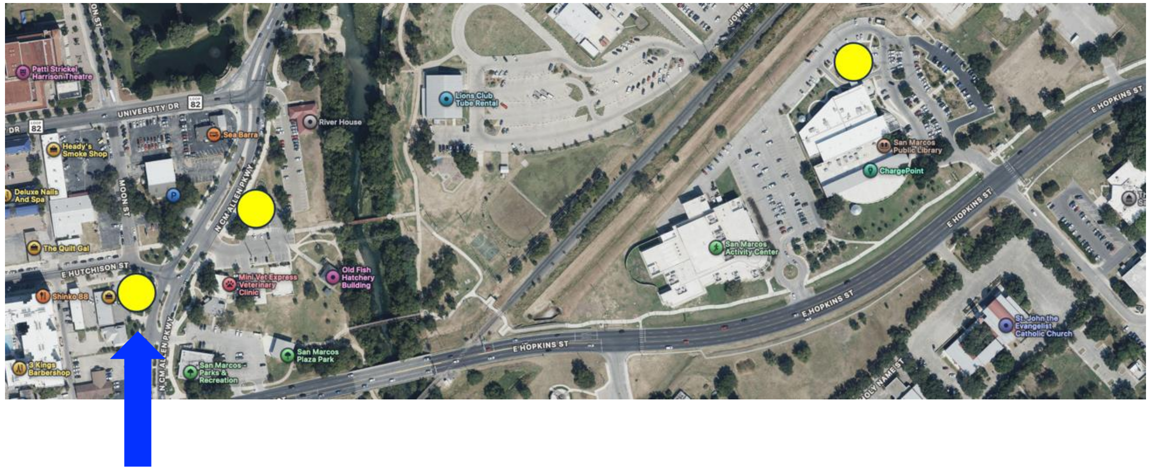




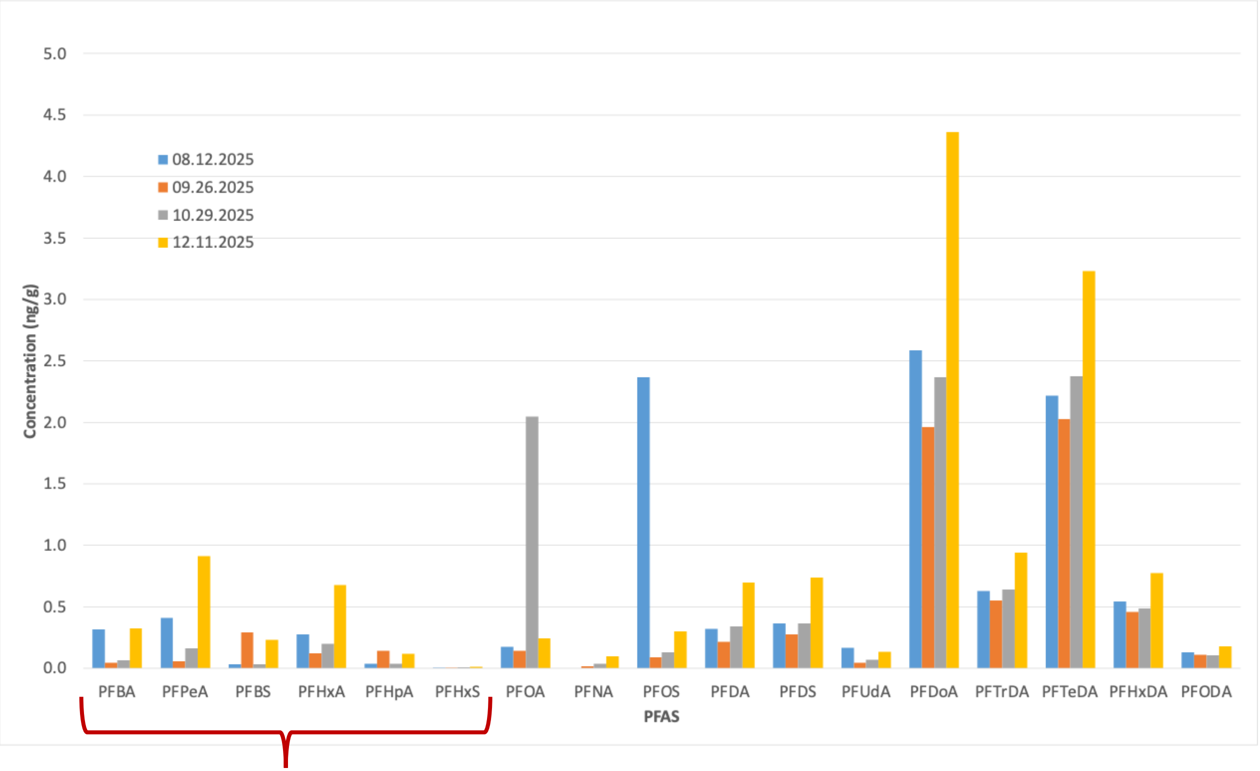
SECTION A-A'

SCALE : H - 1" = 10', V- 1" = 2'





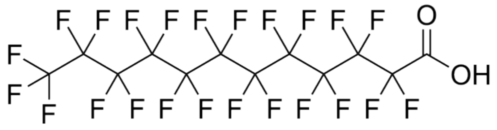
CM Allen BB



Short-chain PFAS

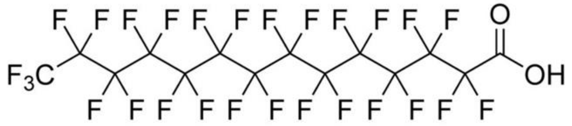
PFDoA (perfluorododecanoic acid)

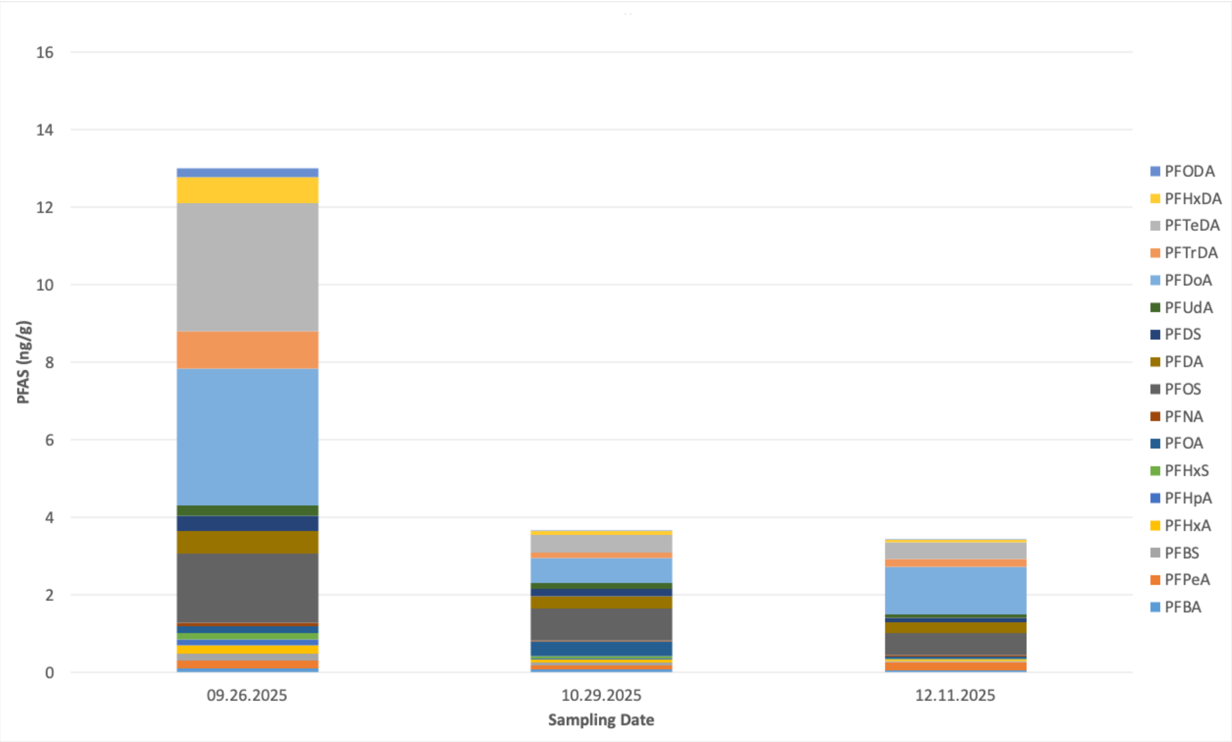
- Stain- and grease-proof coatings on food packaging, couches, and carpets, including Stainmaster.

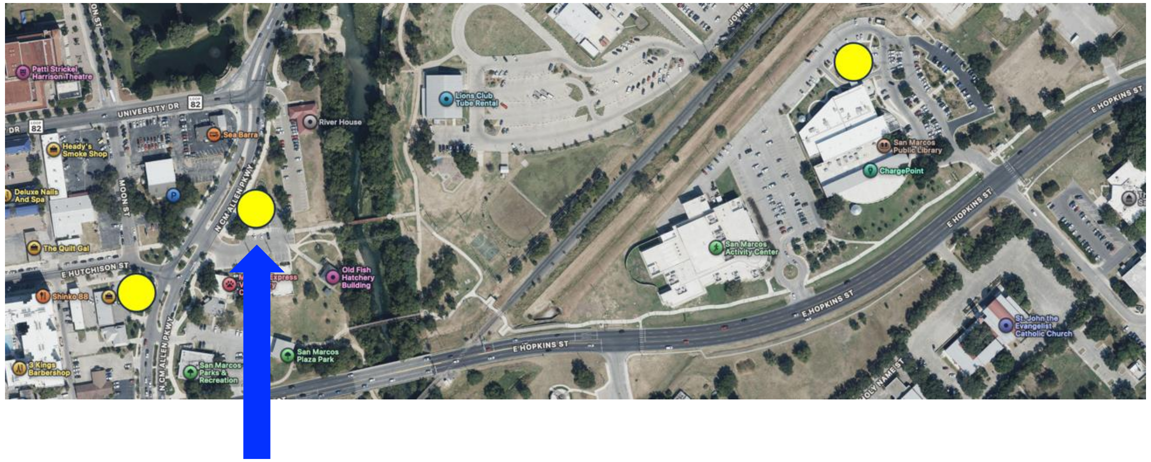


PFTeDA (perfluorotetradecanoic acid)

- Firefighting foams, coatings, and water/stain repellents.







