



MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY

PFAS in Michigan Landfills: A Review

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Mike Jury (EGLE) - Catalyst

Zahra Hooshyar (EGLE Intern) – Painstakingly converting all data into a useable database

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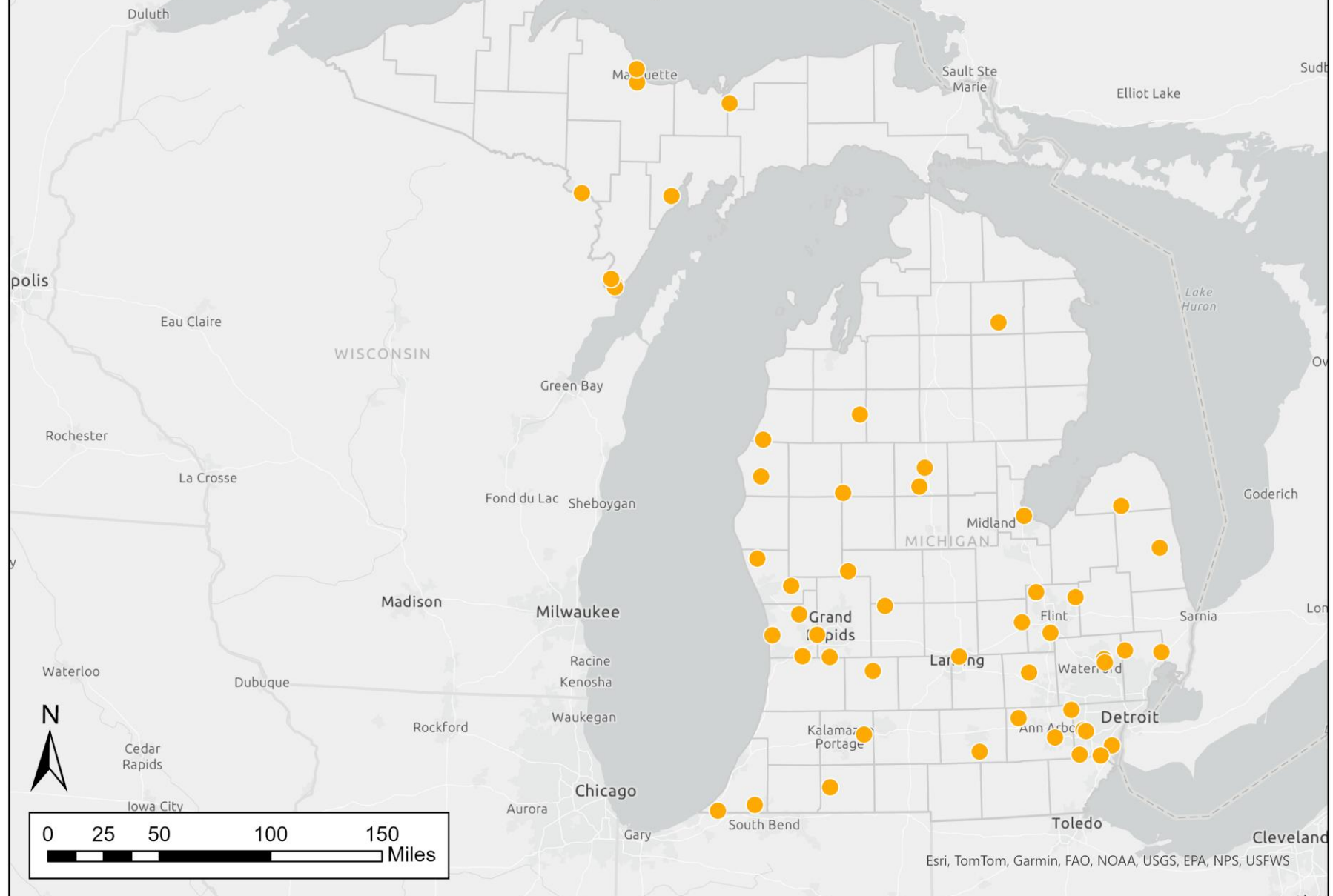
What is Landfill Leachate?

“Landfill leachate, a landfill by-product, is created when rainwater filters through buried wastes in a landfill. The rainwater leaches, or dissolves, constituents that are in those wastes. This process is somewhat similar to the process of making a cup of coffee; the coffee is created when water percolates through the ground coffee beans.”

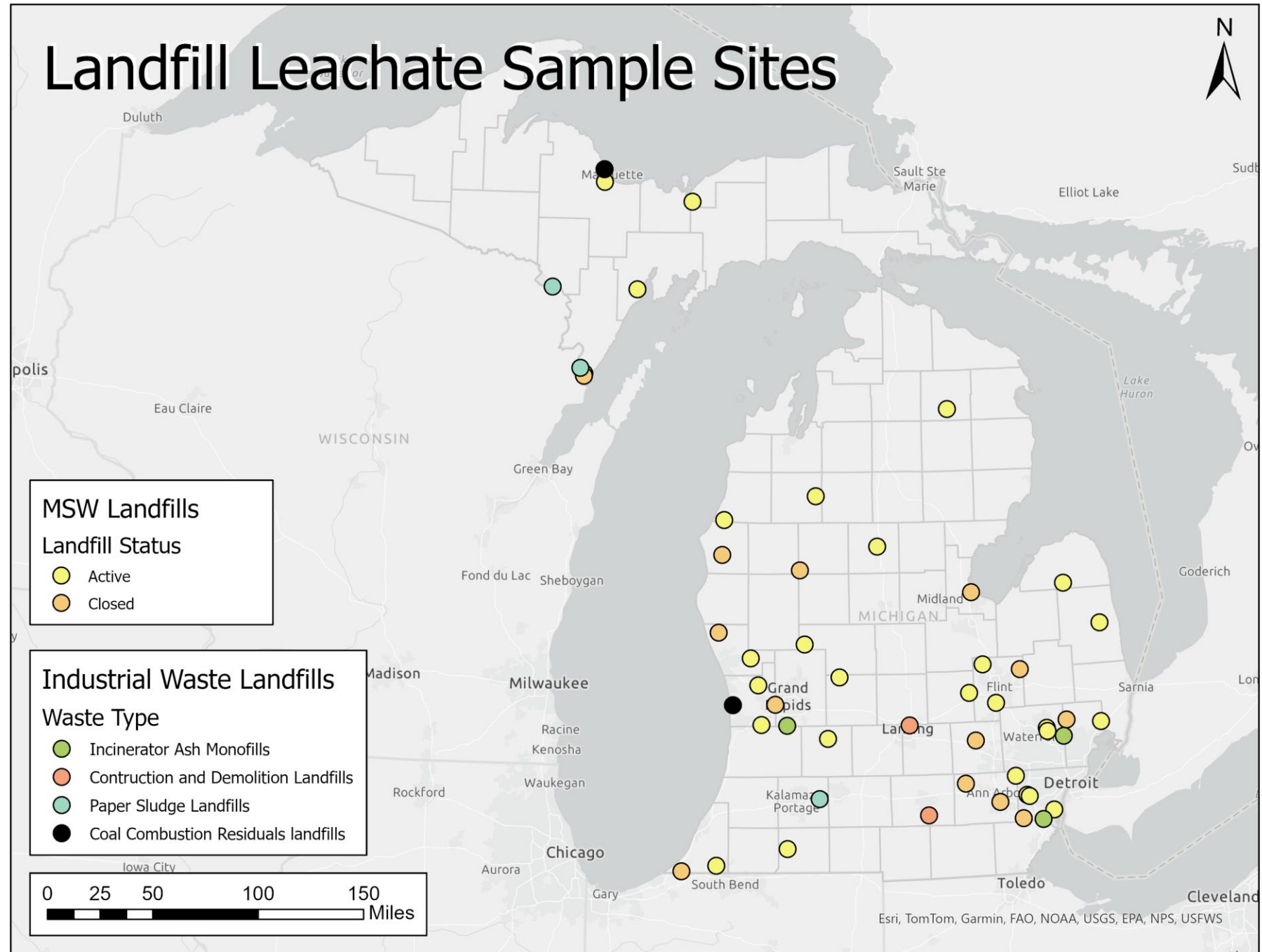
-Fresh Kills Landfill, Staten Island, New York City



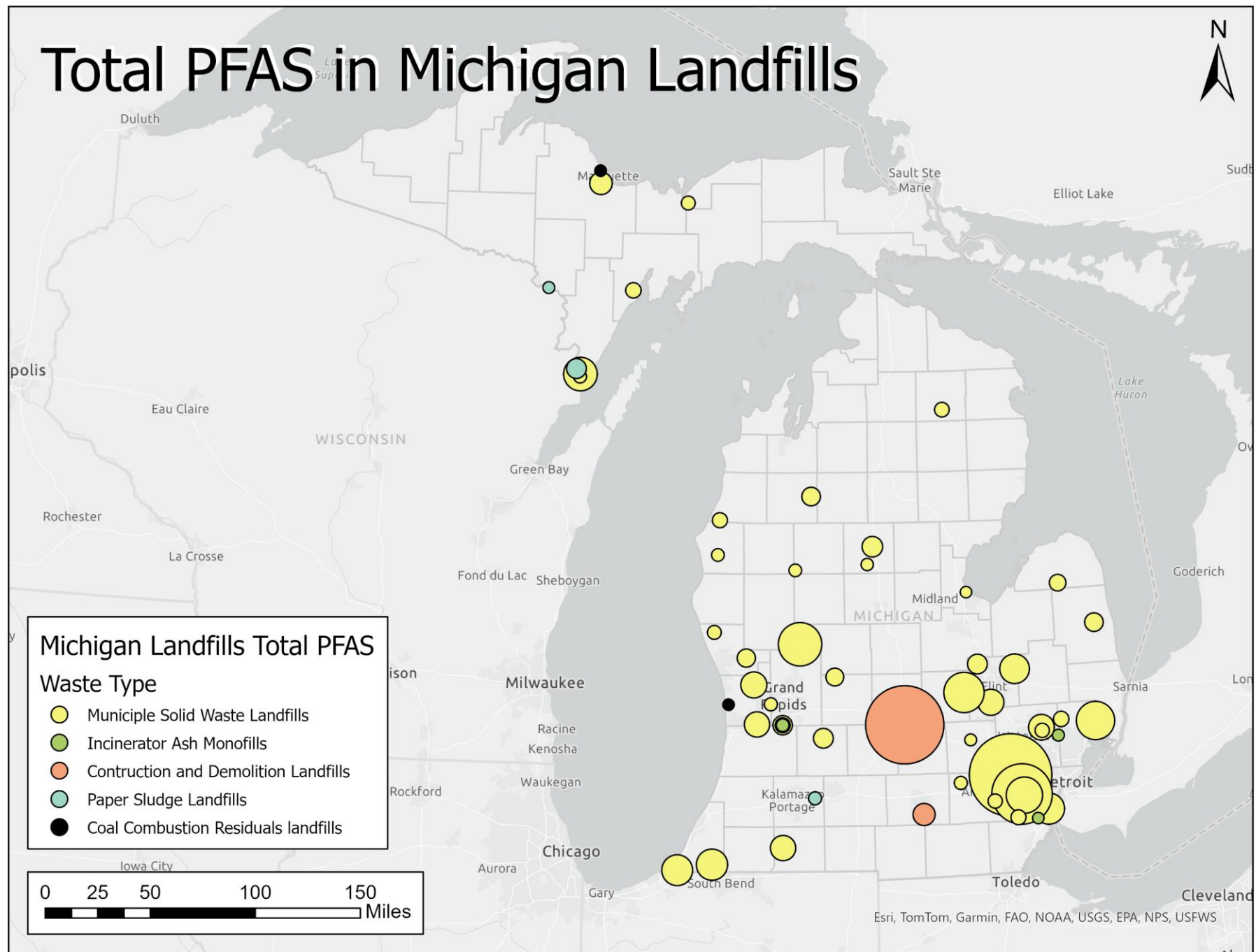
Landfill Leachate Sample Sites



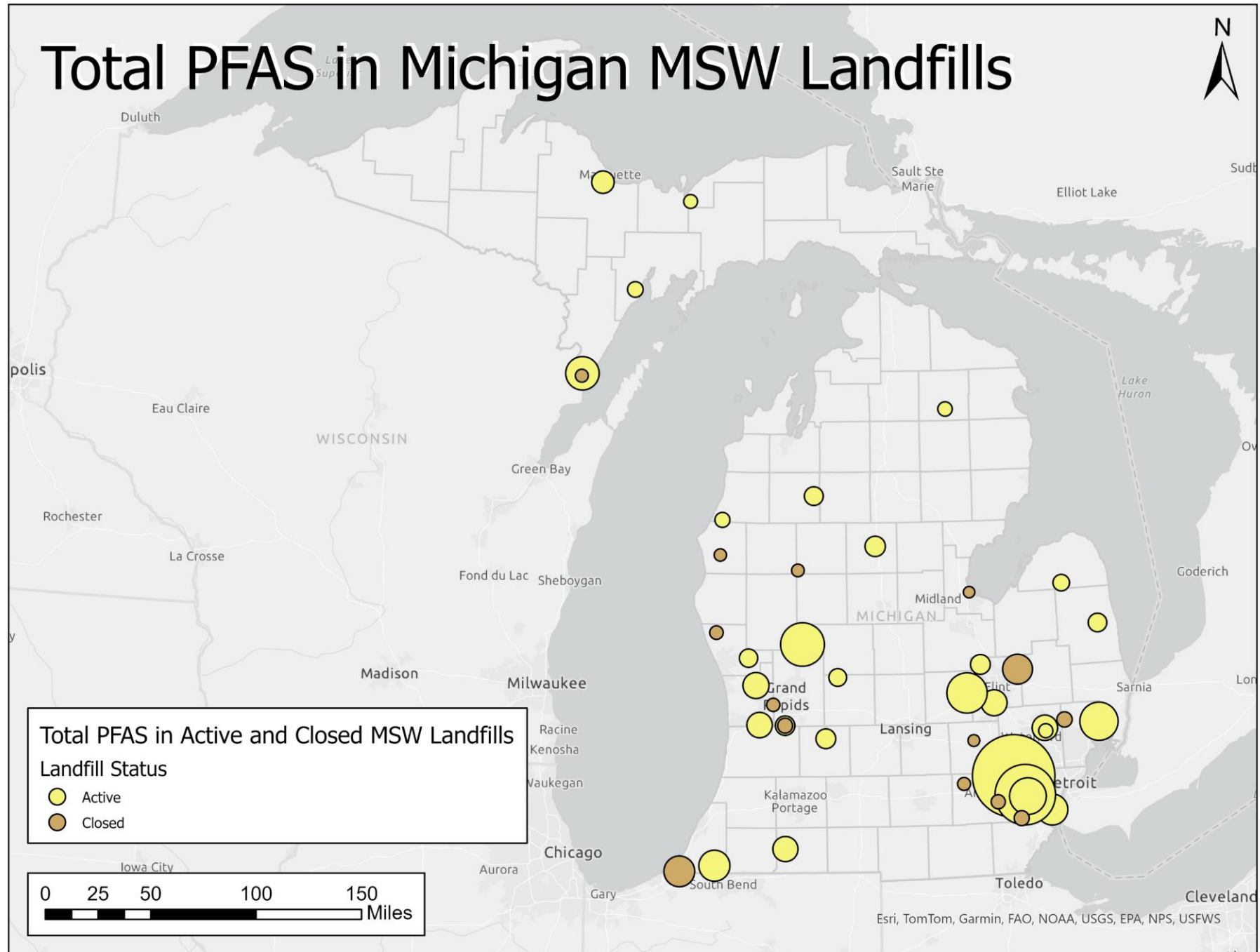
Landfill Leachate Sample Sites



Total PFAS in Michigan Landfills



Total PFAS in Michigan MSW Landfills



What PFAS are Detected in Landfill Leachate?

