Report to the Committee on the Environment and Natural Resources
131st Legislature, Second Session

Report on the Testing of Landfill Leachate for Perfluoroalkyl and Polyfluoroalkyl Substance Contamination

January 2024

Contacts:

Carla Hopkins
Director, Division of Materials Management
207-446-4366
Carla.J.Hopkins@maine.gov

Molly King, L.G.
Director, Division of Technical Services
207-458-8839
Molly.King@maine.gov

MAINE DEPARTMENT OF ENVIRONMENTAL PROTECTION
17 State House Station | Augusta, Maine 04333-0017
www.maine.gov/dep

Executive Summary

This report is submitted to the Joint Standing Committee on Environment and Natural Resources pursuant to Public Law 2021, Chapter 478 which requires the Department of Environmental Protection (Department) to submit a report to the Legislature regarding the testing of landfill leachate for PFAS, the results of the testing, and any recommendations.

I. Introduction and Background

Per- and Polyfluoroalkyl Substances (PFAS) refer to a group of man-made chemicals widely used in consumer products and industrial settings. There are thousands of varieties of these chemicals and as early as the 1940's, PFAS[1] were widely in use. These chemicals were also historically used in firefighting foams due to their effectiveness at quickly extinguishing petroleum-based fires. Because they have a unique ability to repel oil, grease, water, and heat, PFAS are found in many products that consumers commonly use. For example, PFAS have been used to make non-stick cookware, stain resistant carpets and furniture, water-resistant clothing, heat-resistant paper/cardboard food packaging (like microwave popcorn bags and pizza boxes), and personal care products. PFAS break down very slowly and are persistent in the environment. This means that PFAS may build up in people, animals, and the environment over time. Health agencies like the U.S. Centers for Disease Control and Prevention (CDC) are actively assessing the health effects of low level, long-term exposure to PFAS, but have suggested that health impacts from PFAS may include[2] the following:

- Increased cholesterol levels;
- Changes in liver enzymes;
- Small decreases in infant birth weights;
- Decreased vaccine response in children;
- Increased risk of high blood pressure or pre-eclampsia in pregnant women; and
- Increased risk of kidney or testicular cancer.

PFAS have been found throughout Maine including, but not limited to, at agricultural sites, in public and private drinking water supplies, in precipitation,[3] in surface waters, in landfills, in wastewater effluent, at sludge and septage spreading sites, and at remediation and cleanup sites. In general, PFAS can enter the environment through direct releases from specific PFAS-containing products (e.g., certain firefighting foams, and consumer product wastes such as food packaging), as well as from more generalized waste streams including sludge and septage, leachate, wastewater effluent, and air emissions. Many of these pathways are still being studied and evaluated to better understand how PFAS get into and move through the environment.

This report focuses on the Department's landfill leachate testing initiative conducted in accordance with P.L. 2021, Ch. 478, *An Act To Investigate Perfluoroalkyl and Polyfluoroalkyl Substance Contamination of Land and Groundwater*. The law requires the Department to develop and implement a program for the testing of leachate collected and managed by solid waste landfills for PFAS. The law also requires the Department to report to the Joint Standing Committee on Environment and Natural Resources the results of the leachate PFAS testing and provide any recommendations on or before January 15, 2024.

[1] PFAS used early on were mostly PFOA and PFOS. In the early 2000's, manufacturers of these specific PFAS began to phase-out these compounds, Fact Sheet: 2010/2015 PFOA Stewardship Program | US EPA.
[2] Taken from the U.S. CDC website, November 2022; Potential health effects of PFAS chemicals | ATSDR (cdc.gov).
[3] Offenberg, John H. (2022). Initial assessment of a pilot program for measuring Per- and Polyfluorinated Substances (PFAS) in wet deposition in the eastern United States.

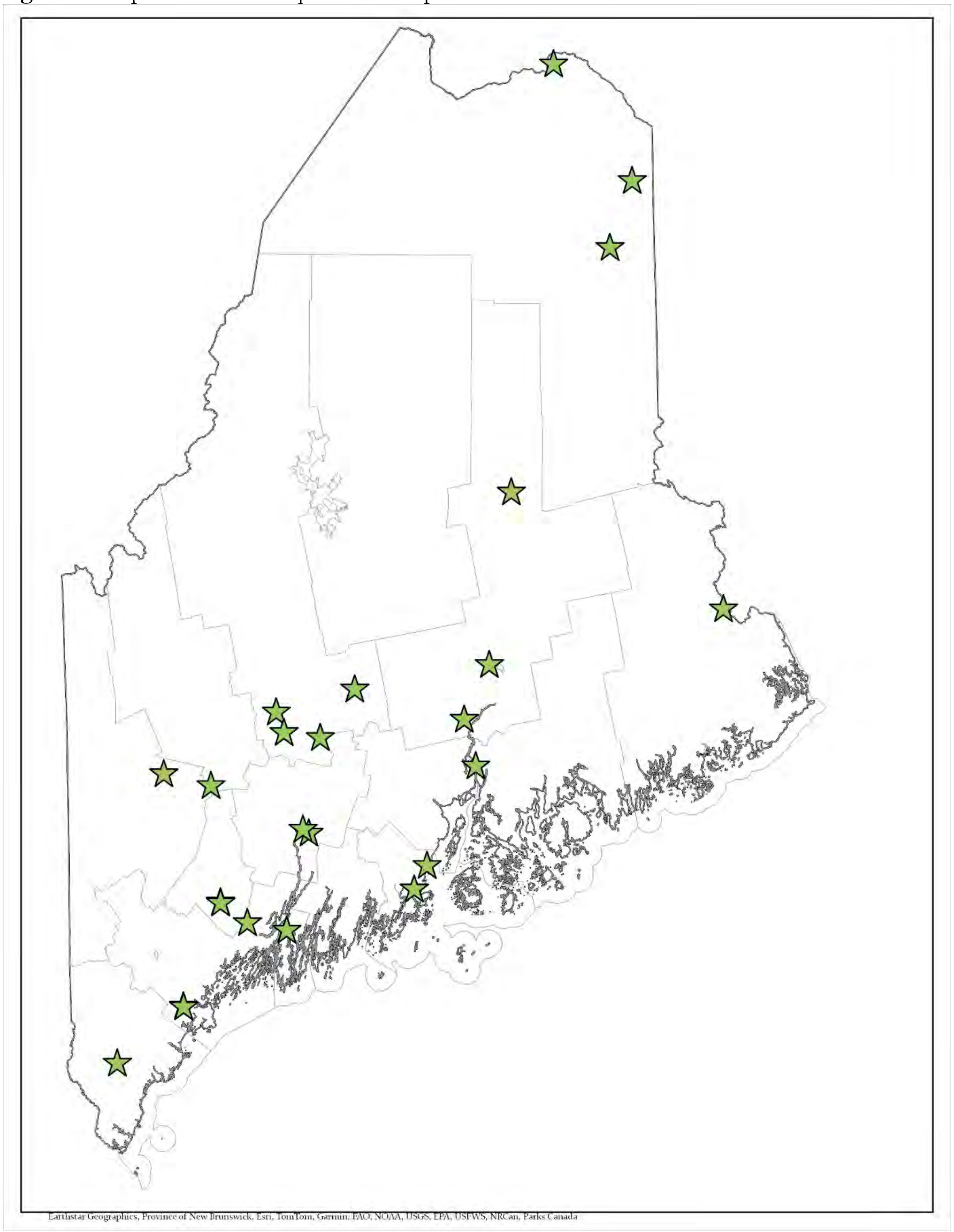
II. Description of the Landfill Leachate Testing Program

P.L. 2021, Ch. 478 became law in July 2021 with an effective date of October 18, 2021. The Department identified 25 landfills (Figure 1) which collect and manage leachate that would be required to test their leachate for PFAS in accordance with the law. In September 2021, the Department notified the 25 landfills and provided a letter outlining the program and its corresponding expectations. Each facility was required to test leachate each fall and spring through 2023 for a total of five sampling rounds. Samples were to be collected at a location that is representative of leachate from the landfills (i.e., not from an open leachate pond that also collects precipitation). At a minimum, the leachate was to be analyzed for a list of 28 PFAS (see Attachment 1 for listing of parameters and their abbreviations), with the Sum of the 6 PFAS (PFOA, PFOS, PFHpA, PFHxS, PFNA, and PFDA) comprising the current Maine Interim Drinking Water Standard (per P.L. 2021, Ch. 82) being reported for comparison purposes.

The program required facilities and their contractors to follow strict and up-to-date guidance when collecting and handling samples, and all samples were to be analyzed as a wastewater matrix by an accredited and Department-approved laboratory. Data were to be submitted to the Department in the most current Electronic Data Deliverable (EDD) format, along with a .pdf copy of the complete laboratory report including quality control and quality assurance information within 15 days of receipt. Following the Department's data quality review, the data were uploaded to the Department's Environmental and Geographic Analysis Database (EGAD). The results of the sampling were posted on the Department's website following each seasonal sampling round.[4] Figure 1 shows the locations of the 25 landfills in Maine required to sample leachate for PFAS under this initiative.

[4] For this study, leachate sample results displayed on the website contained the individual and summation of only the six PFAS comprising the current Maine Interim Drinking Water Standard for ease of reporting.