Hutchison BB

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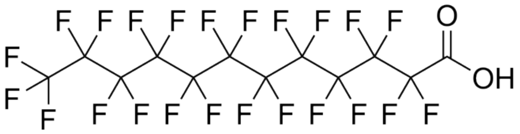

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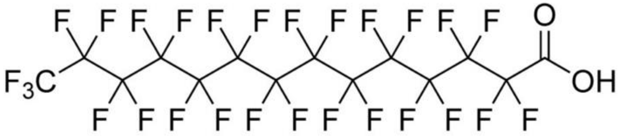
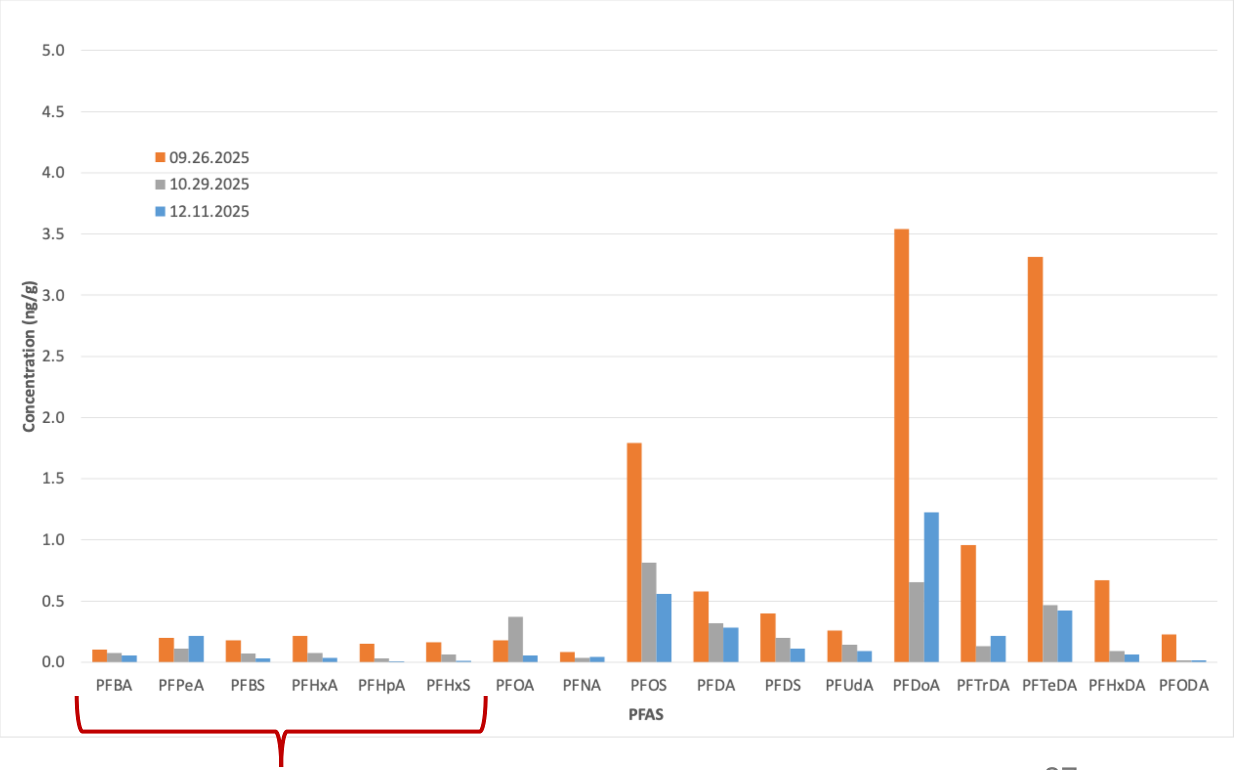
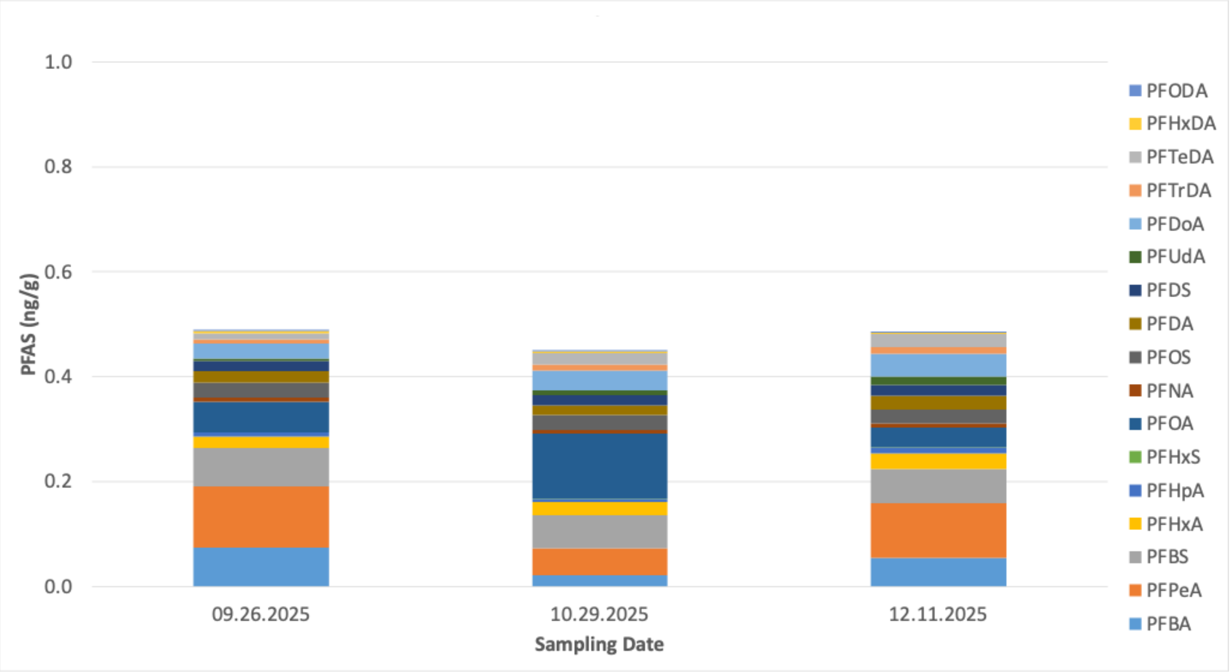
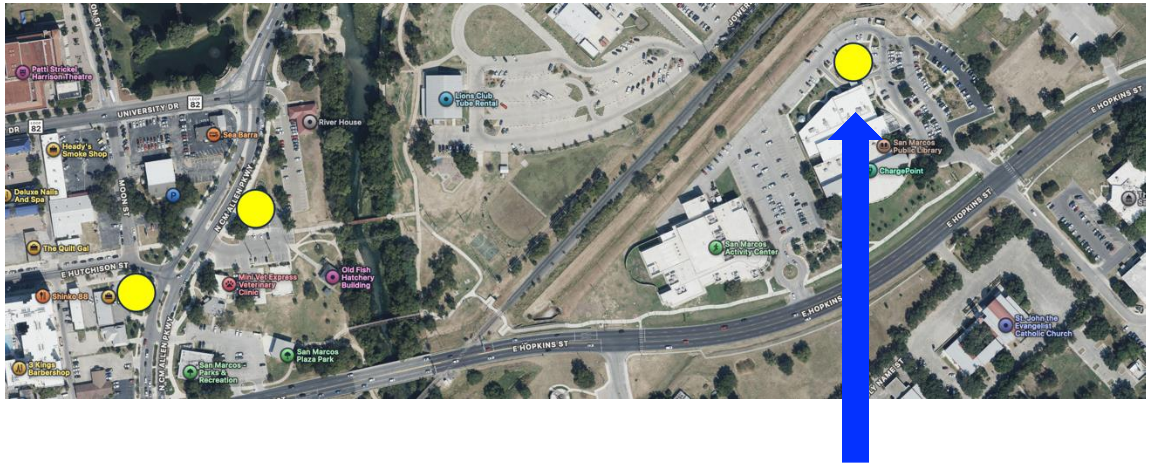




Short-chain PFAS

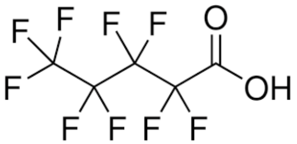




Library BB

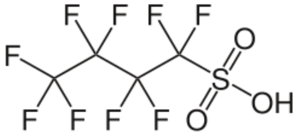
PFPeA (perfluoropentanoic acid)

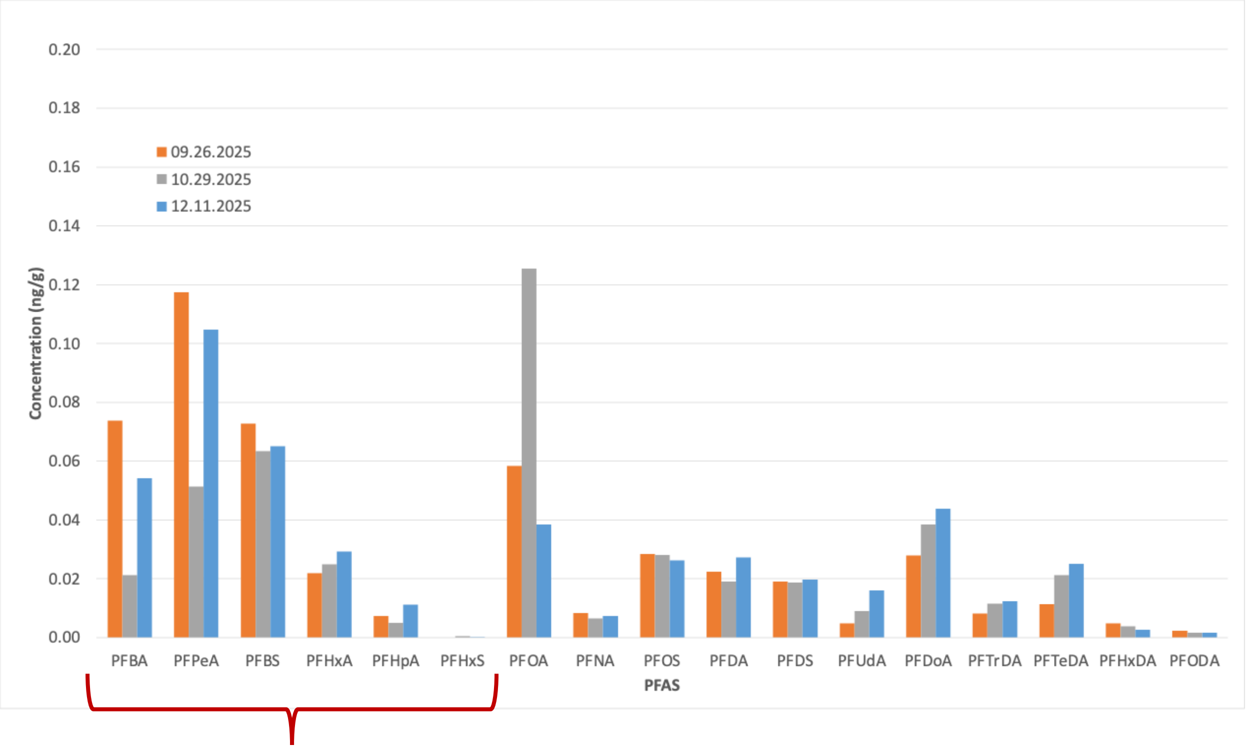
- Food packaging, stain-repellent carpets, apparel, cosmetics, and firefighting foams