Landfill Leachate Composition: MSW Landfills

Active MSW Landfills (29)

Analytes	N	Detection Frequency	Minimum	Mean ± Standard Error	Median	Maximum
Perfluoroalkyl Carboxylic Acids						
PFBA	156	95	26	2945 ± 354	1200	18000
PFPeA	156	96	10	1511 ± 232	820	18000
PFHxA	156	100	48	2831 ± 243	1800	18000
PFHpA	156	99	26	664 ± 66	490	6800
PFOA	196	98	53	1214 ± 114	990	20000
PFNA	156	81	1	56 ± 3.6	43	230
PFDA	156	71	4.3	50 ± 6.4	30	460
PFUnA	156	21	1.4	32 ± 20	5.9	640
PFDoA	156	24	1	14 ± 2	9.8	55
PFTTrDA	156	3.2	2.1	4.1 ± 1.3	2.3	8.4
PFTeDA	156	0.6 (N=1)	21			
Perfluoroalkyl Sulfonic Acids						
PFBS	156	97	15	2290 ± 289	635	16000
PFPeS	153	69	4.5	83 ± 11	36	700
PFHxS	156	97	21.8	743 ± 64	561	7600
PFHpS	153	31	2.4	17 ± 3.3	8	110
PFOS	196	95	11	342 ± 38	210	4600
PFNS	151	1.3 (N = 2)	3.3	4.4 ± 1.1	4.4	5.5
PFDS	151	5.2	1.6	12 ± 3.8	8.4	26
Fluorotelomer Sulfonic Acids						
4:2 FTS	153	32	2.7	28 ± 6.3	11	250
6:2 FTS	153	88	16	1440 ± 380	355	31000
8:2 FTS	153	55	1.2	39 ± 5.1	26	380
Perfluorooctane Sulfonamide and Derivatives						
PFOSA	153	28	1.6	13 ± 3.5	7.7	150
NMeFOSA	153	76	9.8	285 ± 53	180	5800
NEtFOSA	153	68	2.8	214 ± 54	180	4800
Total PFAS						
Total PFAS	110	100	1143	16482 ± 1565	10507	93720

Short
Long
Short
Long

Closed MSW Landfills (14)

Analytes	N	Detection Frequency	Minimum	Mean ± Standard Error	Median	Maximum
Perfluoroalkyl Carboxylic Acids						
PFBA	58	79	6.5	439 ± 64	320	2200
PFPeA	58	79	5.5	357 ± 71	195	2500
PFHxA	58	100	5	593 ± 105	365	3700
PFHpA	58	98	6.8	231 ± 44	120	1600
PFOA	58	100	2.1	594 ± 109	309	3700
PFNA	58	72	1.1	21 ± 4.4	8.5	90
PFDA	58	36	0.9	23 ± 6	5.3	82
PFUnA	58	1.7 (N=1)	2.3			
PFDoA	58	3.4 (N=2)	8.5	8.6 ± 0.1	8.6	5.7
PFTTrDA	58	ND				
PFTeDA	58	ND				
Perfluoroalkyl Sulfonic Acids						
PFBS	58	88	2.7	327 ± 149	28	5400
PFPeS	58	79	2.1	22 ± 2.7	17	83
PFHxS	58	98	4.6	223 ± 38	120	1200
PFHpS	58	45	0.49	4.3 ± 0.6	3.3	14
PFOS	58	98	6.4	155 ± 19	120	610
PFNS	58	1.7 (N=1)	2.5			
PFDS	58	ND				
Fluorotelomer Sulfonic Acids						
4:2 FTS	58	15	2.2	10 ± 2	9.9	21
6:2 FTS	58	57	0.58	114 ± 22	50	380
8:2 FTS	58	60	0.19	20 ± 3.1	12	77
Perfluorooctane Sulfonamide and Derivatives						
PFOSA	58	15	2.7	12 ± 4.2	6.1	37
NMeFOSA	58	62	9.5	84 ± 31	21	800
NEtFOSA	58	81	1.1	108 ± 17	74	510
Total PFAS						
Total PFAS	58	100	21.4	2976 ± 576	1500	17907



Landfill Leachate Composition: Industrial Waste Landfills

Construction and Demolition Landfills (ng/L)

Landfill Status	Collection Time	PfTeDA - P	PfTrDA - P	PfDoA - P	PfUnA - P	PfDA - P	PfNA - P	PfOA - P	PfHpA - P	PfHxA - P	PfPeA - P	PfBA - P	PfDS - P	PfNS - P	PfOS - P	PfHpS - P	PfHxS - P	PfPeS - P	PfBS - P	PfOSA - P	8:2 FTS - F	6:2 FTS - F	4:2 FTS - F	N EtFOSA	NMeFOSA	HFPO-DA	11Cl-PF3C	9Cl-PF3O	ADONA - 4
Closed Landfill	7/1/2021	<2	<2	2	20	435	422	2515	1195	2345	1565	408	5	<2	2890	52	674	91	140	168	154	166	<2	902	3495	<2	<2	<2	<2
	6/28/2022	<2.0	<2.0	<2.0	5.3	170	320	5800	2400	4080	27000	730	<2.0	<2.0	1300	47	1400	180	220	59	58	390	9.6	340	1400	<2.0	<2.0	<2.0	<2.0
	6/7/2024	<2	<2	40.3	178	<2	2450	10200	2440	3060	1900	633	82.1	<2	7330	298	2470	204	211	597	562	1070	6.78	10600	16300	<2	<2	<2	<2
Active Landfill	7/23/2019	<12	<12	<12	<12	<12	38	1400	660	2500	500	170	<12	<12	250	<12	1000	68	2700	<12	<25	330	21	20	80				
	7/23/2019	<1.2	<1.2	<1.2	<1.2	11	27	610	340	1000	930	800	<1.2	<1.2	150	6.4	300	49	900	2.9	4.2	110	2.9	4.1	29				
	7/23/2019	<1.2	<1.2	<1.2	<1.2	2.7	8.5	360	180	540	340	440	<1.2	<1.2	73	2.2	310	32	100	<1.2	<7.5	46	3.9	2.3	12				

Incinerator Ash Monofills (ng/L)

Landfill Status	Collection Time	PfTeDA - P	PfTrDA - P	PfDoA - P	PfUnA - P	PfDA - P	PfNA - P	PfOA - P	PfHpA - P	PfHxA - P	PfPeA - P	PfBA - P	PfDS - P	PfNS - P	PfOS - P	PfHpS - P	PfHxS - P	PfPeS - P	PfBS - P	PfOSA - P	8:2 FTS - F	6:2 FTS - F	4:2 FTS - F	N EtFOSA	NMeFOSA	HFPO-DA	11Cl-PF3C	9Cl-PF3O	ADONA - 4
Closed Landfill	6/12/2018	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1	<21	<21	<21	<21	<21	<21			
	2/5/2020	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8	5	1.8	4.2	5.8	10	<1.8	<1.8	<1.8	<1.8	2.4	<1.8	<1.8	5	<18	<18	<18	<18	<18				
Closed Landfill	12/10/2019	<20	<20	<10	<10	<10	<10	32	<10	30	14	43	<10	<10	62	<10	19	<10	23	<10	<10	<10	<10	<20	<10				
	3/4/2020	<10	<10	<10	<10	<10	<10	37	11	30	11	<10	<10	<10	80	<10	51	<10	<10	<10	<10	<10	<10	<10	<10				
Active Landfill	1/16/23	<1	<1	<1	<1	<1	1.3	100	37	270	100	120	<1	<1	17	<1	48	5.7	130	1.1	<1	10	<1	<1	<1	1.1	<1	<1	<1
	10/18/2023	<9	<9	<9	<9	<9	<4	100	31	200	94	150	<9	<9	16	<4	54	5.7	130	<8	<4	6.1	<4	<18	<18	<4	<8	<8	<4

Paper Waste Landfills (ng/L)

Landfill Status	Waste Type	Collection Time	PfTeDA - P	PfTrDA - P	PfDoA - P	PfUnA - P	PfDA - P	PfNA - P	PfOA - P	PfHpA - P	PfHxA - P	PfPeA - P	PfBA - P	PfDS - P	PfNS - P	PfOS - P	PfHpS - P	PfHxS - P	PfPeS - P	PfBS - P	PfOSA - P	8:2 FTS - F	6:2 FTS - F	4:2 FTS - F	N EtFOSA	NMeFOSA	HFPO-DA	11Cl-PF3C	9Cl-PF3O	ADONA - 4
Closed Landfill	Paper Pulp	6/25/2019	<2.07	<2.07	<2.07	<2.07	<2.07	<2.07	5.57	5.29	20.5	22.6	15.4	<2.07	<2.07	77	<9.7	25	<9.7	31	<9.7	<9.7	200	<9.7	100	28	<9.7	<9.7	<9.7	<9.7
Closed landfill	Paper Pulp - Deinked	5/18/2020	<9.7	<9.7	<9.7	<9.7	<9.7	94	1000	480	2000	560	2800	<9.7	<9.7	16.9	<1.93	3.52	<1.93	<1.93	<1.93	<1.93	14.2	<1.93	6.1	<1.93	<1.93	<1.93	<1.93	<1.93
Closed Landfill	Paper Sludge	10/12/2022	<1.9	<1.9	<1.9	<1.9	3.1	34.2	336	218	743	186	270	<1.9	<1.9	27.1	<1.9	6.7	2.5	3	<1.9	1.9	25.8	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9
		5/18/2023	<52.9	<52.9	<52.9	<52.9	<52.9	<52.9	277	177	589	148	150	<51.1	<50.8	<48.9	<50.3	<48.2	<49.7	<46.8	<52.9	<51.1	<50.3	<49.5	<52.9	<52.9	<52.9	<49.7	<49.2	<50
Active Landfill	Paper Sludge	8/8/2019	<20	5.5	<20	<20	<20	<20	53	<20	48	24	31	<20	<20	11	<20	<20	45	<20	<20	1.2	20	<20	2.8	<20				

Coal Combustion Residuals Landfills (ng/L)

Landfill Status	Collection Time	PFTeDA - P	PFTrDA - P	PFTDoA - P	PFTUnA - P	PFTDA - P	PFTNA - P	PFTOA - P	PFTHpA - P	PFTHxA - P	PFTPeA - P	PFTBA - P	PFTDS - P	PFTNS - P	PFTOS - P	PFTHpS - P	PFTHxS - P	PFTPeS - P	PFTBS - P	PFTOSA - P	8:2 FTS - F	6:2 FTS - F	4:2 FTS - F	N EtFOSA	NMeFOSA	HFPO-DA	11Cl-PF3C	9Cl-PF3O	ADONA - 4
Closed Landfill	5/25/2022	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	6.7	1.0	5.6	0.7	4.6	<1.9	<1.9	2.3	<1.9	<1.8	<1.8	2.7	<1.2	0.9	29	<1.8	<2.0	<2.0	<2.0	<1.9	<1.8	<1.9
	5/25/2022	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	1	1.0	1.7	0.8	3.9	<1.9	<1.9	<1.8	<1.8	<1.8	<1.8	<1.7	<1.9	<1.9	3.8	<1.8	<1.9	0.58	<1.9	<1.9	<1.8	<1.8
Active Landfill	7/15/2021	<.37	<.48	<.59	<.77	<.64	<.80	1.1	0.91	1.1	1.1	2.1	<.53	<.64	<.43	<.57	<.53	<.73	<.47	<.81	<.75	<.59	<.69	<1.4	<1.2	<.85	<.52	<.56	<.31
	7/15/2021	<.37	<.48	<.59	<.77	<.64	<.80	3.4	1.5	1.9	2.8	7.2	<.53	<.64	2.4	<.57	0.98	<.73	1	<.81	<.75	<.59	<.69	<1.4	<1.2	<.85	<.52	<.56	<.31

