Final Report

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Appendix I: Leachability Study for PFAS-Impacted Sediments for Project 1007 Bench-Scale Report

Project 1007 Feasibility Study
Minnesota Pollution Control Agency

MINNESOTA POLLUTION
CONTROL AGENCY

Prepared for:

Minnesota Pollution Control Agency
520 Lafayette Rd
Saint Paul, MN 55155

Prepared by:

AECOM
800 LaSalle Avenue
Minneapolis, MN 55402
(612) 376-2000
aecom.com

Minnesota Pollution Control Agency
520 Lafayette Road North | Saint Paul, MN 55155-4194 |
651-296-6300 | 800-657-3864 | Or use your preferred relay service. | Info.pca@state.mn.us
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Acronyms and Abbreviations

%	percent
µm	micrometers
µM	micromolars
µS/cm	microSiemens per centimeter
AECOM	AECOM Technical Services, Inc.
AGWC	Anna's Grove Wetland Complex
AOC	Area of Concern
cm	centimeters
C_s	concentration of chemical compound in the sediment
C_{weq}	aqueous phase equilibrium concentration
EC	electrical conductivity
EPA	United States Environmental Protection Agency
EPL	Eagle Point Lake
FS	Feasibility Study
g/mL	grams per milliliter
HBV	Health-Based Value
HDPE	high-density polyethylene
HRL	Health Risk Limit
K_d	sediment adsorption/desorption partitioning coefficient
L	liter
L/kg	liters per kilogram
L/S	liquid to solid ratio
LOI	loss on ignition
m/d	meters per day
MCL	Maximum Contaminant Level
MDH	Minnesota Department of Health
mg/kg	milligrams per kilogram on a dry weight basis
mg/L	milligrams per liter
MPCA	Minnesota Pollution Control Agency
mV	millivolts
ng/kg	nanograms per kilogram on a dry weight basis
ng/L	nanograms per liter
ODS	Oakdale Disposal Site
ORP	oxidation reduction potential
PES	polyethersulfone
PSD	particle size distribution
QA/QC	quality assurance/quality control
RL	reporting limit
SDSV	Site-Specific Sediment Screening Value
SSC	Site-Specific Water Quality Criteria
TOC	total organic carbon
URCWC	Upper Raleigh Creek Wetland Complex

PFAS Abbreviations Used in This Report

Individual PFAS abbreviations used in this report are not named at their first use due to the length and complexity of the compound names. To improve readability, individual PFAS abbreviations are instead provided in the table below. The remainder of the acronyms and abbreviations used in the report are compiled in the Acronyms and Abbreviations list and are defined at first use in the body of the report.

Compound **Abbreviation**	Name	CAS Number
6:2 FTS	6:2 Fluorotelomer sulfonic acid	27619-97-2
NEtFOSAA	2-(N-Ethylperfluorooctanesulfonamido)acetic acid	2991-50-6
NMeFOSAA	2-(N-Methylperfluorooctanesulfonamido)acetic acid	2355-31-9
NEtFOSA	N-Ethylperfluorooctanesulfonamide	4151-50-2
NMeFOSA	N-Methylperfluorooctanesulfonamide	31506-32-8
PFBA	Perfluorobutanoic acid	375-22-4
PFBS	Perfluorobutanesulfonic acid	375-73-5
PFDA	Perfluorodecanoic acid	335-76-2
PFDoA	Perfluorododecanoic acid	307-55-1
PFDoS	Perfluorododecanesulfonic acid	79780-39-5
PFDS	Perfluorodecanesulfonic acid	335-77-3
PFHpA	Perfluoroheptanoic acid	375-85-9
PFHpS	Perfluoroheptanesulfonic acid	375-92-8
PFHxA	Perfluorohexanoic acid	307-24-4
PFHxS	Perfluorohexanesulfonic acid	355-46-4
PFMBA	Perfluoro(4-methoxybutanoic) acid	863090-89-5
PFMPA	Perfluoro(3-methoxypropanoic) acid	377-73-1
PFNA	Perfluorononanoic acid	375-95-1
PFNS	Perfluorononanesulfonic acid	68259-12-1
PFOA	Perfluorooctanoic acid	335-67-1
PFOS	Perfluorooctanesulfonic acid	1763-23-1
PFOSA	Perfluorooctanesulfonamide	754-91-6
PFPeA	Perfluoropentanoic acid	2706-90-3
PFPeS	Perfluoropentanesulfonic acid	2706-91-4
PFTrDA	Perfluorotridecanoic acid	72629-94-8
PFUnA	Perfluoroundecanoic acid	2058-94-8

I1 Introduction

The Project 1007 Feasibility Study (FS) evaluated potential remedial alternatives for per- and polyfluoroalkyl substances (PFAS) impacted surface water, sediment, and groundwater to protect drinking water supplies in the Twin Cities East Metro. Three sediment Areas of Concern (AOCs) were identified based on exceedances of the Site-Specific Sediment Screening Values (SDSVs) for PFOS and PFOA. Namely, these are AOC 11: Upper Raleigh Creek Wetland Complex (URCWC), AOC 12: Anna's Grove Wetland Complex (AGWC), and AOC 13: Eagle Point Lake (EPL) Sediment, shown in Figure 161 of Appendix A. A detailed description of these areas is included in Section 5 (Conceptual Site Model) and Section 7 (Areas of Concern) of the FS. In summary, the Oakdale Disposal Site (ODS) is located near the headwaters of Raleigh Creek which then flows through a series of wetlands before joining with Project 1007 and the outflow from the Tri-Lakes at Tablyn Park, shown in Figure 2 of Appendix A. Raleigh Creek contains high concentrations of PFAS, predominantly PFOS and PFOA, which has resulted in elevated concentrations in the wetland areas. Additionally, EPL, located downstream of Tablyn Park, also has concentrations of PFOS and PFOA exceeding the SDSVs. Impacted surface water infiltrates to groundwater in each of these areas, contributing to PFAS impacts observed in the drinking water aquifers.

The purpose of this FS is to determine remedial efforts to address PFAS impacts in the drinking water aquifers to reduce further migration and protect drinking water resources. To address PFAS impacts in Raleigh Creek, a reroute of Raleigh Creek around ODS has been proposed by 3M. This should result in a decrease in the PFAS concentrations in the surface water; however, with this decrease in surface water concentrations, PFAS may leach from the sediment to both surface water and the stream flows through the wetland areas and to groundwater as the surface water infiltrates. The Minnesota Pollution Control Agency (MPCA) retained AECOM Technical Services, Inc. (AECOM) to conduct a bench-scale leachability study to evaluate the mobility of PFAS in impacted wetland sediment samples collected from the Project 1007 Site. The purpose of the bench-scale leachability study is to determine if these impacted sediments could represent a substantial long-term source of PFAS mass that could impact the downgradient water bodies.

This Leachability Study Report describes the approach that was applied to conduct this bench-scale leachability study of PFAS in impacted sediments using unimpacted water. This document describes the objectives, applied methodologies, and interpretation of the results generated from the study.

I1.1 Test Objectives

The general objective of this leachability study is to evaluate the PFAS contamination potential of impacted sediments via leaching. The specific objectives are to:

1. Determine the partitioning coefficient of PFAS between the clean water phase and the impacted sediment phase for each sediment sample.
2. Evaluate the long-term leachability of total and individual PFAS compounds in five different impacted sediments under flow-through conditions.

The data from these objectives can assist in determining if one or more of these sediments could be a source of PFAS contamination when exposed to clean water to simulate Raleigh Creek in the future if Raleigh Creek is rerouted around ODS.

I2 Study Approach

The main tasks of this bench-scale leachability evaluation include:

1. Baseline characterization of the as-received sediments.
2. Batch tests to evaluate the partitioning coefficient between the water and sediment phases of PFAS under static, equilibrium conditions.
3. Column leachability tests to evaluate long-term leachability of PFAS from sediments under flow-through conditions.

The tasks described above were conducted in a sequential manner.

I2.1 Sample Collection and Baseline Characterization of Sediments

Sediments for the leachability study were collected from a representative area at the following Site locations, shown in Figure 164 of Appendix A:

1. AGWC-POND: AGWC sediment collected from ponded area – this area is typically flooded. The naming convention for this wetland has changed over the course of the investigation, thus sample names in the lab reports refer to this sediment location as IAWC1-POND.
2. AGWC-WETLAND: AGWC sediment collected from the wetland area – this area does not always have water but is intermittently flooded and is higher in organic matter. The naming convention for this wetland has changed over the course of the investigation, thus sample names in the lab reports refer to this sediment location as IAWC2-WETLAND.
3. URCWC-C: URCWC-C sediment collected from the wetland area along 32nd St N between Hemingway Ave N and Market Pl – this area is channelized and contains coarser grained sediment with less organic matter. The naming convention for this wetland has changed over the course of the investigation, thus sample names in the lab reports refer to this sediment location as PINZ. Note that URCWC-A and URCWC-B are two other wetland areas that are part of the larger URCWC but were not tested as part of this study.
4. EPL1-SUBMERGED: EPL sediment collected from the middle of the lake – this area is beyond vegetation and therefore is considered “open water”.
5. EPL2-SHORELINE: EPL sediment collected near the shore.

Sediments were shipped to the AECOM Treatability Laboratory located in Austin, Texas and arrived at the laboratory on August 14th, 2024. Chains of custody for all samples are available upon request.

Following receipt, the sediments were characterized for the analyses shown in Table I.1.

Table I.1: AECOM Sediments Physical Characterization Summary.

Analysis	Method
Particle size distribution (PSD)	Laser diffraction
Porosity	AECOM Laboratory Method
Density	ASTM D7263
Loss on ignition (LOI)	ASTM D7348
Percent (%) solids	ASTM D2216
Hydraulic conductivity	AECOM Laboratory Method

AECOM determined the hydraulic conductivity of the sediments by the free-falling head approach using a large, graduated cylinder with an outlet at the base of the cylinder. The outlet was closed off with a stainless-steel nut. The test proceeded as follows:

1. Sediment was added to the graduated cylinder to fill the cylinder to approximately 5.0 centimeters (cm) in height.
2. Water was added to the graduated cylinder to fill the cylinder to approximately 10.0 cm in height.
3. Once the demarcation was clear between the water and solids, each level was recorded.
4. The stainless-steel nut was removed from the apparatus and a timer was started simultaneously. Changes in water and solids levels were recorded over time, with intervals being dependent on the speed of water flowing through the filled media.

AECOM determined the sediment porosity as follows:

1. A known amount of sediment was added to a graduated beaker.
2. Water was added to the beaker until the sediment appeared completely saturated, ensuring that there was no standing water after each water addition.
3. Once the sediment was saturated, the total mass of water was recorded.

I2.2 Batch Leachability Tests

Batch leachability tests were conducted to evaluate the sediment adsorption/desorption partitioning coefficient (K_d) under equilibrium conditions and at constant temperature. The partitioning coefficient is defined as the concentration of a chemical compound in the sediment (C_S) divided by its concentration in the aqueous phase under equilibrium conditions (C_{Weq}):

$$K_d = \frac{C_S}{C_{Weq}}$$

The contact time in these experiments must be sufficient to reach such equilibrium conditions, which is dependent upon the adsorption or desorption kinetics. The sediments and waters were in contact for seven days to ensure full equilibrium conditions.

In this bench-scale leachability study, impacted Site sediments and a control sand were placed in contact with clean, PFAS-free, laboratory water. Each batch reactor contained 150 grams of sediment and 1,200 grams of water in 1.8-liter (L) high-density polyethylene (HDPE) bottles. One duplicate reactor was also generated during this test to assess experimental variability. The duplicate reactor was processed and analyzed independently to serve as an indicator of sediment homogeneity and consistency in AECOM laboratory sample preparation and handling. After the seven-day equilibration time, each slurry was separated into its component liquid and solid phases via filtration using Nalgene Rapid-Flow filtration units equipped with 0.45-micrometer (µm) polyethersulfone (PES) filters. The filtered leachates were collected into appropriate containers provided by SGS AXYS Analytical Services located in Sidney, British Columbia, Canada, and stored under refrigeration until shipment to SGS AXYS. Additionally, total organic carbon (TOC) was also measured by Pace Analytical Services (Minneapolis, Minnesota branch). Analytical samples generated from the batch tests are shown in Table I.2.

Table I.2: Batch Leaching Test Analytical Sample Counts.

Batch Test	PFAS (aqueous)	TOC (aqueous)
Control (1)	1	1
AGWC-POND	1	1
AGWC-WETLAND	1	1
URCWC-C	1	1
EPL1-SUBMERGED	1	1
EPL2-SHORELINE	1	1
QA/QC (2)	1	1

(1) PFAS-free sand.
(2) Quality assurance/quality control (QA/QC) samples (split duplicates).

I2.3 Flow-Through Leachability Tests

Long-term leachability tests are commonly used to assess the fate of contaminants between aqueous and solid phases under flow-through conditions. The main difference with batch static tests is that the advection of the water phase is introduced in addition to the diffusive/adsorptive exchange between the two phases. These tests simulate the exposure of high liquid to solid ratios (L/S) in a fraction of the time compared to similar tests were performed on site in a field-scale application.

I2.3.1 Experimental Design for Flow-Through Tests

AECOM conducted a column evaluation based on United States Environmental Protection Agency (EPA) Method 1314, entitled "*Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio using an Up-Flow Percolation Column Procedure*" (USEPA, 2013). Any method modifications described herein were implemented based on laboratory capabilities and project goals.

EPA Method 1314 is suitable for a wide range of granular solid materials, including wastes, soils, and sediments. In summary, this method consists of pumping eluent upward into a column moderately packed with granular material in an up-flow direction where effluent (eluate) sample collection is performed as a function of the cumulative L/S. The default eluant is typically reagent water, which is pumped at a flow rate of 0.5-1.0 L/S per day to increase the potential of local equilibrium between the solid and aqueous phases (i.e. to provide sufficient contact time). In this leachability study, samples were collected at ten different time intervals.

Clean, PFAS-free laboratory water was used as the eluent to be in contact with the impacted sediments. In a preliminary column trial, clogging issues and flow rate instability were observed due to a low-permeability sample bed and organic carbon within the soils deflocculating within the column. To alleviate these issues, calcium chloride (1.0 micromolar [µM]) was added to the eluent prior to testing and PFAS-free sand (30-mesh) was added to the sample bed at a measured 50% mass ratio, after accounting for sediment moistures. These modifications are listed as approved methods for troubleshooting columns within EPA Method 1314 under section 4.2 (USEPA, 2013). For the purposes of this study, all columns were operated at a flow rate of 1.0 L/S per day when applying the total mass of the sample bed (sediment + sand), (i.e., a rate of 2.0 L/S per day when adjusting for the mass of the sediment only). This troubleshooting step was required in order to run the columns at a manageable flow rate and generate enough eluate sample to support the minimum analytical volumes for PFAS and TOC analyses. Therefore, results will be presented on a sediment content adjusted L/S basis; this means that while the tests were carried out for a total of 20 L/S on a sand + sediment mix basis, the actual total L/S on a sediment-adjusted basis was 40 as the mix contained 50% sediment.

The column tests evaluated leachability of the five sediment samples as well as a clean control. The control column was packed with sand to evaluate any potential changes in PFAS concentrations associated with the experimental apparatus and the sand. A total of 10 eluates were collected for the analyses shown in Table I.3.

Table I.3: Column Leaching Test Aqueous Analytical Sample Counts.

Batch Test	PFAS	TOC	pH/EC/ORP
AGWC-POND	9	9	9
AGWC-WETLAND	9	9	9
URCWC-C	9	9	9
EPL1-SUBMERGED	9	9	9
EPL2-SHORELINE	9	9	9
Control	9	9	9
QA/QC	6	6	6

Legend: EC = electrical conductivity; ORP = oxidation reduction potential; QA/QC = quality assurance/quality control.

I2.4 Analytical Methods

Various analytical methods were employed throughout the leachability study. These methods are summarized in Table I.4. PFAS and TOC were analyzed by SGS AXYS and Pace Analytical, respectively. All other parameters were measured by AECOM's Treatability Laboratory.

Table I.4: Analytical Sample Count for Batch and Column Leaching Tests.

Analyte	Method	Performed by	*# of Samples*			
			Baseline	Batch	Columns	Total
PFAS	EPA 1633	SGS AXYS	10	7	60	77
TOC	EPA 5310	Pace MN	10	7	60	77
pH	Hach® Meter HQ 430d	AECOM	0	0	60	60
ORP	Hach® Meter HQ 430d	AECOM	0	0	60	60
EC	Hach® Meter HQ 430d	AECOM	0	0	60	60
Hydraulic Conductivity	AECOM Laboratory Method	AECOM	5	0	0	5
PSD (1)	Laser diffraction	AECOM	15	0	0	15
% Solids (1)	ASTM D2216	AECOM	15	0	0	15
Density (1)	ASTM D7263	AECOM	15	0	0	15
Porosity (1)	AECOM Laboratory Method	AECOM	15	0	0	15
LOI (1)	ASTM D7348	AECOM	15	0	0	15

(1) Analyses performed in triplicate.