PFBS (perfluorobutane sulfonic acid)

- Food packaging, firefighting foam, and consumer products (such as perfumes, cosmetics, and detergents)





Short-chain PFAS

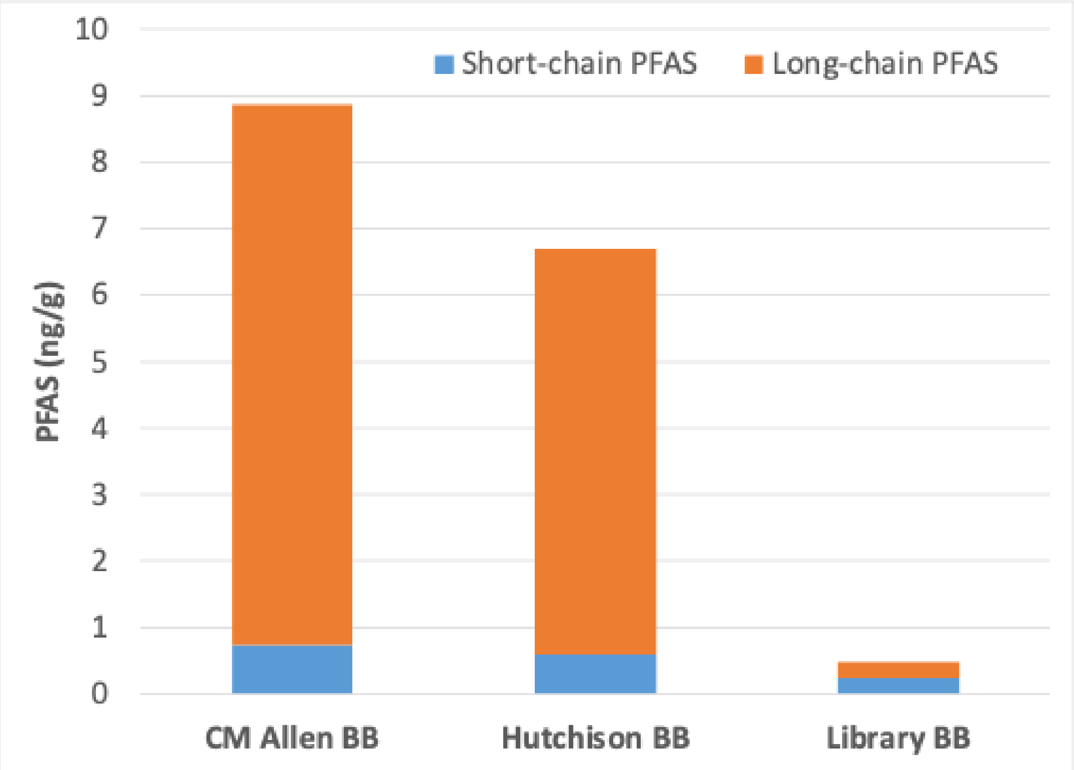
Differences between BBs

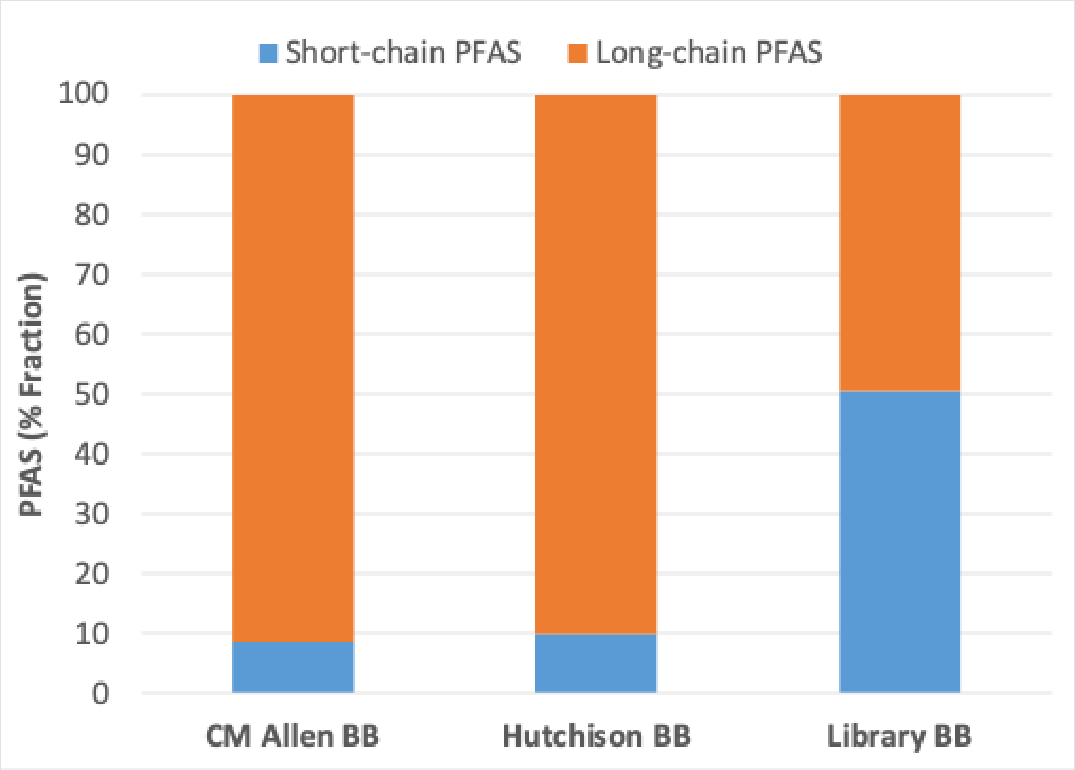
Complex Downtown Contribution Area

- Higher PFAS concentration
- Greater long-chain PFAS %

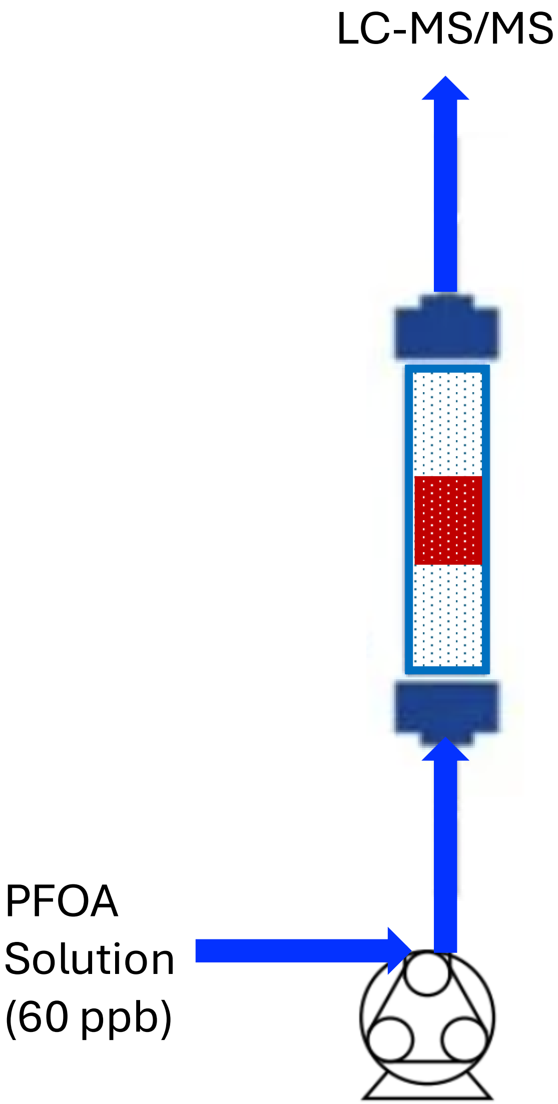
Isolated Relatively Clean Contribution Area

- Significantly lower PFAS concentration
- Similar PFAS % b/w short-chain & long-chain