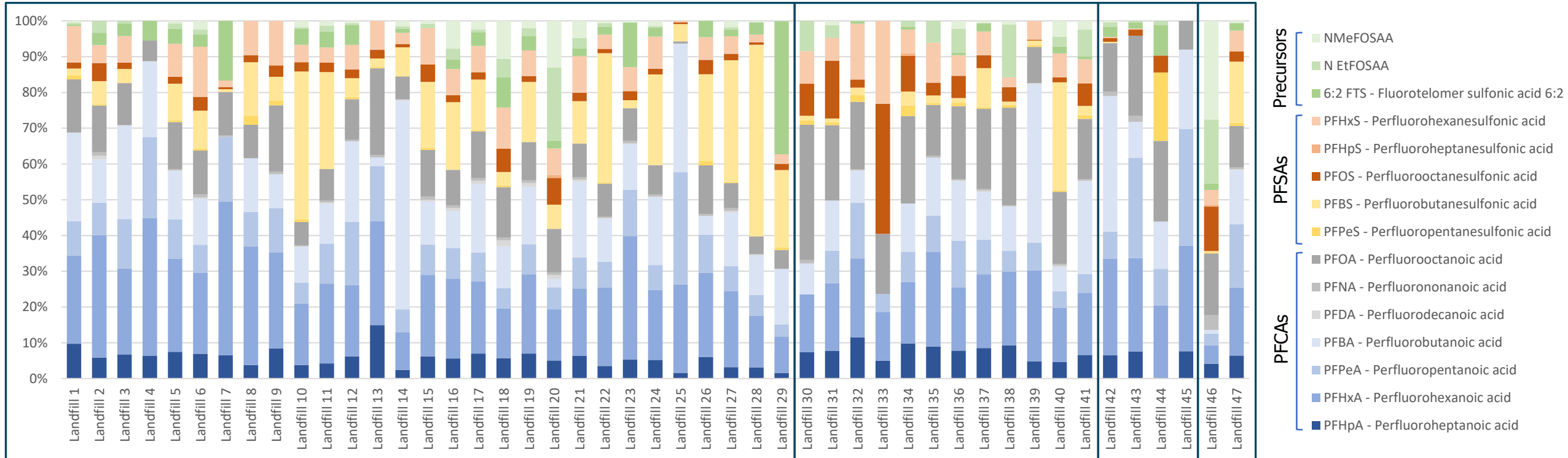


Landfill Leachate PFAS Distribution

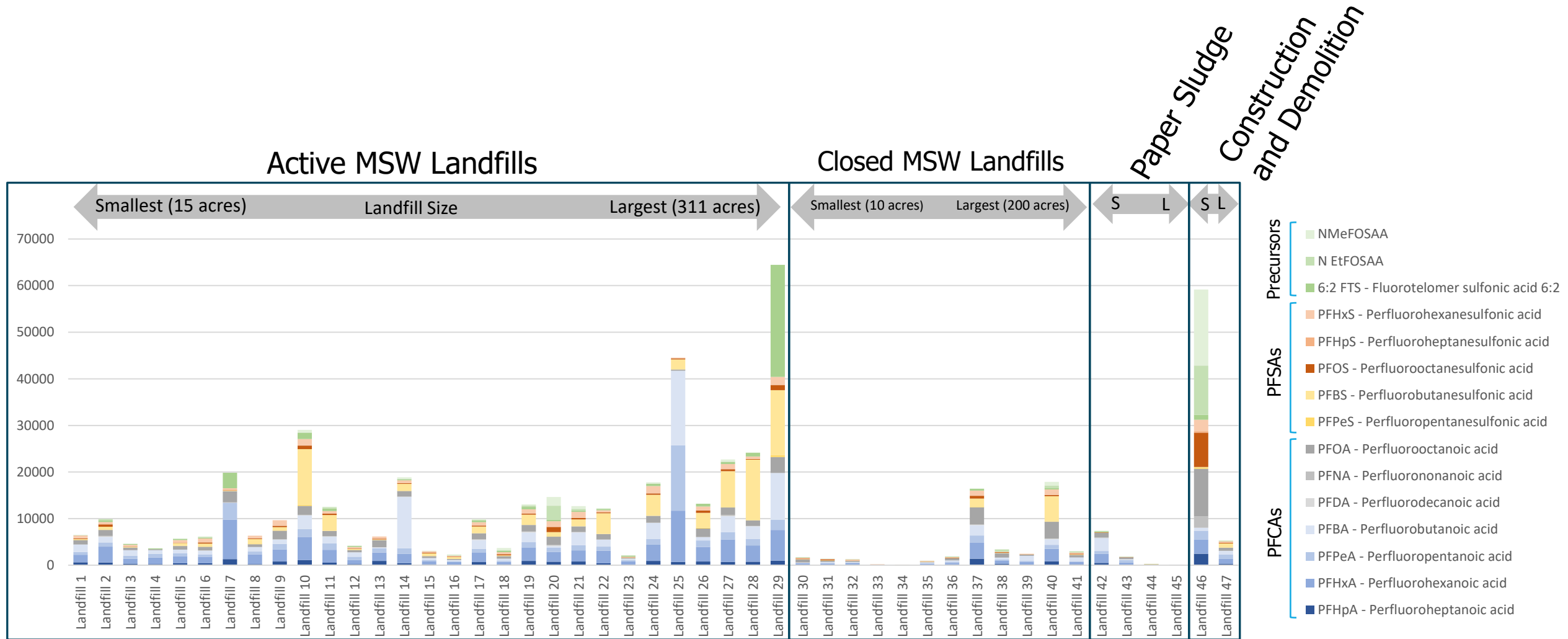
Active MSW Landfills

Closed MSW Landfills

Paper Sludge
Construction
and Demolition



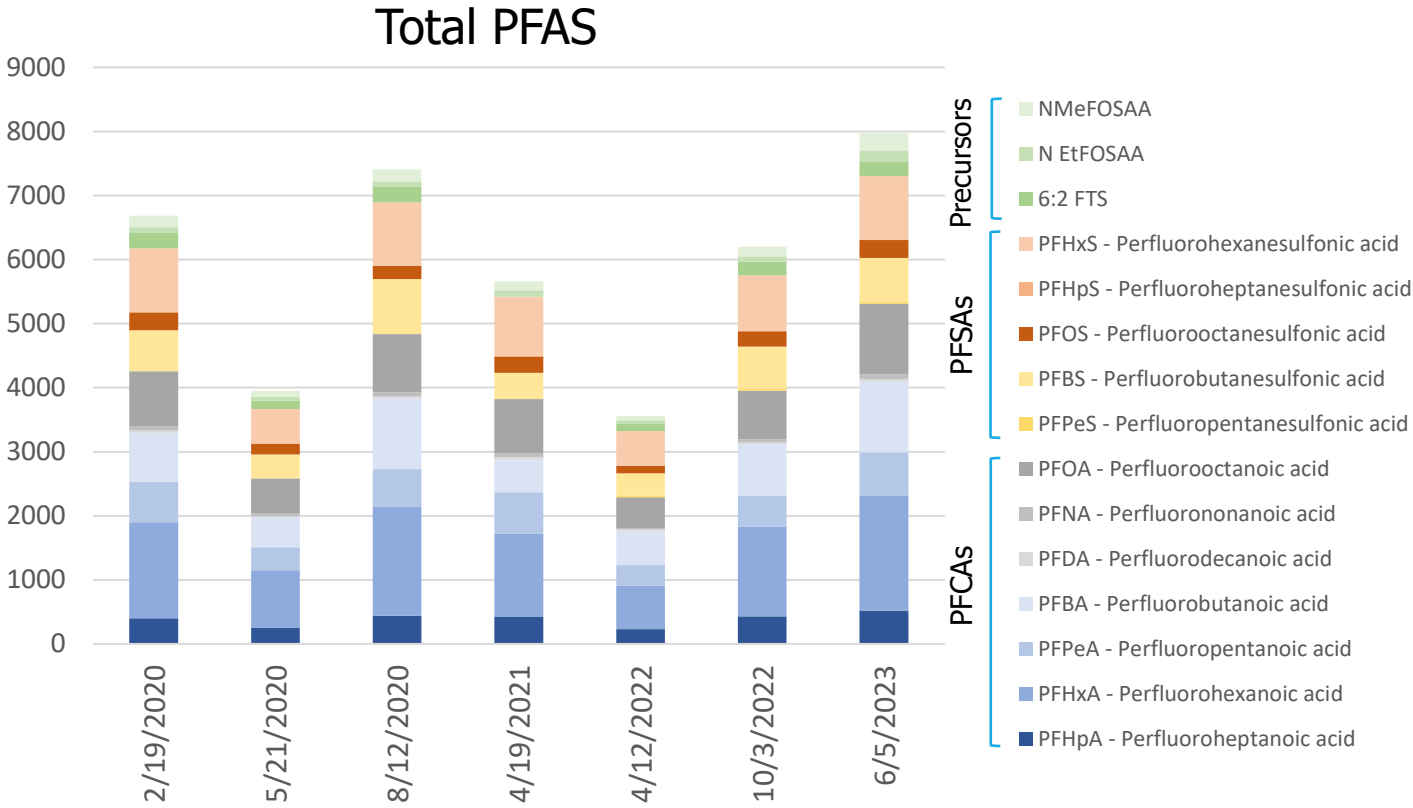
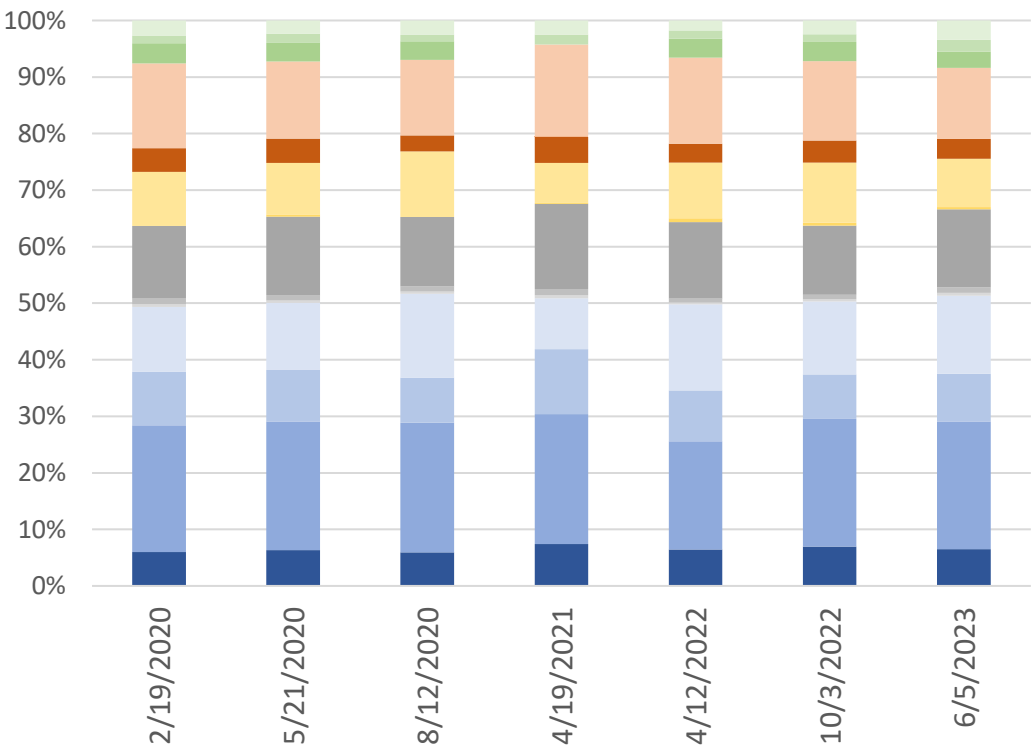
Landfill Leachate PFAS Distribution By Landfill Size



How does the PFAS Distribution in Landfill Leachate Change in Active Landfills?

Stable MSW Landfill Leachate PFAS Distribution

Landfill 6 (Active)

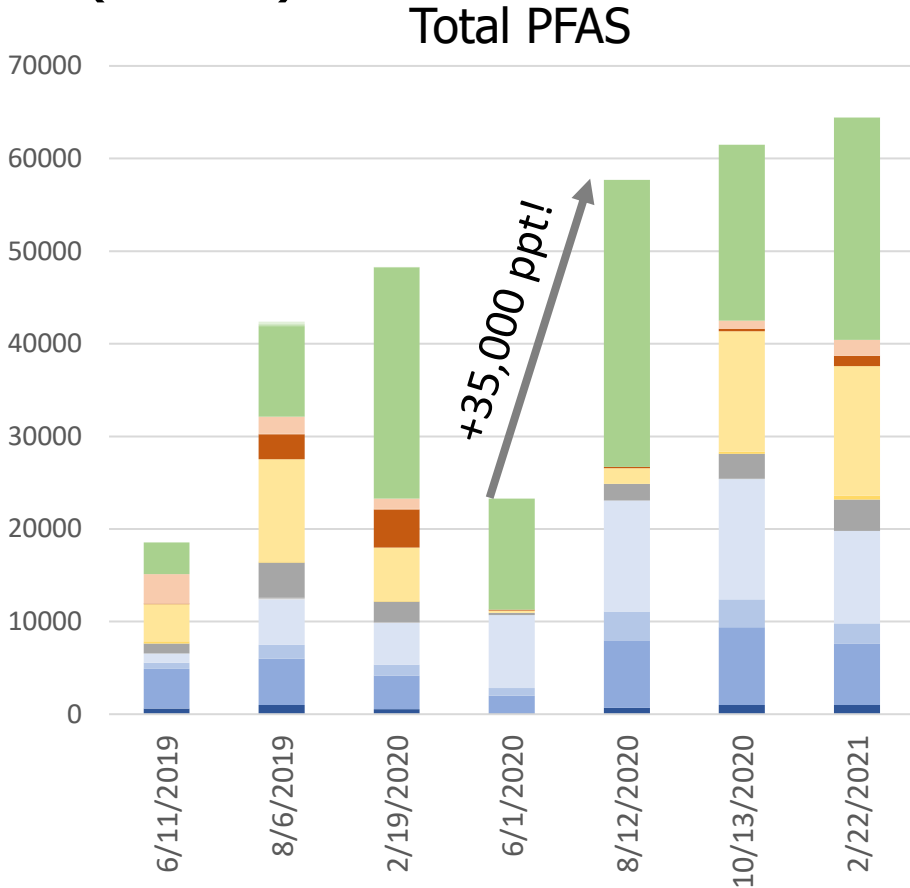
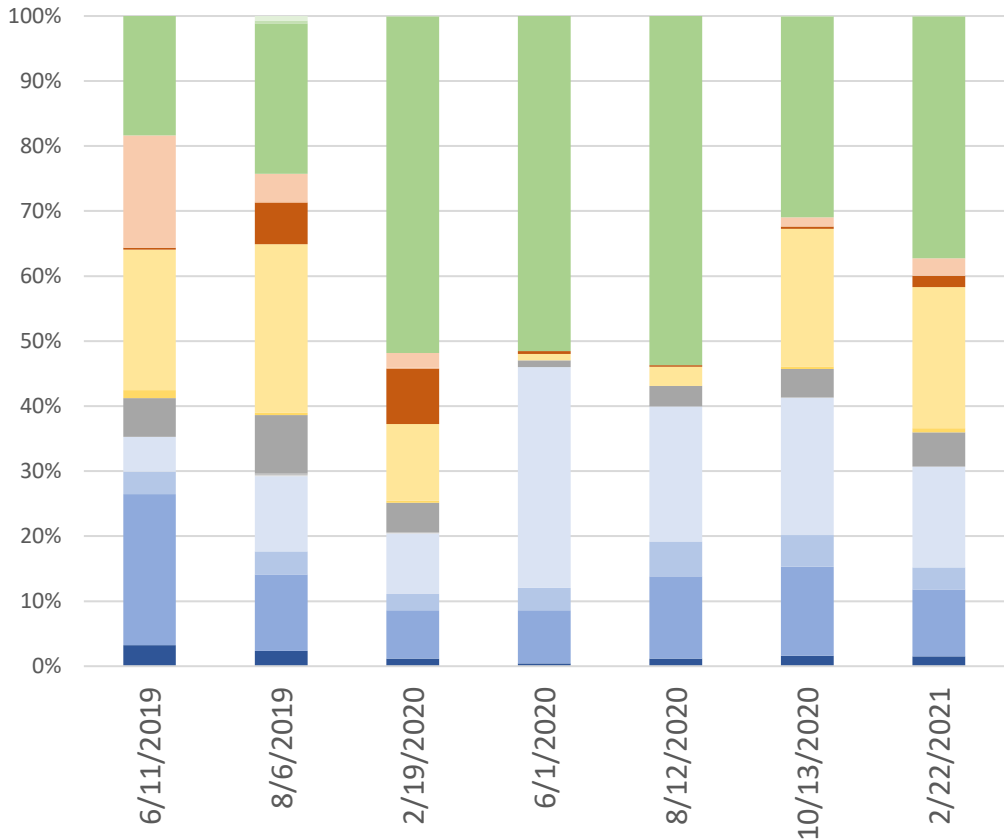


Data shown in ng/L



Unstable MSW Landfill Leachate PFAS Distribution

Landfill 29 (Active)



- Precursors**
 - NMeFOSAA
 - N EtFOSAA
 - 6:2 FTS
- PFSAs**
 - PFHxS - Perfluorohexanesulfonic acid
 - PFHpS - Perfluoroheptanesulfonic acid
 - PFOS - Perfluorooctanesulfonic acid
 - PFBS - Perfluorobutanesulfonic acid
 - PFPeS - Perfluoropentanesulfonic acid
- PFCAs**
 - PFOA - Perfluorooctanoic acid
 - PFNA - Perfluorononanoic acid
 - PFDA - Perfluorodecanoic acid
 - PFBA - Perfluorobutanoic acid
 - PFPeA - Perfluoropentanoic acid
 - PFHxA - Perfluorohexanoic acid
 - PFHpA - Perfluoroheptanoic acid