Figure 1. Map of Landfills Required to Sample PFAS in Landfill Leachate



III. Discussion of Landfills and Current Leachate Management Practices

Table 1 contains leachate production and management information for the 25 landfills required to sample leachate for PFAS under this initiative. Eighteen of the landfill facilities required to test their leachate for PFAS are active facilities and seven are closed facilities. Average annual leachate generation from 2021 through 2023 ranged from approximately 1,800,000 gallons per year (Sanford) to 55,241,000 gallons per year (Androscoggin Mill), with the average volume of leachate generated per year being approximately 18,720,000 gallons. A majority of the landfill facilities tested (22 out of 25) treat their leachate at a Department-licensed wastewater treatment facility, a majority being discharged or pumped to a municipal facility and the remaining being treated at either an on-site or off-site industrial facility. The other three landfill facilities manage their leachate through a series of on-site treatment ponds and discharge treated leachate to surface water bodies (Brunswick and Bucksport Mill) or spray irrigate fields with the treated leachate (Presque Isle) in accordance with a Department-issued wastewater discharge license.

Table 1. Leachate Production and Management Information for Landfills Required to Sample Leachate for PFAS

Landfill Facility	Town	Landfill Status	Approx. Size (Acres)	Primary Waste	Avg. Annual Leachate Volume (2021 - 2023)	Leachate Management Method	Treatment Facility or Alternate
Hatch Hill	Augusta	Active	67	MSW	12,841,000	Discharged to Municipal WWTP	Greater Augusta UD WWTP
Augusta Tissue	Augusta	Closed	40	Sludge	2,634,000	Pumped to Municipal WWTP & Treatment Ponds	Greater Augusta UD WWTP
Woodland Pulp	Baileyville	Active	60	Sludge	47,341,000	Pumped to Facility WWTP	Woodland Pulp WWTP
Bath	Bath	Active	25	MSW	11,071,000	Pumped to Municipal WWTP	Bath WWTP
Brunswick	Brunswick	Closed	16	MSW	2,449,000	On-site Facultative Treatment Lagoons	Androscoggin River
Bucksport Mill	Bucksport	Active	48	Sludge	45,498,000	On-site Leachate Pond	Penobscot River
Dolby	East Millinocket	Closed	158	Sludge	52,950,000	Hauled to Municipal WWTP	East Millinocket WWTP
SAPPI Mill	Fairfield	Active	75	Sludge	25,538,000	Pumped to Facility WWTP	SAPPI WWTP
Tri-Community	Fort Fairfield	Active	39	MSW and Sludge	11,128,000*	Pumped to Municipal WWTP	Caribou UD WWTP
Twin Rivers Mill	Frenchville	Active	23	Sludge	8,783,000	Hauled to Facility WWTP	Twin Rivers WWTP
Pine Tree	Hampden	Closed	58	Special Waste	8,900,000*	Pumped to Municipal WWTP	Bangor WWTP
Hartland	Hartland	Active	8	Sludge, Tannery Waste	7,187,000*	Pumped to Municipal WWTP	Hartland WWTP
Androscoggin Mill	Jay	Active	65	Sludge	55,241,000*	Pumped to Facility WWTP	Androscoggin Mill WWTP
LAWPCA	Lewiston	Closed	15	Sludge	NR	Pumped to Municipal WWTP	Lewiston WWTP
Lewiston	Lewiston	Active	15	MSW Ash	4,637,000*	Pumped to Municipal WWTP	Lewiston WWTP
Anson-Madison Sanitary District	Madison	Closed	5	Sludge	4,352,000*	Pumped to Municipal WWTP	Anson-Madison WWTP
ND Paper	Mexico	Active	37	Sludge	28,855,000	Pumped to Facility WWTP	ND Paper WWTP
Crossroads	Norridgewock	Active	154	Special Waste	24,659,000*	Hauled to Facility WWTP	Anson-Madison WWTP
Juniper Ridge	Old Town	Active	122	Special Waste	17,446,000	Hauled to Facility WWTP	ND Paper WWTP
Presque Isle	Presque Isle	Active	17	MSW	3,982,000*	Soil Attenuation at Spray Irrigation Fields	Spray Irrigation Fields
Rockland Quarry	Rockland	Active	9	CDD	21,377,000	Pumped to Municipal WWTP	Rockland WWTP
Mid-Coast Solid Waste Quarry	Rockport	Active	6	CDD	19,676,000	Pumped to Municipal WWTP	Camden WWTP
Sanford Sewerage District	Sanford	Active	5	Sludge	1,776,000	Pumped to Municipal WWTP	Sandford WWTP
Kimberly Clark Larson-Chapman	Scarborough	Closed	36	Sludge	2,895,000	Pumped to Municipal WWTP	Portland WWTP
ecomaine	South Portland	Active	84.2	MSW Ash	28,164,000	Pumped to Municipal WWTP	Portland WWTP

MSW = Municipal Solid Waste
CDD = Construction Demolition Debris
MSW Ash = Incinerated MSW
NR = Not Reported
WWTP = Wastewater Treatment Plant
UD = Utility District
Total PFAS = Sum of 28 PFAS Analyzed
Note that many of the MSW landfills also accept CDD
*Average annual leachate volumes between 2021 and 2023 incomplete for landfill facility
For Brunswick, see MEPDES #ME0102113 and Waste Discharge License #W004308-6C-F-R
For Bucksport, see MEPDES #ME0002160 and Waste Discharge License #W000598-5N-P-M
For Presque Isle, see MEPDES #MEU508088 and Waste Discharge License #W008088-6B-I-R

IV. Results of the Landfill Leachate Testing Program

This section summarizes the PFAS results from 189 leachate samples collected at the 25 landfills listed above. Every landfill collected at least 5 leachate samples between Fall 2021 and Fall 2023. It is important to note that five of the landfills collected additional leachate samples from different sample locations during each sampling round (Sappi Mill, Rockland, Androscoggin Mill, Lewiston, and ecomaine). This data analysis of PFAS results includes the entire leachate dataset.

The 28 PFAS analyzed in landfill leachate can be divided into the following five groups. Grouping PFAS by their functional groups is a way to evaluate how the compounds may behave in the environment and can provide important information for selecting the most appropriate treatment or remediation technologies. For example, long-chain PFAS are generally more likely to attach to soil particles than short-chain PFAS, which can limit them from entering groundwater. Additionally, Perfluoroalkyl Carboxylic Acids (PFCAs) often readily degrade to shorter-chain PFCAs in the environment when compared to Perfluoroalkyl Sulfonic Acids (PFSAs). Grouping PFAS can also help evaluate sources as different waste streams (e.g., municipal solid waste (MSW), sludge, special waste) can exhibit different PFAS signatures. For example, stain-resistant materials and fabrics (e.g., carpets, furniture) that are disposed at MSW landfills typically use PFAS coatings that readily break down into PFCAs. These are generalizations and not absolutes in all scenarios and environments; site-specific characteristics also dictate how contaminants behave in the environment and how remediation or treatment technologies may be effectively employed.

1. Precursors: Per- and Polyfluoroalkyl compounds commonly used in industries that typically break down or transform into more stable PFAS, such as PFOA and PFOS as well as other PFCAs and PFSAs. This group of precursors includes 8:2 FTS, 6:2 FTS, N-EtFOSAA, N-MeFOSAA, and PFOA-replacement compounds ADONA and HFPO-DA (GenX). Figures and tables in this report differentiate between PFCA and PFSA precursors.

2. Short-Chain PFCAs: Perfluorinated PFAS with a carboxylic acid head group and 7 or fewer carbons. This group includes PFBA, PFPeA, PFHxA, and PFHpA. Short-chain PFCAs have been used as substitutes for longer-chain PFCAs. Some of the most common PFAS precursor compounds break down proportionally into short-chain PFCAs.

3. Long-Chain PFCAs: PFCAs with 8 or more carbons. This group includes PFOA, PFNA, PFDA, PFUnDA, PFDoA, PFTriA, PFTeA, PFHxDA, and PFODA.

4. Short-Chain PFSAs: Perfluorinated PFAS with a sulfonic acid head group and 5 or fewer carbons. This group includes PFBS and PFPeS. Short-chain PFSAs have been used as substitutes for longer-chain PFSAs.

5. Long-Chain PFSAs: PFSAs with 6 or more carbons. This group includes PFOS as wells as PFHxS, PFHpS, PFNS, and PFDS.

Additionally, PFAS summary concentrations are divided into 2 categories:

1. Sum of 6 PFAS: Includes PFOA, PFOS, PFHpA, PFHxS, PFNA, and PFDA. The current State of Maine Interim Drinking Water Standard for Sum of 6 PFAS is 20 nanograms per liter (ng/L).

2. Total PFAS: Includes all 28 PFAS analyzed in landfill leachate samples.

PFAS summary concentrations in this report are often discussed in terms of average and median concentrations. The average concentration for these data generally refers to one value that best represents the entire dataset for that parameter. The median concentration for these data represents the middle (50 percent) value if concentrations are ordered from least to greatest.

A. Summary of PFAS Detections and Concentrations in Landfill Leachate Dataset (Table 2)

Table 2 summarizes PFAS detection frequencies and concentrations for the 189 leachate samples collected at the 25 landfill facilities in the leachate sampling program (See also Figures A3 and A4 in Appendix A). This section focuses on an evaluation of all 189 PFAS samples collected regardless of sample/landfill location. Some notable observations are outlined below:

1. 26 out of 28 PFAS analyzed were detected in at least one leachate sample. ADONA (PFOA-replacement compound) and PFODA (18-carbon PFCA) were not detected in any of the leachate samples.