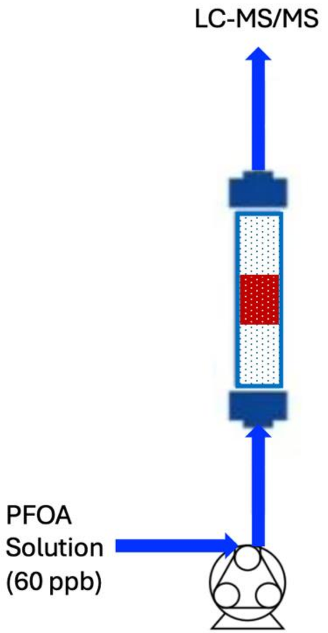


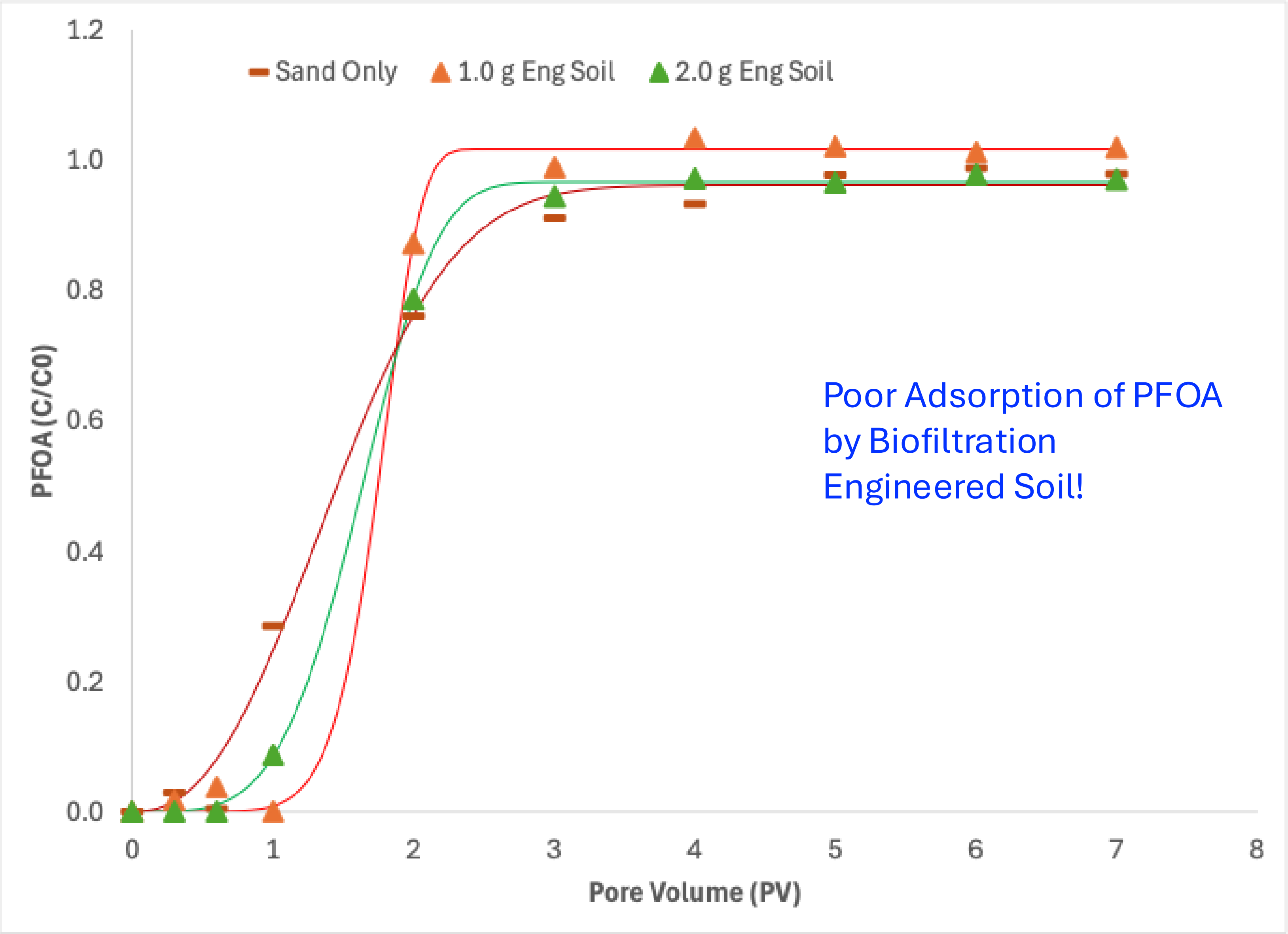


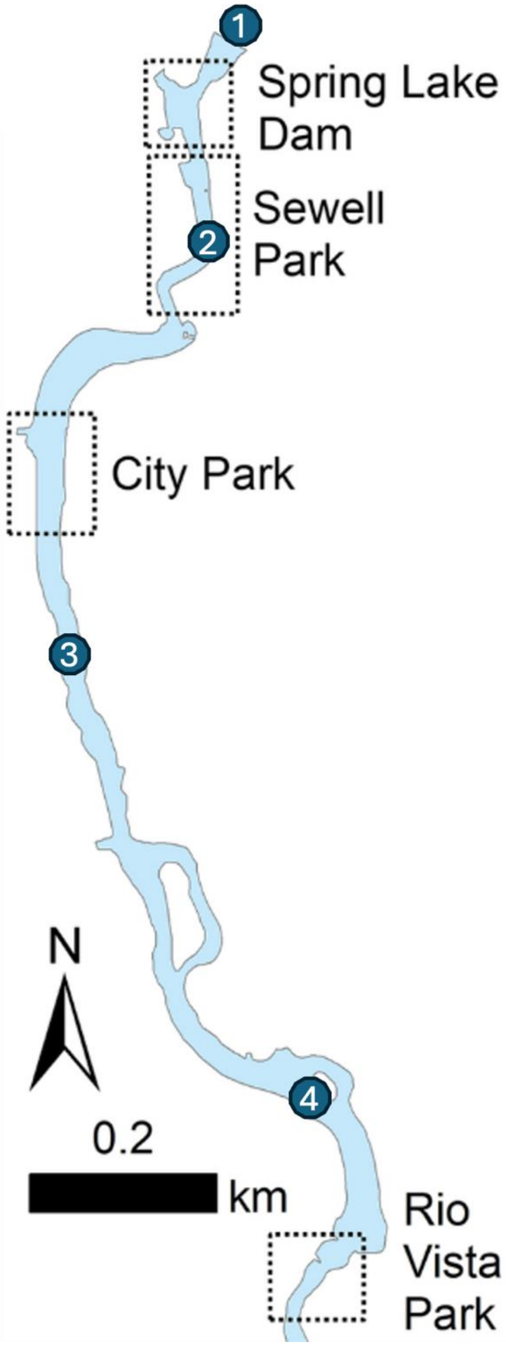
Flow-through Column Study to evaluate the Performance of Biofiltration Engineered Soil for PFAS Adsorption

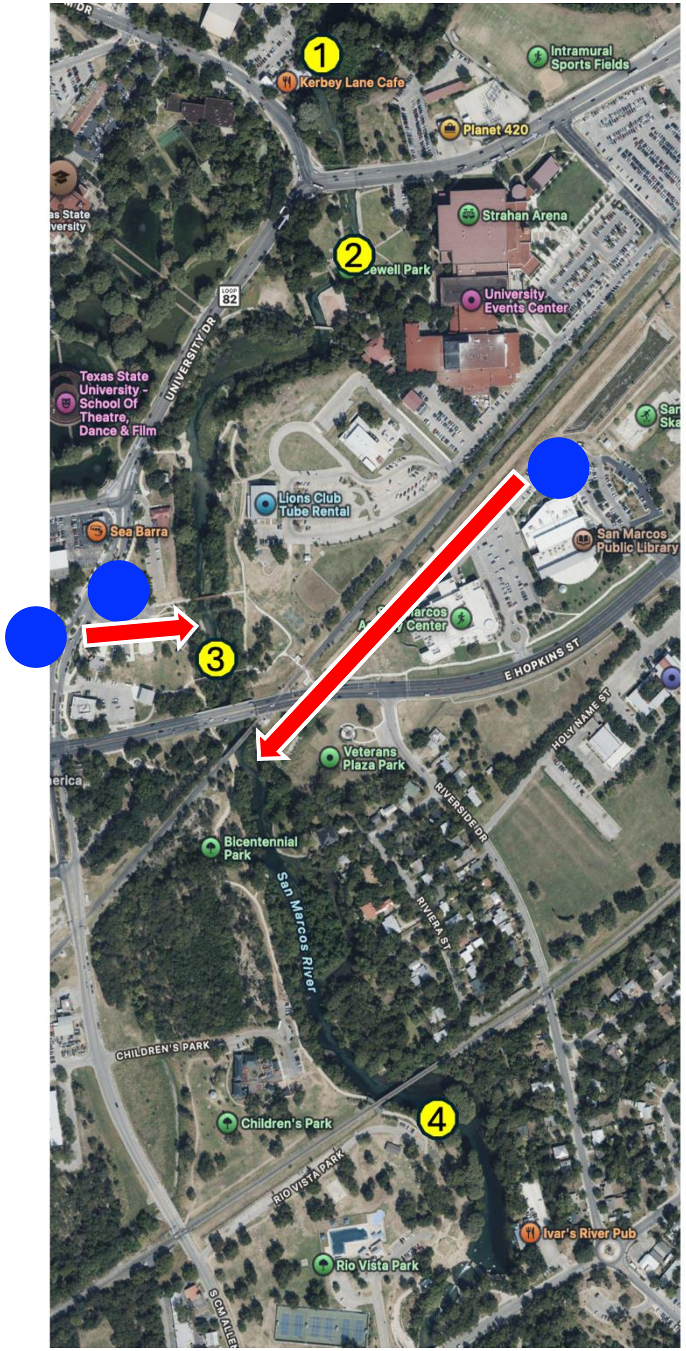


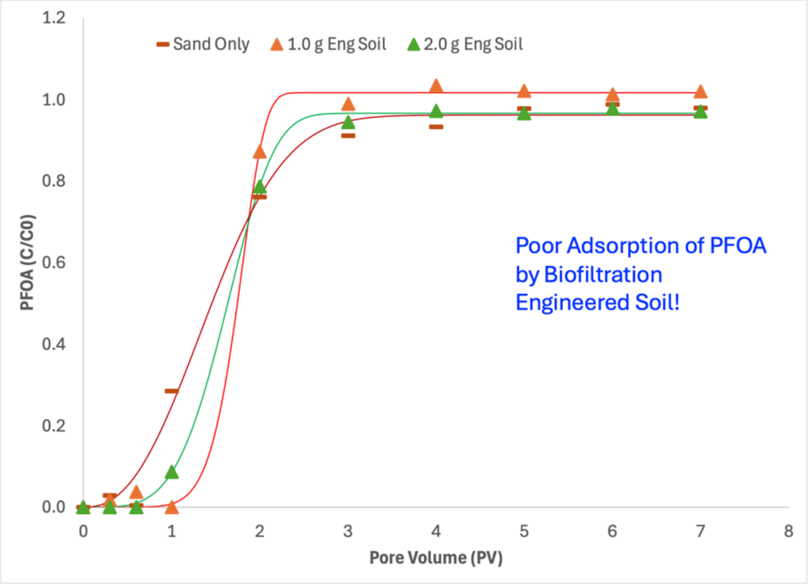
Sand only
Sand+Biofiltration Engineered Soil
Sand+WHBC
Sand+ZVI WHBC
Sand+Commercial Acitivated Carbon


LC-MS/MS
PFOA
Solution
(60 ppb)


1.2
1.0
0.8
0.6
0.4
0.2
0.0
PFOA (C/C0)
Sand Only
1.0 g Eng Soil
2.0 g Eng Soil
0
1
2
3
4
5
6
7
8
Pore Volume (PV)
Poor Adsorption of PFOA
by Biofiltration
Engineered Soil!