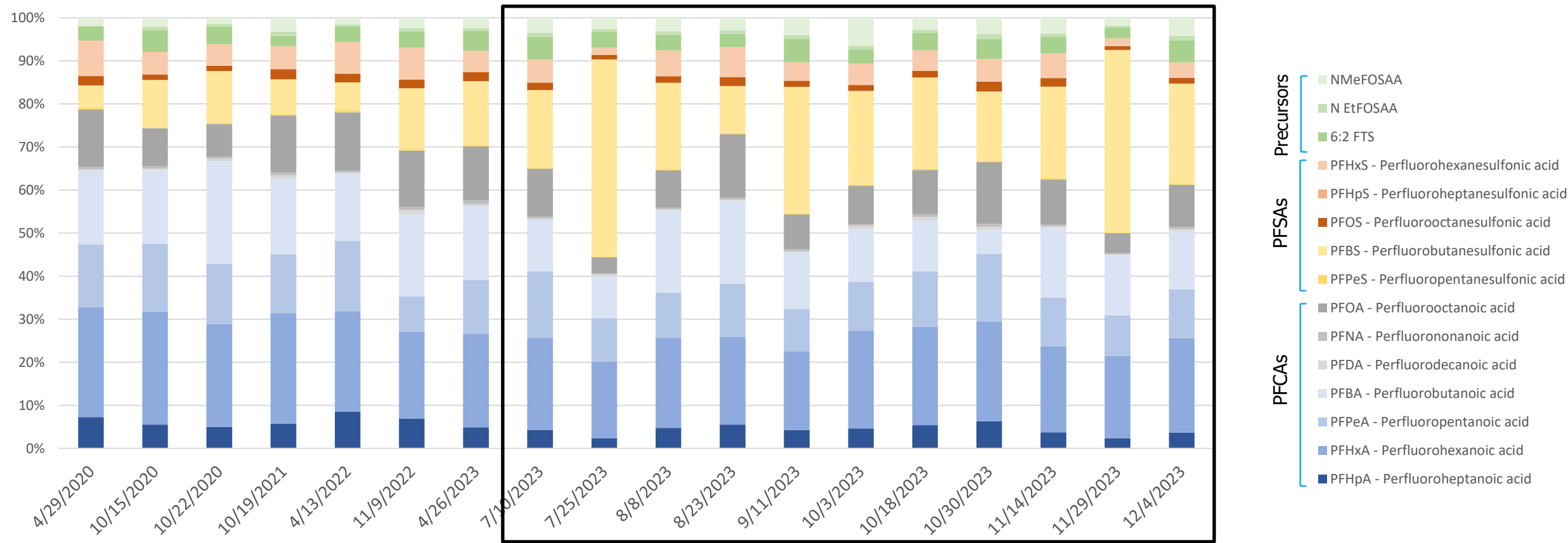
Data shown in ng/L



Total PFAS Variability at Active landfills

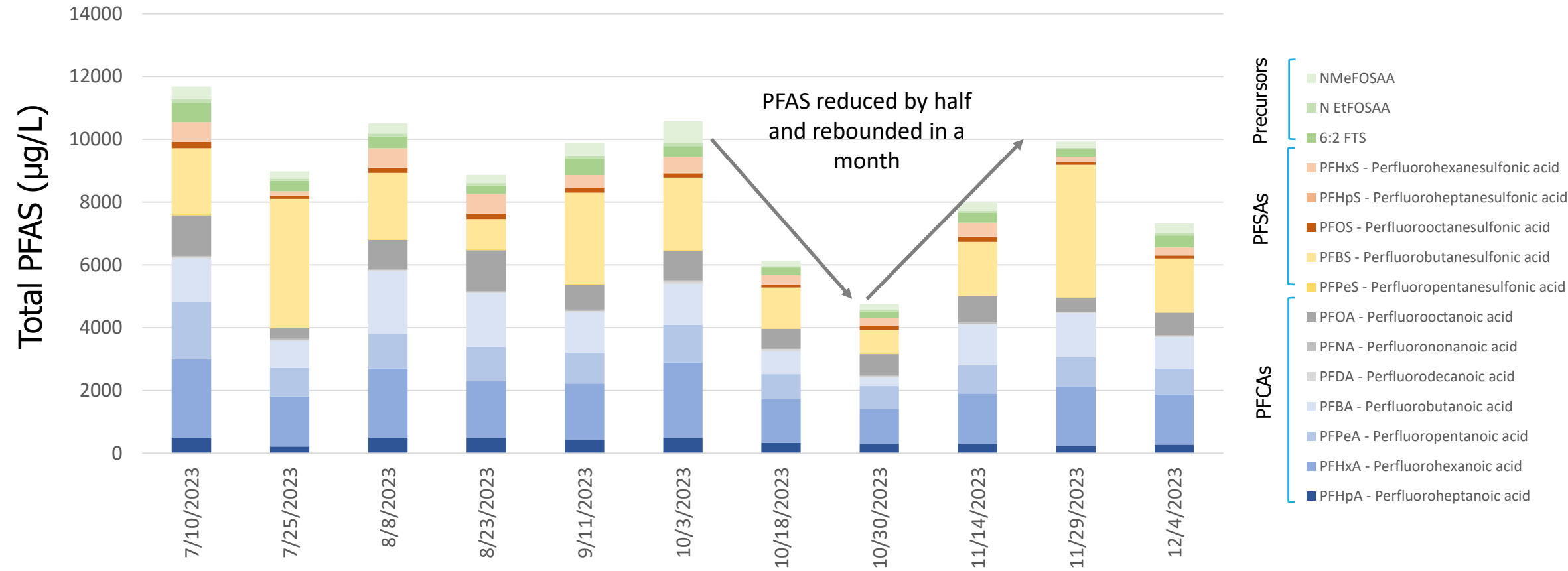
MSW Landfill Leachate PFAS Variability

Landfill 17: MSW Active Landfill



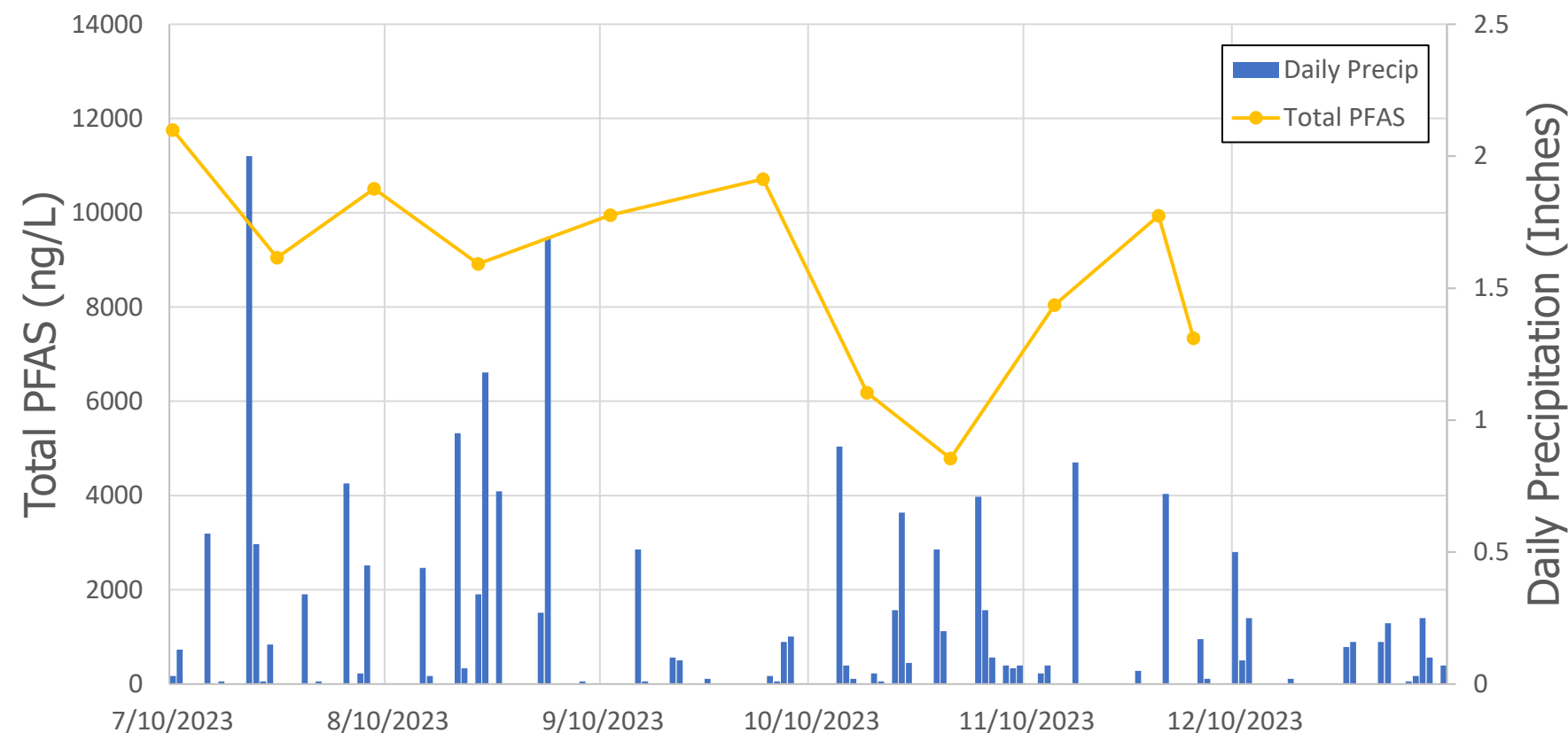
MSW Landfill Leachate PFAS Variability

Landfill 17: MSW Active Landfill



MSW Landfill Leachate PFAS Variability

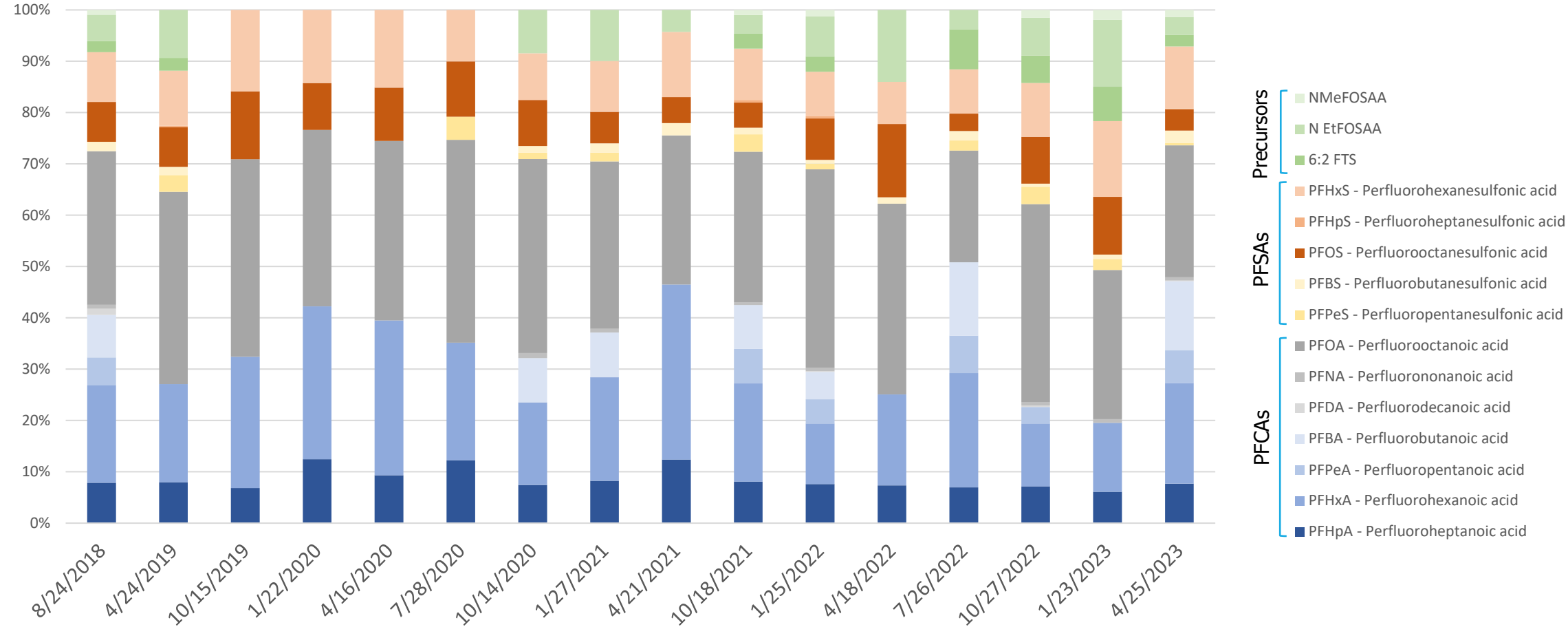
Landfill 17: MSW Active Landfill



How does the PFAS Distribution in Landfill Leachate Change in Closed Landfills?

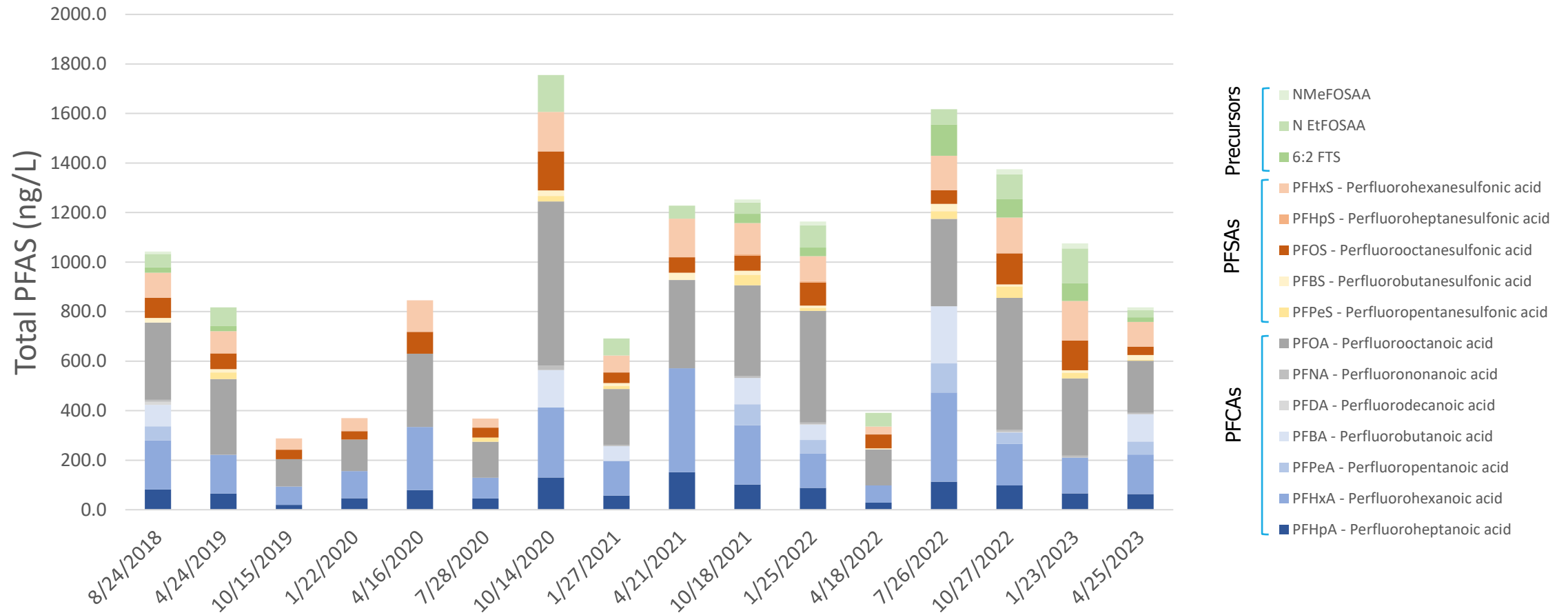
Closed MSW Landfill Leachate PFAS Distribution

Landfill 30: MSW Closed Landfill 1950-1995



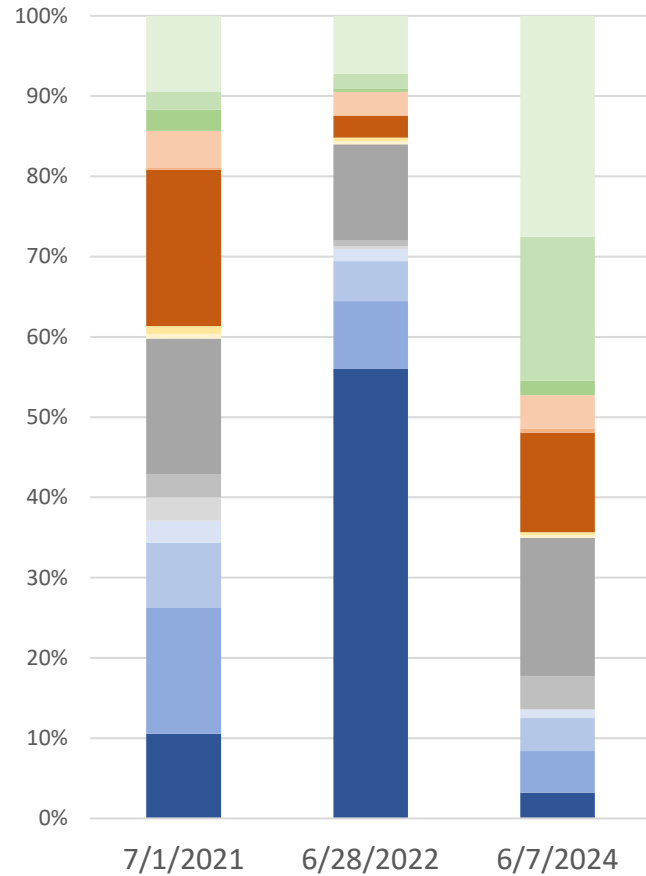
Closed MSW Landfill Leachate PFAS Variability