2. PFOA and PFHxA were the most detected PFAS, detected in approximately 98% of leachate samples. PFHxA had the highest average (1,288 ng/L) and median (525 ng/L) concentrations out of the 28 PFAS analyzed. PFOA had the third highest average (741 ng/L) and median (265 ng/L) concentrations.

3. Short-chain PFCAs were the most detected PFAS group with detections ≥ 95%. In addition to PFHxA, the other short-chain PFCAs also had some of the highest average and median concentrations.

4. PFOS and PFHxS were the most detected PFSAs, with PFOS and PFHxS being detected in 87% and 75% of leachate samples, respectively. PFOS had the greatest maximum concentration (51,400 ng/L) and both PFOS and PFHxS had elevated average and median concentrations.

5. N-EtFOSAA and N-MeFOSAA were the most detected precursor PFAS compounds, being detected in 70% and 64% of leachate samples respectively. Average concentrations for N-EtFOSAA and N-MeFOSAA were 91 ng/L and 86 ng/L, respectively, with median concentrations less than 20 ng/L.

6. Longer-chain PFCAs and PFSAs, as well as 4:2 FTS and HFPO-DA (GenX) were detected in ≤ 10% of leachate samples.

7. The distribution of PFAS detections were highly variable in the leachate dataset. For example, median concentrations for HFPO-DA (GenX) and PFHpS were non-detect (ND) but had maximum concentrations > 2,000 ng/L. The large variability of PFAS detections and concentrations is likely due to the variability of landfill conditions including age, size, waste type(s), leachate generation, and other factors.

Table 2. Summary of PFAS Detections and Concentrations (ng/L) in Landfill Leachate Dataset

Group		PFAS Compound	Percent Detected	Average Concentration	Median Concentration	Max Concentration
Precursors	PFCAs	4:2 FTS	10	0.39	ND	11
		6:2 FTS	59	51	4.7	620
		8:2 FTS	41	14	ND	607
		ADONA	ND	ND	ND	ND
		HFPO-DA (GenX)	7	44	ND	2,800
	PFSAs	N-EtFOSAA	70	91	18	3,470
		N-MeFOSAA	64	86	6.6	6,680
PFCAs	Short-Chain	PFBA	95	672	235	3,820
		PFPeA	95	1,043	276	8,570
		PFHxA	98	1,288	525	8,970
		PFHpA	97	367	136	8,470
	Long-Chain	PFOA	98	741	265	11,800
		PFNA	84	100	21	3,430
		PFDA	65	31	4.8	857
		PFUnDA	19	2.44	ND	96
		PFDoA	8	0.76	ND	56
		PFTriA	2	0.04	ND	7
		PFTeA	4	0.08	ND	8
		PFHxDA	2	0.02	ND	1
		PFODA	ND	ND	ND	ND
PFSAs	SC	PFBS	67	397	10	6,620
		PFPeS	57	40	4.1	2,900
	Long-Chain	PFHxS	75	171	33	10,600
		PFHpS	46	19	ND	2,290
		PFOS	87	642	131	51,400
		PFOSA	30	9.25	ND	701
		PFNS	1	0.04	ND	8
		PFDS	3	0.37	ND	55

PFCAs = Perfluoroalkyl Carboxylic Acids

PFSAs = Perfluoroalkyl Sulfonic Acids

SC = Short-Chain

ND = Non-Detect (below method detection limit)

Number of samples = 189

B. **Summary of PFAS Detections and Concentrations at Landfill Facilities (Table 3)**

Analysis of PFAS detections and concentrations in leachate at individual landfills indicates that there is a significant range of concentrations for individual PFAS among the 25 landfills sampled (See Figure A1 in Appendix A for a chart of landfills and their corresponding Total PFAS concentrations). This speaks to the variability of leachate quality across landfills and at individual landfills throughout time. Below is a discussion of notable observations when evaluating concentrations of detected PFAS at the 25 landfills sampled:

1. Average Sum of 6 PFAS concentrations for the 25 landfills ranged from approximately 4 ng/L (Anson-Madison) to approximately 18,540 ng/L (Hartland), with an average concentration of approximately 2,440 ng/L.

2. Average Total PFAS concentrations for the 25 landfills ranged from approximately 5 ng/L (Anson-Madison) to approximately 27,970 ng/L (Hartland) with an average concentration of approximately 6,130 ng/L. See Figures A2(a) and A2(b) in Appendix A for charts depicting average Total PFAS concentrations for each of the 25 landfills.

3. Landfills with elevated average Sum of 6 PFAS concentrations (> 2,000 ng/L) include three sludge landfills (Hartland, Twin Rivers, and Androscoggin Mill), three special waste landfills (Crossroads, Pine Tree, and Juniper Ridge), and one MSW landfill (Brunswick). These seven landfills also had average Total PFAS concentrations ≥ 5,000 ng/L.

4. In addition to the seven landfills mentioned above, average Total PFAS concentrations were also above 5,000 ng/L at the Hatch Hill (MSW), SAPPI Mill (sludge), Presque Isle (MSW), and Tri-Community (MSW and sludge) landfills.

5. Two sludge landfills (Hartland and Twin Rivers) had significantly higher average Sum of 6 PFAS concentrations compared to the other 23 landfills sampled. Average Sum of 6 PFAS concentrations were approximately 18,540 ng/L and 13,820 ng/L at Hartland and Twin Rivers, respectively, while the next highest average Sum of 6 PFAS concentration was approximately 4,060 ng/L at an MSW landfill (Brunswick).

   Average Total PFAS concentrations at the Hartland and Twin Rivers sludge landfills were approximately 27,970 ng/L and 23,490 ng/L respectively, which were also significantly elevated compared to the other 23 landfills sampled. The Crossroads Landfill (special waste) had the third highest average Total PFAS concentration (18,600 ng/L).

   It is important to note that both landfill facilities had one leachate sample with significantly elevated PFAS concentrations compared to the other four samples collected at the facilities, which skews the average higher (See Figure A5 in Appendix A). Nonetheless, average Sum of 6 and Total PFAS concentrations are still some of the highest values at these two landfills even when excluding the potential outlier results.

6. Evaluating the 25 landfills sampled, the average Sum of 6 PFAS concentration made up less than 50% of the average Total PFAS concentration, indicating that additional PFAS not currently regulated in Maine are present in landfill leachate at significant concentrations.

7. Five PFAS compounds, including PFOA and PFOS, were detected at all 25 landfills sampled while an additional 11 PFAS were detected at most (≥ 75%) of the landfills. Eight PFAS compounds were not routinely detected (≤ 20%) at the 25 landfills sampled (Table 4).

8. Overall, short-chain PFCAs were the dominant PFAS compound group contributing to Total PFAS concentrations for the 28 PFAS analyzed in landfill leachate (Figure 2).

   Other studies[5,6,7] have also shown that short-chain PFCAs tend to dominate landfill leachate. This is most likely influenced by the breakdown of longer-chain PFAS and precursors to short-chain PFCAs as well as the shift in industries to use shorter-chain PFAS in products.

[5] Zhang et al. (2023). Poly- and Perfluoroalkyl Substances (PFAS) in Landfills: Occurrence, Transformation and Treatment. Waste Management, 155, p. 162-178. https://doi.org/10.1016/j.wasman.2022.10.028.

[6] Capozzi et al. (2023). PFAS in municipal landfill leachate: Occurrence, transformation, and sources. Chemosphere, 334. https://doi.org/10.1016/j.chemosphere.2023.138924.

[7] Chen et al. (2023). Evaluation of per- and polyfluoroalkyl substances (PFAS) in leachate, gas condensate, stormwater, and groundwater at landfills. Chemosphere, 318. https://doi.org/10.1016/j.chemosphere.2023.137903.

Table 3. Summary of Average PFAS Concentrations in Landfill Leachate

Landfill Facility	Town	Primary Waste	Avg. Annual Leachate Volume (2021 - 2023)	Avg. Sum of 6 PFAS (ng/L)	Avg. Total PFAS (ng/L)
Hatch Hill	Augusta	MSW	12,841,000	1,930	10,762
Augusta Tissue	Augusta	Sludge	2,634,000	561	2,870
Woodland Pulp	Baileyville	Sludge	47,341,000	207	352
Bath	Bath	MSW	11,071,000	693	1,573
Brunswick	Brunswick	MSW	2,449,000	4,063	8,883
Bucksport Mill	Bucksport	Sludge	43,057,000	21	61
Dolby	East Millinocket	Sludge	52,950,000	1,201	1,362
SAPPI Mill	Fairfield	Sludge	25,538,000	1,202	8,735
Tri-Community	Fort Fairfield	MSW and Sludge	11,128,000	1,596	7,138
Twin Rivers Mill	Frenchville	Sludge	8,783,000	13,820	23,487
Pine Tree	Hampden	Special Waste	8,900,000	2,157	5,675
Hartland	Hartland	Sludge, Tannery Waste	7,187,000	18,539	27,966
Androscoggin Mill	Jay	Sludge	74,000,000	2,533	4,994
LAWPCA	Lewiston	Sludge	NR	606	907
Lewiston	Lewiston	MSW Ash	4,637,000	226	673
Anson-Madison Sanitary District	Madison	Sludge	4,352,000	4	5
ND Paper	Mexico	Sludge	28,855,000	62	170
Crossroads	Norridgewock	Special Waste	24,659,000	2,633	18,599
Juniper Ridge	Old Town	Special Waste	17,446,000	2,066	9,074
Presque Isle	Presque Isle	MSW	3,982,000	1,512	8,297
Rockland Quarry	Rockland	CDD	20,050,000	934	2,062
Mid-Coast Solid Waste Quarry	Rockport	CDD	18,264,000	968	1,920
Sanford Sewerage District	Sanford	Sludge	1,776,000	759	2,604
Kimberly Clark Larson-Chapman	Scarborough	Sludge	2,895,000	1,795	3,061
Ecomaine	South Portland	MSW Ash	28,164,000	873	2,010