I3 Results and Interpretation

I3.1 Initial Characterization

Initial characterization results are presented in Table I.5. Solids content ranged from 27.4% (EPL1-SUBMERGED) to 77.0% (URCWC-C). Generally, the sediments that were higher in solids content were also higher in density. LOI was measured to quantify the amount of organic matter present in the sediments. LOI was lowest in the URCWC-C sediment (3.60%) and highest in the EPL1-SUBMERGED sediment (27.8%).

Table I.5: Initial Characterization Results.

Analyte	Units	AGWC-POND	AGWC-WETLAND	URCWC-C	EPL1-SUBMERGED	EPL2-SHORELINE
Solids Content (1)	%	59.0	55.7	77.0	27.4	55.5
LOI	%	9.30	11.7	3.60	27.8	8.08
Mean PSD	µm	115	82.0	103	221	140
Density	g/mL	1.54	1.47	1.86	1.15	1.45
Hydraulic Conductivity	m/d	Not measurable	9.94×10^{-5}	Not measurable	1.30×10^{-3}	2.62×10^{-2}
Porosity	%	52.5	56.4	41.2	55.0	54.2
Moisture Content (1)	%	41.6	44.7	22.4	73.3	43.9
TOC	mg/kg (dry)	33,850	44,900	12,200	137,500	44,150
Total PFAS	ng/kg (dry)	121,027	232,269	29,429	112,300	22,760

(1) Solids content measured by AECOM; moisture content measured by Pace Analytical MN.

Legend: g/mL = grams per milliliter; m/d = meters per day; mg/kg (dry) = milligrams per kilogram on a dry weight basis; ng/kg (dry) = nanograms per kilogram on a dry weight basis.

The average particle size was above 75 µm and below 425 µm for all samples, indicating the sediments are primarily composed of fine-sized (but not silty) particles (ASTM, 2025). Hydraulic conductivity was extremely low across all sediment samples, with no measurable conductivity in the AGWC-POND and URCWC-C sediments after monitoring over the course of 24 hours. Porosity was between 41.2% and 56.4% for all samples.

Total PFAS in all sediment samples ranged from 22,760 nanograms per kilogram on a dry weight basis (ng/kg) (EPL2-SHORELINE) to 232,269 ng/kg-dry (AGWC-WETLAND). Tabulation of all PFAS compounds detected in each baseline sediment sample can be found in Table I.9. TOC was similar in all sediments–between 12,000 and 45,000 milligram per kilogram on a dry weight basis (mg/kg) – except for the EPL1-SUBMERGED sediment which had a much higher concentration of 137,500 mg/kg.

All analyses were performed in triplicate, except for hydraulic conductivity and total PFAS. Total PFAS was measured in duplicate. Hydraulic conductivity was measured only once per sediment sample, due to sample volume limitations. Table I.5 presents the average of the duplicate or triplicate analyses, where applicable.

Figure I.1 presents the concentrations of PFAS in the baseline sediment samples, including PFOS, PFOA, PFHxS, PFHxA, PFBS, PFBA, and PFOSA. A complete list of detected PFAS in the baseline sediment samples can be found in Table I.5. The primary PFAS compound contributing to the total PFAS concentrations was PFOS. PFOS concentrations ranged from 17,450 ng/kg-dry (EPL2-SHORELINE) to 209,500 ng/kg-dry (AGWC-WETLAND). The two other PFAS compounds that contributed the most to the total PFAS concentrations were PFOA and PFOSA. Similar to PFOS, PFOA concentrations were highest in the AGWC-WETLAND sediment (11,050 ng/kg-dry). The sediment with the lowest PFOA concentration was the URCWC-C sediment (772 ng/kg-dry). PFOSA concentrations ranged from 190 ng/kg-dry (EPL2-SHORELINE) to 2,875 ng/kg-dry (AGWC-POND). These PFAS results indicate a baseline composition that is dominated by long-chain PFAS compounds.

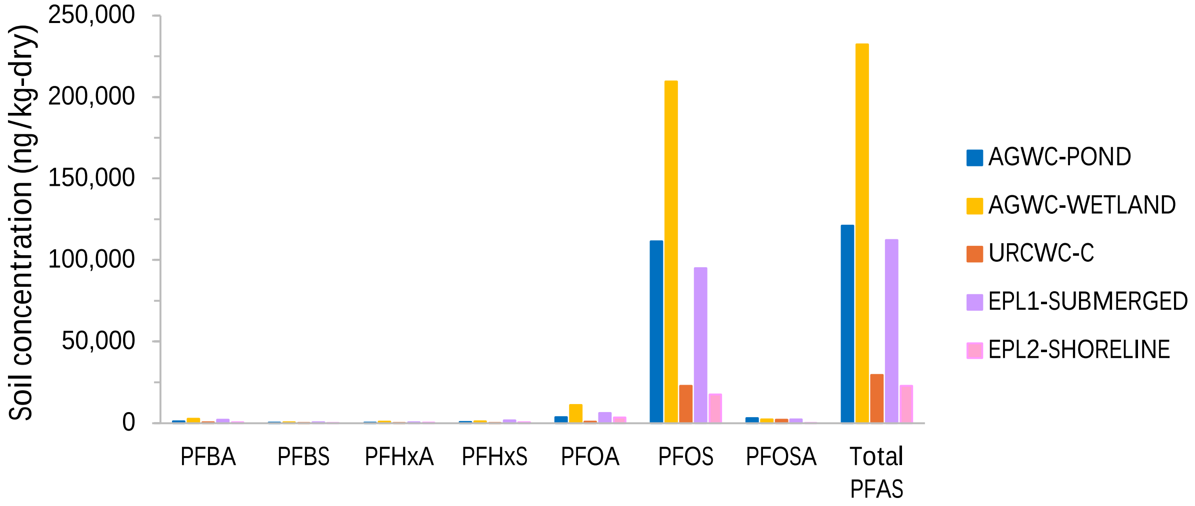

Figure I.1: Baseline Sediment PFAS Characterization.

Table I.6 presents the 2024 SDSVs for the MPCA Site sediments. Notably, all baseline sediment results exceeded the PFOA SDSVs and all sediments except for the EPL2-SHORELINE sediment exceeded the PFOS SDSV. Furthermore, the PFOS concentration measured in the EPL2-SHORELINE sediment was 17,450 ng/kg-dry, indicating that this sediment is near the SDSV limit for PFOS, as well. PFBA, PFBS, PFHxA, and PFHxS concentrations at all sediment locations were below the thresholds shown in Table I.6.

Table I.6: Site-Specific Sediment Clean-Up Values.

PFAS Acronym	Units	MPCA SDSV (1) (5 days a week)	Sediments Above Limit
PFBA	ng/kg	120,000,000	None
PFBS	ng/kg	1,500,000	None
PFHxA	ng/kg	260,000	None
PFHxS	ng/kg	170,000	None
PFOA	ng/kg	400	All
PFOS	ng/kg	18,000	All except EPL2-SHORELINE

(1) Site-Specific Sediment Screening Values

I3.2 Batch Leachability Results

Batch tests were performed to evaluate the partitioning coefficient (K_d) of PFAS under static, equilibrium conditions. K_d is a measure of sorption and is defined as the ratio of the quantity of the adsorbate adsorbed in the solid matrix to the amount of the adsorbate in solution at equilibrium (USEPA, 1999). The K_d was calculated for PFAS between sediment and leachate water assuming a linear sorption model (Sørmo, 2021). Generally, a higher K_d indicates a higher affinity for an analyte to be adsorbed in the sediment matrix at equilibrium and conversely, a lower K_d indicates a higher affinity for an analyte to be in solution at equilibrium.

Table I.7 presents the partition coefficients (K_d) calculated using the baseline sediment and aqueous batch PFAS concentrations. Analytes presented in Table I.7 are ordered vertically in order of increasing carbon chain lengths (top to bottom). Sediments are presented in order of increasing TOC concentrations in the sediment (left to right).

Table I.7: Batch Test Partition Coefficients Presented as Log(Kd[L/kg]).

PFAS Acronym	Carbon chain length	Units	URWC-C	AGWC-POND	AGWC-WETLAND	EPL1-SUBMERGED	EPL2-SHORELINE
PFBA	4	L/kg	0.78	*N/A* (1)	0.85	1.11	1.02
PFBS	4	L/kg	*N/A* (1)	*N/A* (1)	*N/A* (1)	1.66	1.20
PFPeA	5	L/kg	1.76	*N/A* (1)	*N/A* (1)	*N/A* (1)	*N/A* (1)
PFPeS	5	L/kg	*N/A* (1)	*N/A* (1)	*N/A* (1)	1.69	1.27
PFHxA	6	L/kg	0.75	*N/A* (1)	0.55	1.27	1.00
PFHxS	6	L/kg	1.16	1.17	0.44	1.82	1.22
PFHpA	7	L/kg	1.16	*N/A* (1)	0.78	1.10	1.05
PFHpS	7	L/kg	0.92	1.11	0.95	2.00	1.38
PFOA	8	L/kg	0.69	0.86	0.64	1.42	1.08
PFOS	8	L/kg	1.06	1.46	1.35	2.32	1.6
PFOSA	8	L/kg	2.05	1.92	2.77	3.58	2.65
NMeFOSA	8	L/kg	3.03	*N/A* (1)	*N/A* (1)	2.89	*N/A* (1)
NEtFOSA	8	L/kg	2.57	*N/A* (1)	*N/A* (1)	*N/A* (1)	*N/A* (1)
NMeFOSAA	8	L/kg	1.74	*N/A* (1)	*N/A* (1)	*N/A* (1)	*N/A* (1)
NEtFOSAA	8	L/kg	1.89	2.48	2.16	3.51	2.49
PFDA	10	L/kg	1.15	1.44	1.67	2.28	1.67
PFDS	10	L/kg	2.59	2.12	2.55	*N/A* (1)	*N/A* (1)
PFDoA	12	L/kg	2.17	*N/A* (1)	2.19	*N/A* (1)	*N/A* (1)
PFDoS	12	L/kg	2.15	*N/A* (1)	*N/A* (1)	*N/A* (1)	*N/A* (1)
Total PFAS	-	L/kg	1.16	1.44	1.31	2.18	1.46

(1) N/A – not applicable due to baseline sediment result being below laboratory detection limit.
Red Text – lowest partitioning coefficient per sediment.
Green Text – highest partitioning coefficient per sediment.

On a per sediment basis, partitioning coefficients were lowest for PFOA in the URCWC-C sediment (0.69 liters per kilogram [L/kg]) and AGWC-POND sediment (0.86 L/kg), PFHxA in the EPL2-SHORELINE sediment (1.00 L/kg), PFHxS in the AGWC-WETLAND sediment (0.44 L/kg), and PFHpA in the EPL1-SUBMERGED sediment (1.10 L/kg), indicating that these analytes had a lower affinity to their respective sediment matrices and therefore have a higher leaching potential at each respective location. Conversely, PFOSA had the highest observed K_d in the EPL2-SHORELINE (2.65 L/kg), AGWC-WETLAND (2.77 L/kg), and EPL1-SUBMERGED (3.58 L/kg) sediments indicating that the transfer of PFOSA from the sediment matrix to the aqueous phase is lower when compared to other PFAS analytes in the sediments. For the AGWC-POND sediment, the highest K_d was observed for NEtFOSAA (2.48 L/kg). For the URCWC-C sediment, the highest K_d was observed for NMeFOSA (3.03 L/kg).

Generally, a higher K_d was associated with longer chain PFAS compounds, indicating that long-chain PFAS should exhibit a higher affinity to the sediment matrix, and conversely, short-chain PFAS compounds should have a higher affinity to the aqueous matrix, i.e., higher leaching potential. Notably, there are some deviations from this trend as shown in the comparably high K_d for PFBS, PFPeS, and PFHxS in EPL1-SUBMERGED sediment, and PFPeA in URCWC-C sediment. While PFBA was detected in some sediments, it did not show the lowest K_d values; nevertheless, those values are very close to the lowest reported in each sediment, confirming the lack of affinity towards the sediment by PFBA.

Lastly, these K_d values also suggest that TOC concentrations in the sediment can potentially affect PFAS leachability. For example, when comparing the partition coefficients of the URCWC-C sediment (TOC = 12,200 mg/kg) to the EPL1-SUBMERGED sediment (TOC = 137,500 mg/kg) the coefficients were higher in the EPL1-SUBMERGED sediment in all cases except for PFHpA and N-MeFOSA.

Additional tabulations and figures of batch PFAS results for all analytes above the laboratory detection limits can be found in Table I.10 and Figure I.15.

I3.3 Flow-Through Leachability Results

Flow-through leachability tests were conducted to obtain the PFAS leachability in each respective sediment as a function of L/S, and to calculate the cumulative PFAS release from sediments versus L/S. Tabulations of all PFAS data from the column testing for analytes above the detection limit are presented in Tables I.11 through I.16.

I3.3.1 PFAS Results

Table I.8 presents the Minnesota Department of Health (MDH) Site-specific groundwater and Site-Specific Water Quality Criteria (SSC), as well as the EPA Maximum Contaminant Levels (MCLs). These criteria were applied to the flow-through leachability data to determine if exceedances were present.

Table I.8: EPA and Site-Specific Groundwater and Surface Water Quality Criteria.

PFAS Acronym	Units	Site-Specific Groundwater Criteria		SSC	EPA MCL
		HRL	HBV		
PFBA	ng/L	7,000	-	5,700	-
PFBS	ng/L	100	-	140	2,000
PFHxA	ng/L	200	-	220	-
PFHxS	ng/L	47	-	20	10
PFOA	ng/L	35	0.24	25	4
PFOS	ng/L	300	2.3	0.05	4

Legend: HBV = Health-Based Value; HRL = Health Risk Limit; MCL = Maximum Contaminant Level; ng/L = nanogram per Liter; SSC = Site-Specific Water Quality Criteria.

Figure I.2 presents the total PFAS concentrations in nanograms per liter (ng/L) measured in column effluents as a function of L/S, adjusted for the sediment content. AGWC-WETLAND showed the highest PFAS leaching relative to each sediment location, with the highest leaching occurring at 4 L/S with a total PFAS effluent concentration of 8,747 ng/L. At 12 L/S, total PFAS leached from the AGWC-WETLAND column dropped to 3,282 ng/L and slowly tapered off to 1,309 ng/L in the final sample at 40 L/S. Maximum total PFAS leached from all other column effluents occurred at 2 L/S with 2,909 ng/L (AGWC-POND), 2,195 ng/L (EPL1-SUBMERGED), 1,449 ng/L (EPL2-SHORELINE), and 1,365 ng/L (URCWC-C) of total PFAS leaching from each column, respectively. Similar to the trend observed in the AGWC-WETLAND column, PFAS leaching slowly decreased as L/S increased. The control column leached 33 ng/L of total PFAS at 2 L/S and leached at or below 10 ng/L total PFAS for all other sampling events. The control leachate concentrations had a few individual PFAS compounds detected at very low levels (less than 7 ng/L); most of the PFAS detections in the control eluate samples were under the reporting limit or under the detection limit. In addition, these detected PFAS concentrations are negligible compared to the sediment's leachate concentrations, as they were two to three orders of magnitude lower. This confirmed that the addition of sand did not have any consequences to the results presented.

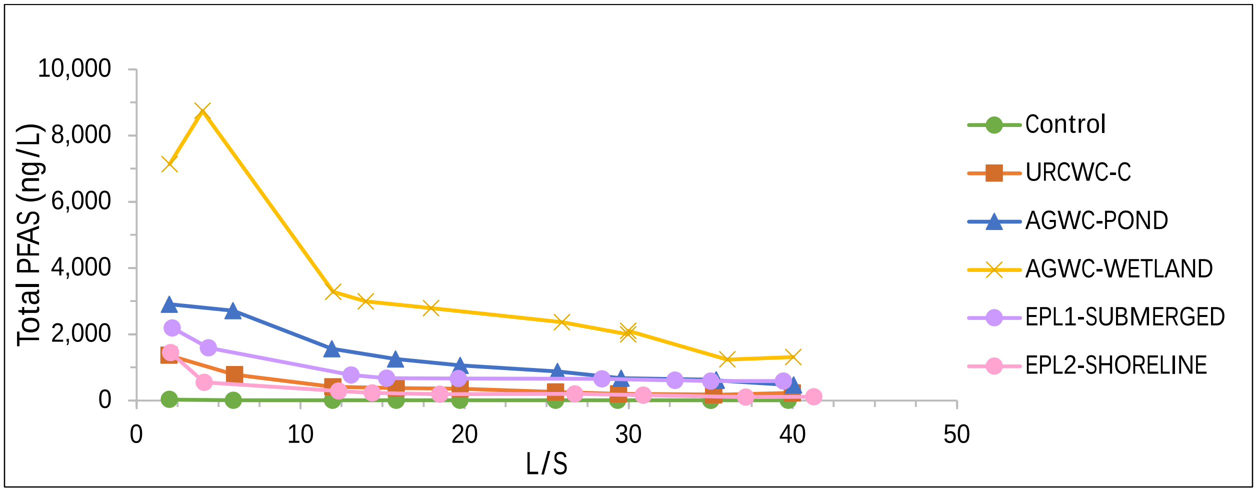

Figure I.2: Column Test Total PFAS Effluent Concentrations (ng/L) as a Function of L/S.

