Connecticut Department of Energy and Environmental Protection

Trailer Demonstration Project Summary Report

Winsted Trailer

August 2022

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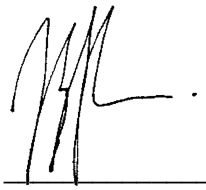

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Acronyms and Abbreviations

µg/L	micrograms per liter
AFFF	aqueous film-forming foam
Arcadis	Arcadis U.S., Inc.
AFT	attack foam trailer
APS	additional polluting substance
CTDEEP	Connecticut Department of Energy and Environmental Protection
DESPP	Connecticut Department of Emergency Services and Public Protection
EBCT	empty bed contact time
F3	fluorine free foam
FAO	fire apparatus operator
GAC	granular activated carbon
gal	gallon
IBC	intermediate bulk container
LCMSMS	liquid chromatography with tandem mass spectrometry
ND	non-detect
ng/L	nanograms per liter
PFAAs	perfluoroalkyl acids
PFAS	per- and polyfluoroalkyl substances
PFBS	Perfluorobutane sulfonic acid
PFDA	perfluorodecanoic acid
PFDoA	perfluorododecanoic acid
PFHxS	perfluorohexanesulfonic acid
PFNS	Perfluorononanesulfonic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctanesulfonic acid
PFNA	perfluorononanoic acid
PFTeA	perfluorotetradecanoic acid
PFTrDA	perfluorotridecanoic acid
PFUdA	perfluoroundecanoic acid
ppb	parts per billion

PPE	personal protective equipment
TOP	total oxidizable precursor
USEPA	United States Environmental Protection Agency
v/v	concentration by volume

1 Introduction

Arcadis U.S., Inc. (Arcadis) is pleased to present the successful results of performing a per- and polyfluoroalkyl substances (PFAS) cleaning on a fire-fighting apparatus. This work was requested by the Connecticut Department of Energy and Environmental Protection (CTDEEP) to perform a cleaning of one (1) attack foam trailer (AFT) owned by Connecticut Department of Emergency Services and Public Protection (DESPP) stationed in Winsted, Connecticut. Cleaning activities took place at the Old Saybrook garage operated by CTDEEP in Old Saybrook, Connecticut (Site). Historically, the apparatus contained National Foam Universal Gold 1% / 3% Alcohol-Resistant aqueous film-forming firefighting foam (AFFF), inclusive of long chain PFAS. Execution of cleaning activities followed a PFAS Cleaning standard operating procedure (SOP) prepared by Arcadis in July 2021 specifically for use with its proprietary and trade-secret protected cleaning agent, Fluoro Fighter™. This cleaning agent has been shown to effectively remove PFAS associated with process and emergency response infrastructure (Anderson, Theriault et al. 2021). This summary report includes documentation of work performed, including any deviations from the SOP, a summary of data collected during execution of the infrastructure cleaning, and recommendations for future modifications of the SOP for the CTDEEP State-Wide AFFF Take Back Program.

1.1 PFAS Cleaning Objectives

The PFAS cleaning objective discussed herein was to reduce PFAS levels on the wetted surfaces of the AFT as much as possible. Arcadis used an equivalent analytical method to United States Environmental Protection Agency (USEPA) Method 537 Modified and total oxidizable precursor (TOP) assay methods to provide confirmation of cleaning and to quantify the PFAS mass removed during cleaning.

1.2 Fluoro Fighter™

Fluoro Fighter™ is a proprietary aqueous organic solvent developed by Arcadis to facilitate comprehensive cleaning of infrastructure that has been exposed to PFAS. The cleaning agent was applied as an aqueous solution that is chemically compatible with equipment associated with AFFF storage, distribution, and use. In a typical application, the cleaning agent remains in contact with wetted surfaces for a minimum of eight hours, after which the cleaning agent solution is then extracted and stored for disposal as a PFAS-impacted waste.

1.3 Sample Analysis and Total Oxidizable Precursor Assay

Cleaning activities included the collection of grab samples for confirmation. Collected samples were submitted to Eurofins Lancaster Laboratories Environmental, LLC, (Eurofins) in Lancaster, Pennsylvania, for analysis using Department of Defense Quality Systems Manual 5.3-compliant Eurofins Method PFC_IDA including isotope dilution (i.e., liquid chromatography with tandem mass spectroscopy [LC-MS-MS]), an equivalent method to USEPA Method 537 modified. Laboratory analysis also included a sample preparation method called TOP assay to indirectly measure the total polyfluorinated (i.e., “precursor”) concentration in samples. Conventional PFAS analysis using LC-MS-MS reports a limited list of the many potential PFAS that can be present in an AFFF-related sample. The TOP assay is an oxidative digestion that converts precursors to measurable PFAS, thus enabling an accounting of total PFAS (Houtz and Sedlak 2012). The difference in the total PFAS between pre- and post-TOP assays represents the quantity of precursors in the sample.

Confirmation samples were collected throughout the cleaning procedure and analyzed to document changes in the concentrations of PFAS through each step of the procedure. Arcadis staff collected all samples for PFAS analysis and packaged them for delivery to Eurofins for analysis. Samples were collected and analyzed by the lab upon receipt. Duplicates and trip blanks were collected, as necessary, to assist with validation of the data.