MSW = Municipal Solid Waste

CDD = Construction Demolition Debris

MSW Ash = Incinerated MSW

NR = Not Reported

Total PFAS = Sum of 28 PFAS Analyzed

Note that many of the MSW landfills also accept CDI

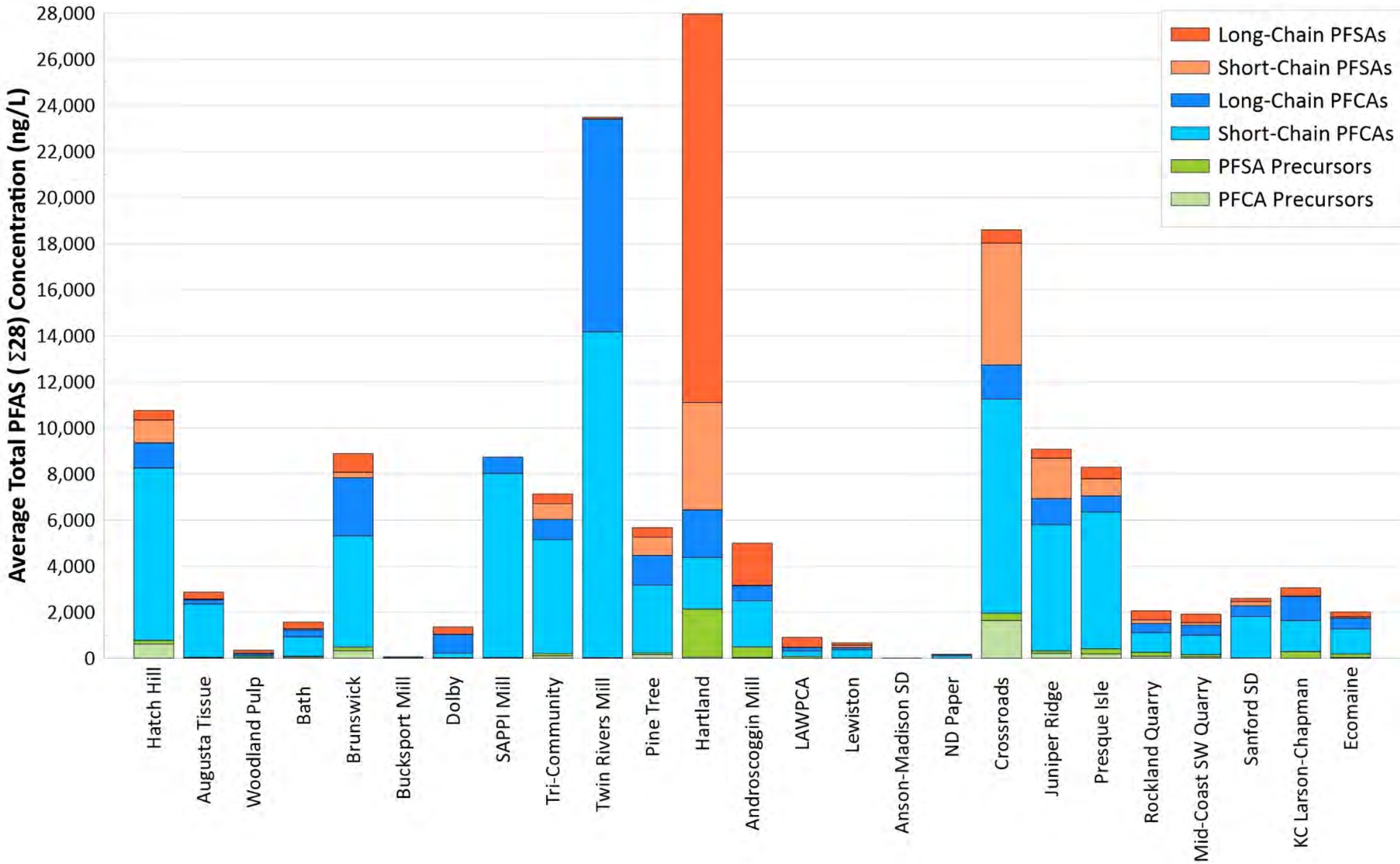
Average annual leachate volumes based on available data submitted to the Department. Some landfills did not provide complete volumes for all three years

Table 4. Distribution of PFAS in Landfill Leachate

PFAS Compounds Detected at All Landfills Sampled			PFAS Compounds Detected at Most (75%) Landfills Sampled			PFAS Compounds Detected at Few (≤ 25%) Landfills Sampled		
	PFHxA		8:2 FTS	PFBA	PFBS	4:2 FTS	PFTriA	PFNS
6:2 FTS	**PFHpA**	**PFOS**	N-EtFOSAA	PFPeA	PFPeS	HFPO-DA	PFTeA	PFDS
	PFOA		N-MeFOSAA	**PFNA**	**PFHxS**	(GenX)	PFHxDA	
				PFDA				

ADONA and PFODA were not detected at any of the landfills sampled.
Bold Text = Sum of 6 PFAS
Number of values = 25 (individual landfill PFAS averages)

Figure 2. Distribution of Average PFAS Concentrations in Landfill Leachate



C. PFAS Data Limitations/Gaps

The PFAS results for landfill leachate from the 25 landfills sampled indicate a wide range of detections and concentrations, which highlights the variability in landfill conditions in the dataset. In addition to this variability, there are some data gaps that should be considered for future investigations of PFAS at landfills:

1. Landfill leachate samples were analyzed for 28 PFAS using United States Environmental Protections Agency (U.S. EPA) Modified Method 537.1 (EPA 537.1 Mod.), which is the currently established method for PFAS analysis. However, other similar studies on landfill leachate have shown that additional PFAS are present at landfills that are not included in EPA 537.1 Mod. For example, landfill PFAS studies[5,6,7] have shown that 5:3 FTCA (PFCA precursor) is a dominant PFAS unique to the biogeochemical processes created at landfills. Since 5:3 FTCA is not analyzed in EPA 537.1 Mod., this PFAS is missing from the landfill leachate dataset that could significantly influence PFAS concentration trends. An updated PFAS analysis method is expected to be finalized in 2024 (U.S. EPA Method 1663) which would expand the list of PFAS analyzed to 40 compounds, including 5:3 FTCA.

2. This study focused on leachate samples from engineered landfills that are at least partially lined and have leachate collection systems. PFAS analysis of groundwater from landfill monitoring wells was not included in this study. It is clear from the 25 landfills sampled that significant concentrations of PFAS are present at landfills and in landfill leachate that have the potential to impact groundwater and/or surface water in vicinity of the landfills.

   Additionally, analysis of leachate-contaminated groundwater from unlined landfills that do not have leachate collection systems is not included in this study. There are over 400 closed MSW landfills throughout Maine, most of which are unlined, that are overseen by the Department. A subset of these unlined MSW landfills have had PFAS samples collected from monitoring wells and water supplies deemed at-risk by the Department associated with these facilities.

3. Studies have shown[5] that certain PFAS can be transported by air emissions and are present in landfill air/gas. Although beyond the scope of this study, analysis of PFAS in landfill gas has not been fully evaluated as laboratory methods have not been completely established and validated.

V. Other Relevant Information

A. Bureau of General Services Study and Report

Resolve 2021, Ch. 172, *Resolve, To Address Perfluoroalkyl and Polyfluoroalkyl Substances Pollution at State-owned Solid Waste Landfills,* required the Maine Department of Administrative and Financial Services' Bureau of General Services (BGS) to conduct a study of methods to treat PFAS in leachate collected from two State-owned landfills - the Dolby Landfill in East Millinocket and the Juniper Ridge Landfill in Old Town. Specifically, the study was to identify readily available methods to reduce the concentration of the Sum of 6 PFAS to no more than 20 ng/L, which is the current Maine Interim Drinking Water Standard for PFAS. The study was completed and the report, titled "Study to Assess Treatment Alternatives for Reducing PFAS in Leachate From State-Owned Landfills" was submitted to the Joint Standing Committee on Environment and Natural Resources in January 2023.

The study presented results of leachate characterization (quantity and quality), assessed and evaluated potential PFAS treatment options for the landfill leachate, provided scope and cost estimates for implementing certain landfill leachate treatment technologies, and outlined next step recommendations.