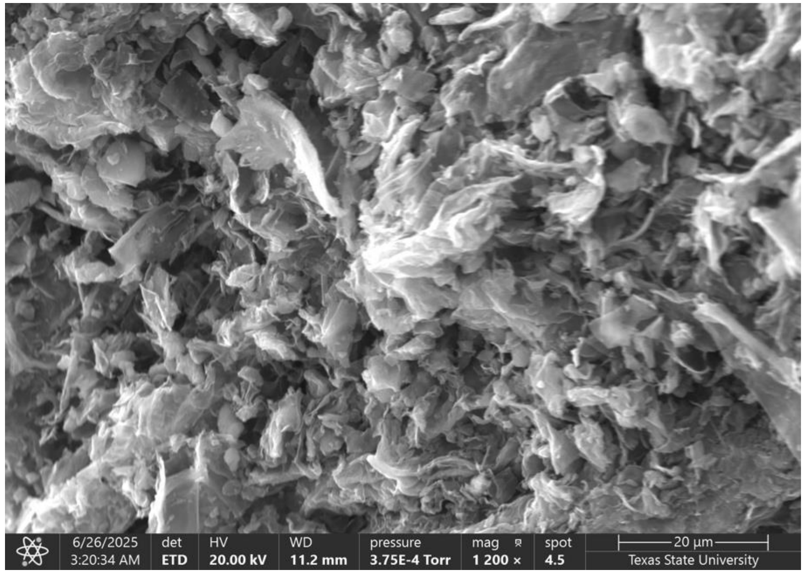


- Their outfall to the San Marcos River
- Need to augment/replace with media good at PFAS control

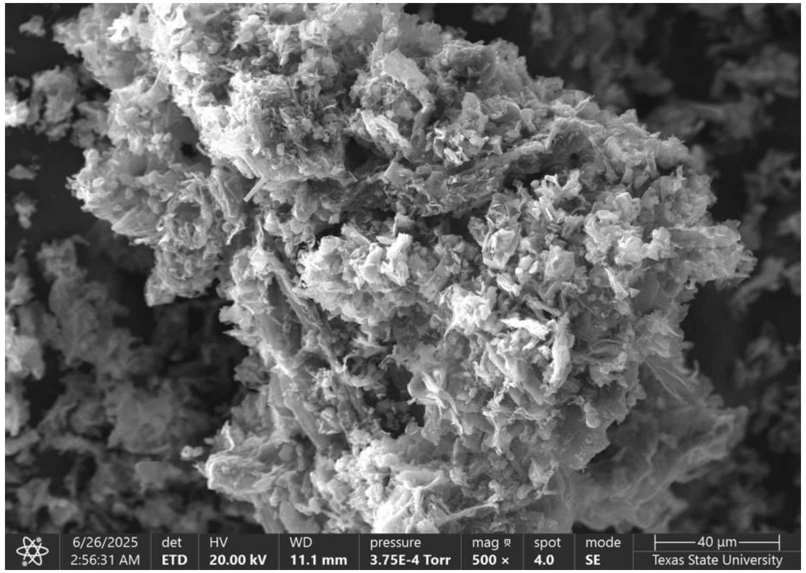
Biochar Addition to Biofiltration Engineered Soil?

Pyrolysis

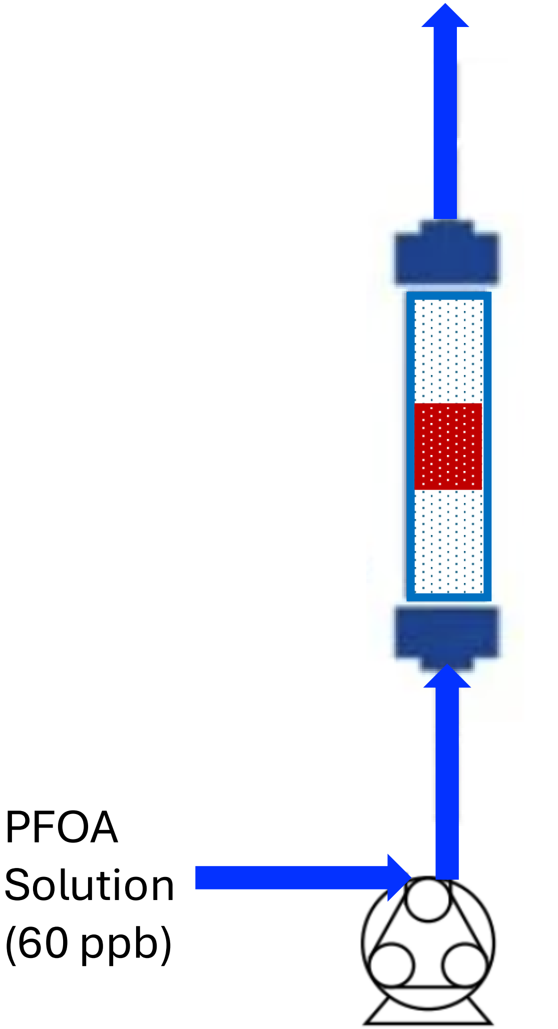
Water Hyacinth Biochar (WHBC)