Figure I.3 presents the PFBA concentrations in ng/L measured in column effluents as a function of L/S. EPL1-SUBMERGED and AGWC-WETLAND columns expressed the highest leaching of PFBA with 513 ng/L and 369 ng/L of PFBA being leached at 2 L/S for each column, respectively. Notably, no PFBA exceedances were observed in any column leachates with respect to the MDH Health Risk Limit (HRL) and SSC. On each of these graphs, the reporting limits (RLs) are included for reference. Effluents from the AGWC sediments had a higher reporting limit.

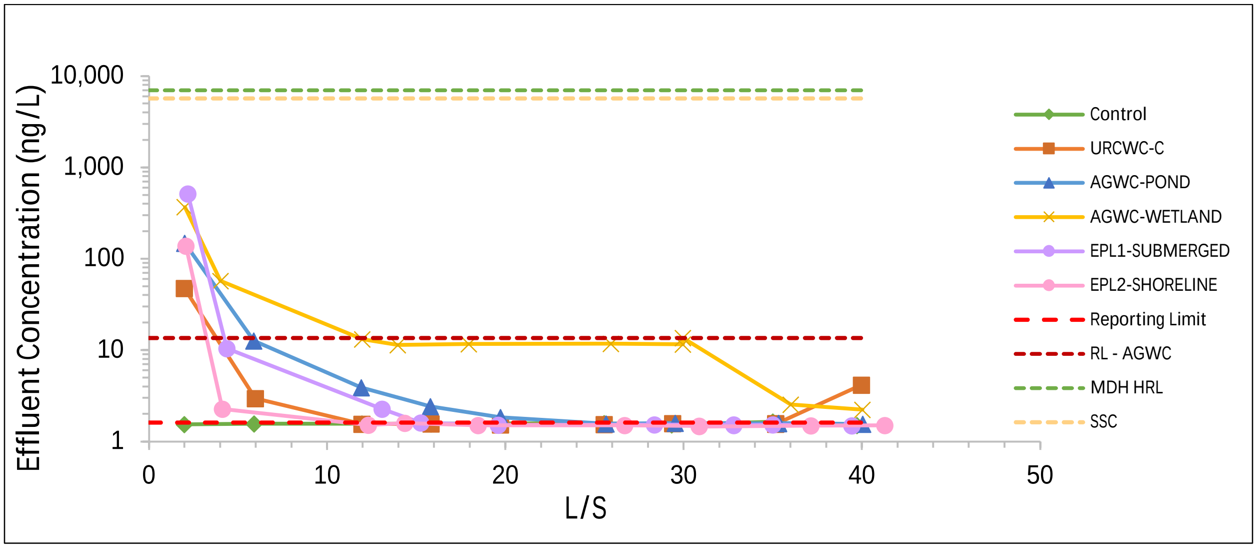

Figure I.3: Column Test PFBA Effluent Concentrations (ng/L) as a Function of L/S.

Figure I.4 presents the PFBS concentrations in ng/L measured in effluents as a function of L/S. Similar to the trend observed in Figure I.3, the columns that expressed the highest leaching of PFBS occurred at 2.0 L/S where PFBS in the effluents was 64.5 ng/L (EPL1-SUBMERGED) and 31.8 ng/L (AGWC-WETLAND), respectively. Still, no columns in this study exceeded the MDH HRL or SSC for PFBS at any measured point during the study.

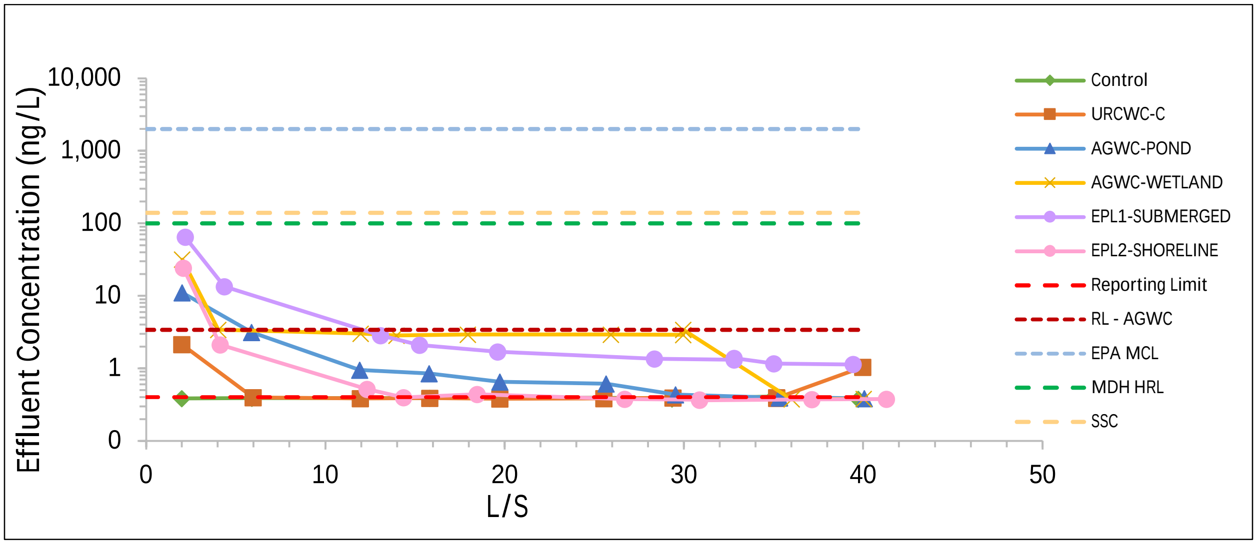

Figure I.4: Column Test PFBS Effluent Concentrations (ng/L) as a Function of L/S.

Figure I.5 presents the PFHxA concentrations in ng/L measured in effluent samples as a function of L/S. The largest amount of leaching occurred at 2 L/S, with PFHxA effluent concentrations ranging from 11.1 ng/L (URCWC-C) to a maximum of 185 ng/L (EPL1-SUBMERGED). Though no exceedances with respect to the MDH HRL and SSC were observed for any columns throughout this phase of testing, AECOM notes that PFHxA concentrations at 2 L/S were near the established Site-specific limits for this analyte in the EPL1-SUBMERGED column (185 ng/L) and AGWC-WETLAND (136 ng/L); thus, it would be possible that the earliest fraction (1 L/S) of eluate could have presented a higher concentration. For qualitative purposes, even though PFHxA did not exceed the Site-specific limit, it could be considered that this PFAS compound would be likely to leach above such limit early on during the leaching process.

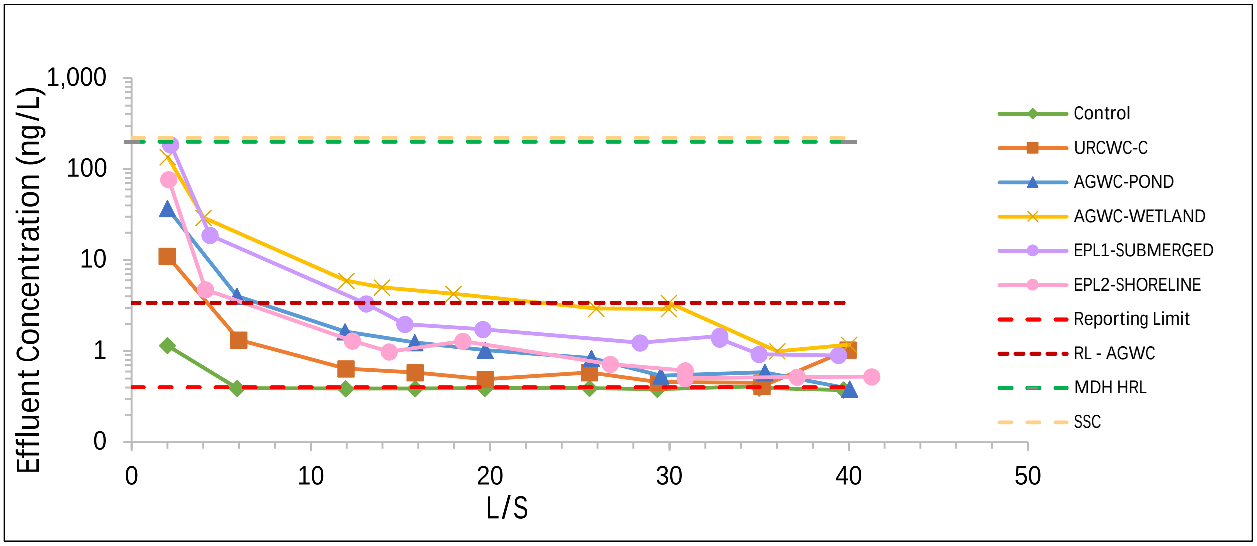

Figure I.5: Column Test PFHxA Effluent Concentrations (ng/L) as a Function of L/S.

Figure I.6 presents the PFHxS concentrations (ng/L) measured in effluent samples as a function of L/S. All sediment column effluents except for the URCWC-C effluent exceeded the EPA MCL, MDH HRL and SSC at 2 L/S. The URCWC column exceeded only the EPA MCL at 2.0 L/S, and fell below all relevant threshold limits at/after 6 L/S. The AGWC-POND, AGWC-WETLAND, and EPL2-SHORELINE column's PFHxS concentrations in the effluents fell below the relevant threshold limits at 12, 14, and 12 L/S, respectively. PFHxS concentrations in the EPL1-SUBMERGED effluents remained above the relevant threshold limits the longest out of all the columns, and did not fall below the threshold limits until approximately 28 L/S.

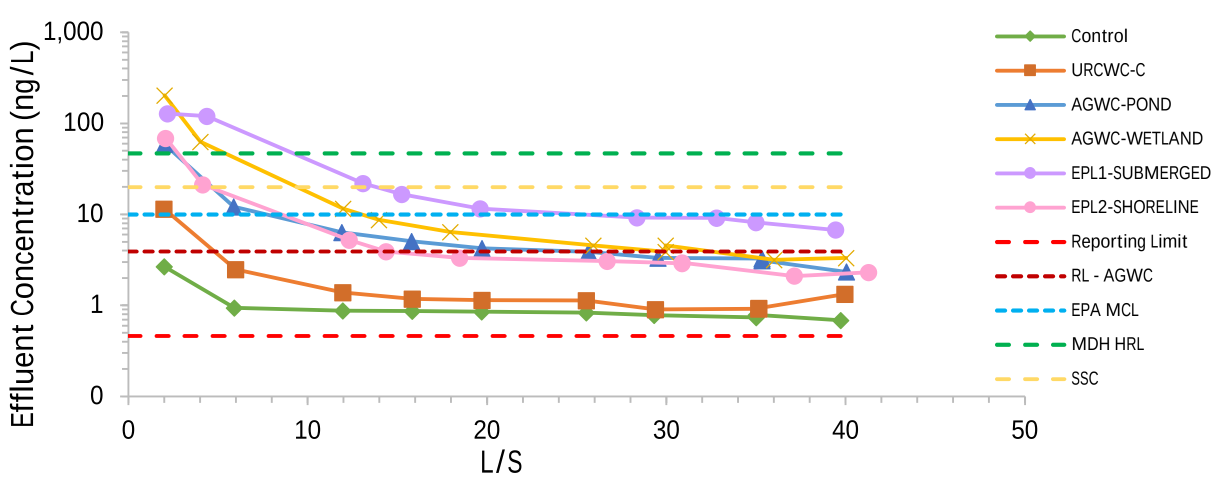

Figure I.6: Column Test PFHxS Effluent Concentrations (ng/L) as a Function of L/S.

Figure I.7 presents the PFOA concentrations (ng/L) measured in effluent samples as a function of L/S. All sediment column effluents exceeded the EPA MCL, MDH HRL, MDH Health-Based Value (HBV), and SSC from 2 L/S to approximately 12 L/S, indicating not only a strong presence of PFOA in the sediments, but also a high leachability potential at all locations that were tested in this treatability study. Concentrations of PFOA in the URCWC-C and AGWC-WETLAND effluents remained above all relevant threshold limits throughout the entire column study (40 L/S), indicating that these locations would be the highest points of concern for long term PFOA leaching. AGWC-POND and EPL2-SHORELINE PFOA effluent concentrations fell below the MDH HRL and MDH HBS after approximately 20 L/S and EPL1-SUBMERGED PFOA effluent concentrations were below those same limits toward the end of the test (35 L/S).

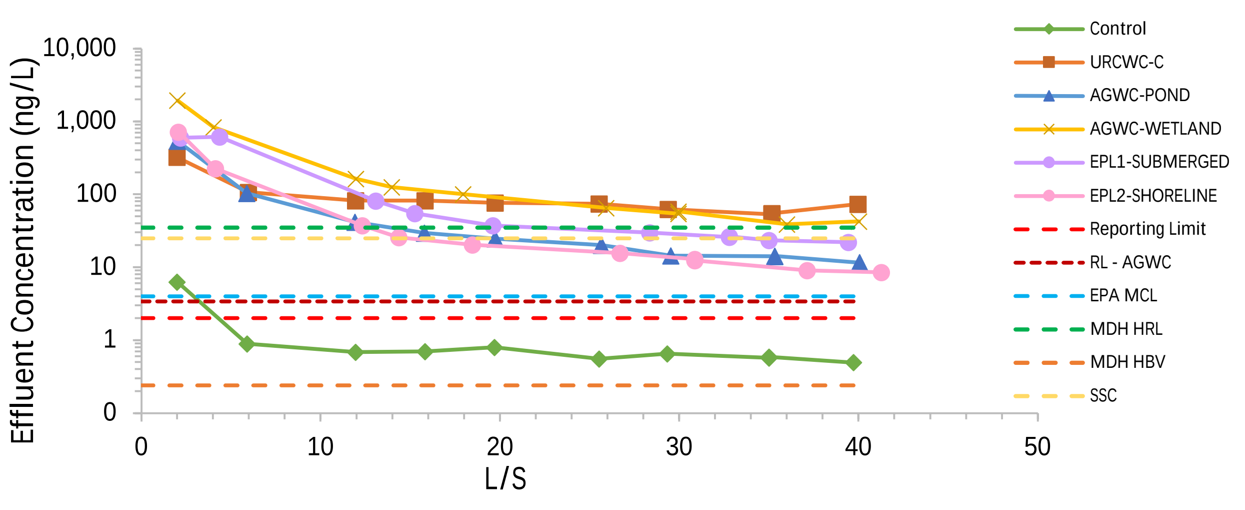

Figure I.7: Column Test PFOA Effluent Concentrations (ng/L) as a Function of L/S.

Notably, all sample effluents (except for the control column) exceeded the EPA MCL and MDH HBV for PFOA for the entire duration of the study, indicating further leaching of PFOA could occur passed 40 L/S.

Although the control effluent showed PFOA at 6.29 ng/L at 2 L/S, subsequent samples showed that PFOA was below the analytical method's reporting limits.

Figure I.8 presents the PFOS concentrations (ng/L) measured in column effluent samples as a function of L/S. For all columns—except for the control column— effluent PFOS concentrations exceeded the EPA MCL, MDH HBV, and SSC throughout the entire column study (40 L/S). Additionally, AGWC-POND, AGWC-WETLAND, and EPL1-SUBMERGED effluents exceeded the MDH HRL for the entire study. However, the EPL2-SHORELINE and URCWC-C effluents fell below the MDH HRL at approximately 4 and 16 L/S, respectively. Similar to the trend observed in PFOA effluent concentrations, effluent concentrations measured in the column leachates indicate a strong presence of PFOS in the sediments and a high leachability potential at all Site locations that were measured within this leachability study.

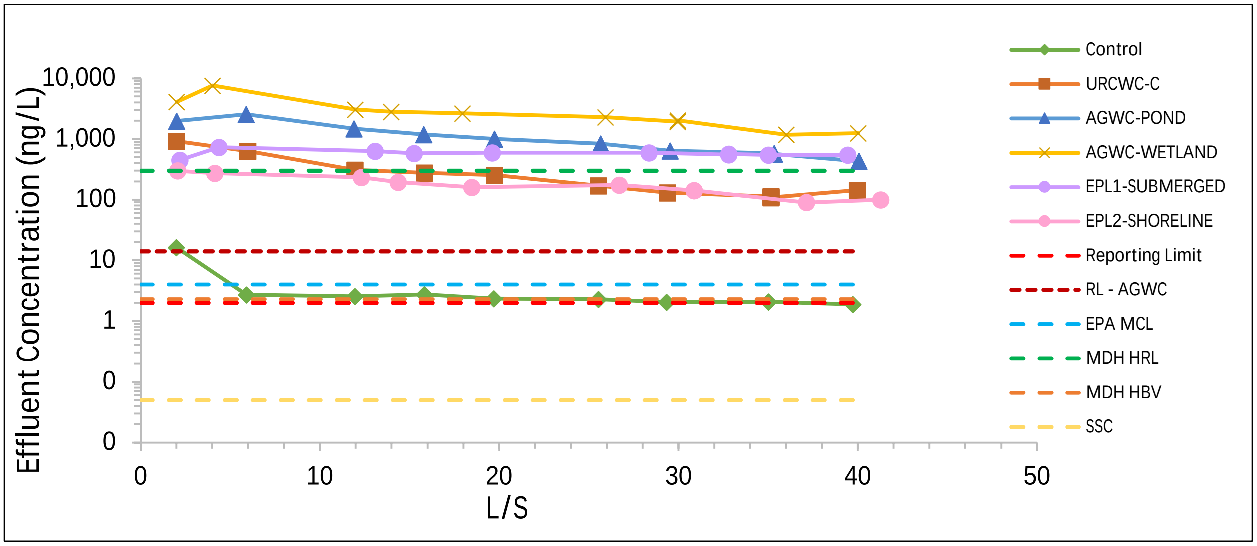

Figure I.8: Column Test PFOS Effluent Concentrations (ng/L) as a Function of L/S.