Landfill 30: MSW Closed Landfill 1950-1995

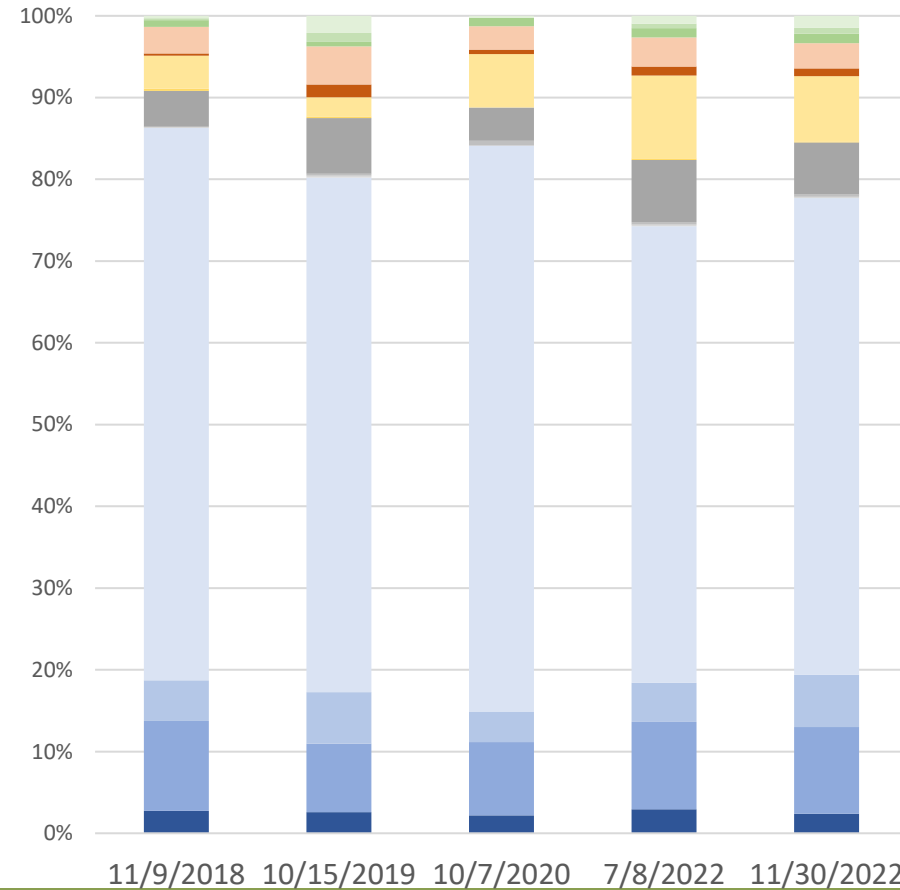


Landfill Leachate Unique PFAS Distributions

Landfill 46: Closed C&D Landfill



Landfill 14: Active MSW Landfill

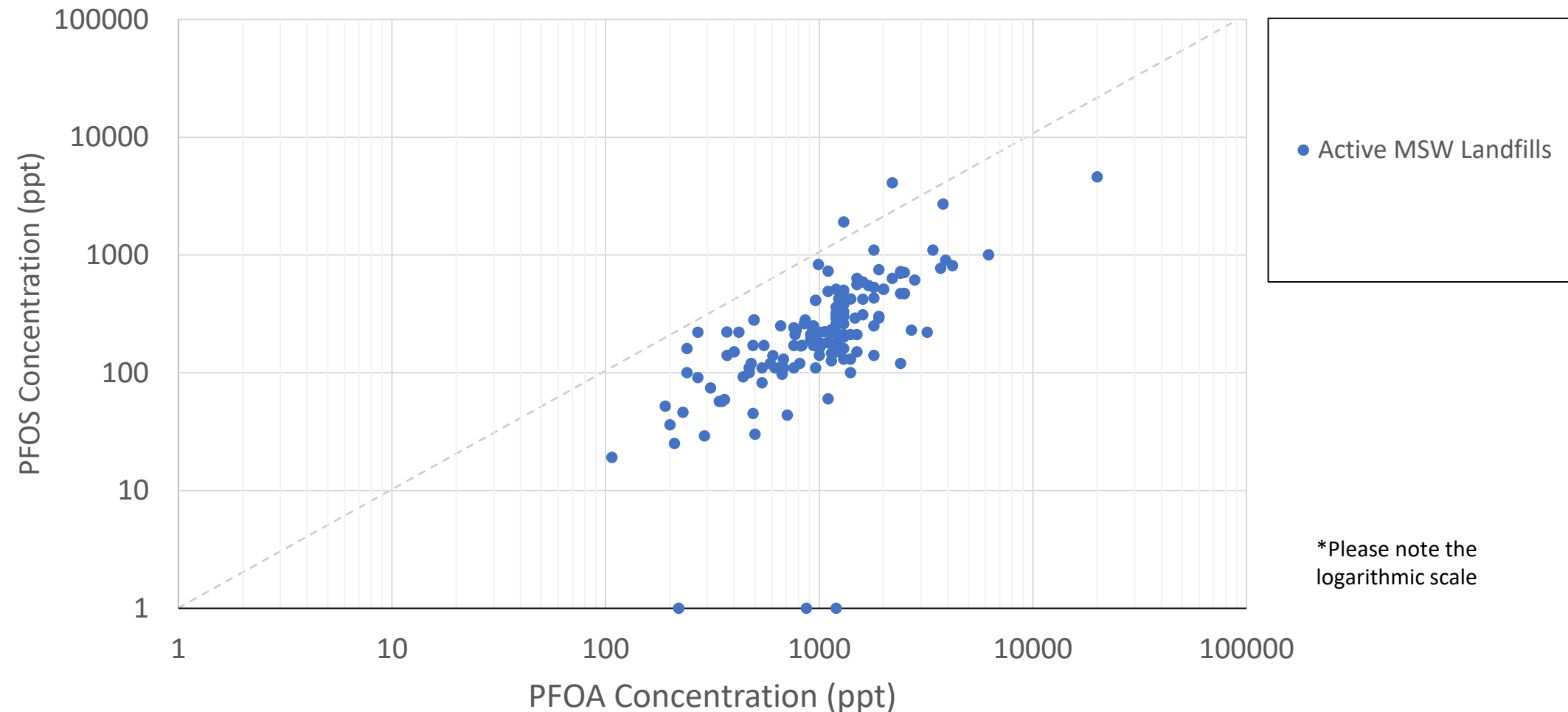


- Precursors
 - NMeFOSAA
 - N EtFOSAA
 - 6:2 FTS
- PFAS
 - PFHxS - Perfluorohexanesulfonic acid
 - PFHpS - Perfluoroheptanesulfonic acid
 - PFOS - Perfluorooctanesulfonic acid
 - PFBS - Perfluorobutanesulfonic acid
 - PFPeS - Perfluoropentanesulfonic acid
- PFCAs
 - PFOA - Perfluorooctanoic acid
 - PFNA - Perfluorononanoic acid
 - PFDA - Perfluorodecanoic acid
 - PFBA - Perfluorobutanoic acid
 - PFPeA - Perfluoropentanoic acid
 - PFHxA - Perfluorohexanoic acid
 - PFHpA - Perfluoroheptanoic acid

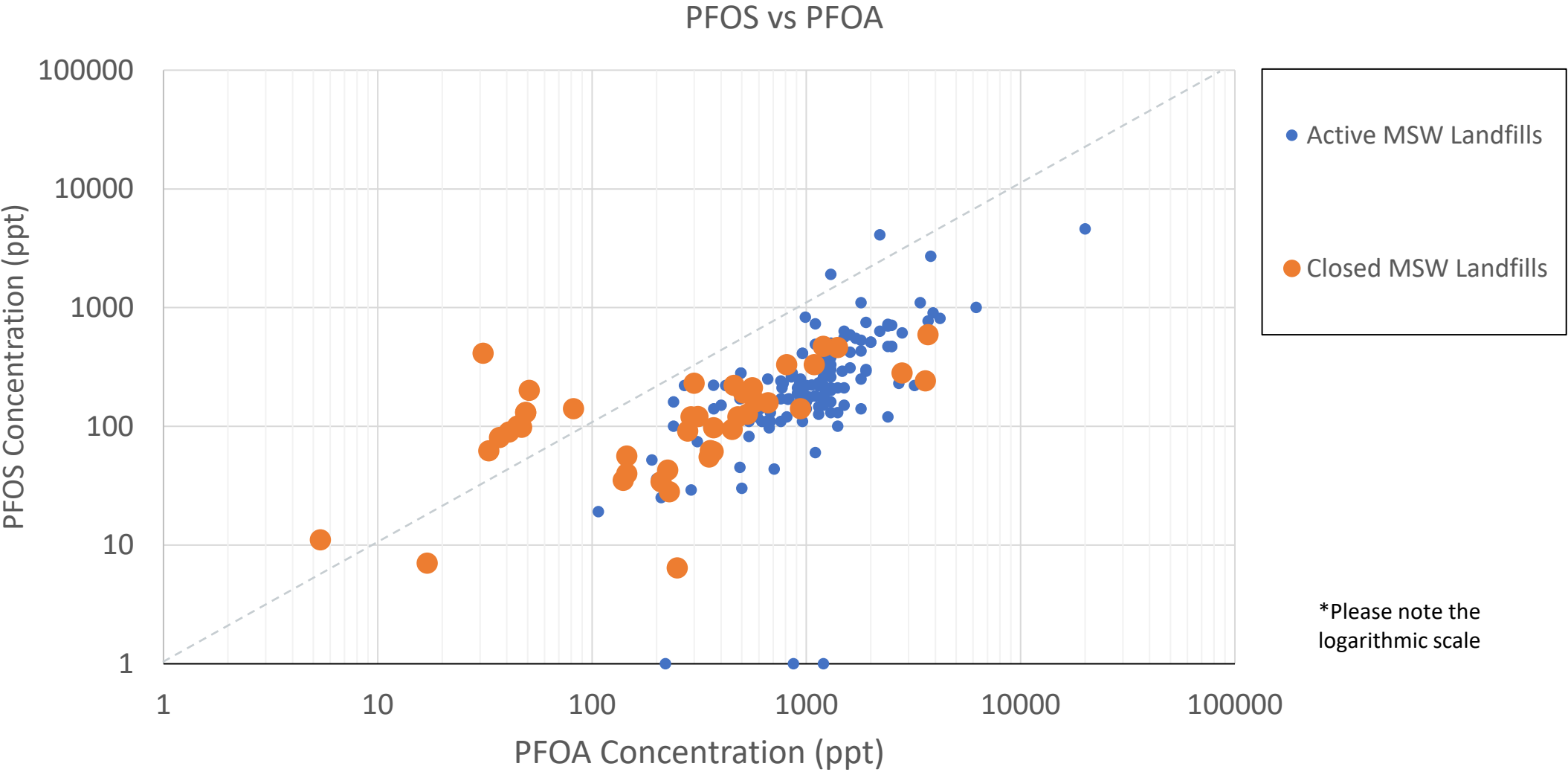
PFOS and PFOA in Michigan Landfill Leachate