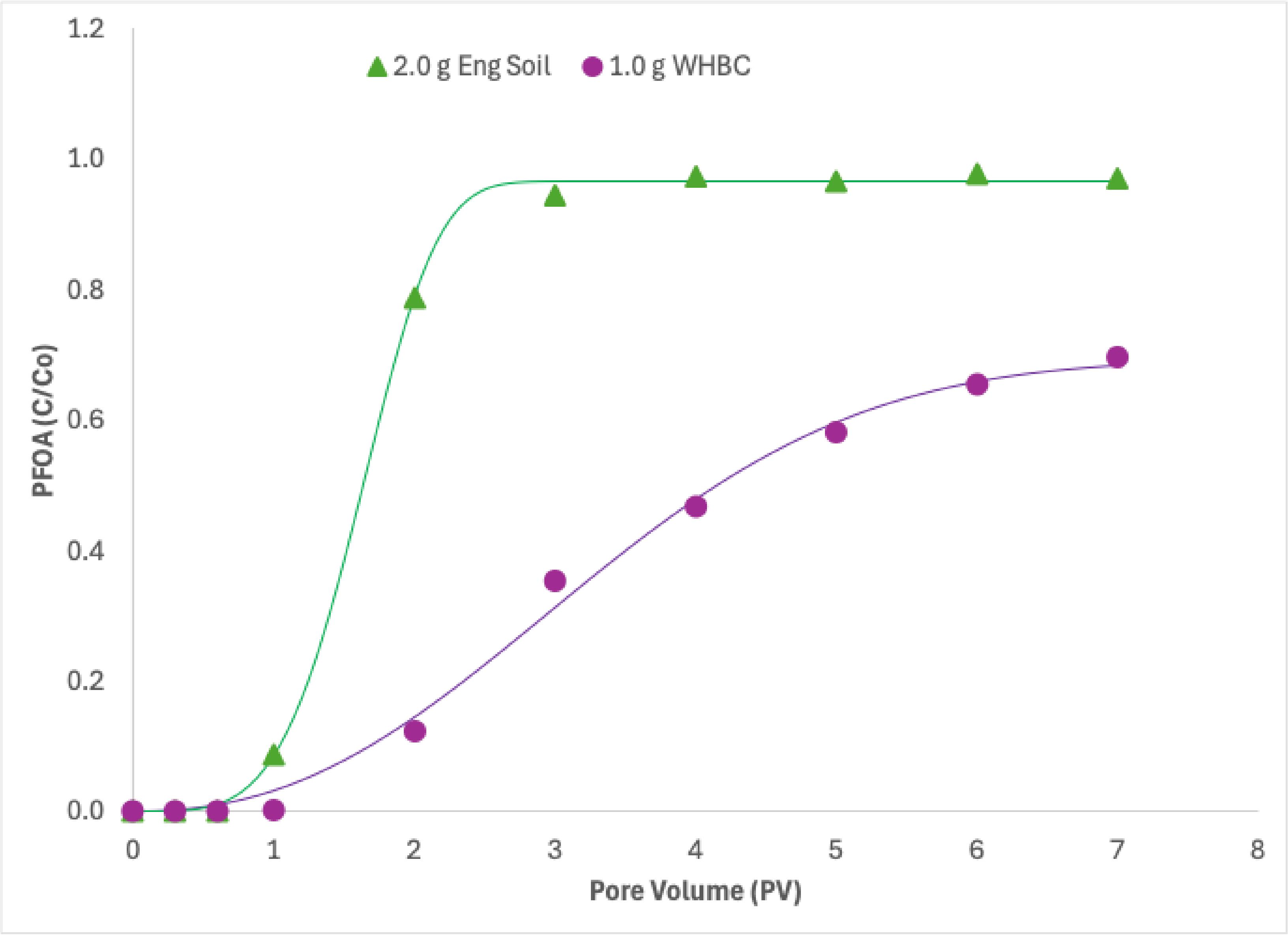


SEM Image of WHBC

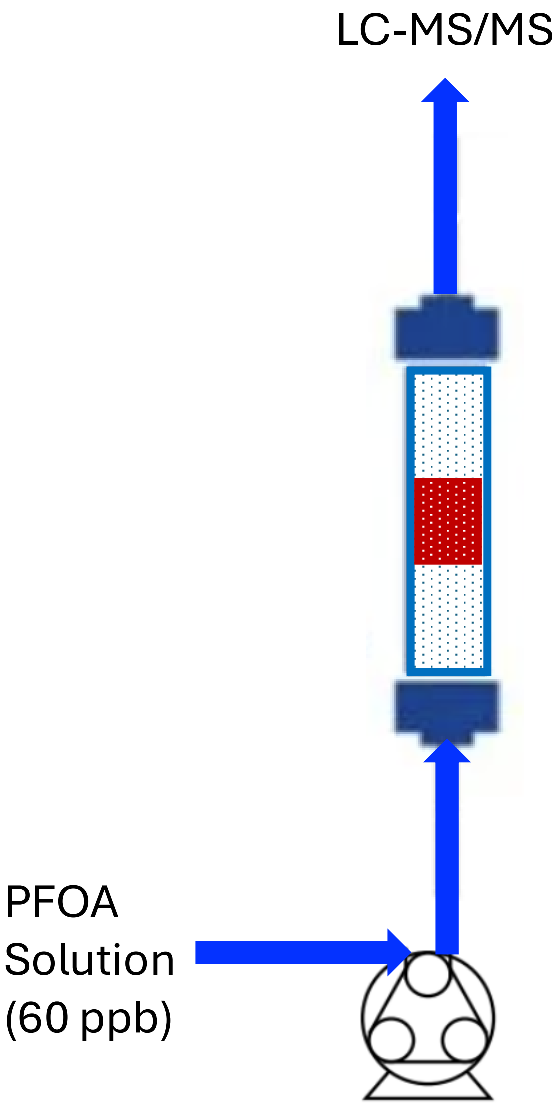


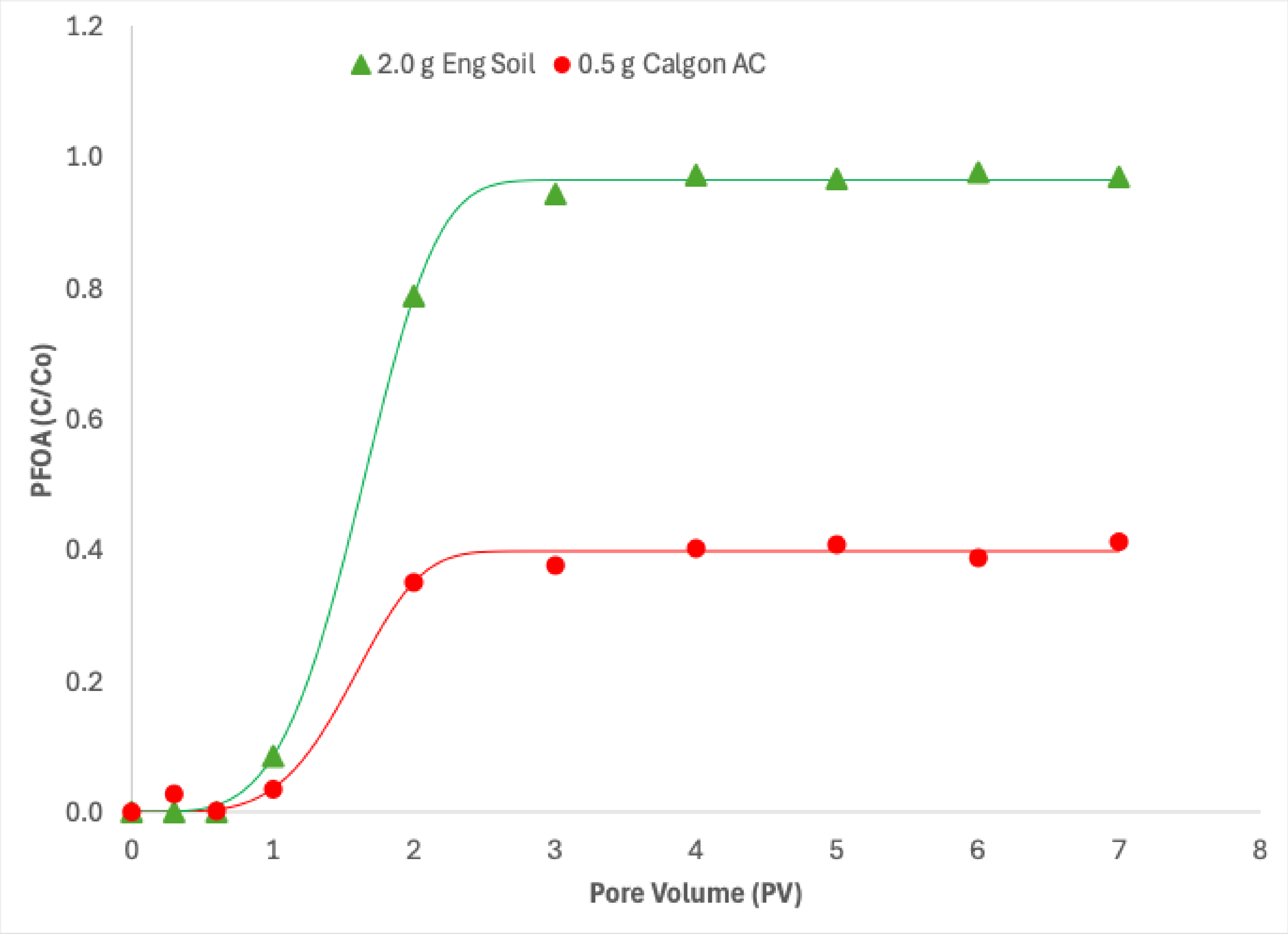
WHBC?


LC-MS/MS
PFOA
Solution
(60 ppb)

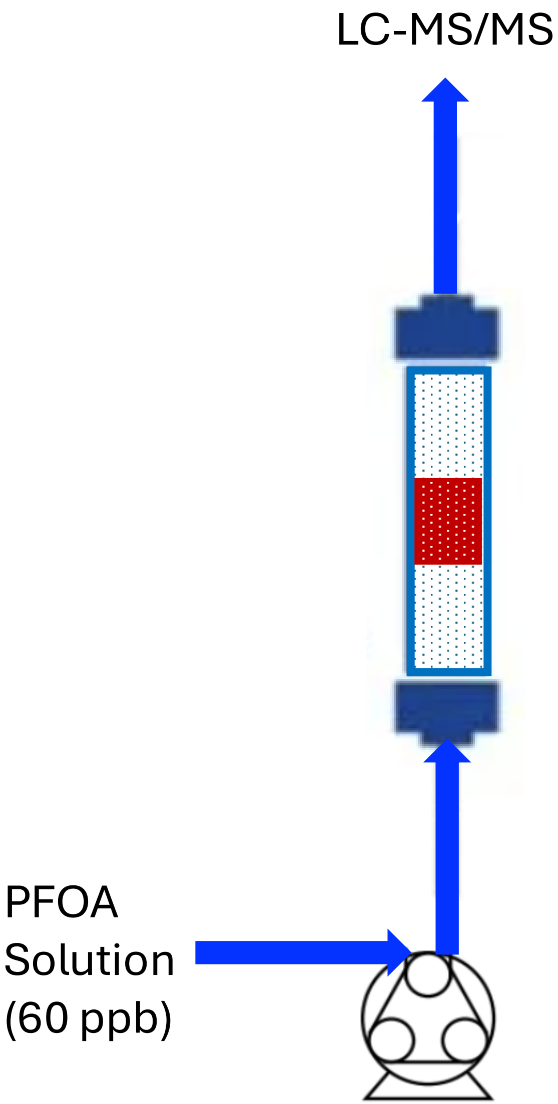

2.0 g Eng Soil
1.0 g WHBC
PFOA (C/Co)
Pore Volume (PV)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8

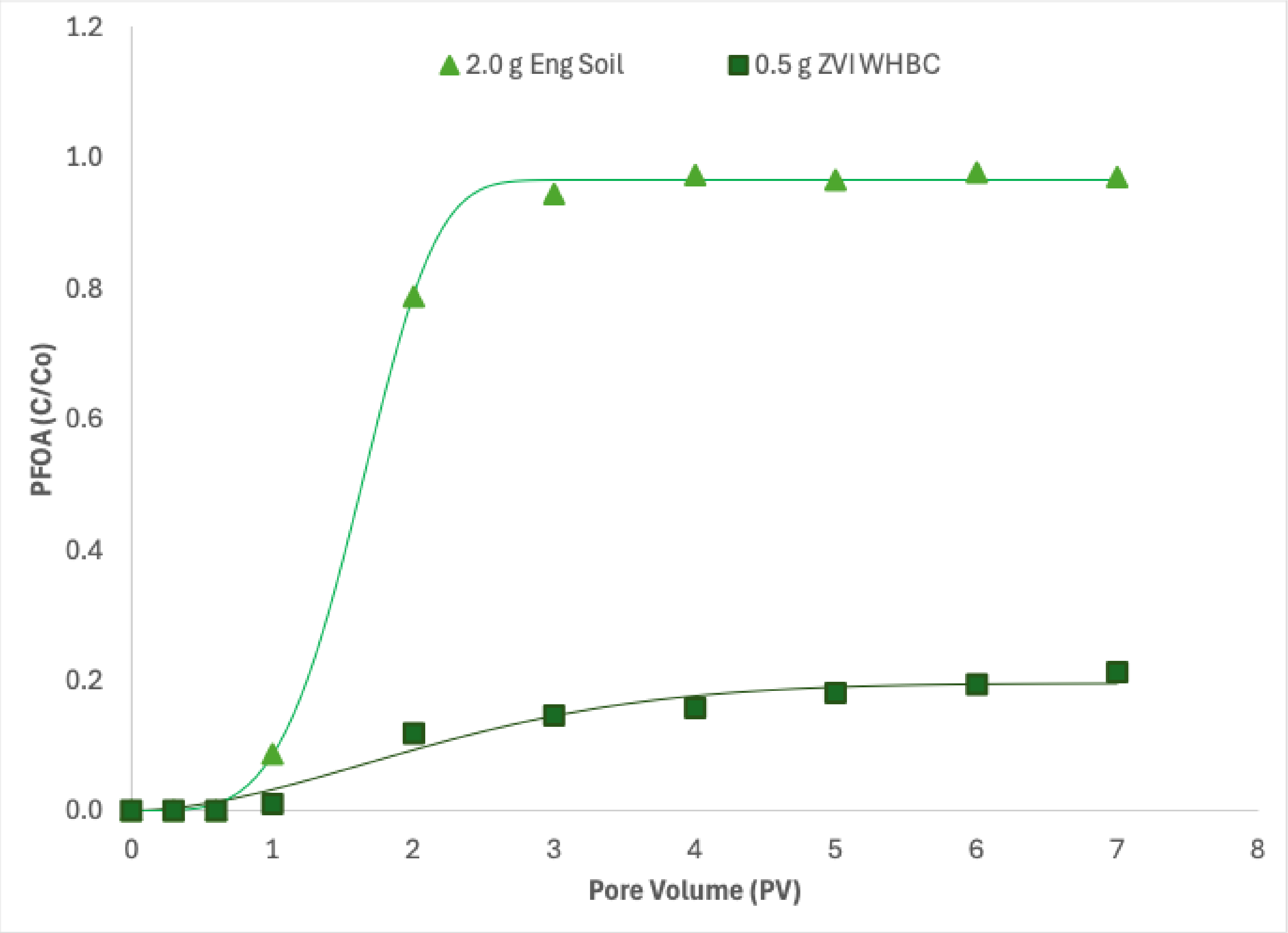
Commercial Activated Carbon?