Additional figures related to column effluent concentrations as a function of L/S can be found in Figures I.16 through I.26.

Figure I.9 presents the total PFAS released from each column on a mass basis. Overall, AGWC-WETLAND leached the most PFAS on a total mass basis throughout the study. Notably, the most PFAS were leached between 0.7 and 4.3 L of water passed through the columns. AGWC-POND released the second highest amount of total PFAS. This trend is consistent with the total PFAS measured in the sediments during the baseline characterization (i.e., these two sediments contained the highest PFAS concentrations in the baseline characterization and leached the most PFAS on a mass basis during the column study). The control sand showed negligible mass of PFAS leached, in comparison to the Site's sediments.

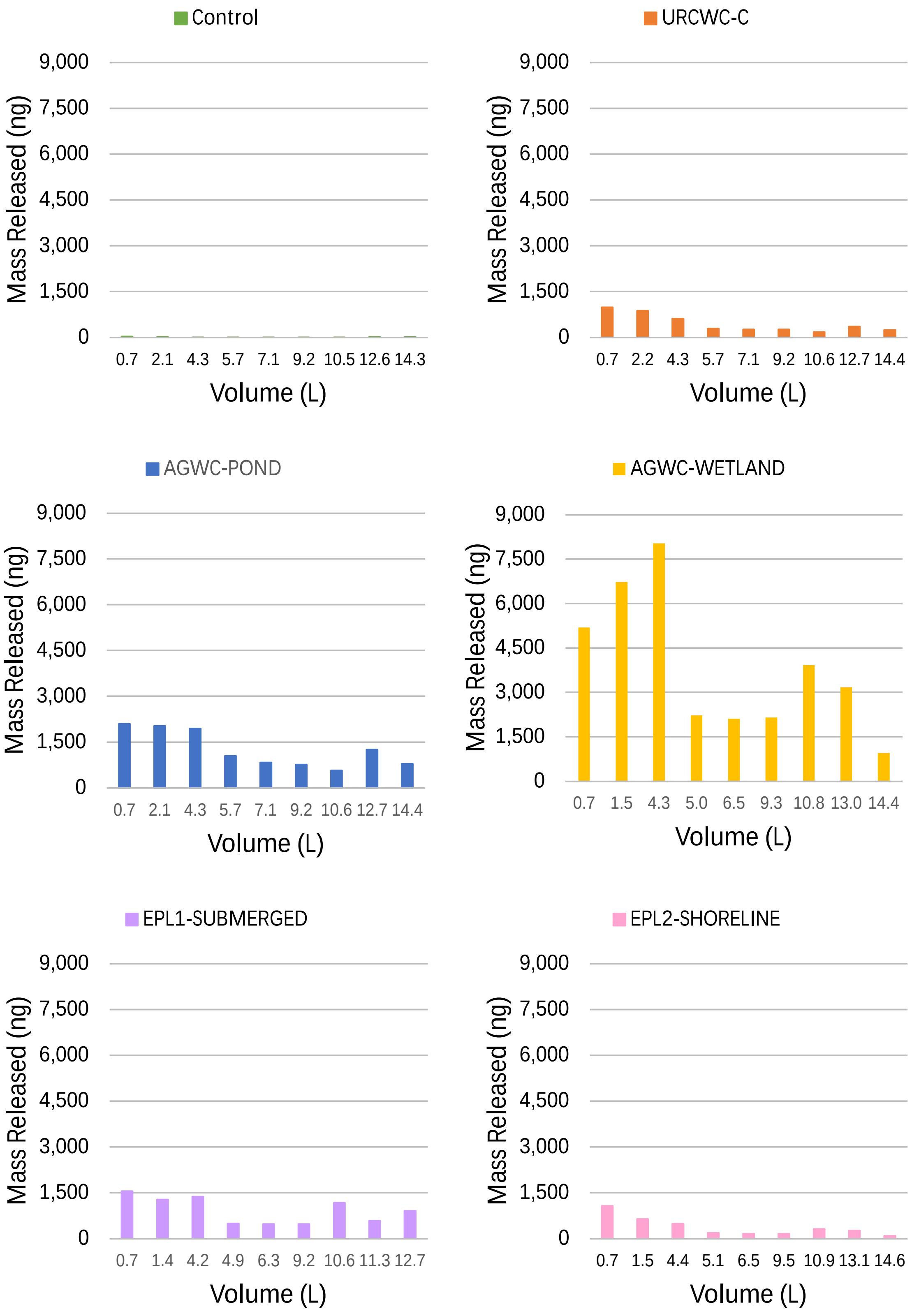

Figure I.9: Total PFAS Released (on a Mass Basis) Throughout the Column Study.

Figures I.27 and I.28 present the total PFOA and PFOS released from each column on a mass basis, as well. PFOA and PFOS were the analytes dominating the total PFAS concentrations, and thus, the same trends observed in Figure I.10 are observed in Figures I.27 and I.28.

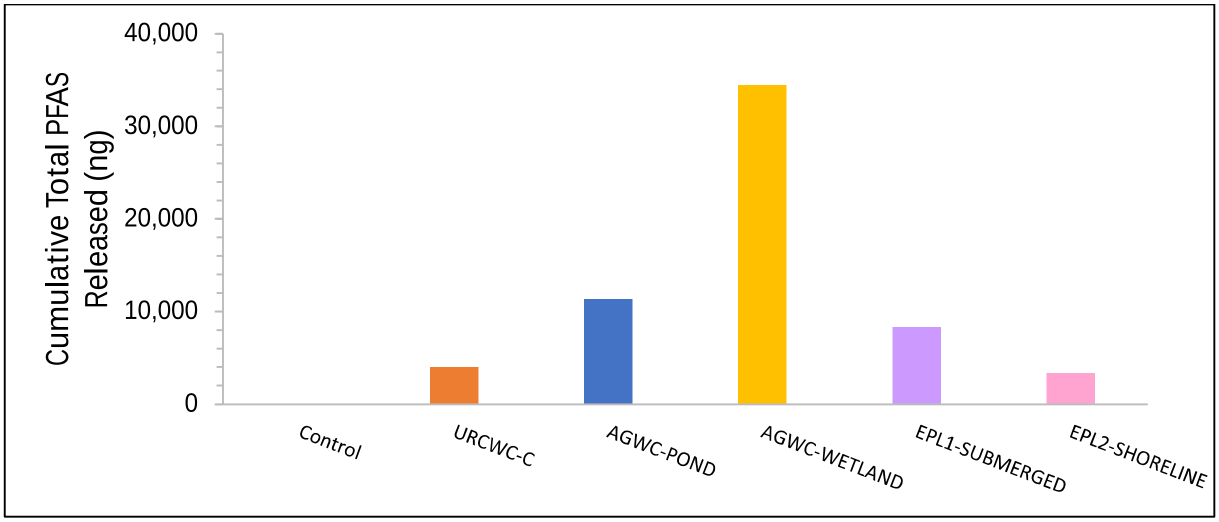

Figure I.10: Cumulative PFAS Released (on a Mass Basis) Throughout the Column Study.

Figure I.10 presents the cumulative PFAS on a mass basis released throughout the entire column study (40 L/S) for each column. AGWC-WETLAND leached the most PFAS with a total of 34,479 ng. AGWC-POND was the location that leached the second highest amount of PFAS (11,335 ng). EPL1-SUBMERGED, URCWC-C, and EPL2-SHORELINE released 8,304 ng, 4,040 ng, and 3,345 ng, respectively.

I3.3.2 General Chemistry Results

Figure I.11 presents the effluent TOC concentrations from the column study. The highest observed TOC concentration in the effluents occurred at 2 L/S in the EPL1-SUBMERGED column, with a TOC concentration of 70.7 milligrams per liter (mg/L). After 2 L/S, TOC in the EPL1-SUBMERGED effluent dropped to 24.6 mg/L and continually decreased to 5.9 mg/L at 39 L/S. TOC effluent concentrations in all other columns were 20 mg/L at 2 L/S and relatively stable (between 5 and 11 mg/L) for all other sampling events.

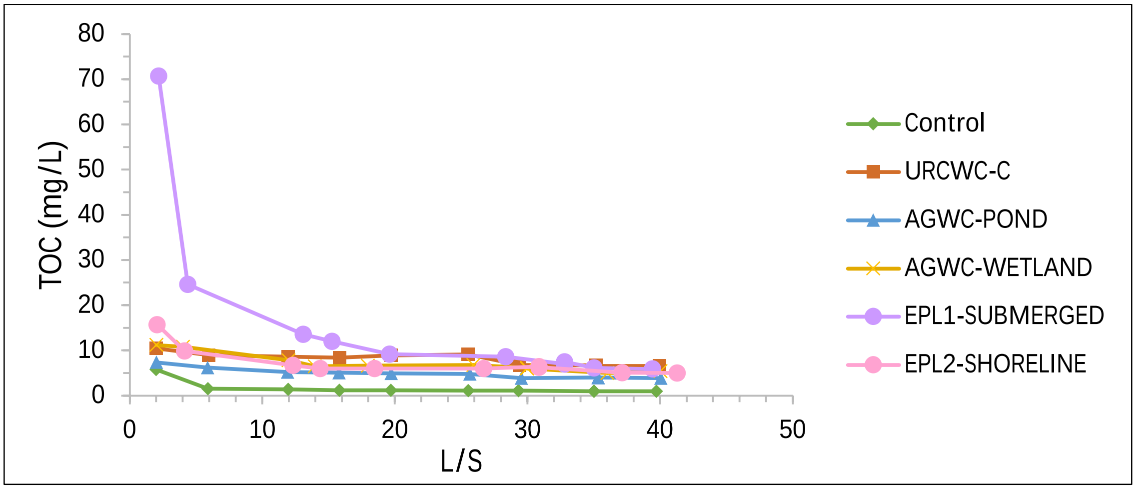

Figure I.11: Column Study Effluent TOC Results.

All PFAS and TOC data packages (PDF reports) are available upon request. PFAS results above the detection limits are summarized in Section I7.

Figure I.12 presents the effluent pH results from the column study. pH in the effluents remained circumneutral for the entire duration of the study for all columns, with the exception of the control column at 1 L/S which has a pH of 9.33. Overall, there were no general increases or decreases of pH observed as L/S increased over time.

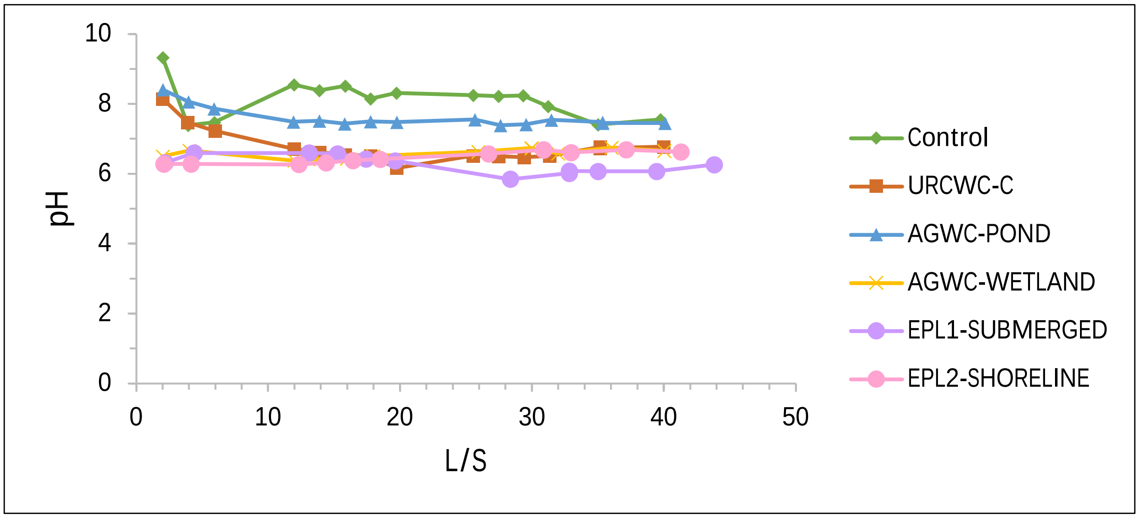

Figure I.12: Column Study Effluent pH Results.

Figure I.13 presents the oxidation reduction potential (ORP) in column effluents as a function of L/S. ORP remained stable and between 400 and 500 millivolts (mV) through the entire study period for all test columns, indicating that the leachate was maintained at oxidizing conditions.

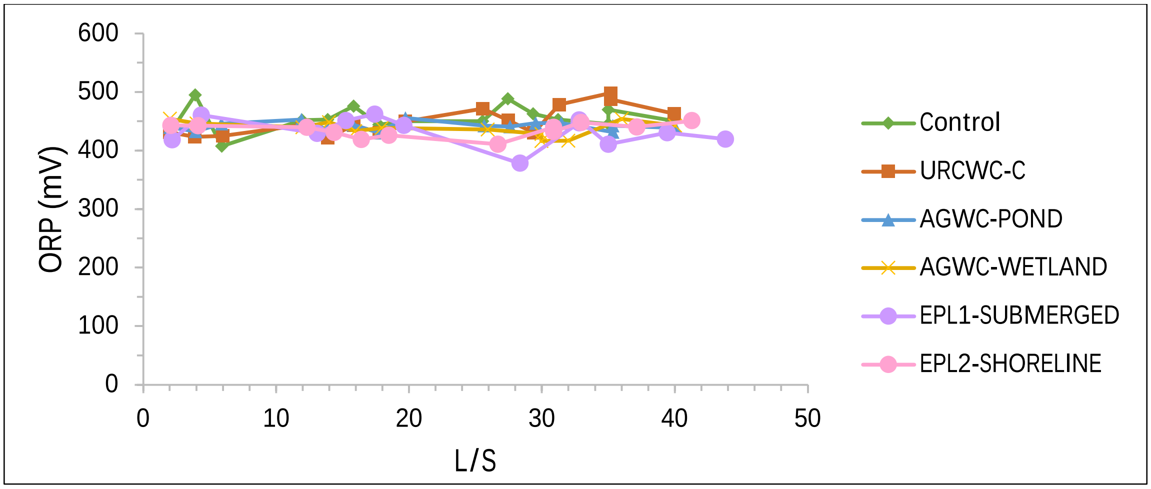

Figure I.13: Column Study Effluent ORP Results.

Figure I.14 presents the electrical conductivity in column effluents as a function of L/S. All columns displayed the highest electrical conductivity at 2.0 L/S ratios, indicating that possible salts (ions) present within the sediments were leaching between 0 L/S and approximately 4 L/S. After 4 L/S, the electrical conductivity stabilized to approximately 100 to 300 microSiemens per centimeter (µS/cm). Notably, as discussed in Section I3.3.1, a 1.0 µM calcium chloride solution (in deionized water) was used as the eluent for this column testing to troubleshoot column clogging and solids deflocculation. Thus, these electrical conductivity results may be biased slightly high. However, the control column effluent electrical conductivity remained steady at 200-400 µS/cm, suggesting that the increased electrical conductivity exhibited in the sediment samples at 2 and 4 L/S are reflective of the true electrical conductivity of the sediment effluents.