The report focused on four technologies for reducing PFAS concentrations in leachate – foam fractionation, reverse osmosis, electrochemical advanced oxidation process, and adsorption. Of the four technologies researched, foam fractionation was identified as the most appropriate technology at the time to treat leachate from the two landfills for PFAS. The report identified adsorption or electrochemical advanced oxidation as being appropriate technologies to treat or manage the foamate byproduct of the foam fractionation process. Cost estimates provided in the report include start up and infrastructure costs. For the Dolby Landfill, the cost estimate range for the first five years was $15.8 to $22 million. For the Juniper Ridge Landfill, a cost estimate range for the first five years was $7.2 to $10.4 million.

The report recommended additional steps including continued leachate quality testing which include PFAS analysis, and pilot testing the various PFAS treatment systems outlined in the report.

B. Projects and Research in Maine

In accordance with P.L. 2021, Ch. 641, the Department's Bureau of Water Quality initiated a program to require entities licensed to discharge wastewater to groundwater or any waters of the State to sample their effluent discharged for PFAS and report the results to the Department. The Department identified 105 publicly owned treatment works and 19 private facilities that are in the Department's Toxics Program or had a reasonable potential to have PFAS in the effluent. Analytical costs for the public facilities were funded by the Department through a U.S. EPA grant, and private facilities were required to pay for their sampling and analysis. This initiative began in September 2022, and the initial phase was completed in September 2023. Generally, wastewater effluent was sampled monthly for a 10-month period. Spray irrigation facilities also collected monthly lagoon effluent samples for a 10-month period before being sprayed and quarterly groundwater samples over a one-year period. The results of the sampling were made available on the Department's website in a November 2023 Report. The results of this phase of the project are also being added to the Toxscan program for use in facility and watershed analysis and evaluation if there is a need for future regulation, subject to the U.S. EPA's development of ambient water quality Human Health Criteria.

Based on the sampling results, the Bureau of Water Quality initiated a second phase of sampling to further evaluate inputs to certain wastewater treatment facilities. The public facilities with the top 10% highest PFAS concentrations or loadings are currently being further analyzed to characterize PFAS sources in their collection systems. The purpose is to assess procedural and/or infrastructure needs to reduce PFAS loadings depending on future water quality regulation. While this investigation does not directly target leachate management, a result of PFAS discharge limitations could be that upstream wastewater discharges, such as leachate from landfill facilities, are required to pretreat their discharge prior to it entering the wastewater stream at a wastewater treatment facility. Additionally, certain landfill facilities in Maine are licensed to discharge treated leachate to surface and groundwater, and these facilities' licenses and likely their treatment systems, will need to be modified to ensure that any effluent limitations for PFAS are met.

The Department is aware of multiple projects (pilot and full-scale) to address PFAS impacts in several media including wastewater, sludge, and leachate. Technologies are being tested and explored at landfill facilities and wastewater treatment facilities in Maine to address disposal challenges with several media. Cost estimates to address these problems vary significantly and have the potential to impact local and/or state ratepayers significantly if implemented. The Department is aware of the following projects:

Waste Management Disposal Services of Maine (WMDSM) has piloted a foam fractionation unit to treat leachate for PFAS at its Crossroads Landfill facility in Norridgewock, Maine and is presently working on a foam fractionation process for permitting at the facility. This will allow leachate disposal options beyond their current arrangement with a municipal wastewater treatment facility. WMDSM anticipates submitting an application to the Department in the second quarter of 2024. WMDSM has also submitted an application to the Department to construct a processing facility to dry municipal wastewater treatment plant sludge prior to disposal at the landfill. The dryer would reduce the water content in the sludge from approximately 80 percent to 20 percent. For more information on WMDSM's work, contact Jeff McGown at jmcgown@wm.com.

Portland Water District (PWD) is presently preparing their master plan for sludge management with a draft anticipated by mid-January 2024. The plan will likely look at two options. One option may address management and handling of septage and sludge at one of their facilities. This could include replacing or upgrading equipment and adding digestion and dryer technologies to reduce volume and delivery frequencies to disposal facilities. The other option would include off-site treatment of sludge which could include high solids digestion and thermal hydrolysis with pyrolysis. Any dryer activity would include thermal oxidizers to control emissions. For more information on PWD's work, contact Scott Firmin at sfirmin@pwd.org.

Sanford Sewerage District (SSD) is exploring sewage and wastewater treatment options for the facility. They are working with a company to trial supercritical water oxidation as a treatment technology to remove PFAS from their sludge. They are also exploring a sludge and/or septage drying project at their facility. For more information on SSD's work, contact André Brousseau at abrousseau@sanfordsewerage.org.

Anson-Madison Sanitary District (AMSD) is implementing a project to create a centralized facility to receive and treat municipal and industrial wastewater as well as other PFAS-contaminated materials such as leachate, septage, and cow manure and milk. This project is anticipated to include upgrading the on-site lagoon system and related equipment and installing new chemical treatment systems to remove PFAS from the wastewater. PFAS treatment technologies being proposed include a foam fractionation treatment system and a membrane bioreactor, and ion exchange treatment using resin that can be regenerated. A secondary goal of this project is to progress to destroying all captured PFAS. Destruction technologies currently being evaluated by AMSD include supercritical water oxidation and high temperature plasma gasification. This project, like many others, is expected to be implemented in multiple phases and is designed to allow for flexibility as new or improved treatment and destruction technologies develop. For more information on AMSD's work, contact Peter Elias at pelias.amsd@gmail.com.

The outcome or success of these projects and others should be considered and incorporated when determining the most appropriate approach to managing PFAS in landfill leachate.

In August of 2022, P.L. 2021, Ch. 641, banned the land application, selling, and distribution of sludge and sludge-derived products in Maine. With fewer outlets to manage or use sludge and sludge derived products, Maine was left with many solid waste management challenges. In 2023, the Department, in collaboration with the Maine Water Environment Association, commissioned Brown and Caldwell to complete a study and report to evaluate sludge management practices in Maine and provide recommendations for the future. The report, titled "An Evaluation of Biosolids Management in Maine and Recommendations for the Future" was finalized on December 15, 2023.

The Department has requested or completed PFAS sampling of groundwater and/or other environmental media outside of the requirements of this law as a proactive approach to managing potential PFAS impacts surrounding closed MSW landfills in Maine. Since 2016, the Department has sampled groundwater and water supplies surrounding certain closed MSW landfill facilities. There are over 400 closed MSW landfills in Maine, and the Department has prioritized sampling the facilities and nearby water supplies by risk, sampling those determined to be most at risk first. To date, investigations have either been completed or initiated at 95 of these facilities, with 10 being completed in 2023. These investigations have included sampling 314 drinking water supply wells and have identified 51 water supplies with concentrations of PFAS above 20 ng/L for the Sum of 6. In response to this work, 44 filtration systems have been installed on impacted water supplies and 16 properties have been connected to public water systems to mitigate the impacts to the water supplies from PFAS.

C. Actions from the U.S. EPA and other States

The U.S. EPA Effluent Guidelines Program Plan 15 announced that changes to the effluent guidelines and standards are warranted to address PFAS impacts in landfill leachate. These updated guidelines and rules would apply to any landfill facility that is licensed to discharge effluent directly to a surface waterbody. The Brunswick and Bucksport landfill facilities are two landfills that are licensed by the Department's Bureau of Water Quality to discharge leachate and stormwater to Maine's rivers and would be subject to these federal rule and guideline updates.

Other States in the northeast are investigating the potential impacts that PFAS in landfills, including the leachate, can have on industries and the environment. While other northeast states have not initiated a leachate sampling program similar to Maine's, they have sampled groundwater, leachate, wastewater, and other waste media for PFAS to gain an understanding of PFAS sources and management in the waste cycle. It does not appear that any state in the northeast has placed limitations on PFAS concentrations in leachate, though some standards have been placed on landfill facilities due to private industrial or business practices of a receiving treatment facility. Like Maine, most are compiling data and completing research fitting for their state to develop a practical path forward for PFAS management in the environment. While some states have many active landfills that manage leachate, other states have very few, or none, which is why each state or entity approaches these concerns differently. Additionally, many concentration limitations will ultimately be based on a federal drinking water standard or a receiving waterbody standard, and until these standards are finalized, developing a holistic path forward to manage PFAS in the waste stream is challenging.

D. Considerations for Managing and Treating Leachate

Landfill facilities do not actively use or produce PFAS as part of their operations, rather they accept and manage waste streams that contain PFAS – materials such as sludge, MSW, industrial wastes, and construction and demolition debris. As PFAS are eliminated from consumer goods and products, they will become less prevalent and persistent in our waste stream. Additionally, it is important to recognize that landfill leachate is one waste stream among many with the potential to contribute PFAS to the environment. Recognizing that most landfill leachate is impacted with PFAS is important, but understanding that a holistic approach to managing PFAS in waste is vital to successfully keeping PFAS out of the environment and protecting public health.

There are several factors to consider when approaching treating any media for a contaminant. A recommended treatment system or combination of systems will depend on many facility-specific data points; no singular PFAS treatment or destruction system design will work for all Maine landfills that collect and manage leachate.

Technologies to address PFAS in leachate are considered either destructive or non-destructive. Destructive technologies include processes such as Electrochemical Oxidation, Chemical Advanced Oxidation (AOP) and Advanced Reduction Process (ARP). These destruction technologies are currently in pilot stage and have limited field applicability. They will require significant testing to determine whether they are feasible on a scaled-up version.