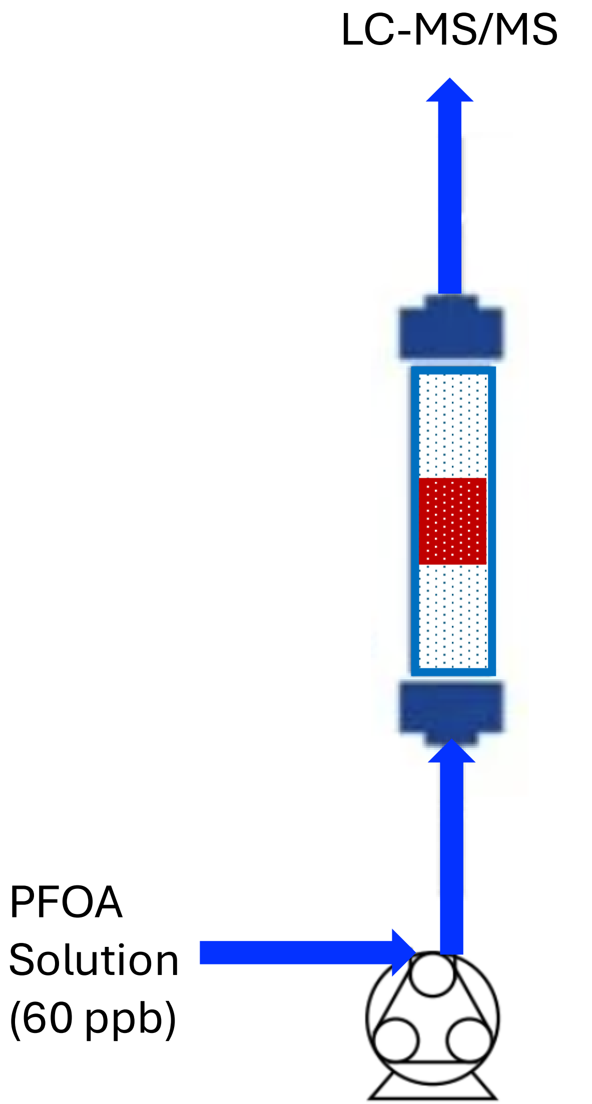


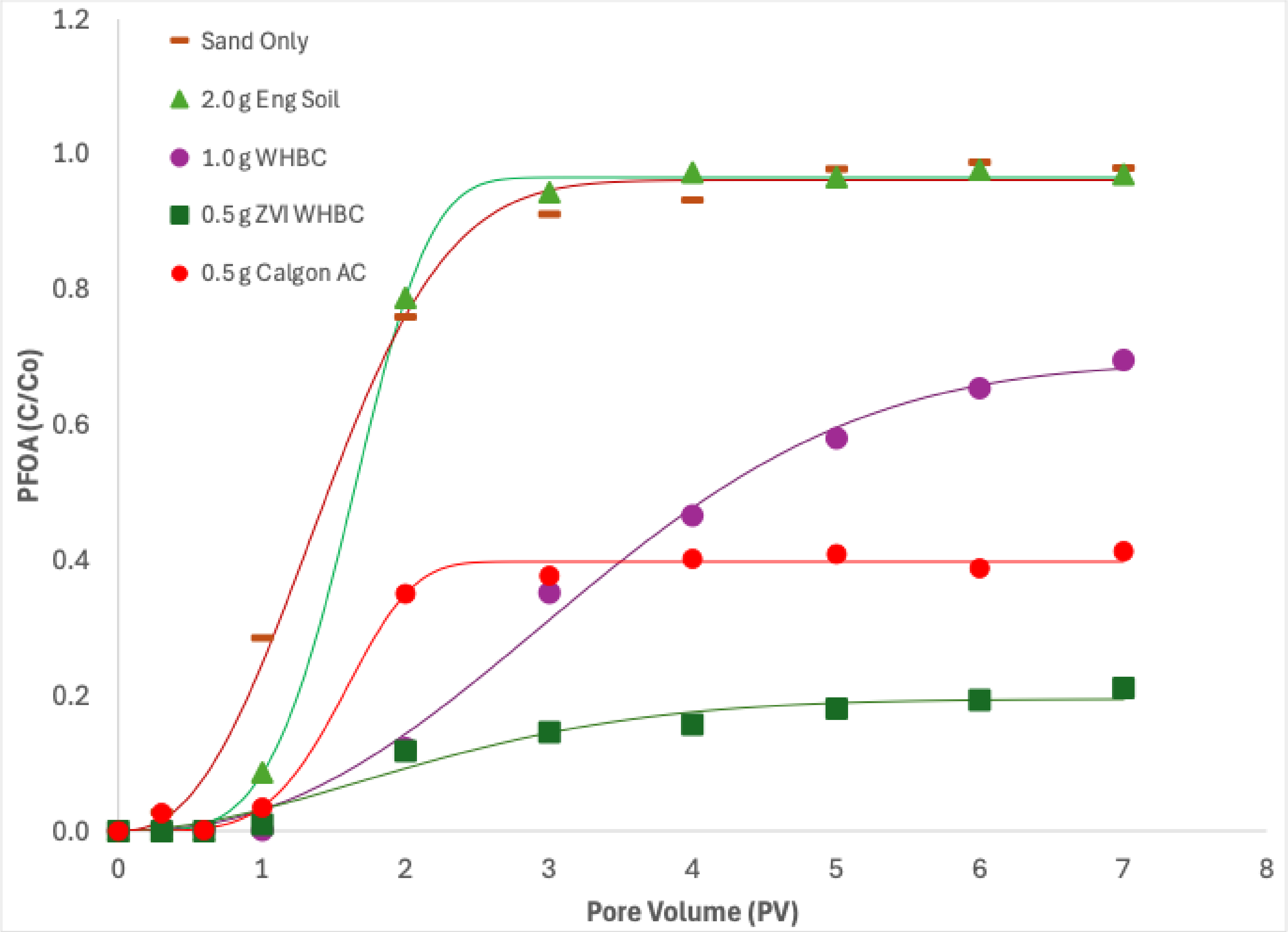
ZVI-Modified WHBC?





Flow-through Column Study

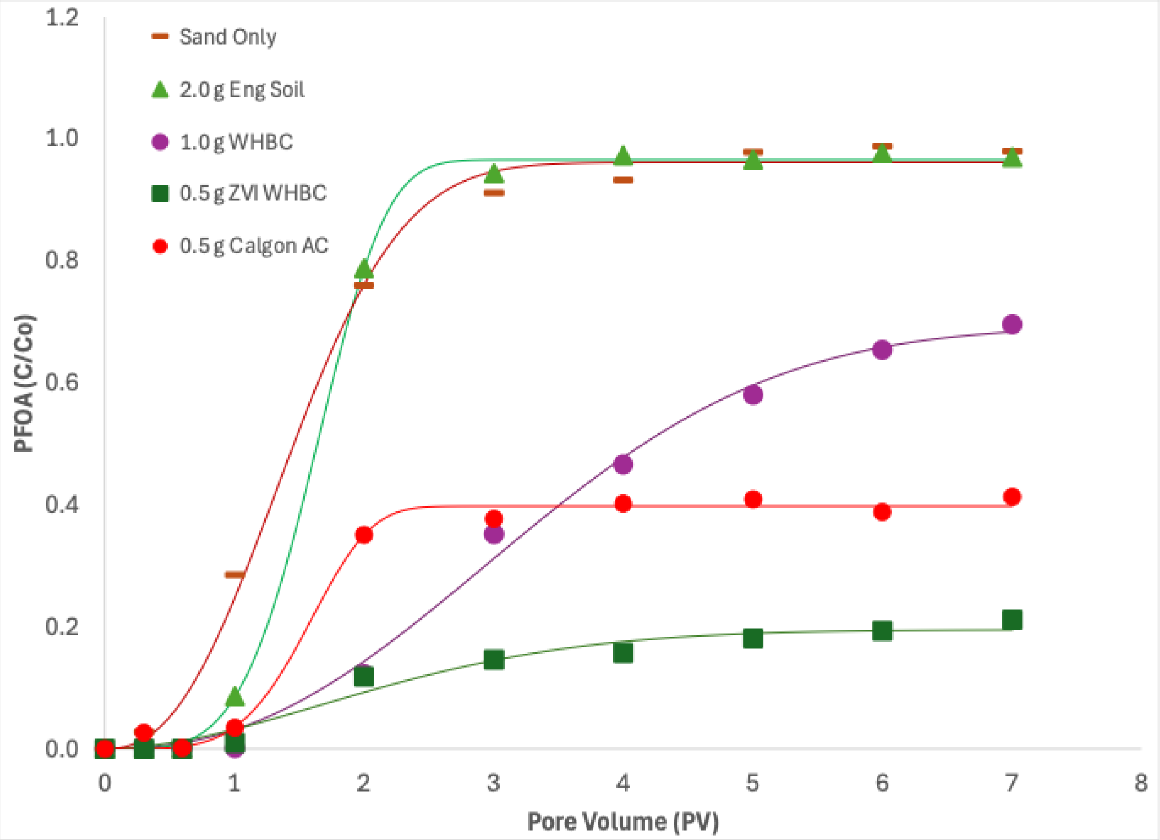




Avrami Equation

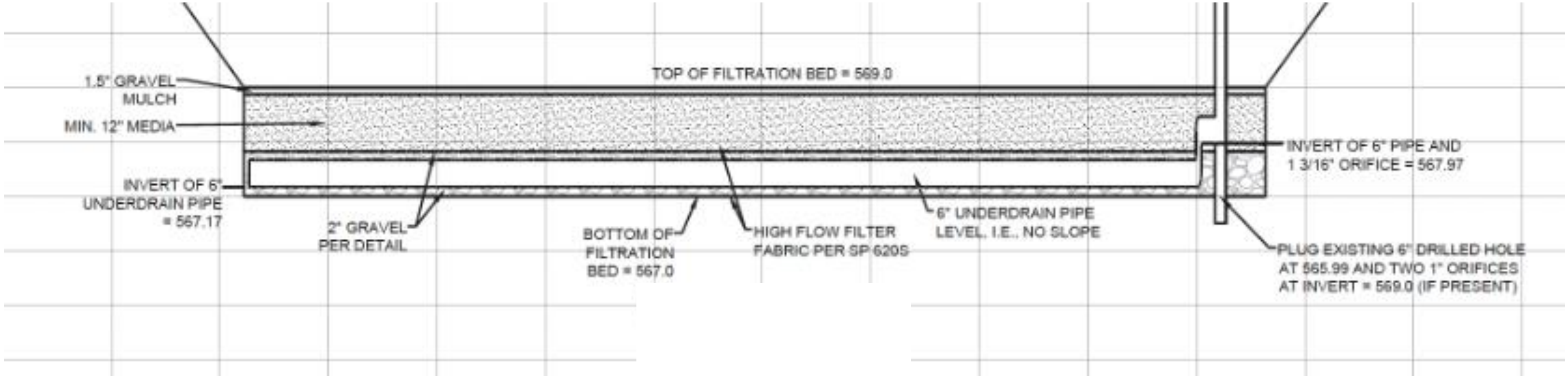
$$\frac{C}{C_o} = 1 - exp(-k \cdot PV^n)$$