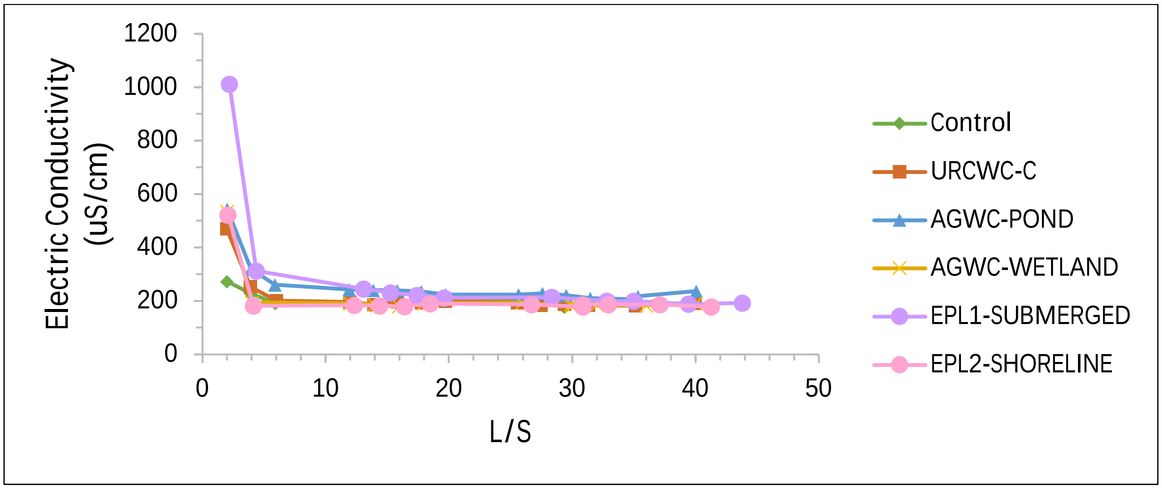

Figure I.14: Column Study Effluent Electrical Conductivity Results.

I4 Conclusions

The bench-scale leachability study evaluated the release of PFAS compounds from sediment samples collected from five locations at the Project 1007 Site: AGWC-POND, AGWC-WETLAND, URCWC-C, EPL1-SUBMERGED, and EPL2-SHORELINE. The leachability study characterized the PFAS concentrations and their composition, as well as the TOC content in the sediments. Partitioning coefficients for PFAS compounds were derived using batch tests under equilibrium conditions, whereas leachability of PFAS was characterized under flow-through conditions via EPA Method 1314. All sediments exhibited release of PFAS when in contact with water, either during batch or column tests. The AGWC-WETLAND sediment showed the highest release of PFAS under flow-through conditions.

This leachability study achieved its objectives as follows:

1. *Determine the partitioning coefficient of PFAS between the clean water phase and the impacted sediment phase for each sediment sample*. Partitioning coefficients were obtained for all sediments, and for most PFAS. The batch tests showed that the sediments can release PFAS into the aqueous phase. Generally, long-chain PFAS compounds exhibited the highest partitioning, as expected.

2. *Evaluate the long-term leachability of total and individual PFAS compounds in five different impacted sediments under flow-through conditions*. Up to 40 L/S ratios were evaluated for the leachability of PFAS from the sediments under flow-through conditions. This high L/S ratio represents a long-time frame given the usual slow groundwater velocities observed under natural conditions. This evaluation was successful, as the major PFAS compounds that impacted the water phase were identified, as well as the sediment that constituted the major source of PFAS mass: AGWC-WETLAND.

Major observations from this leachability study are:

- Total PFAS in the sediment's matrix varied greatly (one order of magnitude), with the AGWC-WETLAND sediment having the highest total PFAS concentrations.
- PFAS composition was dominated by PFOS in all sediments evaluated.
- TOC varied across the sediments with EPL-SUBMERGED having the highest concentration and URCWC-C having the lowest concentration of TOC.
- Hydraulic conductivities could not be measured for two sediments: AGWC-POND and URCWC-C. The other three sediments varied over four orders of magnitude with EPL2-SHORELINE having the highest hydraulic conductivity and AGWC-WETLAND having the lowest measured hydraulic conductivity.
- Batch partitioning coefficient tests could not be determined for all PFAS in all sediments because some PFAS were below detection limits; the number and identity of these undetected PFAS compounds varied across the different sediments.
- Due to the extremely low hydraulic conductivities (in some cases, unmeasurable), and to maintain the integrity of the flow-through column tests, each sediment was mixed with sand to create a 50%/50% sand/sediment mixture. This allowed for proper flowrate under laboratory conditions and the recovery of sufficient eluate for PFAS analysis. This mixing is in accordance with recommendations in the method and does not impact the overall conclusions of this study.
- For the flow-through experiments, the results presented against L/S are shown on a sediment basis (50% of the solid mix), as PFAS leaching only originated from the sediment.
- During flow-through leachability tests, the largest mass of PFAS leached within 2-4 L/S.

- Most sediments exceeded most PFAS leachability threshold concentrations, indicating that the sediments could be a source of PFAS for surface water and groundwater.
- EPL2-SHORELINE and URCWC-C sediments exhibited the lowest mass of PFAS release, whereas AGWC-WETLAND showed the highest mass released; this is in agreement with the initial total PFAS concentration.

It is important to note that for the flow-through leachability tests, a much higher concentration could have been measured at L/S values below 2.0. As a reminder, the sediment was mixed with 50% sand to increase the hydraulic conductivity. This does not impact the overall conclusions of the results; however, this is certainly a limitation of the data as, due to decreased sediment content in columns from 100% to 50%, leached PFAS concentrations may be underestimated at the beginning of the column. Nevertheless, the data collected for L/S at and beyond 2.0 show clear trends for each sediment and accurately characterizes the release of PFAS as more liquid is passed through the sediment. To account for the mixing of sand, the results presented against L/S for the flow-through experiments are shown on a sediment basis (50% of the solid mix), as PFAS leaching only originated from the sediment.

While carbon-chain length (hydrophobicity) did clearly show an effect on PFAS partitioning and leachability, the effect of TOC was less clear. The highest leachability of TOC was observed in the EPL1-SUBMERGED sediment. However, this sediment was moderate in terms of release of PFAS during the flow-through leachability tests.

The results clearly show that most of the PFAS leaching occurs within the first 4 L/S, and then leachability gradually decreases. After approximately 10-15 L/S, the leaching becomes more consistent as the effluent concentrations were observed to vary less with the higher L/S ratio. This characterization is key to understanding which sediment is the most relevant source of PFAS for water systems and understanding at which time frames the highest leachate concentrations would be expected. While it is not expected that Site conditions and Site results will exactly replicate the results obtained in this bench-scale study, the trends observed here are substantially clear and provide guidance on which sediment is the largest potential source of PFAS for water impacts, which PFAS compounds would be the most dominant during leaching, and how long the leachate concentrations would remain above the threshold levels.

The conclusions from this study can be used to support the proposed remedial alternatives and the order in which the specific actions within the recommended alternative occur. For example, 3M has proposed a reroute of Raleigh Creek around ODS to limit the PFAS migrating downstream of ODS through Project 1007, as explained in the Conceptual Site Model (Section 5) of the FS. Prior to that reroute, efforts should be made to implement an in-stream permeable adsorptive barrier (PAB), the proposed surface water treatment remedy, to limit the PFAS mass that could be released and transported downgradient via surface water. More details on the proposed PABs can be found in Appendix M (Project 1007 Surface Water Treatment Evaluation). These results also indicate that PFOS and in some areas, PFOA, are expected to leach off the sediment, resulting in surface water concentrations that are in exceedance of the MPCA SSC and the MDH HRL for an extended period of time. As sediment remediation is expensive, additional sampling efforts may also be warranted after the Raleigh Creek reroute is complete and the initial leaching has occurred to better focus potential sediment removal activities. Repeating this study with sediment at that time may also be advantageous to understand how the conditions have changed.

I5 References

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Sørmo, Erlend, et. al. (2021). Stabilization of PFAS-contaminated Soil with Activated Biochar. (Vol. 763, April 2021, pp. 1-11

USEPA. (1999). Understanding Variation in Partition Coefficient, K_d, Values. (Vol 1., Issue August, pp. 62-68).

USEPA. (2013). Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio using an Up-Flow Percolation Column Procedure (Vol.14405, Issue January, pp. 1-26).

I6 Additional Figures

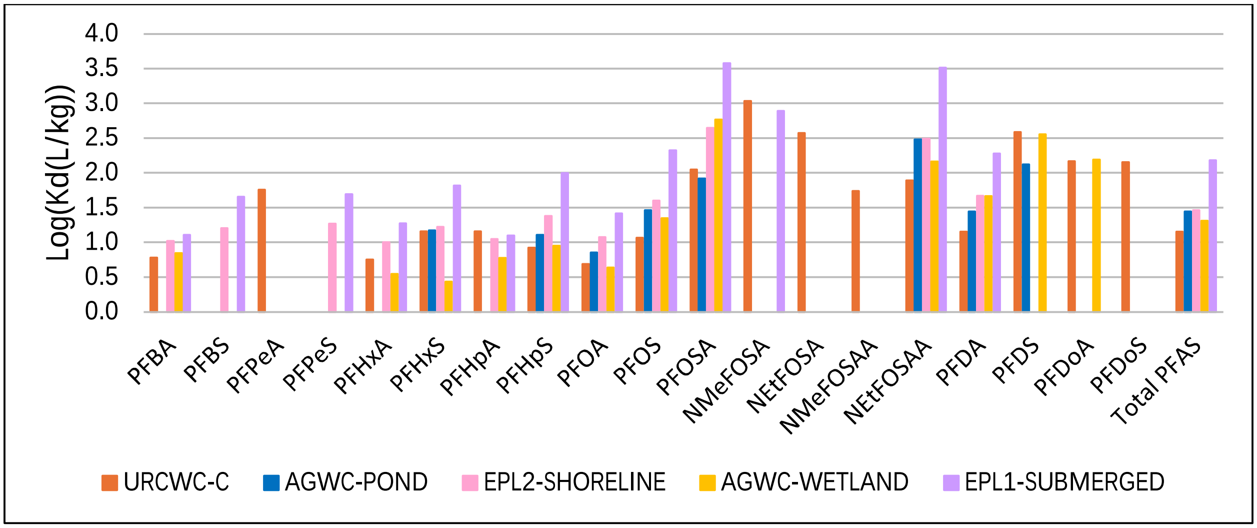

Figure I.15: Batch Test PFAS Partition Coefficients (Log[Kd (L/kg)]).

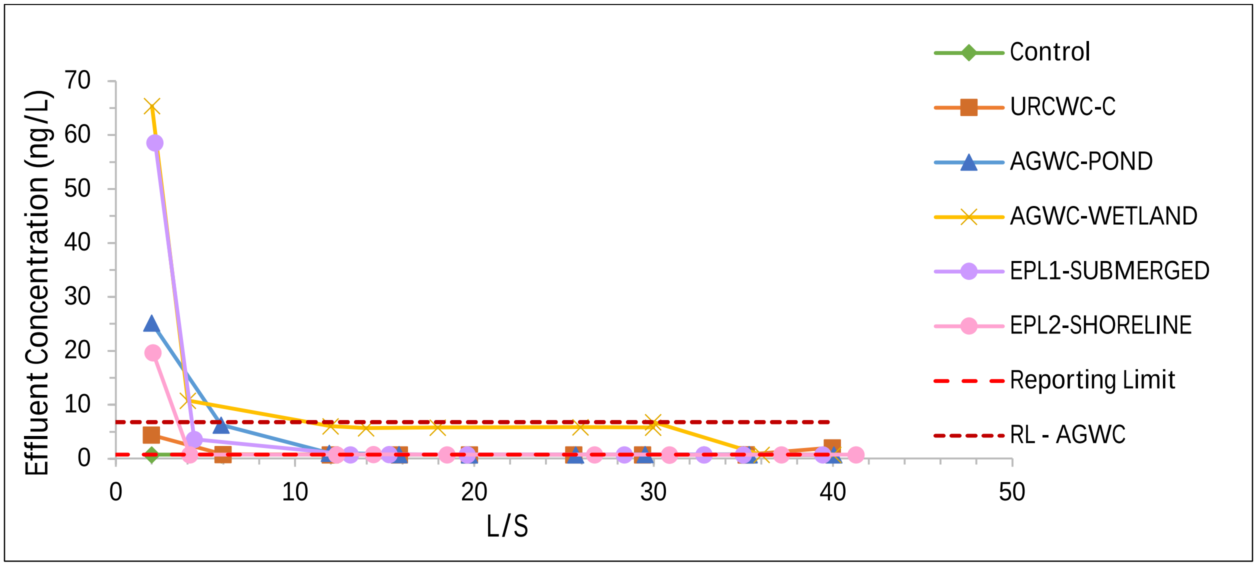

Figure I.16: Column Test PFPeA Effluent Concentrations (ng/L) as a Function of L/S.

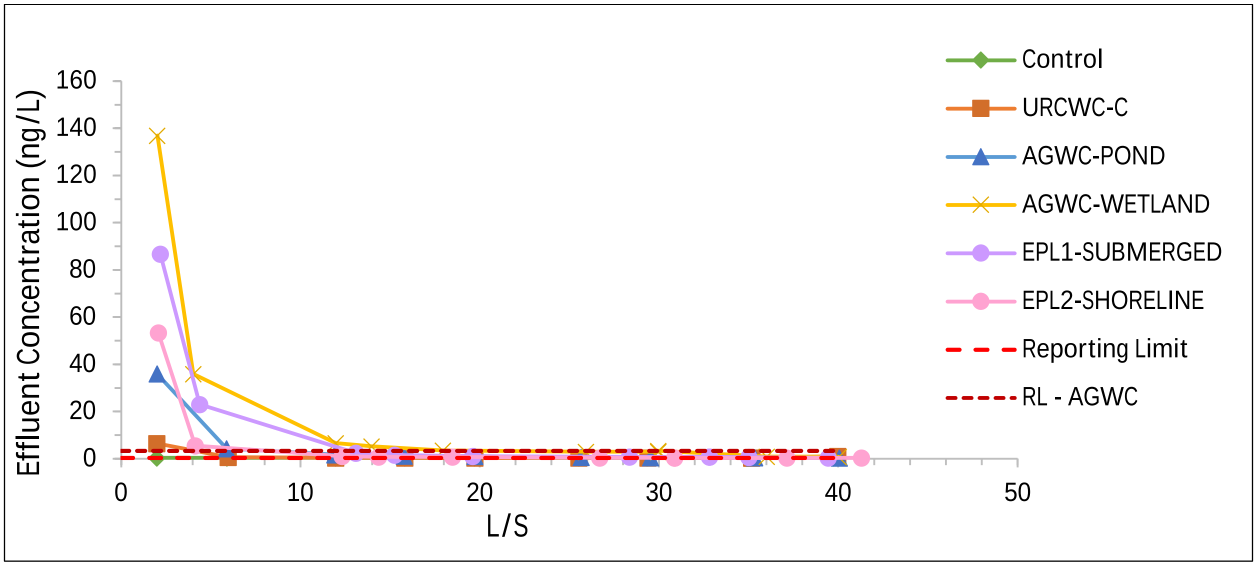

Figure I.16: Column Test PFHpA Effluent Concentrations (ng/L) as a Function of L/S.

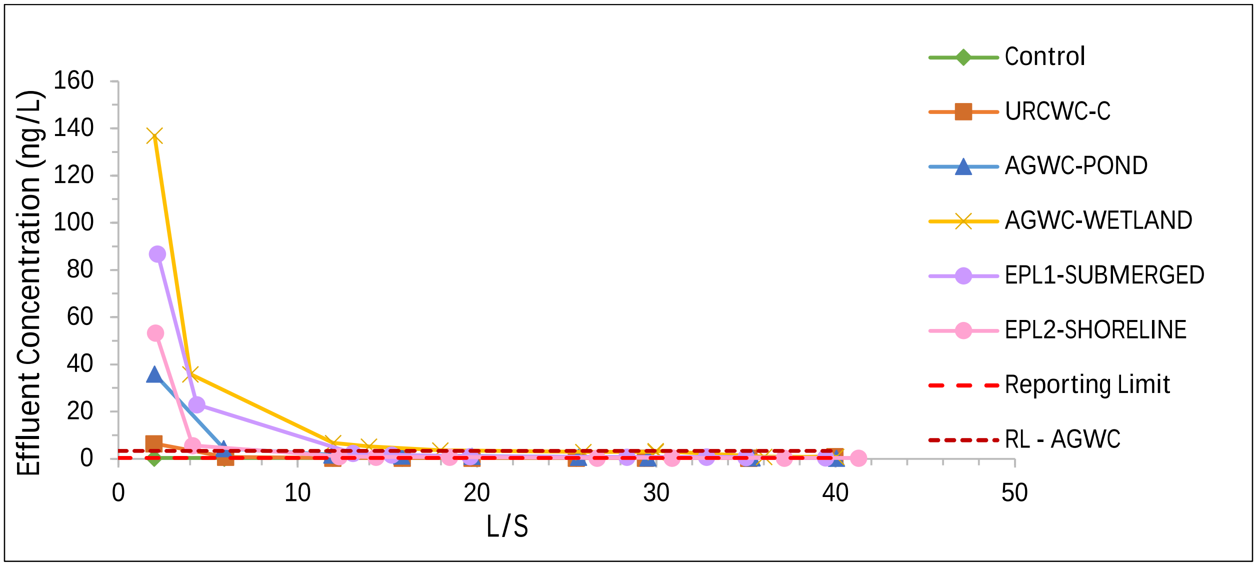

Figure I.17: Column Test PFNA Effluent Concentrations (ng/L) as a Function of L/S.