Landfill Leachate PFOA and PFOS

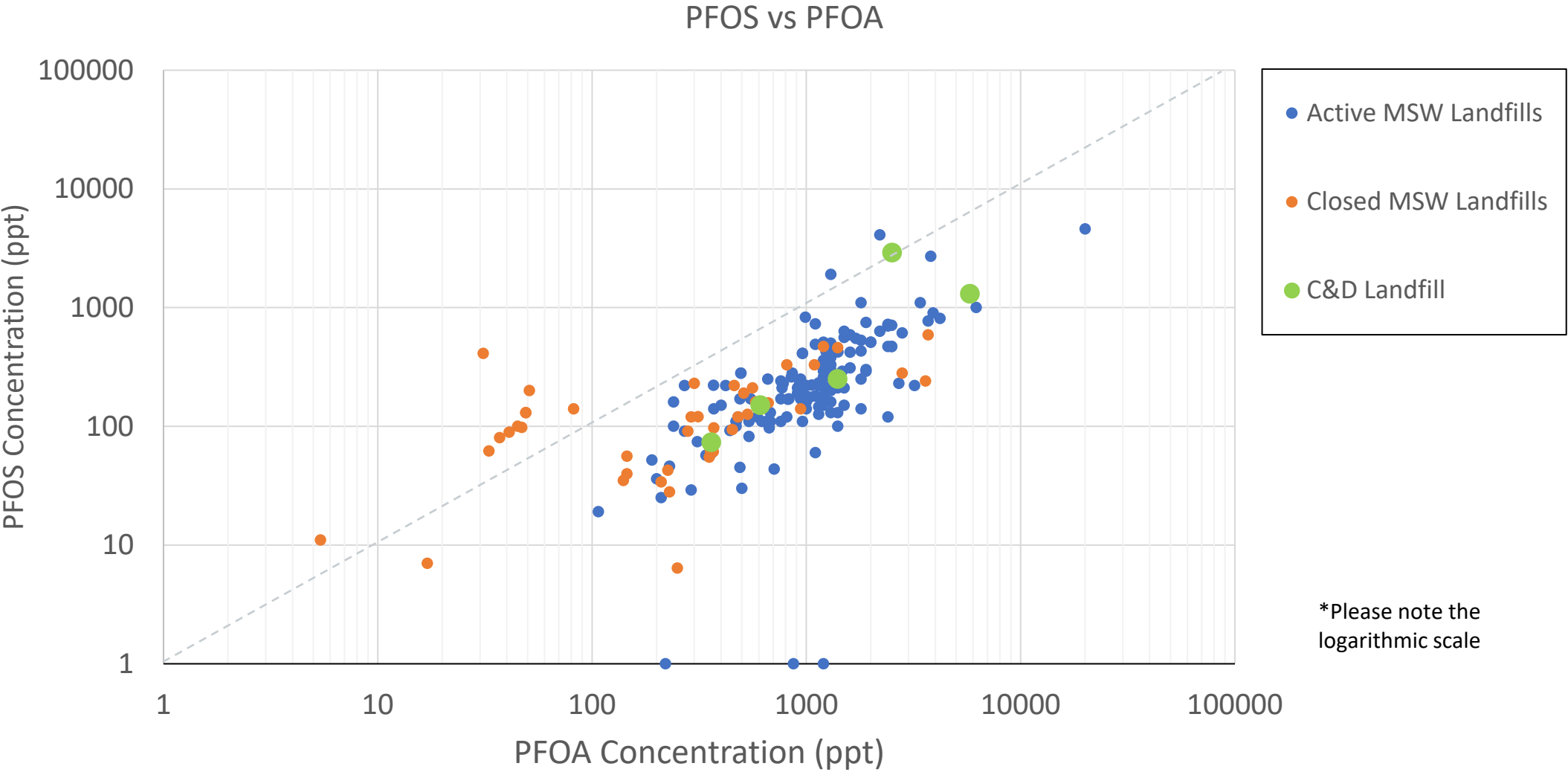
PFOS vs PFOA



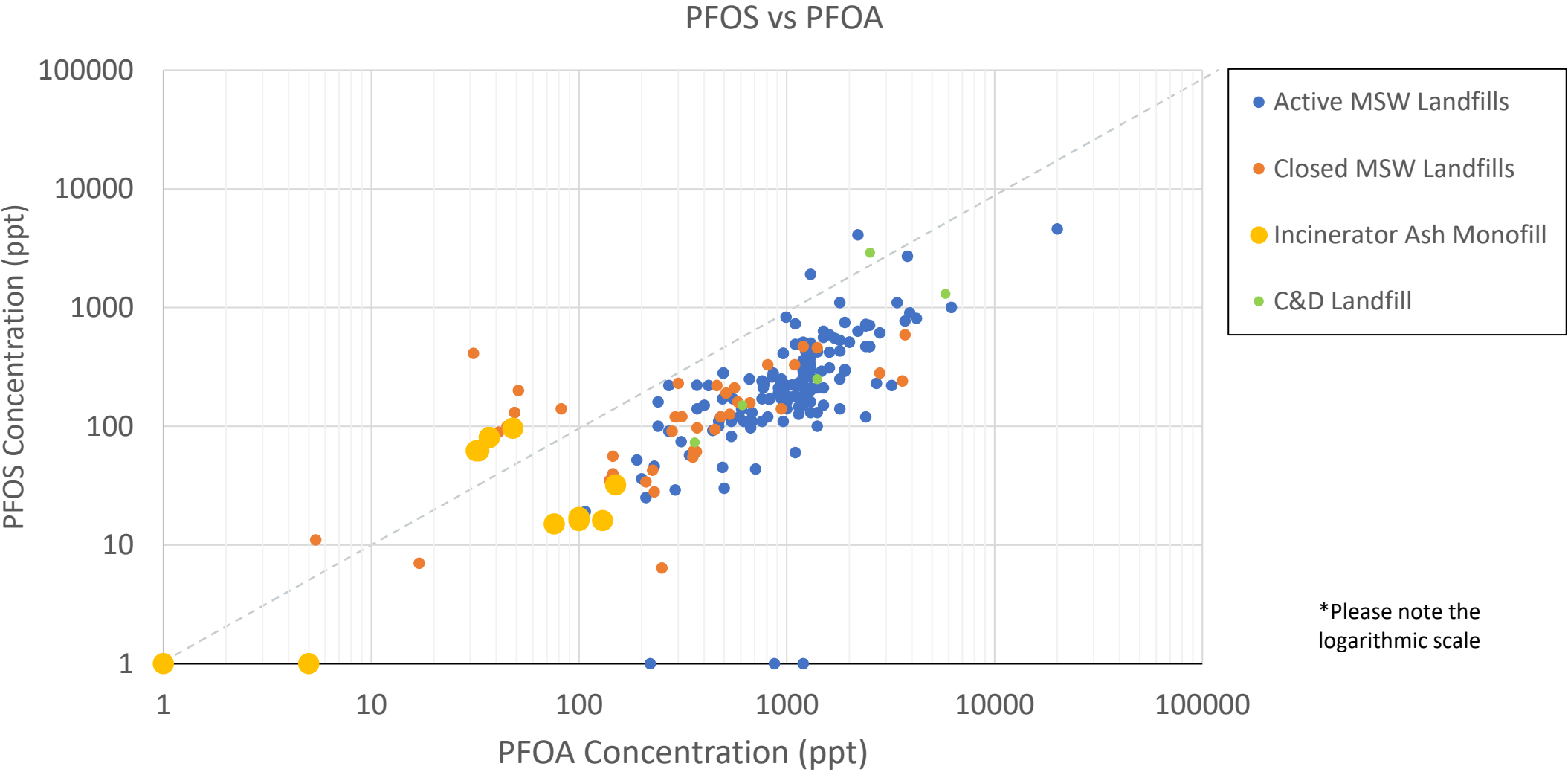
Landfill Leachate PFOA and PFOS



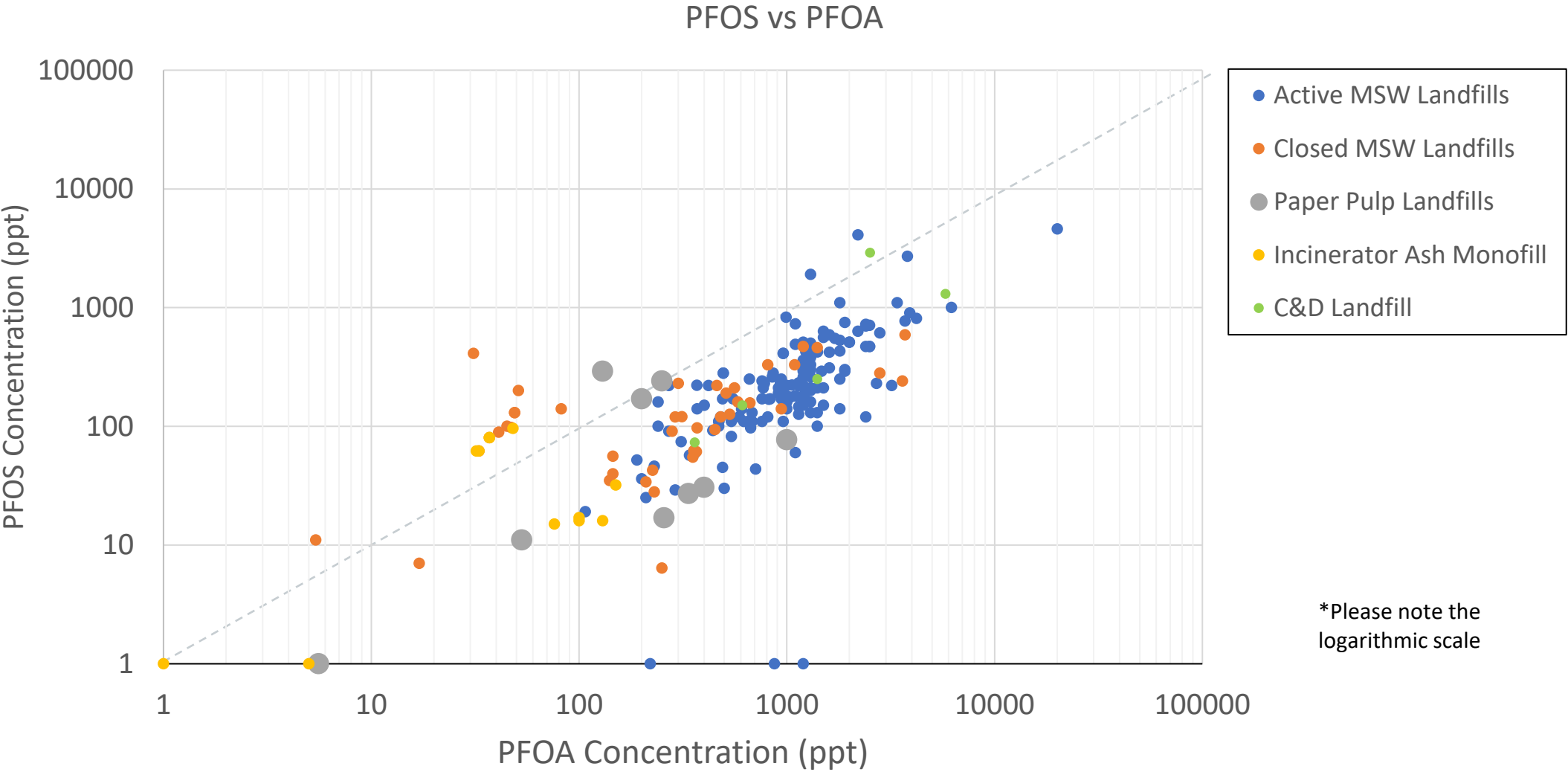
Landfill Leachate PFOA and PFOS



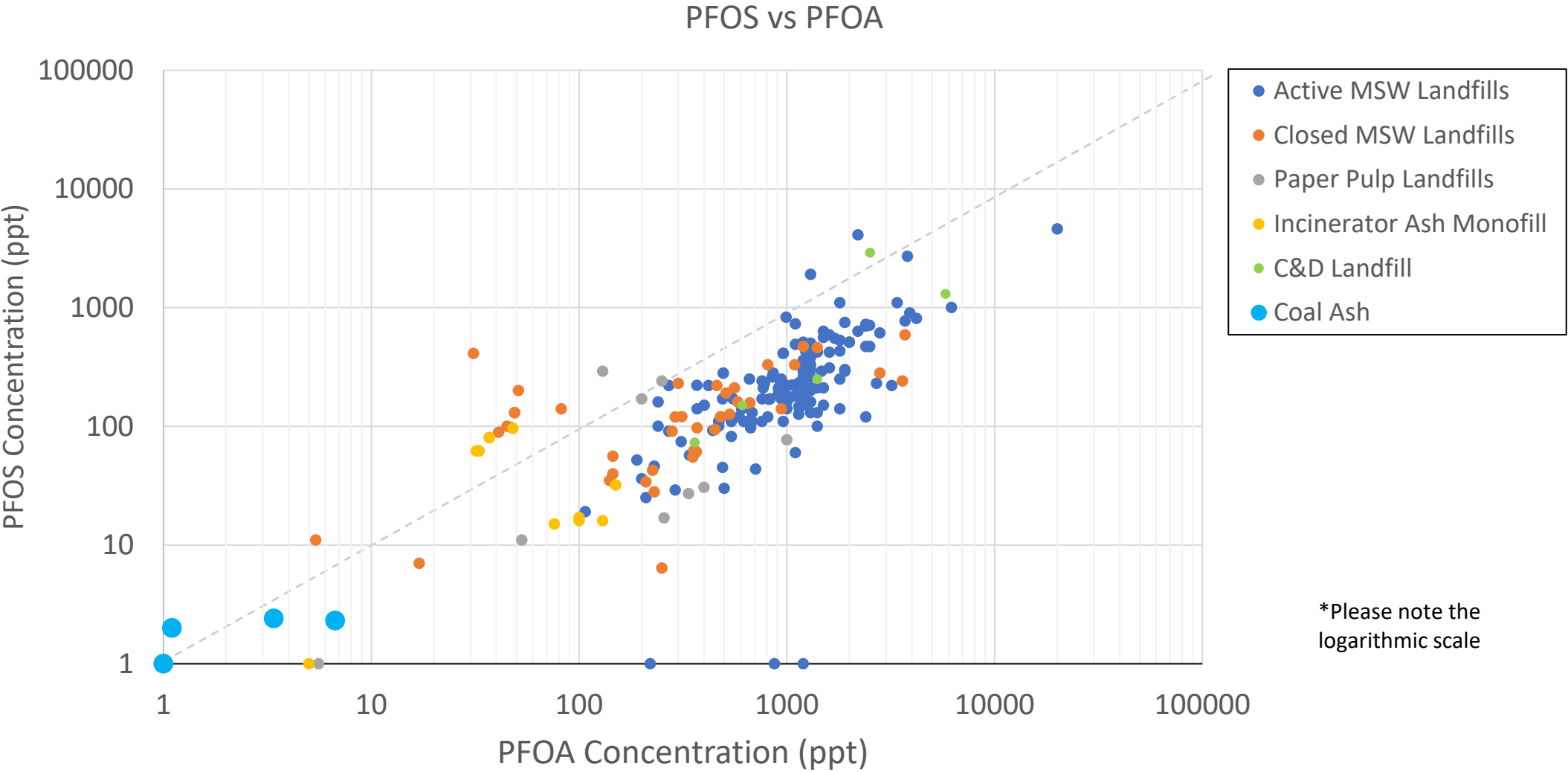
Landfill Leachate PFOA and PFOS



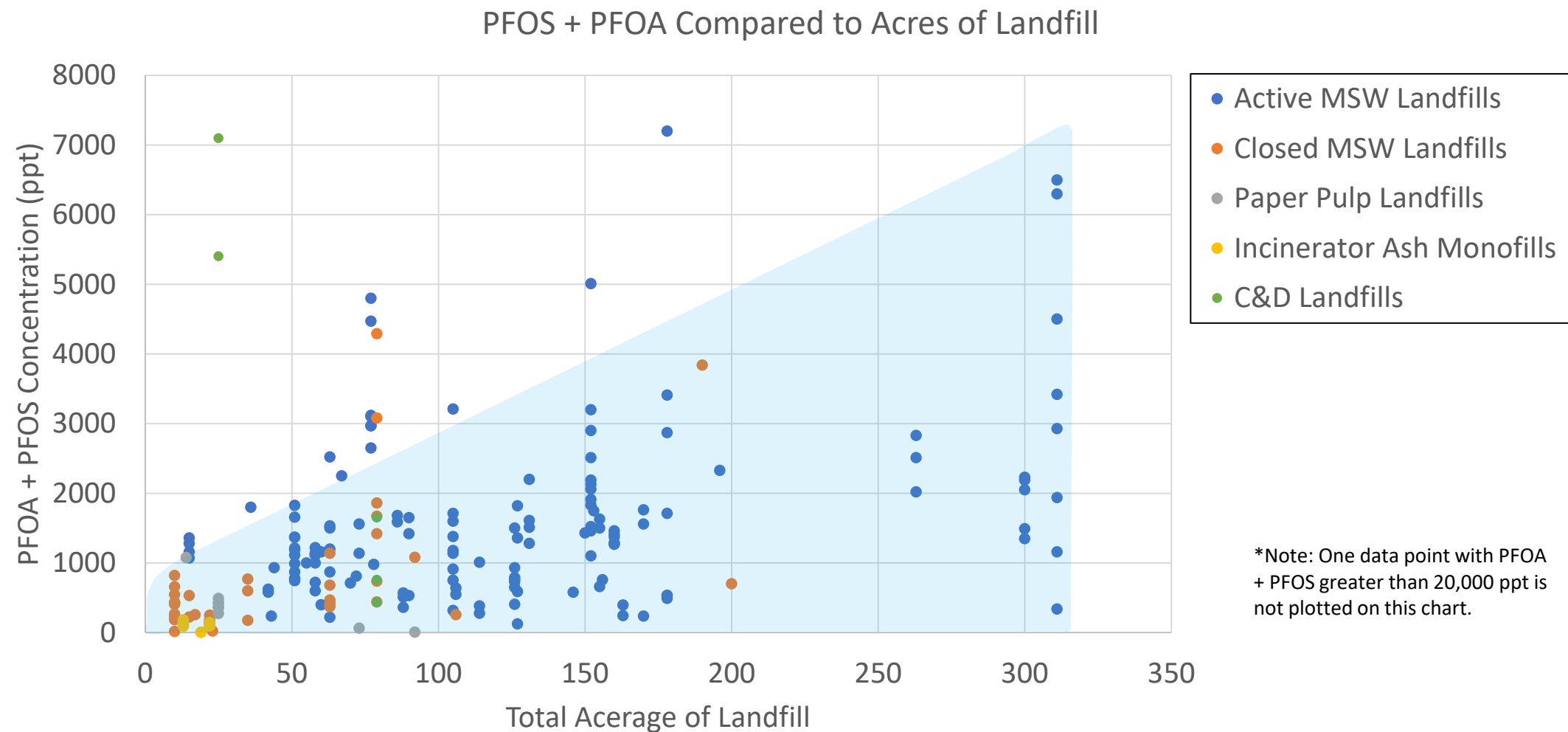