Non-destructive technologies involve the concentration of PFAS into a separate waste stream which requires further treatment or disposal. Non-destructive absorptive methods such as Granulated Activated Carbon (GAC) or Ion Exchange (IX) resins absorb PFAS from leachate onto the media as a flow-through system. Non-destructive separation methods include i) Precipitation and Sedimentation; ii) Foam Fractionation and Ozofractionation; iii) Reverse osmosis (RO) and Ultrafiltration; and iv) Evaporation. Foam Fractionation and RO are both considered mature and deployable technologies, and each has concentrated effluents that need to be managed through other means.

Note that these treatment technologies should be considered part of a holistic approach to dealing with PFAS in other PFAS-contaminated media (i.e., sludge, septage, soil). As with all of these technologies, the leachate may require pretreatment to enhance or improve the efficiency of the treatment technology. The efficiency to remove PFAS from leachate depends on various factors including type of treatment, co-contaminants, leachate volume and flow, disposal options, discharge limits, etc. For example, a final engineering design could include combining treatment methods of separation, concentration, and destruction for optimal performance.

VI. Conclusions

Five leachate PFAS sampling events were completed at 25 landfill facilities in Maine between the fall of 2021 and the fall of 2023. A majority of the 28 PFAS analyzed were detected in leachate with short-chain PFCAs making up greater than 95% of the detections and representing some of the highest average and median concentrations reported. Five PFAS, including PFOA and PFOS, were detected in the leachate from all 25 landfill facilities sampled, and an additional 11 PFAS were detected at greater than 75% of the landfill samples. Eight PFAS were detected in less than 20% of the landfills sampled, and many long-chain PFCAs and PFSAs, along with GenX were detected in less than 10% of leachate samples.

The concentrations of individual PFAS range widely among the leachate sampled indicating significant variability across landfills and at individual landfills throughout time. The average of the Sum of 6 PFAS and Total PFAS concentrations ranged from single digit concentrations to over 15,000 ng/L. Seven of the 25 landfill facilities sampled reported average Sum of 6 concentrations above 2,000 ng/L – three sludge landfills, three special waste landfills, and one MSW landfill. When considering average Total PFAS concentrations in leachate, the seven facilities mentioned above plus four others (two MSW landfills, one sludge landfill, and one MSW/Sludge landfill) reported average Total PFAS concentrations greater than 5,000 ng/L. Two Sludge landfills showed significantly higher average concentrations of PFAS in their leachate, approximately three times higher than the next highest average leachate concentration for the Sum of 6 PFAS.

The dataset evaluated for this report is limited regarding the number of sample events, the duration of study period, and potentially the specific PFAS analyzed.

VII. Recommendations

Based on the data collected and the information analyzed, the Department provides these recommendations for consideration by the legislature.

- The Department recommends continued testing of leachate at the 25 landfill facilities twice per year paired with the addition of groundwater and/or surface water samples from select monitoring locations at each site. Once finalized, the Department will evaluate integrating

EPA's updated PFAS analysis method (U.S. EPA Method 1663) for these samples. This new method will include 40 compounds, including 5:3 FTCA.

It should be noted that there is a cost to this continued testing. The initial phase of leachate testing required under this law was completed and funded by the licensed landfill facilities themselves. The Department estimates that the cost of analysis alone, excluding consultant/contractor costs to collect samples and provide data to the Department, was at least $15,000 per year total for all of the 25 facilities. Expanded testing could cost an additional approximately $50,000 per year total for the 25 facilities to complete the testing as recommended in this report. The increased cost is due to the addition of analytical parameters and sampling locations. If this testing is continued and/or expanded, this financial burden will fall to facility owners or operators which in some cases are municipalities with tight budgets.

As PFAS are not currently regulated parameters or pollutants for any licensed activities at landfills in Maine, expanded testing will require legislative authorization.

- The Department recommends the continuation of groundwater monitoring at Maine's 400-plus closed unlined municipal landfills in accordance with the process already ongoing through the closed municipal landfill program administered under 38 M.R.S. §1310-F. Municipalities are encouraged to work closely with the Department in deploying these efforts and in planning for future funding required of the municipality as part of this program.

- The Department recommends analyzing PFAS in landfill gas once laboratory methods are established and validated to better understand air migration pathways from landfills and to determine the risk to off-site receptors through air deposition to the environment.

Attachment 1

List of PFAS Parameters and their Abbreviations

CAS Number	Parameter Name	Abbreviated Name
375-22-4	Perfluorobutanoic Acid	PFBA
2706-90-3	Perfluoropentanoic Acid	PFPeA
375-73-5	Perfluorobutanesulfonic Acid	PFBS
757124-72-4	1H,1H,2H,2H-Perfluorohexanesulfonic Acid	4:2FTS
307-24-2	Perfluorohexanoic Acid	PFHxA
2706-91-4	Perfluoropentanesulfonic Acid	PFPeS
375-85-9	Perfluoroheptanoic Acid	PFHpA
355-46-4	Perfluorohexanesulfonic Acid	PFHxS
335-67-1	Perfluorooctanoic Acid	PFOA
27619-97-2	1H,1H,2H,2H-Perfluorooctanesulfonic Acid	6:2 FTS
375-92-8	Perfluoroheptanesulfonic Acid	PFHpS
375-95-1	Perfluorononanoic Acid	PFNA
1763-23-1	Perfluorooctanesulfonic Acid	PFOS
335-76-2	Perfluorodecanoic Acid	PFDA
39108-34-4	1H,1H,2H,2H-Perfluorodecanesulfonic Acid	8:2 FTS
68259-12-1	Perfluorononanesulfonic Acid	PFNS
2355-31-9	N-Methyl Perfluorooctanesulfonamidoacetic Acid	NMeFOSAA
2058-94-8	Perfluoroundecanoic Acid	PFUnA
335-77-3	Perfluorodecanesulfonic Acid	PFDS
754-91-6	Perfluorooctanesulfonamide	FOSA
2991-50-6	N-Ethyl Perfluorooctanesulfonamidoacetic Acid	NEtFOSAA
307-55-1	Perfluorododecanoic Acid	PFDoA
72629-94-8	Perfluorotridecanoic Acid	PFTrDA
376-06-7	Perfluorotetradecanoic Acid	PFTA
13252-13-6	2,3,3,3-Tetrafluoro-2-[1,1,2,2,3,3,3-Heptafluoropropoxy]- Propanoic Acid	HFPO-DA
9119005-14-4	4,8-Dioxa-3h-Perfluorononanoic Acid	ADONA
67905-19-5	Perfluorohexadecanoic Acid	PFHxDA
16517-11-6	Perfluorooctadecanoic Acid	PFODA
PFAS, Total (6)	Sum of PFOA, PFOS, PFNA, PFHpA, PFHxS, and PFDA	

Appendix A: Supplemental PFAS Figures

Figure A1: Stacked bar charts depicting PFAS group concentrations across the twenty-five (25) landfills that sampled landfill leachate between Fall 2021 and Fall 2023. Note the difference in scale between the two charts. The chart on the left depicts the landfills with average Total PFAS concentrations greater than 4,000 ng/L while the chart on the right depicts landfills with average Total PFAS concentrations less than 4,000 ng/L.