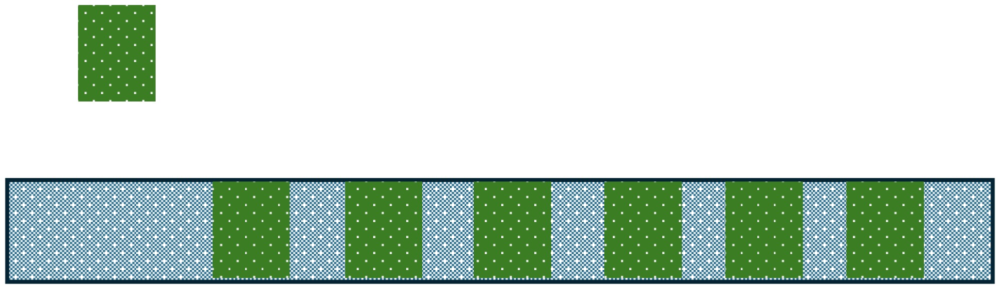
- k = Avrami rate constant (breakthrough rate)
  - Low k → delayed breakthrough (better adsorbent)
  - High k → early breakthrough
- n = Avrami exponent
  - n < 1 → gradual, broad breakthrough
  - n = 1 → exponential-type breakthrough
  - n > 1 → sharp, steep breakthrough



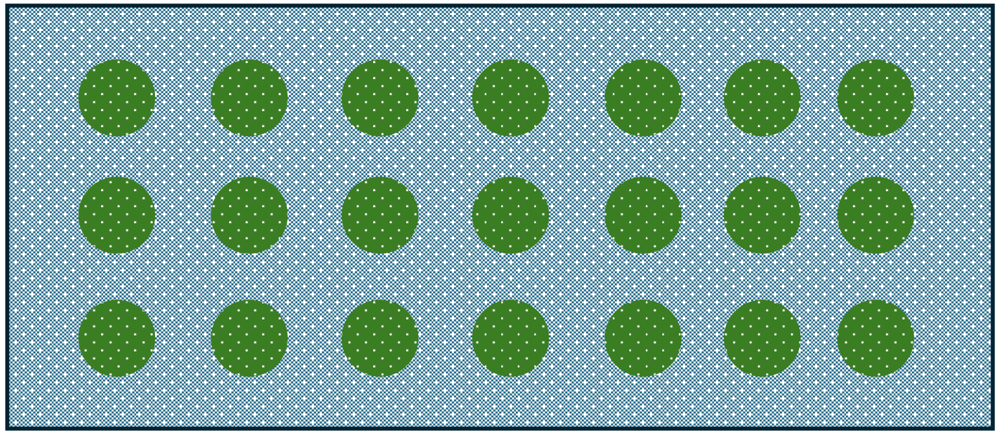
	$\frac{C}{C_o}$	k	n	R^2
Sand	0.962	0.296	2.40	0.994
2 g Engineered Soil	0.966	0.091	4.21	0.999
1 g WHBC	0.693	0.046	2.33	0.999
0.5 g ZVI-WHBC	0.195	0.179	1.84	0.974
0.5 g Calgon Activated Carbon	0.398	0.093	4.51	0.996

Biochar Augmentation?

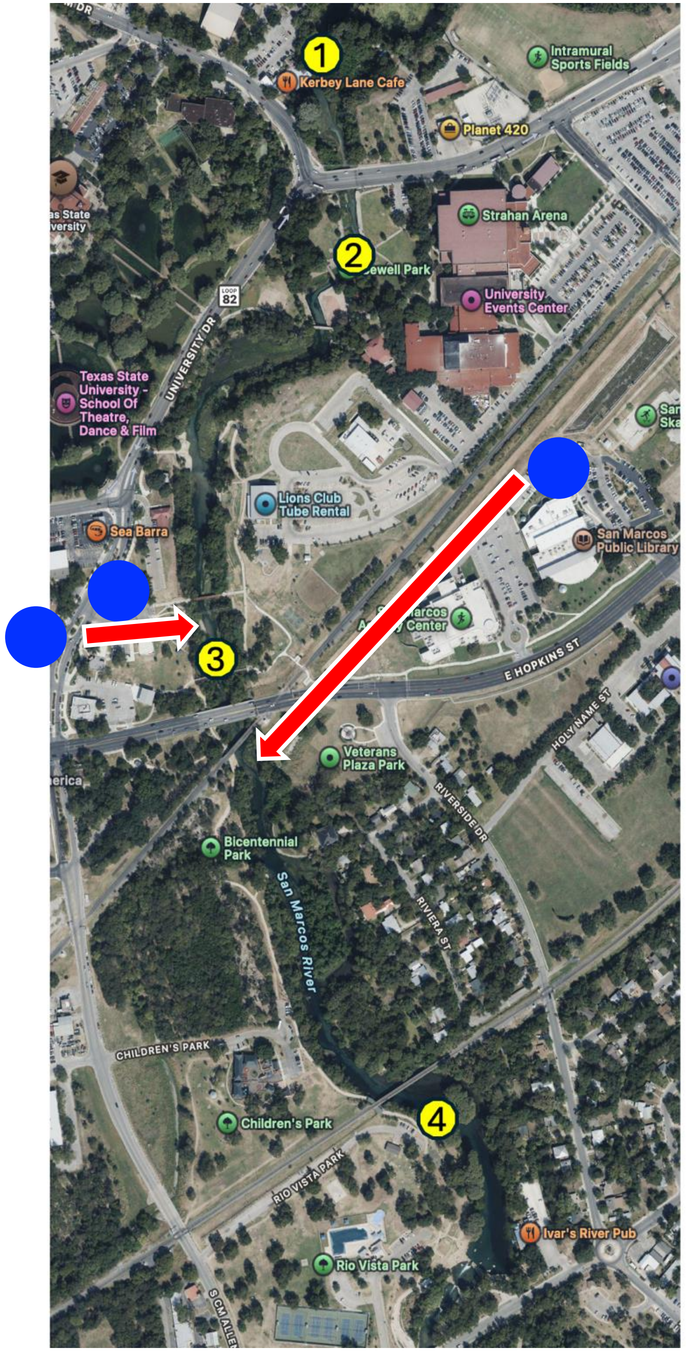




Cross-sectional View



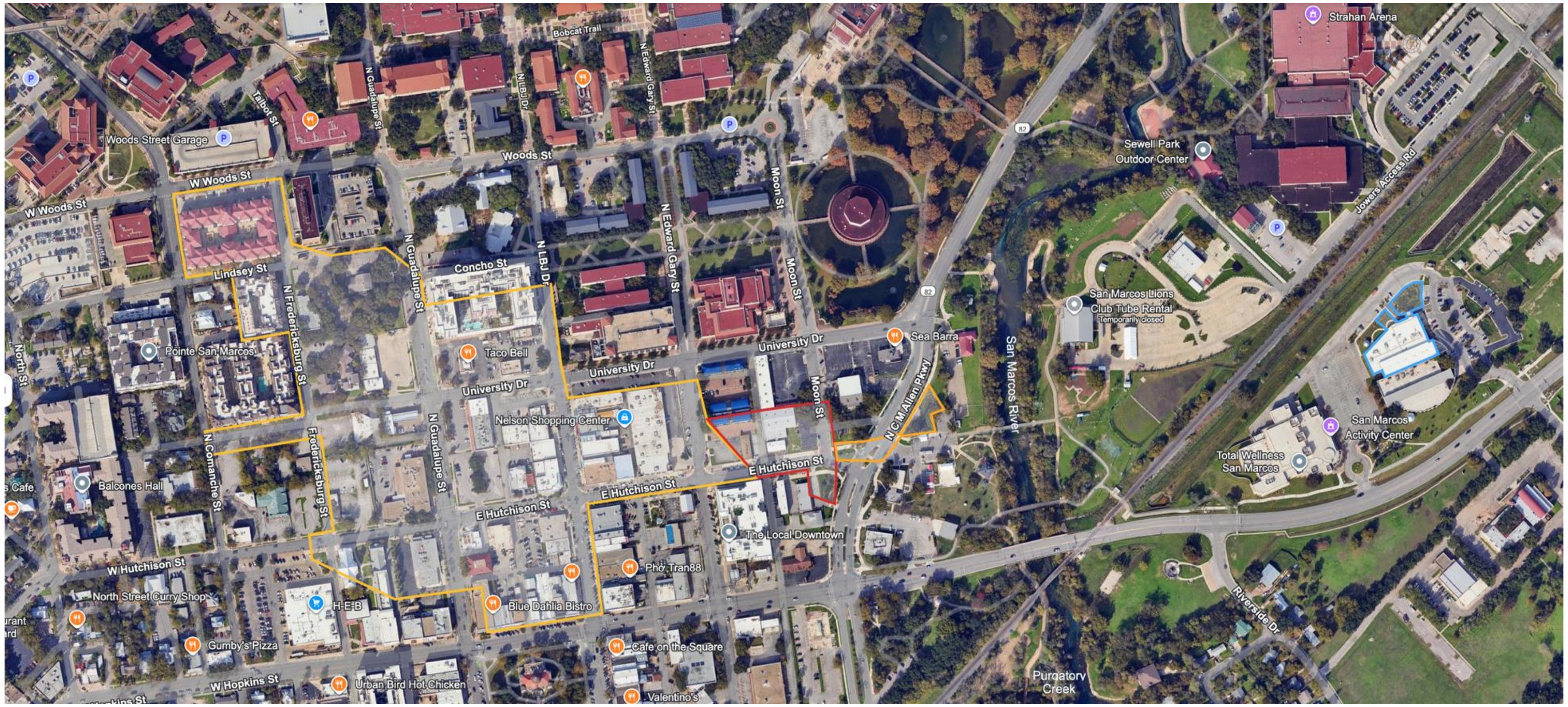
Plan View



PFBA
PFPeA
PFBS
PFHxA
PFHpA
PFHxS
PFOA
PFNA
PFOS
PFDA
PFDS
PFUdA
PFDoA
PFTrDA
PFTeDA
PFHxDA
PFODA

PFAS Source Apportionment

- Ongoing effort to identify and quantify the sources contributing to PFAS levels in the biofiltration basins



Conclusions

- Occurrence of PFAS in the engineered soil of the biofiltration basins (BBs)
  - Much higher PFAS concentration in BBs receiving runoff from complex downtown area
- Poor adsorption of PFOA by BB engineered soil
  - Need to augment/replace with media good at PFAS adsorption
- Promising adsorption of PFOA by biochar derived from water hyacinth
  - Especially, ZVI-modified water hyacinth biochar
  - Possible incorporation into BB engineered soil
- Continuing PFAS source apportionment
  - Identification of key contributors
  - Providing PFAS management guidelines
- Research on enhanced biodegradation (or something) to destruct the adsorbed PFAS in BB engineered soil

Acknowledgement

Funding

- Department of Energy
  - Office of Environmental Management
- Texas State University
  - Division of Research

Collaboration

- City of San Marcos
  - Greg Schwarz & Garrett Johnson
- Texas State University
  - Peyton Austin

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