Landfill Leachate PFOA and PFOS



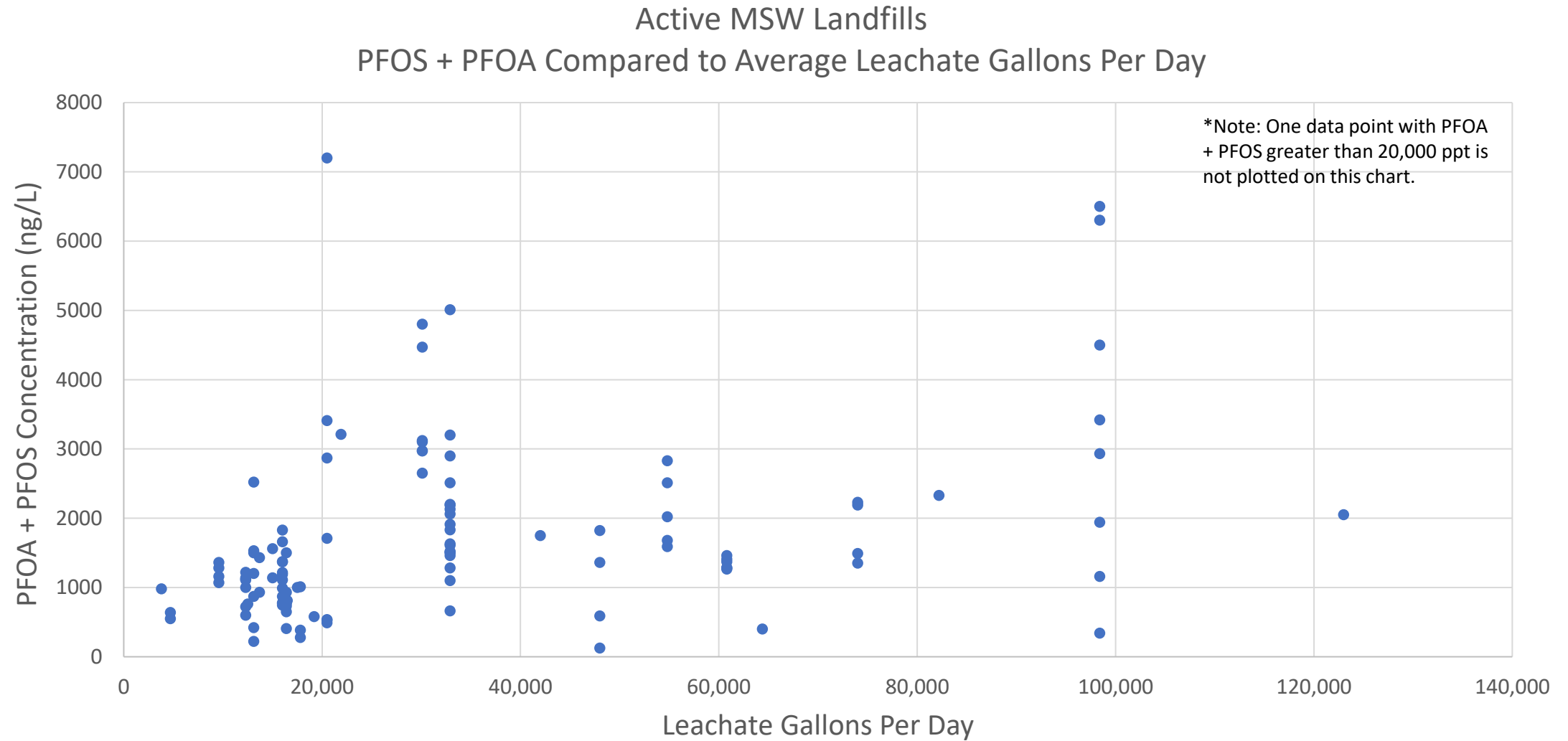
Landfill Leachate PFOA and PFOS



Landfill Leachate PFOA + PFOS Compared to Landfill Size



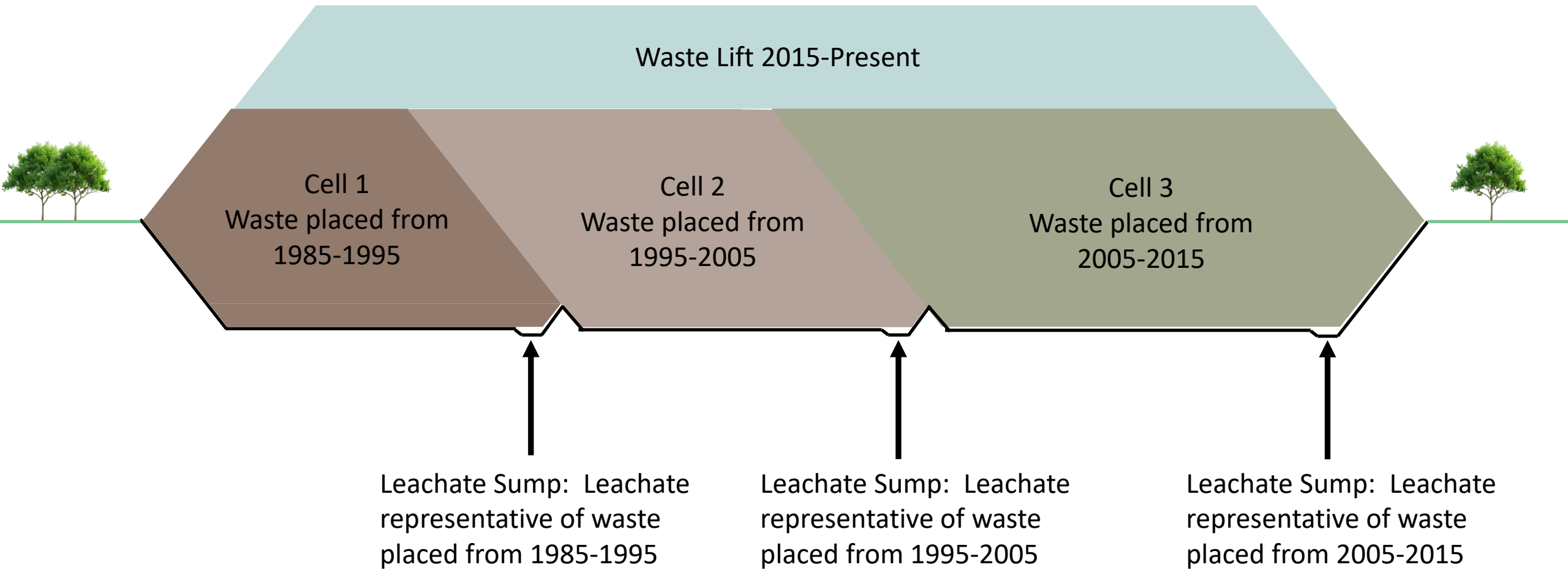
Landfill Leachate PFOA + PFOS Compared to Leachate Quantity



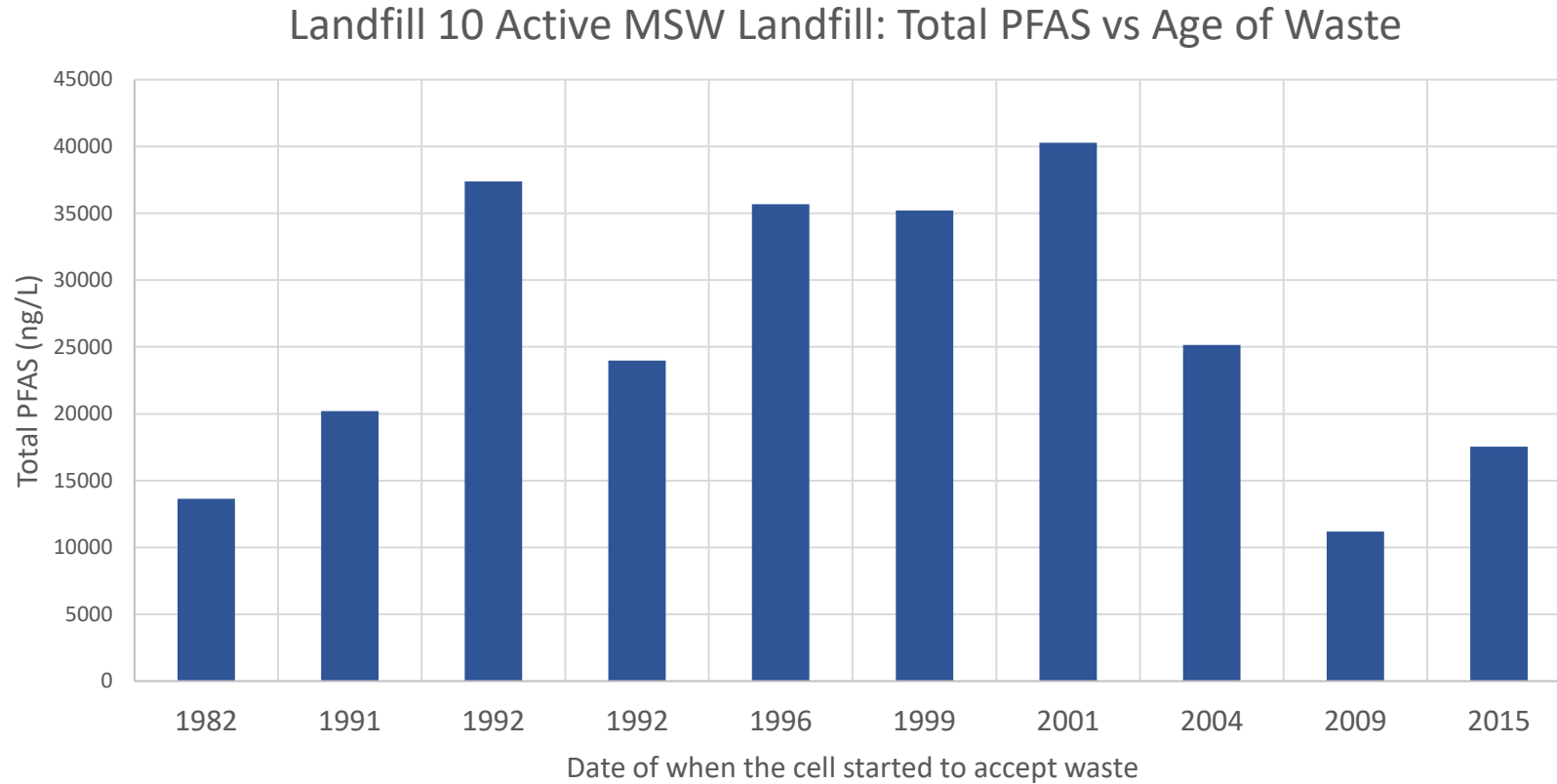
Landfill Leachate Transformation through Time at an Active MSW Landfill