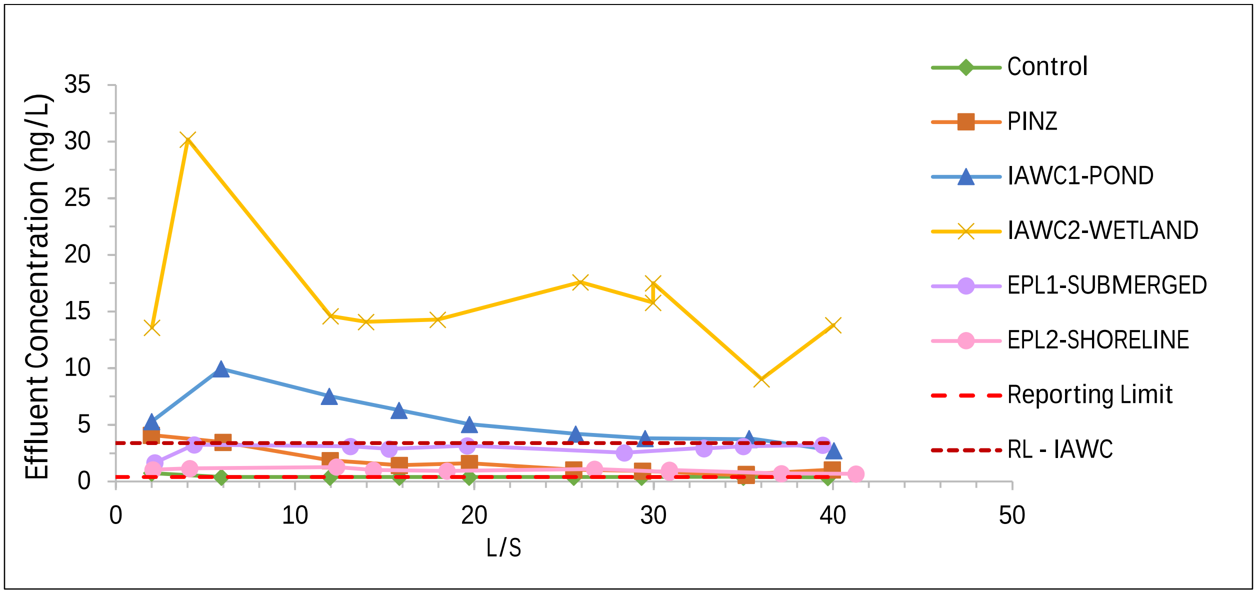

Figure I.18: Column Test PFNA Effluent Concentrations (ng/L) as a Function of L/S.

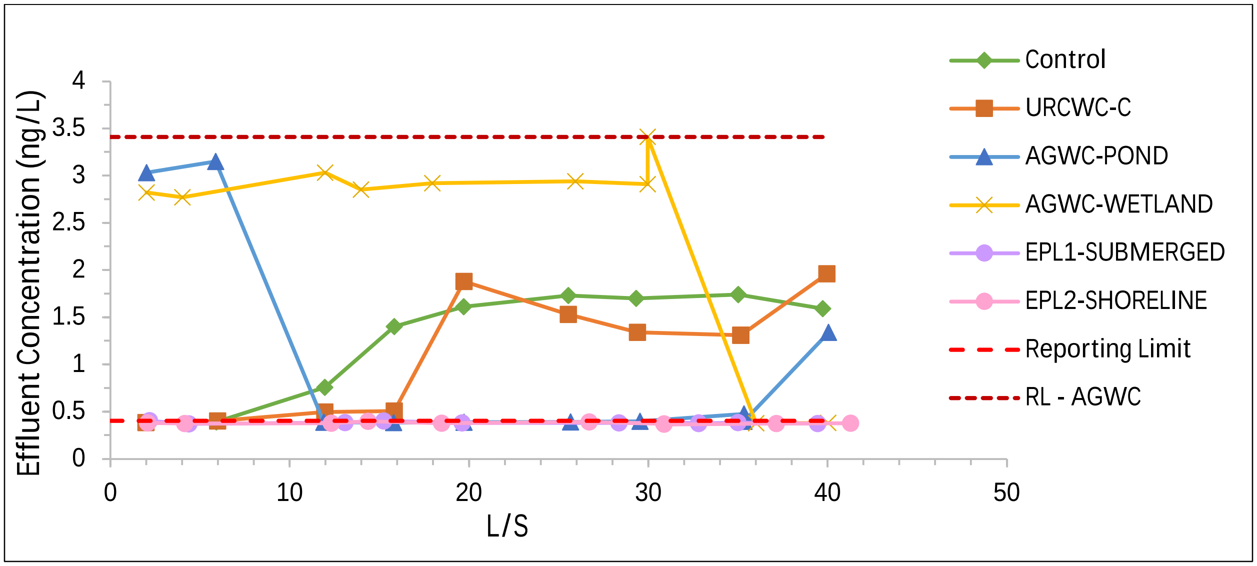

Figure I.19: Column Test PFUnA Effluent Concentrations (ng/L) as a Function of L/S.

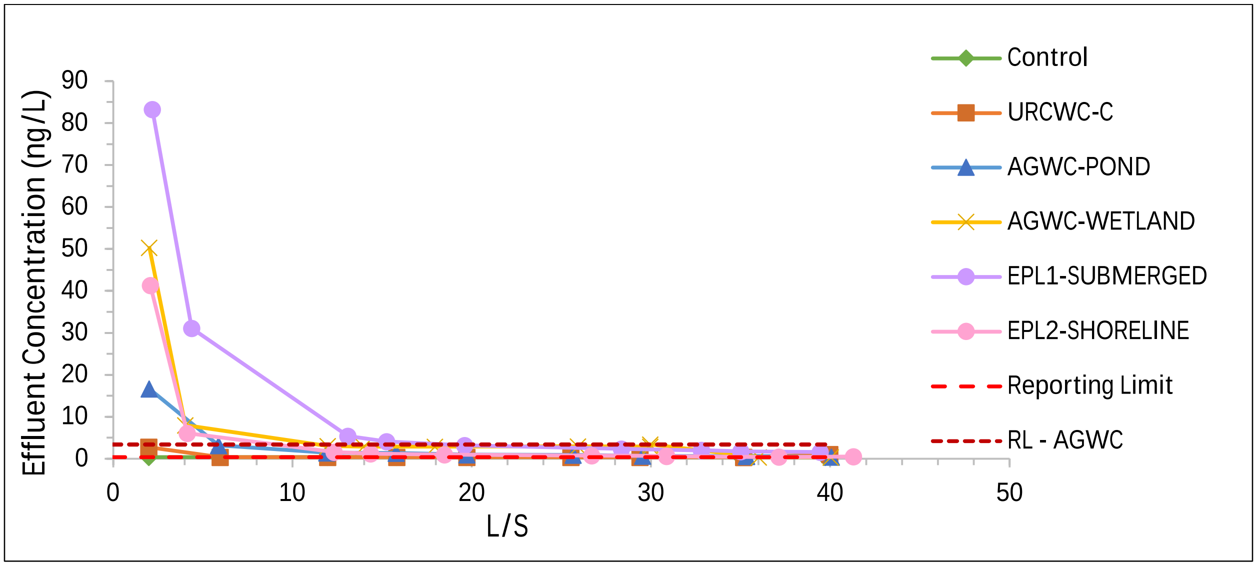

Figure I.20: Column test PFPeS Effluent Concentrations (ng/L) as a Function of L/S.

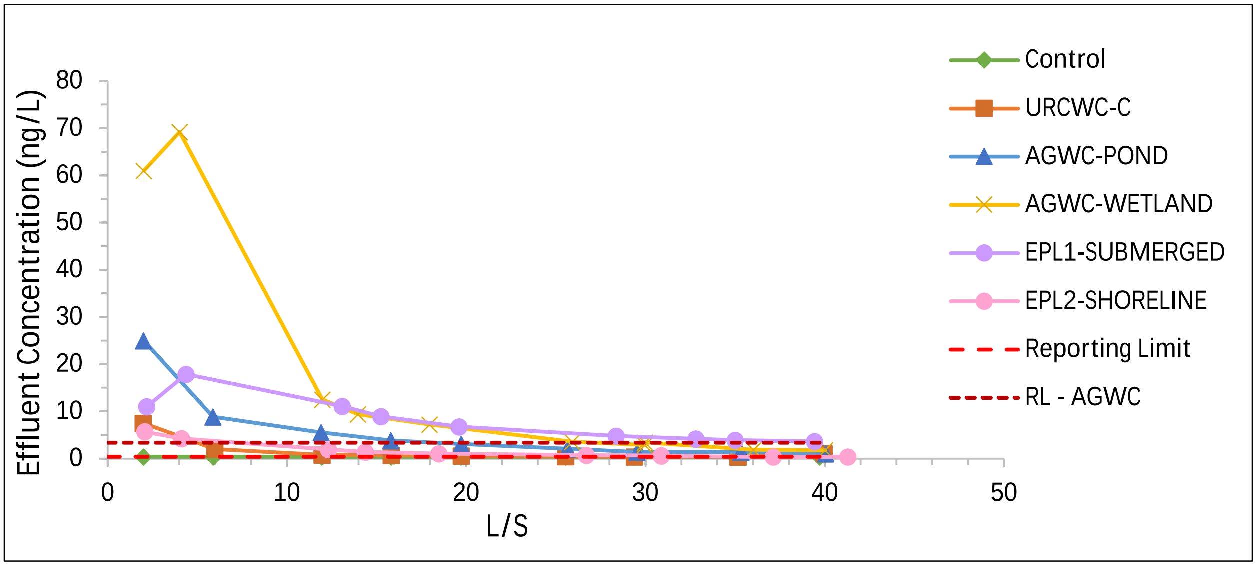

Figure I.21: Column Test PFHpS Effluent Concentrations (ng/L) as a Function of L/S.

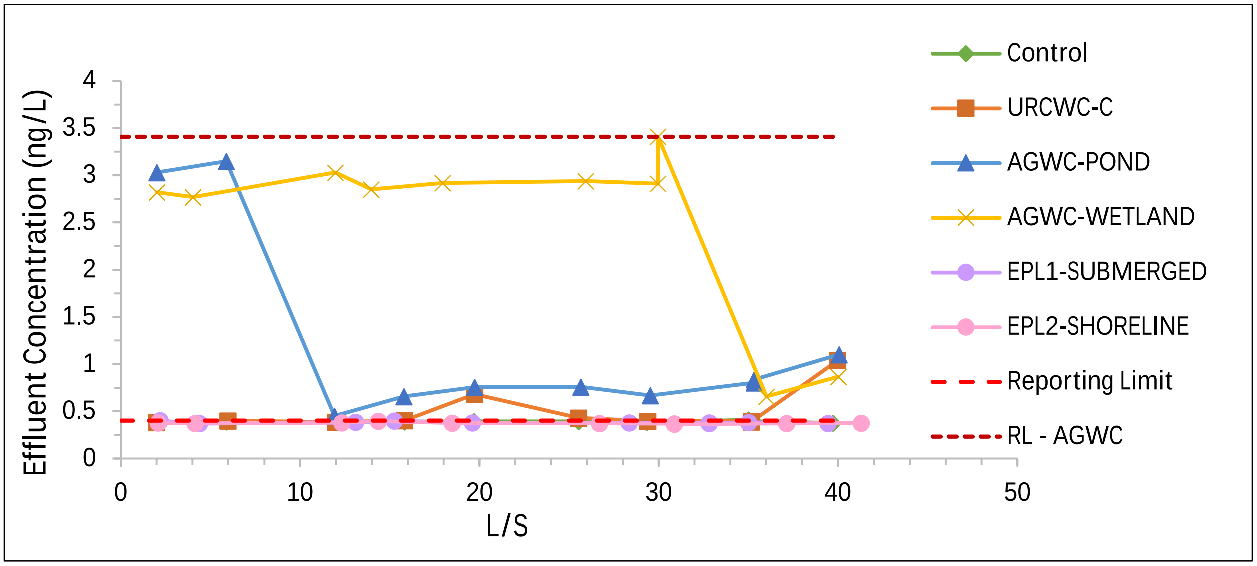

Figure I.22: Column Test PFNS Effluent Concentrations (ng/L) as a Function of L/S.

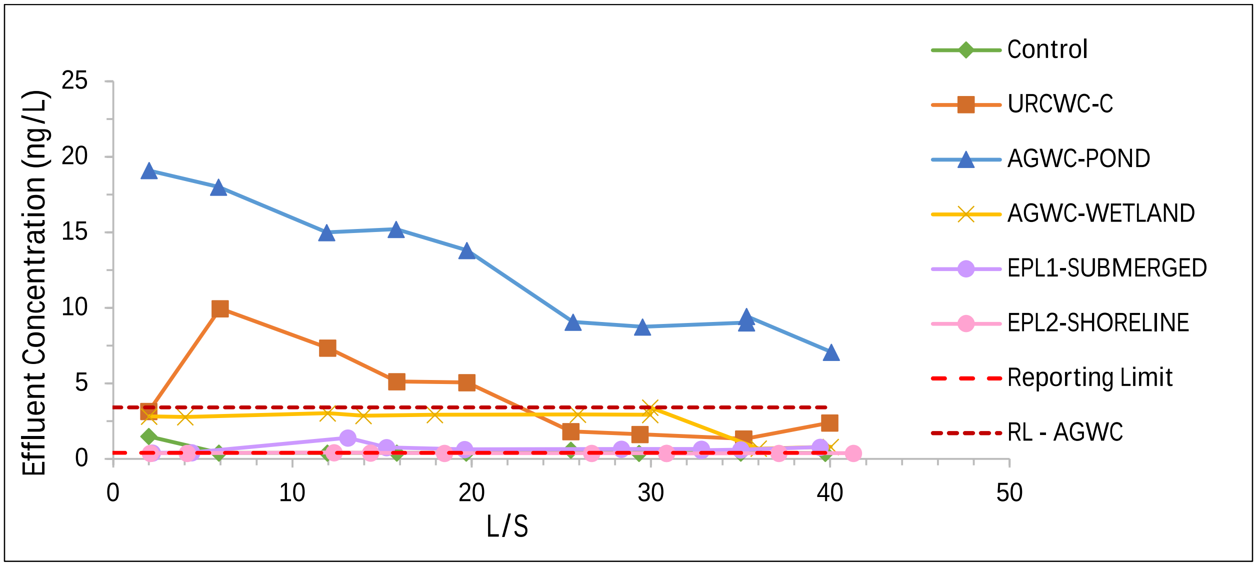

Figure I.23: Column Test PFOSA Effluent Concentrations (ng/L) as a Function of L/S.

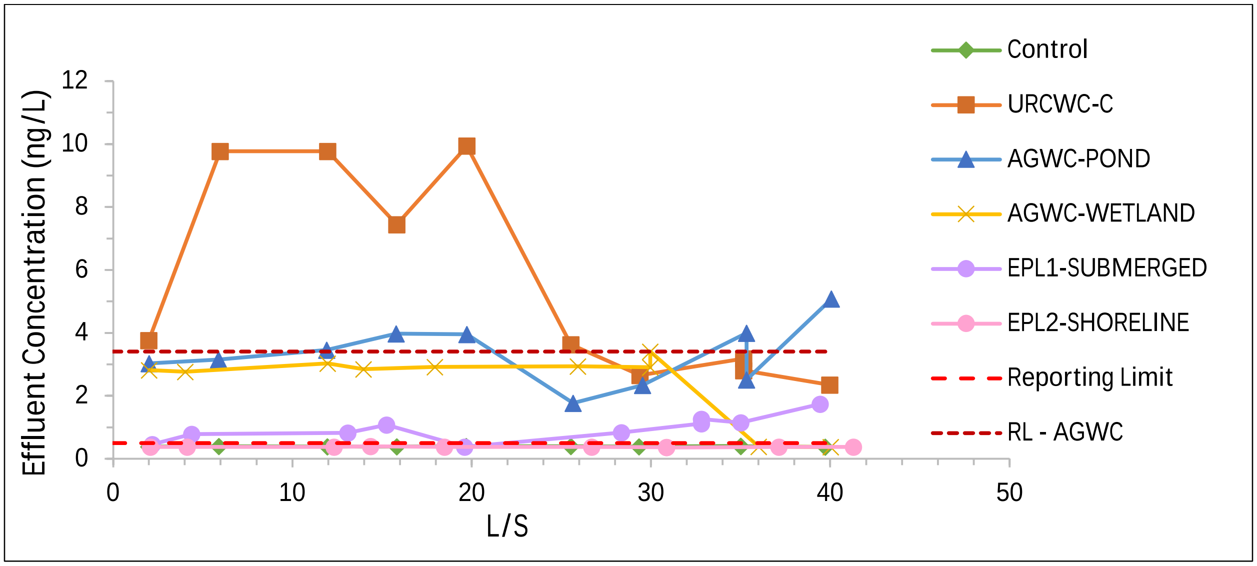

Figure I.24: Column Test NEtFOSAA Effluent Concentrations (ng/L) as a Function of L/S.