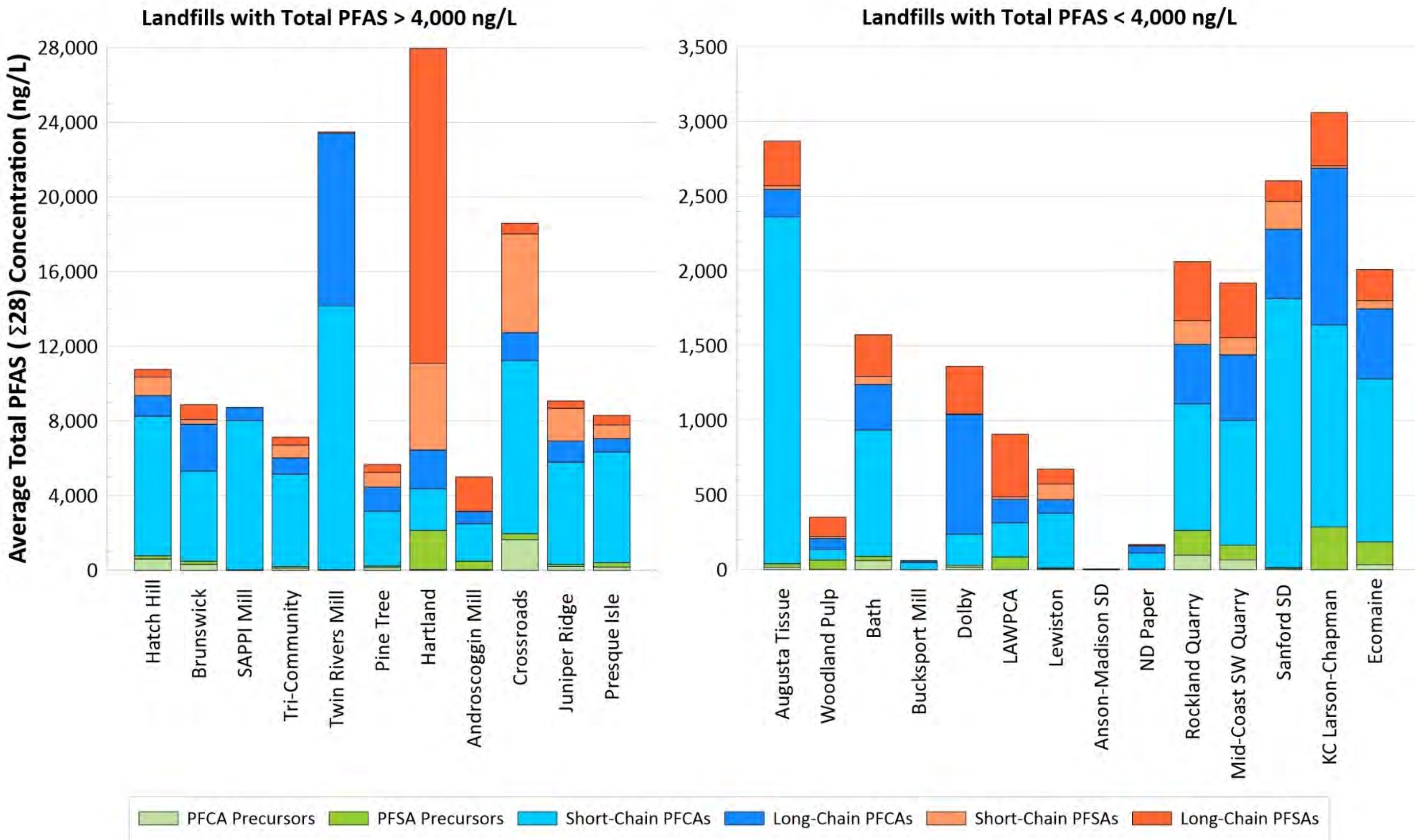


Figure A2(a). Pie charts depicting average PFAS concentrations for the six PFAS Groups analyzed in landfill leachate. This figure is sorted from highest to lowest average Total PFAS concentrations at the twenty-five (25) landfills sampled.

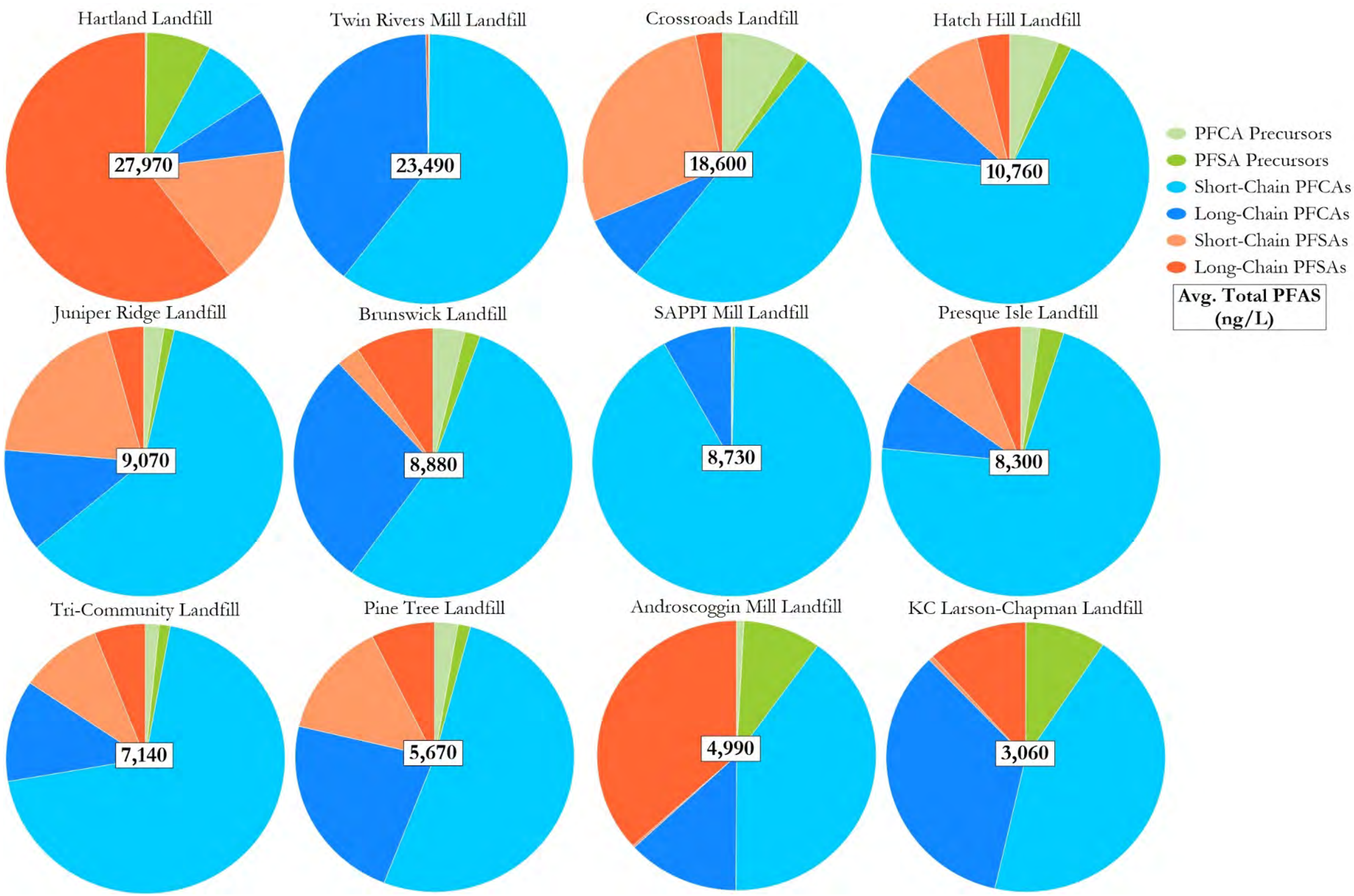


Figure A2(b). Pie charts depicting average PFAS concentrations for the six PFAS Groups analyzed in landfill leachate. This figure is sorted from highest to lowest average Total PFAS concentrations at the twenty-five (25) landfills sampled. Note that the Anson-Madison Sanitary District Landfill had an average Total PFAS concentration of 5 ng/L so a pie chart was not generated for that landfill.

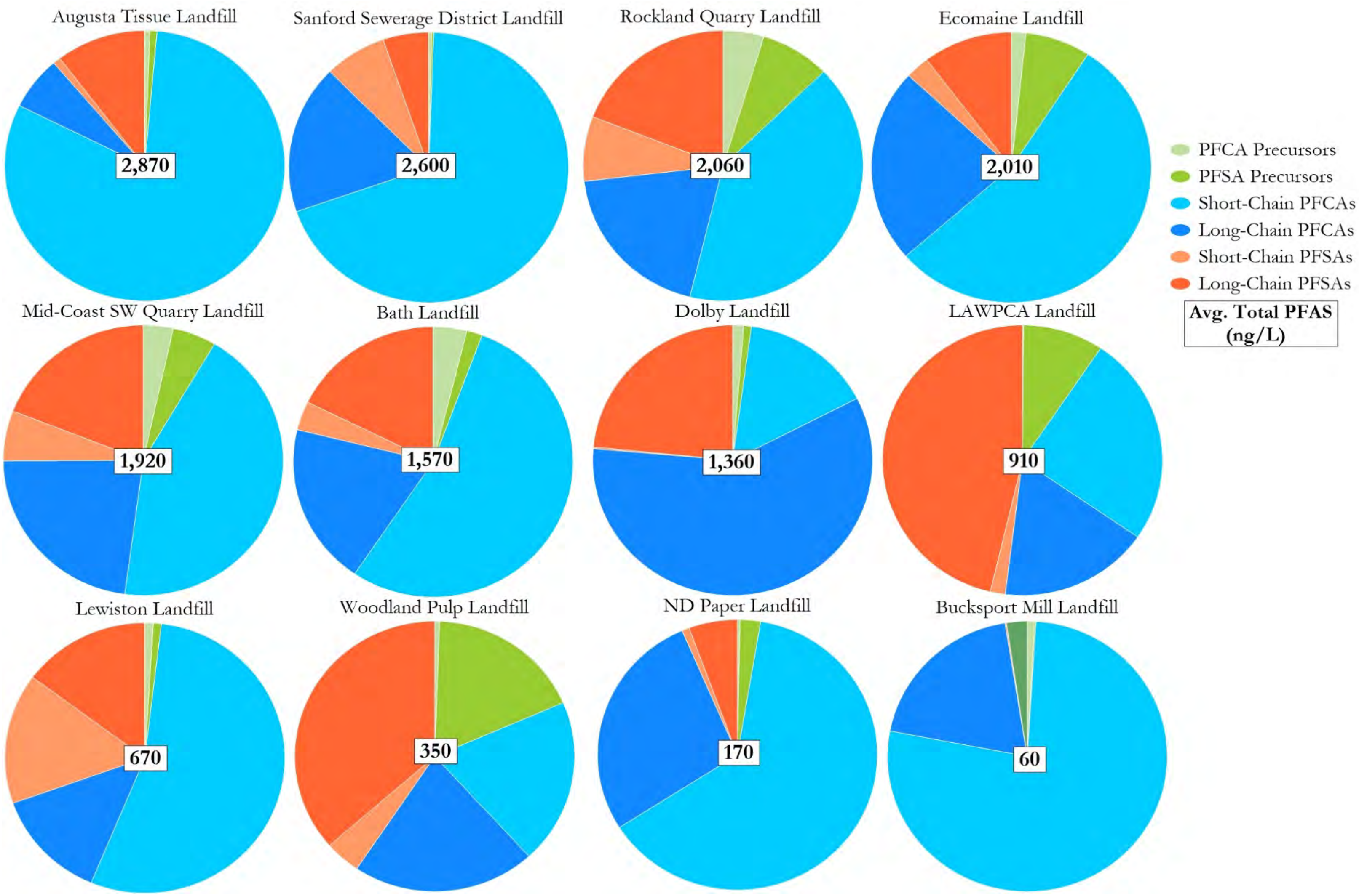


Figure A3. Box-and-whisker plot of PFAS concentrations for the 28 PFAS analyzed in 189 landfill leachate samples. The blue box represents the lower (25%) percentile (bottom line of box), the median (line inside box), and the upper (75%) percentile (top line of box). The whiskers above and below the box represent 1.5-times the upper and lower percentiles. Blue dots are outliers, which are concentrations that are greater than 1.5-times the percentiles.