Landfills are like Time Capsules

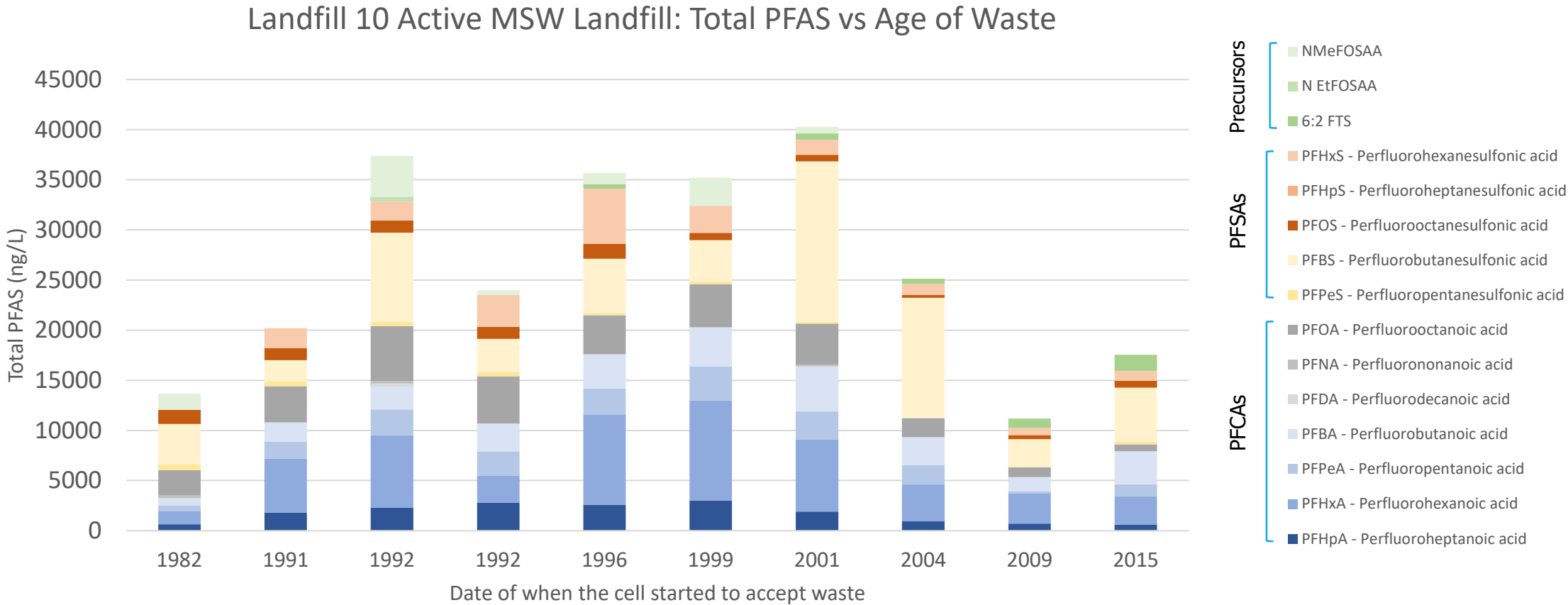




Landfill Leachate Composition Change Through Time

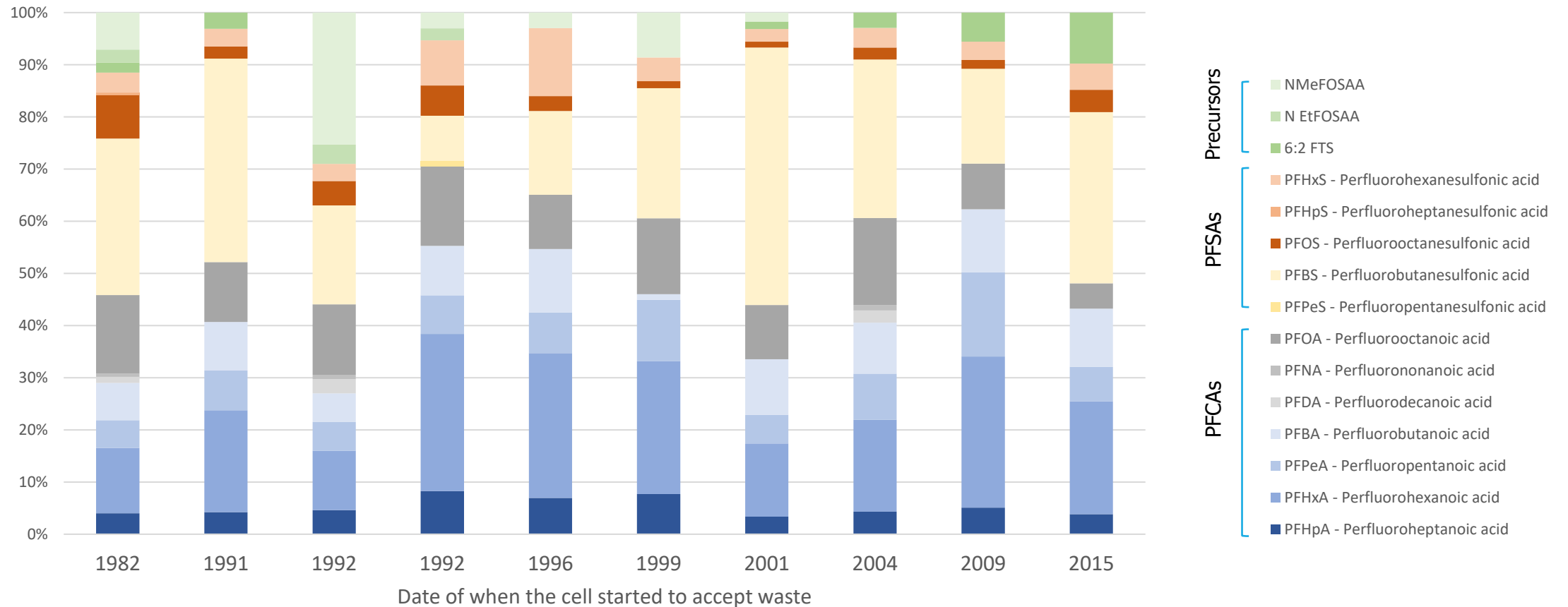


Landfill Leachate Composition Change Through Time

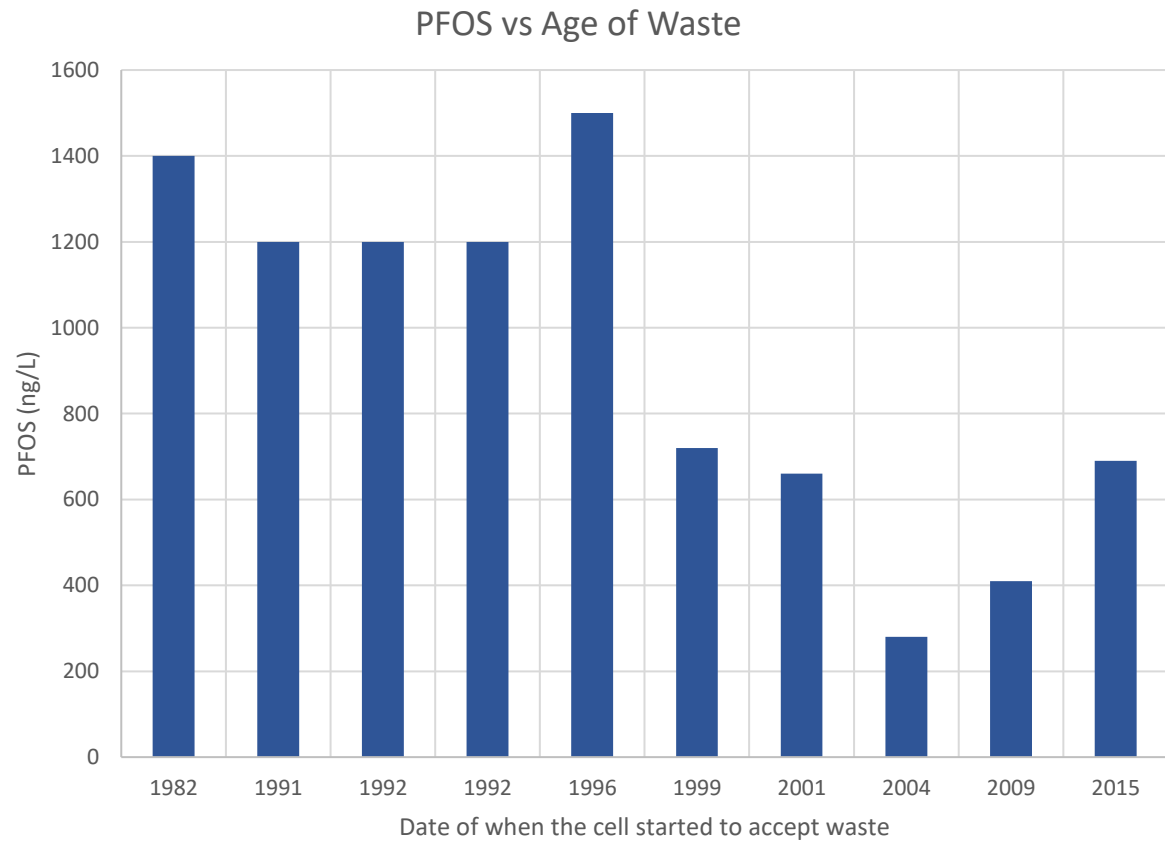
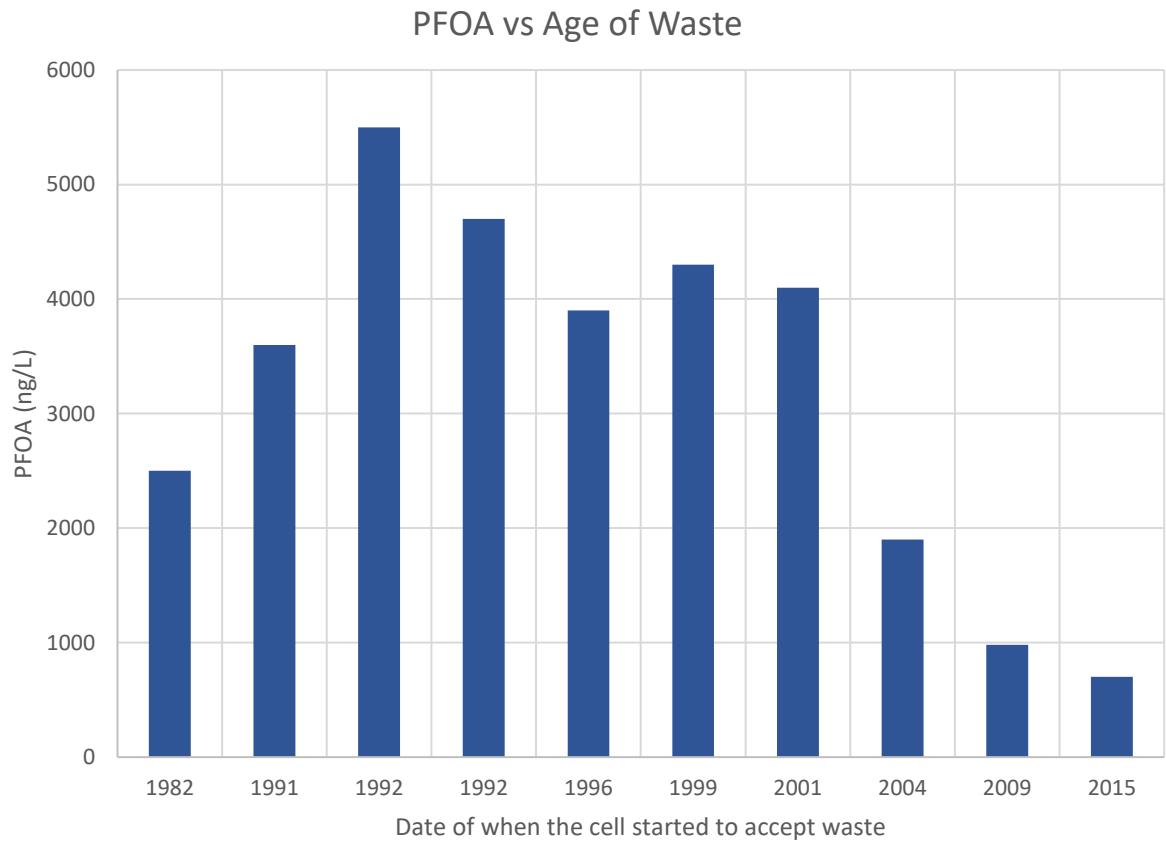


Data shown in ng/L

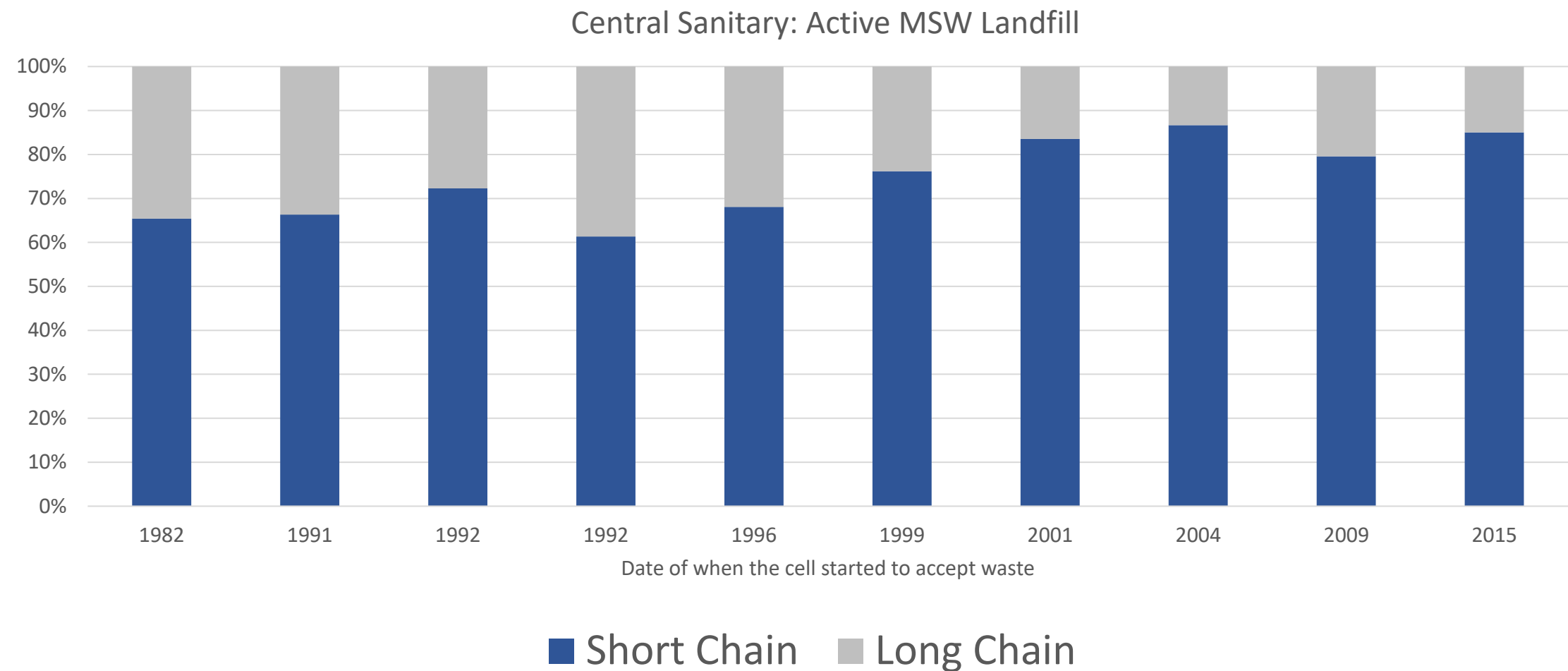
Landfill Leachate Composition Change Through Time



Landfill Leachate Composition Change Through Time



Landfill Leachate Short Chain vs Long Chain PFAS Change Through Time



How Does Michigan Landfill Leachate Compare to Other States?



How Does Michigan MSW Leachate Compare to Other States?

Michigan Landfills

Analytes	Michigan	Washington State
Detection Frequency		
Perfluoroalkyl Carboxylic Acids		
PFBA	95	100
PFPeA	97	100
PFHxA	100	100
PFHpA	99	100
PFOA	98	100
PFNA	81	100
PFDA	72	97
PFUnA	22	72
PFDaA	24	62
PFTTrDA	3.7	14
PFTeDA	0.7 (N=1)	28
Perfluoroalkyl Sulfonic Acids		
PFBS	97	100
PFPeS	73	97
PFHxS	97	100
PFHpS	34	83
PFOS	95	100
PFNS	1.5 (N = 2)	0
PFDS	6	36
Fluorotelomer Sulfonic Acids		
4:2 FTS	34	52
6:2 FTS	88	86
8:2 FTS	56	66
Perfluorooctane Sulfonamide and Derivatives		
PFOSA	30	86
NMeFOSA	77	34
NEtFOSA	69	17

	Michigan	Washington State	Florida	Michigan	Washington State	Florida
Analytes	Mean ± Standard Error			Median		
Perfluoroalkyl						
PFBA	2945 ± 354	1890 ± 325	1265 ± 652	1200	1300	301
PFPeA	1511 ± 232	1395 ± 237	557 ± 72	820	934	367
PFHxA	2831 ± 243	2643 ± 493	1595 ± 162	1800	1990	1032
PFHpA	664 ± 66	629 ± 117	560 ± 58	490	362	390
PFOA	1214 ± 114	1292 ± 276	1346 ± 194	990	715	966
PFNA	56 ± 3.6	66 ± 12	83 ± 20	43	55	43
PFDA	50 ± 6.4	55 ± 17	68 ± 12	30	20	35
PFUnA	32 ± 20	4.4 ± 0.94	6.8 ± 1.9	5.9	2.7	2.8
PFDaA	14 ± 2.0	7.2 ± 2.0	9.7 ± 1.8	9.8	4.9	3.6
PFTTrDA	4.1 ± 1.3	2.4 ± 0.81	12 ± 5.9	2.3	2.6	2.6
PFTeDA		2.6 ± 0.77	7.1 ± 2.6		2.1	3.1
Perfluoroalkyl						
PFBS	2290 ± 289	2212 ± 678	1061 ± 217	635	253	255
PFPeS	83 ± 11	49 ± 11	71 ± 8.1	36	23	49
PFHxS	743 ± 64	412 ± 103	695 ± 92	561	211	469
PFHpS	17 ± 3.3	8.1 ± 1.7	16 ± 5.2	8	5	11
PFOS	342 ± 38	241 ± 53	409 ± 90	210	155	200
PFNS	4.4 ± 1.1			4.4		
PFDS	12 ± 3.8	3.2 ± 0.54	11 ± 3.6	8.4	2.8	5.1
Fluorotelomer						
4:2 FTS	28 ± 6.3	17 ± 3.8	2.3 ± 0.51	11	11	1.9
6:2 FTS	1440 ± 380	232 ± 38	203 ± 36	355	207	139
8:2 FTS	39 ± 5.1	112 ± 24	51 ± 9.6	26	64	20
Perfluorooctane						
PFOSA	13 ± 3.5	12 ± 2.0	17 ± 3.9	7.7	11	8.3
NMeFOSA	285 ± 53	2.6 ± 0.36	299 ± 92	180	2.6	111
NEtFOSA	214 ± 54	1.6 ± 0.58	221 ± 43	180	1	87

Landfills (Landfills = 16)

Michigan	Washington State	Florida
Maximum		
18000	5600	41965
18000	4400	2844
18000	10400	5079
6800	2250	2269
20000	5150	11786
230	261	1333
460	359	617
640	16	98
55	36	75
8.4	3.8	235
	7.3	86
16000	15200	9440
700	202	296
7600	1900	3278
110	30	140
4600	1080	5785
5.5		
26	6.55	41
250	62	8.2
31000	639	2102
380	329	434
150	41	110
5800	4.6	6009
4800	3.8	1800

Data shown in ng/L

from Capozzi et al 2023

et al 2023

Key Takeaways

- Total PFAS in leachate at landfills near urban areas is typically higher than rural areas (special waste exceptions)
- Total PFAS concentrations in closed landfills are approximately 70% less than active landfills
- Municipal Solid Waste (MSW) landfills typically have the highest concentrations of PFAS in leachate
- Total PFAS in landfill leachate could be linked to landfill size.
- Short chain Perfluoroalkyl Carboxylic Acids (PFCAs) dominate landfill leachate composition in both closed and active landfills
- PFBS is much higher in concentration than the other Perfluoroalkyl Sulfonic Acids (PFSA)s
- There is a higher percentage of longer chain PFCAs and PFSA)s in closed landfills (Older landfills)
- The distribution of PFCAs and PFSA)s typically stays consistent regardless of total PFAS concentrations
- Precipitation events could affect total PFAS concentrations in leachate at active landfills.
- Total PFAS concentrations can vary significantly at both active and closed MSW landfills on a monthly timescale
- PFOA is detected at about an order of magnitude higher than PFOS in landfill leachate
- Short chain PFAS become increasingly dominant with newer waste streams.
- PFAS Concentrations in Michigan Landfill Leachate is consistent with Florida and Washington State data.

Moving Forward

- Add additional landfill data
 - Superfund landfills
 - Dumps
 - Hazardous waste landfills
- PFAS forensics
- Principle Component Analysis and Cluster Analysis
- Track leachate PFAS changes from a recently closed landfill

References

- Capozzi, S. L., Leang, A. L., Rodenburg, L. A., Chandramouli, B., Delistraty, D. A., & Carter, C. H. (2023). Pfas in municipal landfill leachate: Occurrence, transformation, and sources. *Chemosphere*, 334, 138924.
- Chen, Y., Zhang, H., Liu, Y., Bowden, J.I.A., Tolaymat, T.M., G. Townsend, T., & Solo-Gabriele, H. (2023). Evaluation of per- and polyfluoroalkyl substances (pfas) in leachate, gas condensate, stormwater and groundwater and landfills. *Chemosphere*, 318, 137903



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