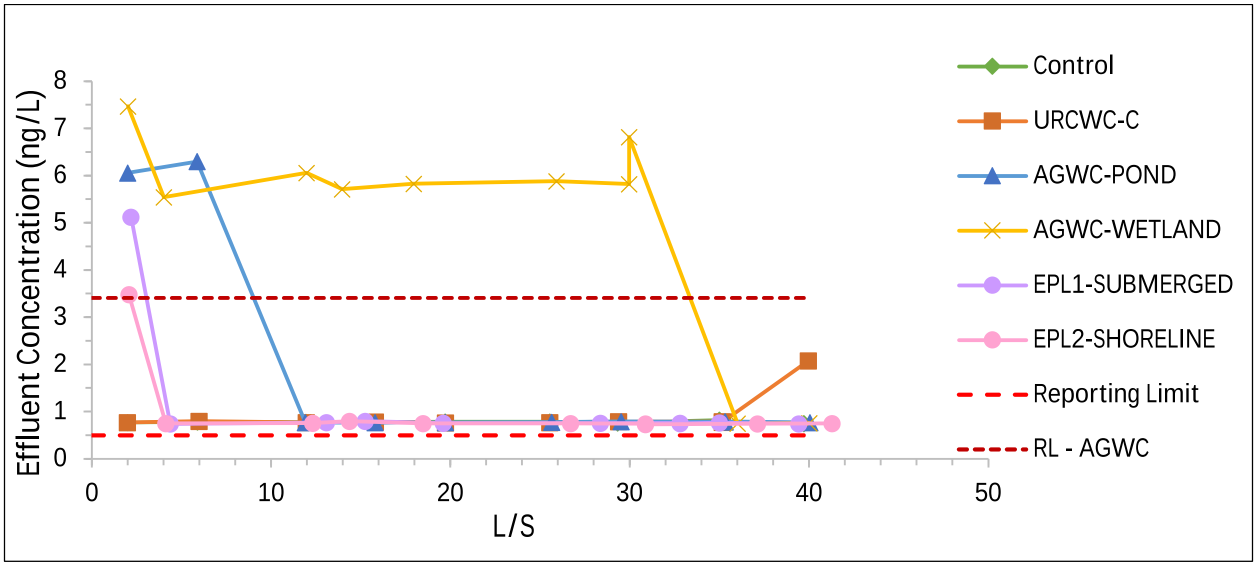

Figure I.25: Column Test PFMPA Effluent Concentrations (ng/L) as a Function of L/S.

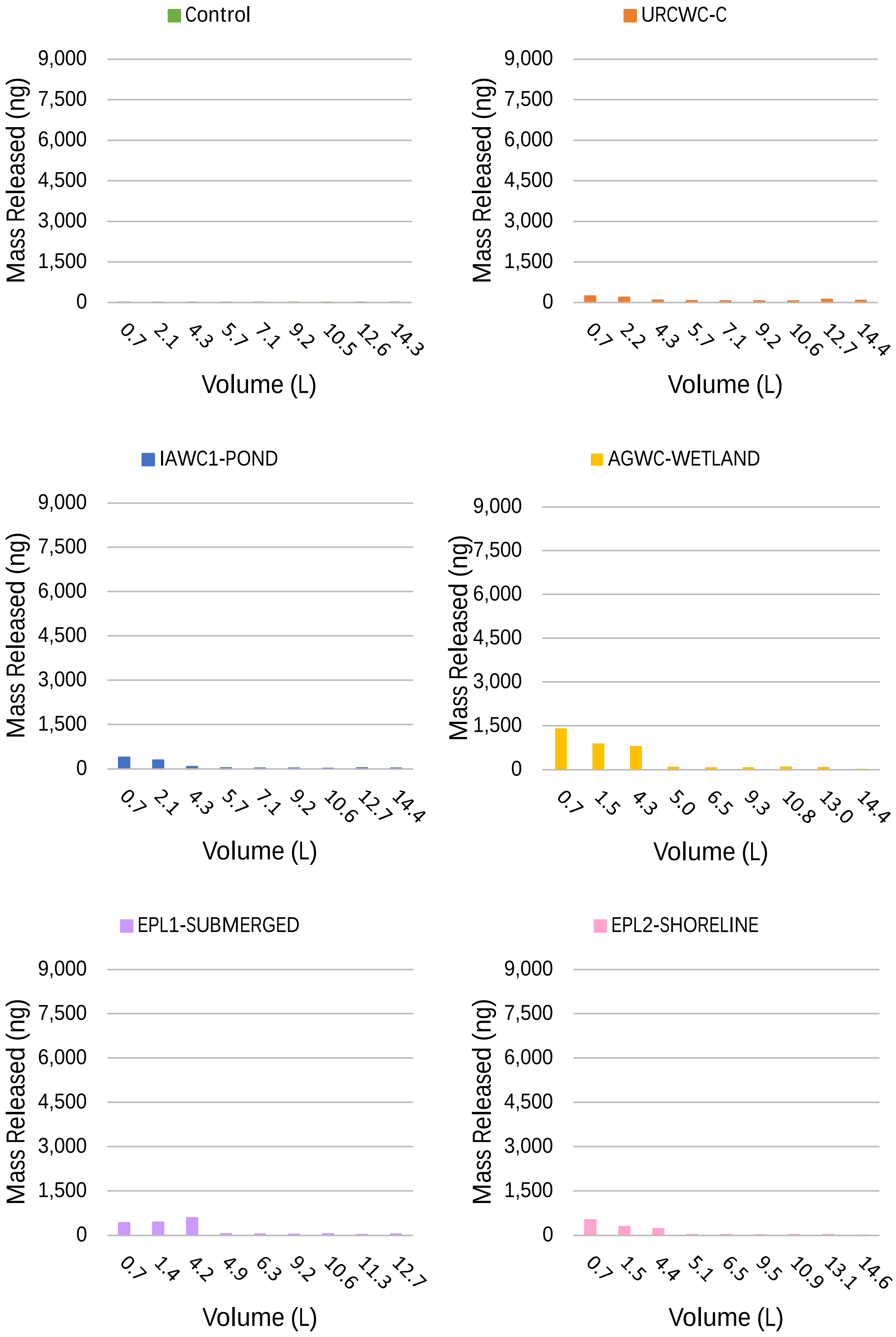

Figure I.26: PFOA Released (on a Mass Basis) Throughout the Column Study.

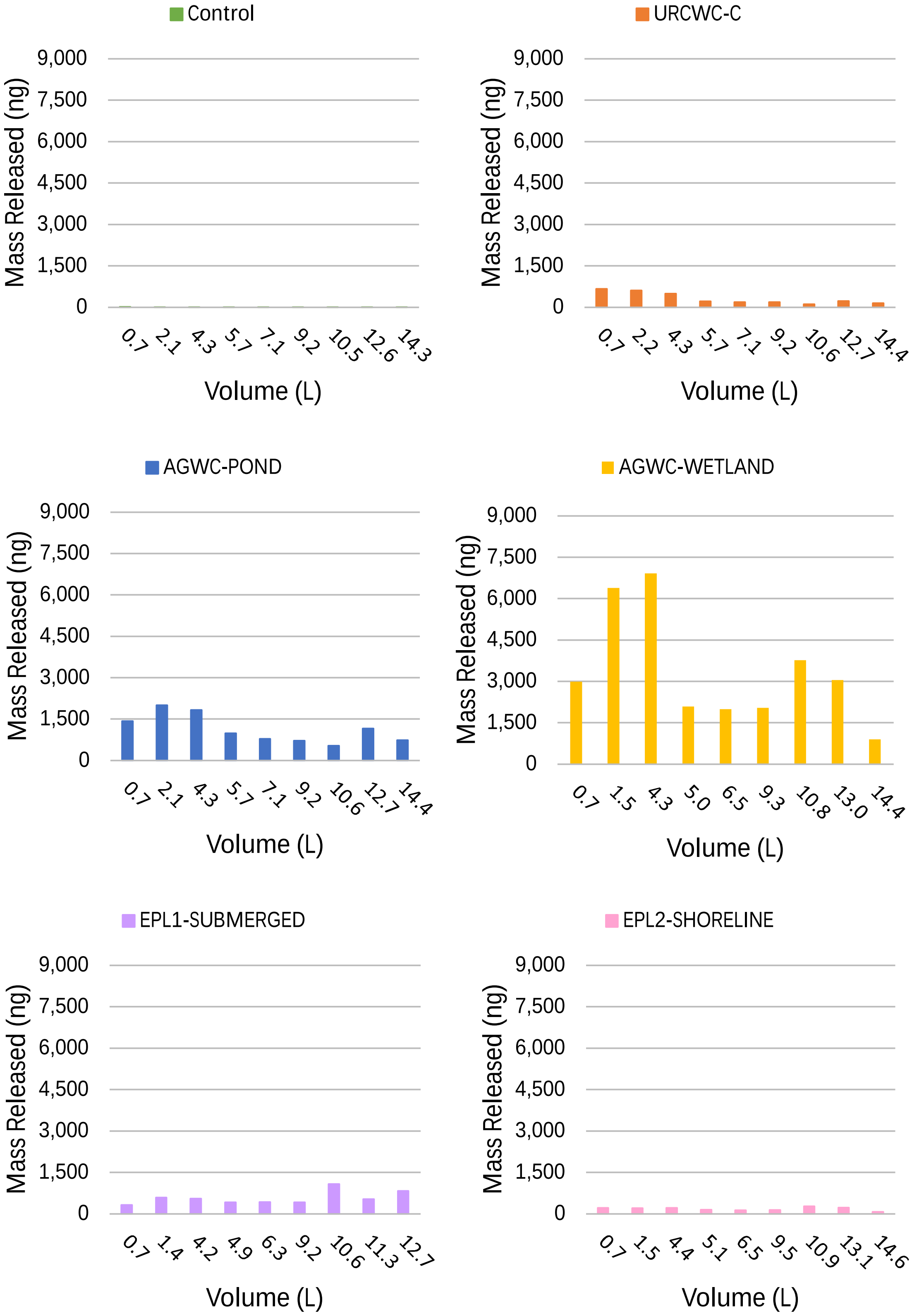

Figure I.27: PFOS Released (on a Mass Basis) Throughout the Column Study.

I7 Additional Tables

Table I.9: PFAS and TOC Initial Characterization Results.

PFAS Acronym (1)	Units	URCWC-C	AGWC-POND	AGWC-WETLAND	EPL1-SUBMERGED	EPL2-SHORELINE
PFBA	ng/kg-dry	337 J	<1,095	2,500 J (2)	1,955 J	457.5 J
PFPeA	ng/kg-dry	128	<546	<955.5	<493	<141
PFHxA	ng/kg-dry	64.05	<273	719 J	419.5 J	223 J
PFHpA	ng/kg-dry	64.05	<273	738 J	275.5 J	158 J
PFOA	ng/kg-dry	771.5	3,485	11,050	6,135	3,335
PFDA	ng/kg-dry	148.5 J	794.5 J	1,855	529	118 J
PFDoA	ng/kg-dry	53 J	<218	409	<197.5	<56.4
PFBS	ng/kg-dry	<64.05	<273	<478	383.5 J	86.5 J
PFPeS	ng/kg-dry	<64.35	<274.5	<480	404 J	132 J
PFHxS	ng/kg-dry	143 J	518 J	958.5 J	1635	363.5
PFHpS	ng/kg-dry	81 J	313.5 J	734.5 J	611 J	95.5 J
PFOS	ng/kg-dry	22,800	111,500	209,500	94,950	17,450
PFDS	ng/kg-dry	166.5 J	439.5 J	1130 J	<246.5	<70.5
PFDoS	ng/kg-dry	64.3 J	<273	<478	<246.5	<70.5
PFOSA	ng/kg-dry	2,070	2,875	2,190	2,115	190 J
NMeFOSA	ng/kg-dry	455.5	<273	<478	357 J	<70.5
NEtFOSA	ng/kg-dry	451 J	<764.5	<1340	<690	<197.5
NMeFOSAA	ng/kg-dry	66.8 J	<273	<478	<246.5	<70.5
NEtFOSAA	ng/kg-dry	1,565	1,101 J	484.5 J	2,530	151 J
Total PFAS	ng/kg-dry	29,429	121,027	232,269	112,300	22,760
% Moisture		22.4	41.6	44.7	73.3	43.9
TOC	mg/kg	12,200	33,850	44,900	137,500	44,150

(1) Only analytes above the laboratory detection limit are tabulated here. Complete laboratory results are available upon request.

(2) J flagged data indicates the reported result is an estimated value that generally is below the limit of quantitation but above the limit of detection.

Table I.10: Batch PFAS and TOC Results.

PFAS Acronym (1)	Units	Control (2)	URCWC-C (3)	AGWC-POND	AGWC-WETLAND	EPL1-SUBMERGED	EPL2-SHORELINE
PFBA	ng/L	1.73	20.5	31.6 J (4)	117	46.5	22.3
PFPeA	ng/L	0.863	1.885	6.04	22.3 J	4.73	3.45
PFHxA	ng/L	0.431	3.99	8.55 J	40.2	8.74	11.1
PFHpA	ng/L	0.431	2.575	7.47 J	36.3	6.6	7.47
PFOA	ng/L	0.825 J	50.45	168	590	111	152
PFNA	ng/L	26.3	18.45	11.9 J	16.4	9.49	10.2
PFDA	ng/L	<0.431	6.02	10.9 J	30.6	2.41	2.08
PFUnA	ng/L	4.52	1.495	<3.02	<3.03	<0.443	0.469 J
PFBS	ng/L	<0.431	1.295	3.26 J	7.66 J	5.13	3.33
PFPeS	ng/L	<0.433	1.335	4.4 J	8.7 J	5.16	4.61
PFHxS	ng/L	<0.496	5.78	18.2	56.1	17.2	13.6
PFHpS	ng/L	<0.431	4.31	11.9 J	31.5	4.75	2.81
PFOS	ng/L	<0.431	1,036.5	2,620	5,720	395	349
PFNS	ng/L	<0.431	1.0005	<3.02	<3.03	<0.443	<0.42
PFOSA	ng/L	<0.431	16.9	29.9	3.67 J	0.554 J	0.42
NMeFOSAA	ng/L	<0.431	1.021	<3.02	<3.03	<0.443	<0.42
NEtFOSAA	ng/L	<0.431	17.75	3.47 J	<3.03	0.772 J	0.475 J
Total PFAS	ng/L	35	1,191	2,936	6,680	618	583
TOC	mg/L	<0.22	4.0	4.0	5.5	3.2	5.8

(1) Only analytes above the laboratory detection limit are tabulated here. Complete laboratory results are available upon request.

(2) PFAS-free sand.

(3) An average of duplicate samples presented.

(4) J flagged data indicates the reported result is an estimated value that generally is below the limit of quantitation but above the limit of detection.

Table I.11: Control Column Leaching PFAS Results.

PFAS Acronym	Units	L/S									
		2	6	12	16	20	26	29	35	35-duplicate	40
PFBA	ng/L	<1.54	<1.56	<1.56	<1.56	<1.57	<1.57	<1.53	<1.64	<1.58	<1.50
PFPeA		<0.768	<0.782	<0.779	<0.78	<0.786	<0.78	<0.77	<0.82	<0.79	<0.75
PFHxA		1.16 J	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
PFHpA		<0.384	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
PFOA		6.29	0.891 J	0.683 J	0.697 J	0.801 J	0.554 J	0.651 J	0.569 J	0.591 J	0.495 J
PFNA		4.22	3.7	3.81	4.03	4.02	3.91	3.93	4.04	3.86	3.31
PFDA		0.751 J	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
PFUnA		<0.384	<0.391	0.757 J	1.4 J	1.61	1.73	1.7	1.74	1.74	1.59
PFTrDA		<0.384	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
PFBS		<0.384	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
PFPeS		<0.386	<0.393	<0.391	<0.392	<0.395	<0.39	<0.38	<0.41	<0.40	<0.38
PFHxS		2.68	0.941 J	0.876 J	0.865 J	0.851 J	0.833 J	0.783 J	0.738 J	0.786 J	0.687 J
PFHpS		<0.384	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
PFOS		16.4	2.69	2.53	2.73	2.34	2.27	2.04	2.07	2.08	1.88
PFNS		<0.384	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
PFDS		<0.384	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
6:2 FTS		<1.38	<1.41	<1.4	<1.41	<1.42	<1.41	<1.38	<1.48	<1.42	<1.36
PFOSA		1.49 J	<0.391	<0.389	<0.39	<0.393	0.583 J	<0.38	<0.41	<0.40	<0.38
NMeFOSA		<0.384	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
NMeFOSAA		<0.384	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
NEtFOSAA		<0.384	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
PFMPA		<0.768	<0.782	<0.779	<0.78	<0.786	<0.78	<0.77	<0.82	<0.79	<0.75
PFMBA		<0.384	<0.391	<0.389	<0.39	<0.393	<0.39	<0.38	<0.41	<0.40	<0.38
Total PFAS		33	8	9	10	10	9	9	9	9	8
TOC	mg/L	5.80	1.50	1.40	1.20	1.20	1.10	1.10	<1.00	<1.00	<1.00

Table I.12: URCWC-C Column Leaching PFAS Results.