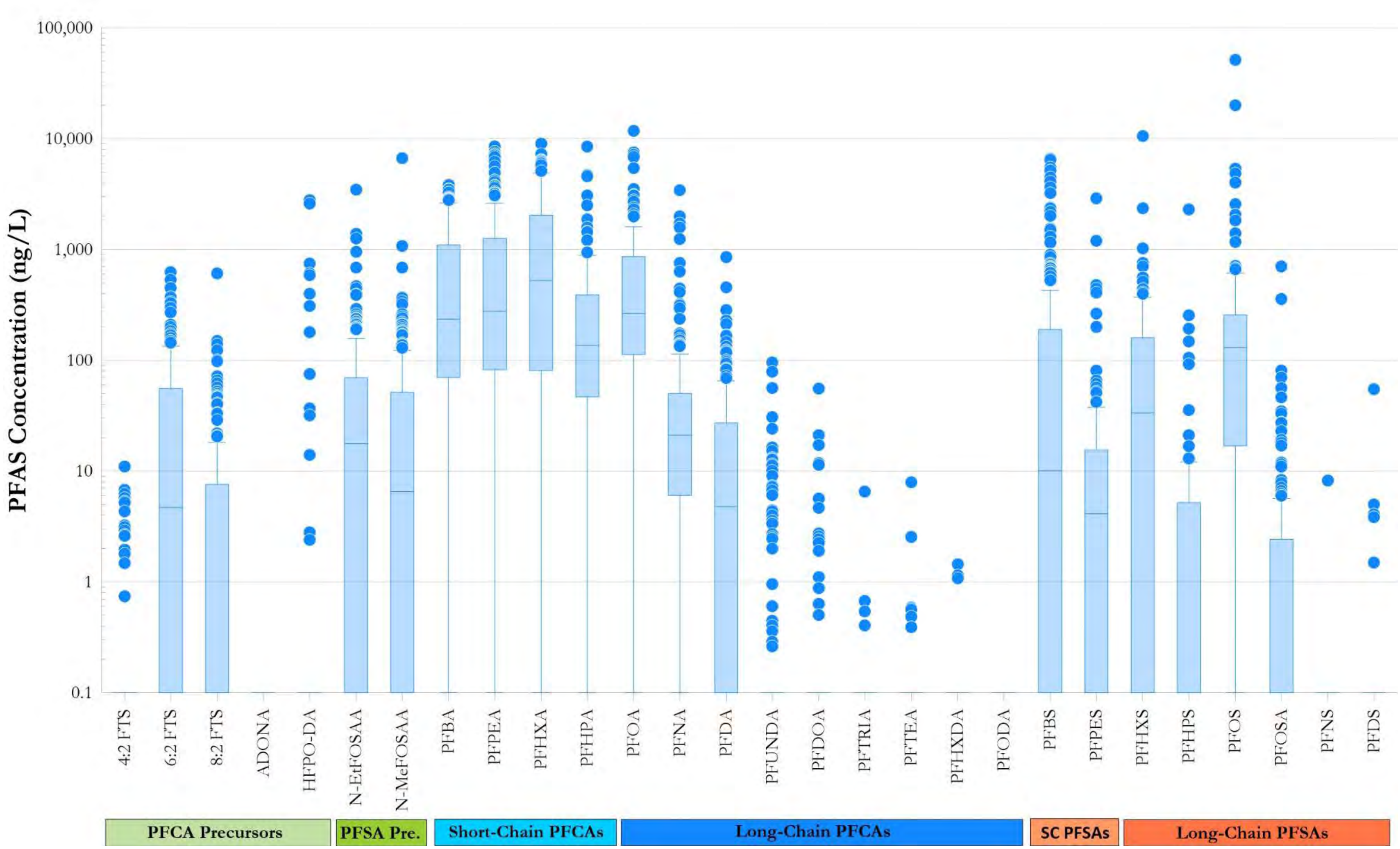


Figure A4. Box-and-whisker plot of the six (6) PFAS Groups analyzed in 189 landfill leachate samples. The blue box represents the lower (25%) percentile (bottom line of box), the median (line inside box), and the upper (75%) percentile (top line of box). The whiskers above and below the box represent 1.5-times the upper and lower percentiles. Blue dots are outliers, which are concentrations that are greater than 1.5-times the percentiles.

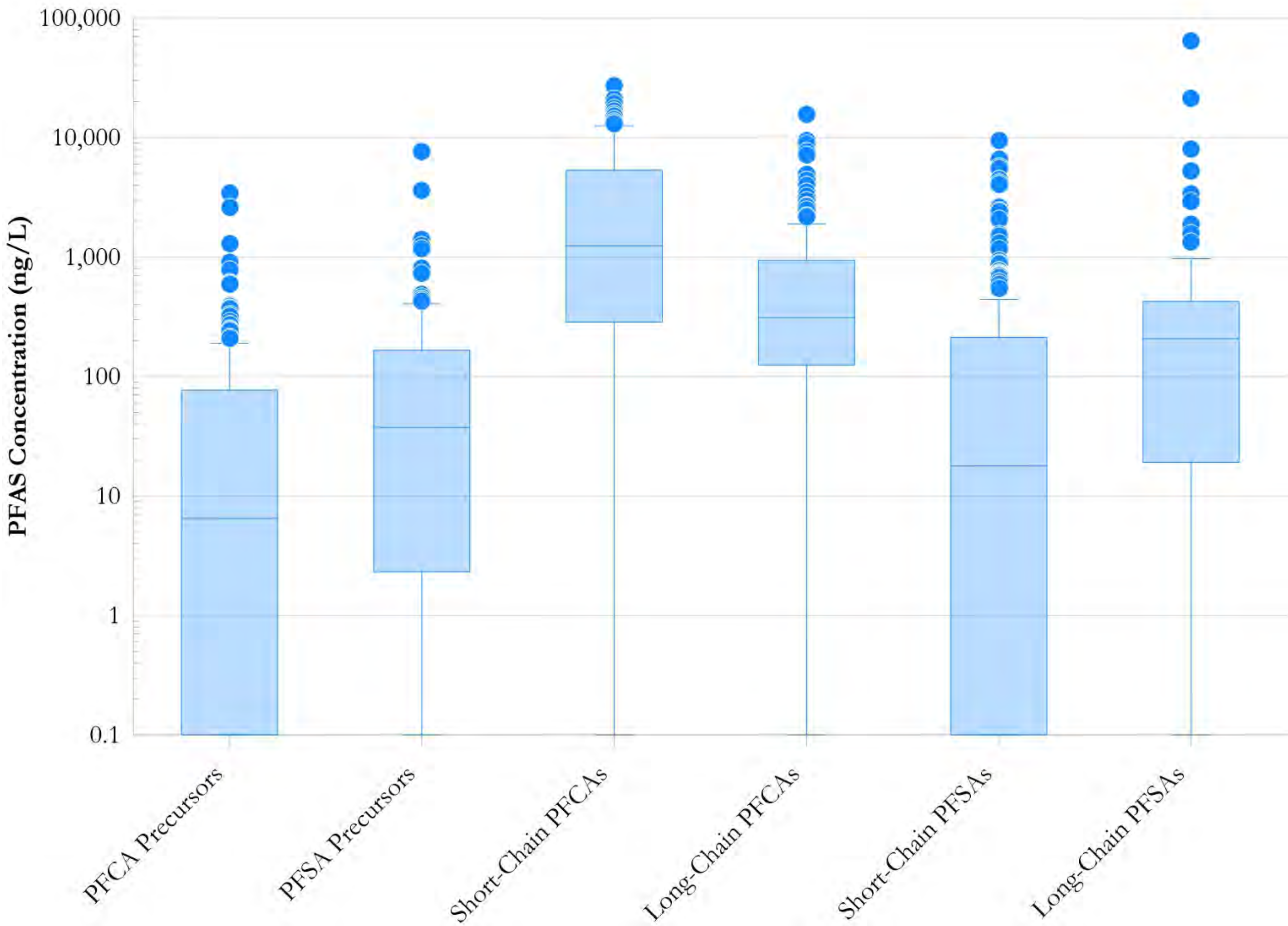


Figure A5. Time-series plots of Sum of 6 PFAS concentrations at the Hartland and Twin Rivers landfills, which had the highest average PFAS concentrations of the twenty-five landfills sampled. Note that each landfill had one sampling event with a Sum of 6 PFAS concentrations that was significantly greater than the other four samples analyzed.