PFAS Acronym	Units	L/S									
		2	6	12	16	20	26	29	35	35-duplicate	40
PFBA	ng/L	47.6	2.95 J	<1.55	<1.56	<1.53	<1.54	<1.58	<1.58	<1.55	<4.15
PFPeA		4.43	<0.797	<0.774	<0.782	<0.764	<0.77	<0.79	<0.79	<0.78	<2.08
PFHxA		11.1	1.33 J	0.641 J	0.581 J	0.492 J	0.581 J	0.456 J	0.451 J	0.413 J	<1.04
PFHpA		6.5	0.716 J	0.399 J	<0.391	<0.382	<0.39	<0.40	<0.40	<0.39	<1.04
PFOA		324	107	82.4	81.9	76.2	73.8	62.2	53.6	54.7	73.6
PFNA		15.9	6.44	4.67	4.27	4.31	4.37	3.97	4.14	4.3	5.82
PFDA		4.11	3.48	1.86	1.45 J	1.6	1.05 J	0.922 J	0.562 J	0.663 J	<1.04
PFUnA		<0.384	<0.399	0.494 J	0.504 J	1.88	1.53 J	1.34 J	1.31 J	1.31 J	1.96 J
PFTrDA		<0.384	0.542	<0.387	<0.391	<0.382	<0.39	<0.40	<0.40	<0.39	<1.04
PFBS		2.15	<0.399	<0.387	<0.391	<0.382	<0.39	<0.40	<0.40	<0.39	<1.04
PFPeS		2.78	<0.401	<0.389	<0.393	<0.384	<0.39	<0.40	<0.40	<0.39	<1.04
PFHxS		11.5	2.48	1.39 J	1.18 J	1.14 J	1.13 J	0.907 J	0.915 J	0.937 J	1.33 J
PFHpS		7.51	1.98	0.761 J	0.739 J	0.619 J	0.486 J	<0.40	<0.40	<0.39	<1.04
PFOS		921	631	308	276	252	170	130	112	109	144
PFNS		<0.384	<0.399	<0.387	0.404 J	0.681 J	0.429 J	<0.40	<0.40	<0.39	<1.04
PFDS		<0.384	<0.399	<0.387	<0.391	<0.382	0.446 J	<0.40	<0.40	<0.39	<1.04
6:2 FTS		<1.38	<1.44	<1.4	<1.41	<1.38	<1.39	<1.43	<1.43	<1.40	<3.74
PFOSA		3.14	9.95	7.34	5.12	5.06	1.81	1.63	1.33 J	1.31 J	2.38 J
NMeFOSA		<0.384	<0.399	<0.387	<0.391	<0.382	<0.39	<0.40	<0.40	<0.39	<1.04
NMeFOSAA		<0.384	<0.399	<0.387	<0.391	0.423 J	<0.39	<0.40	<0.40	<0.39	<1.04
NEtFOSAA		3.76	9.77	9.77	7.44	9.94	3.63	2.65	3.18	2.81	2.35 J
PFMPA		<0.768	<0.797	<0.774	<0.782	<0.764	<0.77	<0.79	<0.79	<0.78	<2.08
PFMBA		<0.384	<0.399	<0.387	<0.391	<0.382	<0.39	<0.40	<0.40	<0.39	<1.04
Total PFAS		1,365	778	418	292	272	259	204	177	175	86
TOC	mg/L	10.50	9.00	8.60	8.40	8.90	9.10	6.80	6.70	6.60	6.60

Table I.13: AGWC-POND Column Leaching PFAS Results.

PFAS Acronym	Units	L/S									
		2	6	12	16	20	26	29	35	35-duplicate	40
PFBA	ng/L	148	<12.6	3.88 J	2.42 J	1.84 J	<1.56	<1.59	<1.57	<1.59	<1.55
PFPeA		25.2	<6.3	1.07 J	0.813 J	<0.771	<0.78	<0.79	<0.79	<0.79	<0.77
PFHxA		37	4.03 J	1.65	1.25 J	1.03 J	0.837 J	0.54 J	0.59 J	0.581 J	<0.39
PFHpA		36	4.38 J	1.78	1.27 J	1.14 J	0.727 J	0.5 J	0.6 J	0.531 J	0.407 J
PFOA		540	103	41.6	29.4	24.7	20	14.4	14.1	14.2	11.6
PFNA		6.89 J	5.94 J	4.4	4.09	4.32	3.93	4.05	3.75	4.13	3.76
PFDA		5.3 J	9.96 J	7.54	6.3	5.05	4.21	3.82	3.73	3.82	2.75
PFUnA		<3.03	<3.15	<0.386	<0.385	<0.386	<0.39	<0.40	0.47 J	<0.40	1.34 J
PFTrDA		<3.03	<3.15	<0.386	<0.385	<0.386	<0.39	<0.40	<0.39	<0.40	<0.39
PFBS		11.1 J	<3.15	0.956 J	0.852 J	0.654 J	0.614 J	0.44 J	<0.39	0.4 J	<0.39
PFPeS		16.7	<3.17	1.45 J	1.35 J	1.02 J	0.939 J	0.72 J	0.61 J	0.65 J	0.419 J
PFHxS		59.1	12.1 J	6.38	5.05	4.24	3.87	3.32	3.26	3.12	2.34
PFHpS		25	8.84 J	5.54	3.86	3.07	2.07	1.39 J	1.38 J	1.47	1.06 J
PFOS		1,980	2,550	1,470	1,180	996	829	637	581	563	432
PFNS		<3.03	<3.15	0.452 J	0.656 J	0.755 J	0.758 J	0.67 J	0.8 J	0.836 J	1.1 J
PFDS		<3.03	<3.15	<0.386	<0.385	<0.386	<0.39	<0.40	<0.39	<0.40	0.564 J
6:2 FTS		<10.9	<11.4	<1.39	<1.39	<1.39	<1.41	<1.43	<1.42	<1.43	<1.39
PFOSA		19.1	18	15	15.2	13.8	9.06	8.74	9.01	9.44	7.07
NMeFOSA		<3.03	<3.15	<0.386	<0.385	<0.386	<0.39	<0.40	0.73 J	<0.40	0.536
NMeFOSAA		<3.03	<3.15	<0.386	<0.385	<0.386	<0.39	<0.40	<0.39	<0.40	<0.39
NEtFOSAA		<3.03	<3.15	3.46	3.98	3.96	1.77	2.34	4	2.51	5.08
PFMPA		<6.06	<6.3	<0.773	<0.77	<0.771	<0.78	<0.79	<0.79	<0.79	<0.77
PFMBA		<3.03	<3.15	<0.386	<0.385	<0.386	<0.39	<0.40	<0.39	<0.40	<0.39
Total PFAS		2,909	2,716	1,565	1,256	1,062	878	678	624	605	470
TOC	mg/L	7.40	6.20	5.20	5.10	4.90	4.80	3.90	4.00	4.00	3.90

Table I.14: AGWC-WETLAND Column Leaching PFAS Results.

PFAS Acronym	Units	L/S									
		2	6	12	16	20	26	29	35	35-duplicate	40
PFBA	ng/L	369	57.1	13.2 J	<11.4	<11.7	<11.8	<11.6	<13.6	2.54 J	2.23 J
PFPeA		65.4	10.8 J	<6.06	<5.71	<5.83	<5.88	<5.82	<6.82	<0.752	<0.76
PFHxA		136	29.3	5.94 J	5.01 J	4.28 J	<2.94	<2.91	<3.41	1 J	1.18 J
PFHpA		137	35.9	6.69 J	5.28 J	3.58 J	<2.94	<2.91	<3.41	0.924 J	0.871 J
PFOA		1940	834	163	126	100	64.9	54	58.4	38.9	42.3
PFNA		15.1	16.2	4.47 J	4.29 J	3.81 J	3.82 J	3.36 J	<3.41	1.9	2.26
PFDA		13.6	30.2	14.6	14.1	14.3	17.6	15.8	17.5	9.05	13.8
PFUnA		<2.82	<2.77	<3.03	<2.85	<2.92	<2.94	<2.91	<3.41	<0.376	<0.38
PFTrDA		<2.82	<2.77	<3.03	<2.85	<2.92	<2.94	<2.91	<3.41	<0.376	<0.38
PFBS		31.8	3.4 J	<3.03	<2.85	<2.92	<2.94	<2.91	<3.41	<0.376	<0.38
PFPeS		50.3	8.01 J	<3.05	<2.87	<2.93	<2.96	<2.92	<3.43	<0.378	<0.382
PFHxS		203	62.6	11.6 J	8.71 J	6.43 J	4.56 J	3.89 J	4.56 J	3.18	3.32
PFHpS		61	69.2	12.5	9.4 J	7.22 J	3.57 J	<2.91	<3.41	1.89	1.78
PFOS		4,110	7,590	3,050	2,820	2,650	2,270	1,920	2,020	1,180	1,240
PFNS		<2.82	<2.77	<3.03	<2.85	<2.92	<2.94	<2.91	<3.41	0.658 J	0.867 J
PFDS		<2.82	<2.77	<3.03	<2.85	<2.92	<2.94	<2.91	<3.41	<0.376	<0.38
6:2 FTS		<10.2	<9.98	<10.9	<10.3	<10.5	<10.6	<10.5	<12.3	<1.36	<1.37
PFOSA		<2.82	<2.77	<3.03	<2.85	<2.92	<2.94	<2.91	<3.41	0.687 J	0.807 J
NMeFOSA		<2.82	<2.77	<3.03	<2.85	<2.92	<2.94	<2.91	<3.41	<0.376	<0.38
NMeFOSAA		<2.82	<2.77	<3.03	<2.85	<2.92	<2.94	<2.91	<3.41	<0.376	<0.38
NEtFOSAA		<2.82	<2.77	<3.03	<2.85	<2.92	<2.94	<2.91	<3.41	0.382 J	<0.38
PFMPA		7.47 J	<5.54	<6.06	<5.71	<5.83	<5.88	<5.82	<6.82	<0.752	<0.76
PFMBA		<2.82	<2.77	<3.03	<2.85	<2.92	<2.94	<2.91	<3.41	<0.376	<0.38
Total PFAS		7,140	8,747	3,282	2,993	2,790	2,364	1,997	2,100	1,241	1,309
TOC	mg/L	11.2	10.8	7.8	6.5	6.6	6.8	6.1	6.0	5.0	5.4

Table I.15: EPL1-SUBMERGED Column Leaching PFAS Results.

PFAS Acronym	Units	L/S									
		2	6	12	16	20	26	29	35	35-duplicate	40
PFBA	ng/L	513	10.4	2.26 J	<1.6	<1.51	<1.52	<1.52	<1.5	<1.53	<1.49
PFPeA		58.6	3.64	0.792 J	<0.8	<0.757	<0.758	<0.759	<0.748	<0.764	<0.744
PFHxA		185	18.8	3.32	1.98	1.74	1.24 J	1.47 J	1.36 J	0.923 J	0.9 J
PFHpA		86.8	23	2.4	1.67	1.01 J	0.824 J	0.831 J	0.867 J	0.618 J	0.462 J
PFOA		597	616	80.8	54.6	37.4	29.8	25.9	26.4	23.4	22.1
PFNA		3.34	4.71	3.73	3.19	3.37	3.32	3.23	3.29	3.42	3.55
PFDA		1.68	3.25	3.11	2.88	3.15	2.53	2.97	2.92	3.11	3.22
PFUnA		<0.403	<0.371	<0.385	<0.4	<0.379	<0.379	<0.38	<0.374	<0.382	<0.372
PFTrDA		<0.403	<0.371	<0.385	<0.4	<0.379	<0.379	<0.38	<0.374	<0.382	<0.372
PFBS		64.5	13.4	2.85	2.09	1.69	1.36 J	1.31 J	1.38 J	1.16 J	1.14 J
PFPeS		83.3	31.1	5.43	4.13	3.19	2.36	1.99	2.03	1.78	1.6
PFHxS		128	120	22	16.7	11.6	9.25	9.15	9.18	8.2	6.76
PFHpS		11	17.9	11.1	8.9	6.74	4.78	4.21	4.2	3.89	3.65
PFOS		451	730	628	577	591	594	553	562	542	546
PFNS		<0.403	<0.371	<0.385	<0.4	<0.379	<0.379	<0.38	<0.374	<0.382	<0.372
PFDS		<0.403	<0.371	<0.385	<0.4	<0.379	<0.379	<0.38	<0.374	<0.382	<0.372
6:2 FTS		5.56 J	2.8 J	<1.39	<1.44	<1.37	<1.37	<1.37	<1.35	<1.38	<1.34
PFOSA		<0.403	0.418 J	1.4 J	0.752 J	0.633 J	0.65 J	0.648 J	0.566 J	0.617 J	0.779 J
NMeFOSA		<0.403	<0.371	<0.385	<0.4	<0.379	<0.379	<0.38	<0.374	<0.382	<0.372
NMeFOSAA		<0.403	<0.371	<0.385	<0.4	<0.379	<0.379	<0.38	<0.374	<0.382	<0.372
NEtFOSAA		0.454 J	0.786 J	0.823 J	1.08 J	<0.379	0.836 J	1.12 J	1.26 J	1.15 J	1.74
PFMPA		5.12	<0.742	<0.771	<0.8	<0.757	<0.758	<0.759	<0.748	<0.764	<0.744
PFMBA		0.591 J	<0.371	<0.385	<0.4	<0.379	<0.379	<0.38	<0.374	<0.382	<0.372
Total PFAS		2,195	1,596	768	675	662	651	606	615	590	592
TOC	mg/L	70.7	24.6	13.6	12.0	9.2	8.6	7.0	7.5	6.1	5.9

Table I.16: EPL2-SHORELINE Column Leaching PFAS Results.

PFAS Acronym	Units	L/S									
		2	6	12	16	20	26	29	35	35-duplicate	40
PFBA	ng/L	138	2.26 J	<1.51	<1.59	<1.5	<1.5	<1.48	<1.46	<1.49	<1.5
PFPeA		19.7	<0.747	<0.755	<0.797	<0.752	<0.748	<0.741	<0.73	<0.746	<0.752
PFHxA		76.9	4.76	1.3 J	0.988 J	1.29 J	0.72 J	0.613 J	0.506 J	0.52 J	0.523 J
PFHpA		53.4	5.59	1.04 J	0.792 J	0.757 J	0.417 J	0.435 J	0.424 J	<0.373	<0.376
PFOA		715	225	37.3	25.6	20.2	15.6	12.9	12.4	9.05	8.51
PFNA		2.79	2.27	1.67	1.45 J	1.75	2.93	2.79	2.78	2.63	3.46
PFDA		1.04 J	1.17 J	1.29 J	1.03 J	0.928 J	1.09 J	0.846 J	1.02 J	0.716 J	0.678 J
PFUnA		<0.38	<0.373	<0.378	<0.398	<0.376	0.392 J	<0.37	<0.365	<0.373	<0.376
PFTrDA		<0.38	<0.373	<0.378	<0.398	<0.376	<0.374	<0.37	<0.365	<0.373	<0.376
PFBS		24.2	2.13	0.52 J	<0.398	0.439 J	0.378 J	<0.37	<0.365	<0.373	<0.376
PFPeS		41.3	6.06	1.56	1.2 J	1.02 J	0.756 J	0.648 J	0.626 J	0.43 J	0.514 J
PFHxS		68.9	21.3	5.25	3.9	3.33	3.06	2.91	2.94	2.11	2.31
PFHpS		5.72	4.22	1.95	1.4 J	1.09 J	0.753 J	0.622 J	0.616 J	0.378 J	0.392 J
PFOS		299	273	234	193	159	174	142	141	89.9	99.1
PFNS		<0.38	<0.373	<0.378	<0.398	<0.376	<0.374	<0.37	<0.365	<0.373	<0.376
PFDS		<0.38	<0.373	<0.378	<0.398	<0.376	<0.374	<0.37	<0.365	<0.373	<0.376
6:2 FTS		<1.37	<1.35	<1.36	<1.44	<1.36	<1.35	<1.34	<1.32	<1.34	<1.36
PFOSA		<0.38	<0.373	0.424 J	<0.398	<0.376	<0.374	<0.37	<0.365	<0.373	<0.376
NMeFOSA		<0.38	<0.373	<0.378	<0.398	<0.376	<0.374	<0.37	<0.365	<0.373	<0.376
NMeFOSAA		<0.38	<0.373	<0.378	<0.398	<0.376	<0.374	<0.37	<0.365	<0.373	<0.376
NEtFOSAA		<0.38	<0.373	<0.378	<0.398	<0.376	<0.374	<0.37	<0.365	<0.373	<0.376
PFMPA		3.48	<0.747	<0.755	<0.797	<0.752	<0.748	<0.741	<0.73	<0.746	<0.752
PFMBA		<0.38	<0.373	<0.378	<0.398	<0.376	<0.374	<0.37	<0.365	<0.373	<0.376
Total PFAS		1,449	548	286	229	190	200	164	162	106	115
TOC	mg/L	15.7	9.9	6.7	6.0	6.0	6.0	6.4	6.3	5.1	5.0