2 PFAS Cleaning Execution

Arcadis executed the cleaning defined in the SOP for one (1) AFT:

- The AFT stationed at the Winsted Fire Department (Winsted AFT) was cleaned as the proof-of-concept demonstration for subsequent cleaning procedures. The Winsted AFT manufactured by United Plastic Fabricating, Inc. in 2002 for the State of Connecticut has a 500-gallon (gal) Class B foam cell.
- The Winsted AFT arrived onsite containing AFFF. Based on information provided by CTDEEP the foam contained within the AFT foam cell was National Foam Universal Gold 1% / 3% Alcohol-Resistant AFFF.
- Cleaning of the Winsted AFT was conducted over five days spanning the period of September 20 through September 29, 2021.
- Cleaning commenced with a potable water rinse of the Winsted AFT's foam cell, followed by an initial Fluoro Fighter™ application and subsequent water rinse (Step A). Step A was repeated in three identical application and rinse steps.

The following sections include observations from cleaning execution and any significant deviations from the SOP. A photo log of the work performed in Phase 1 is attached in **Appendix A**. Field notes of work performed are provided in **Appendix B** for reference.

2.1 Cleaning Execution Observations

Clean Harbors personnel removed approximately 385 gallons of AFFF from the foam cell associated with the Winsted Trailer on September 14, 2021 and placed the waste material in 55-gallon United States Department of Transportation (DOT)-certified steel drums for disposal. Arcadis mobilized two personnel to Old Saybrook, Connecticut on September 20, 2021, to commence cleaning activities. Upon arrival, a PFAS cleaning agent conveyance and application system was assembled, consisting of pumps, hoses, piping, and segregated 275-gallon totes for storage of each type of waste and interim cleaning process waste storage. Arcadis constructed and operated the application system within a secondary containment berm sized to allow for ample space for cleaning and to hold the maximum volume of the largest vessel in the system. The selected flow path for cleaning the Winsted AFT used the on-board proportioner valves and associated piping along with an auxiliary pump to load the cleaning solution. The trailer's rear drain and associated piping was used for unloading the cleaning solution.

On September 24, 2021, Arcadis performed a potable water rinse of the AFT to remove residual AFFF from the foam cell. This initial rinse included a rinse of the four (4) foam proportioners located at the front of the AFT.

On September 25, 2021, Arcadis commenced cleaning of the Winsted Trailer. Due to baffles in the trailer's foam cell, the cleaning solution was distributed throughout the foam cell using a "fill and drain" method, consisting of a series of cycles of filling and draining the foam cell with cleaning solution to induce agitation. Additionally, Arcadis used overnight soaking and recirculation methods to apply cleaning solution to the foam cell and associated foam system piping.

The three Fluoro Fighter™ application steps (Step A, Step B, and Step C) consisted of an overnight soak, a series of fill and drain cycles, a system recirculation, and a second series of fill and drain cycles. The duration of soaking cycles and the number of fill and drain cycles varied slightly due to field sequencing. Samples were collected after the overnight soak and at the end of each series of fill and drain cycles.

The spent rinse water and Fluoro Fighter™ from each step were passed through granular activated carbon (GAC) to remove PFAS prior to containment in waste totes for disposal.

2.2 Deviations from PFAS Cleaning SOP

PFAS cleaning mostly followed the SOP. Deviations from the SOP are documented below.

1. The SOP calls for three identical Fluoro Fighter™ application steps with no prior rinsing. Arcadis performed a potable water rinse of the AFT (to remove residual AFFF concentrate) before starting the Fluoro Fighter™ applications. The AFFF concentrate draining step, performed by others, had not fully removed the concentrate from the AFT. This residual rinse also included a rinse of the AFT's four (4) foam proportioners.
2. Waste management procedures described in the SOP entail waste segregation and storage, but do not call for treatment. The waste streams generated during this project were treated with GAC prior to storage in waste totes for disposal. Notably, the waste streams, and the GAC used to treat them, were stored separately from the unused Fluoro Fighter™ solution.

3 Cleaning Agent Data Analysis

Confirmation samples were collected during the trailer cleaning demonstration at the following intervals:

1. Initial Water Rinse (to remove residual AFFF)
2. Pre-Step A Water Rinse
3. Step A Application
4. Post-Step A Water Rinse
5. Step B Application
6. Post Step B Water Rinse
7. Step C Application
8. Post Step C Water Rinse

Confirmation samples were sent to Eurofins Laboratory in Lancaster, Pennsylvania (Eurofins) for analysis using United States Environmental Protection Agency (USEPA) Method 537 Modified to include isotope dilution and total oxidizable precursor (TOP) assay. Both methods used an analyte list of 24 PFAS. Additional samples were collected and submitted to Eurofins for analysis using USEPA Method 537 Modified for disposal profiling after passing each waste stream through GAC vessels to remove PFAS.

Table 3-1 presents confirmation sampling data via USEPA Method 537 Modified both before and after TOP assay with calculated removal percentages between each water rinse step. USEPA Method 537 Modified data reports the PFAS that are analyzed as part of the Eurofins analyte list. The TOP assay sample preparation method uses a strong oxidant to transform precursors into terminal perfluoroalkyl acids (PFAAs) that are on the USEPA Method 537 Modified analyte list. For the purposes of this report, terminal PFAAs are defined as PFAS that have fully fluorinated tails and either carboxylate or sulfonate head groups. Terminal PFAAs cannot undergo further transformation by TOP assay. After TOP assay, the sample is reanalyzed. Analyzed data is presented as prior to TOP assay sample preparation (“pre-TOP”) and after TOP assay sample preparation (“post-TOP”). A significant increase in reported PFAS post-TOP indicates that the PFAS present in the original sample includes a large number of precursors. For this trailer demonstration, each water rinse step and Fluoro Fighter™ application step saw a 20- to 100-fold increase in reported PFAS in the post-TOP data with respect to the pre-TOP data. Such an increase post-TOP is consistent with data originating from AFFF applications.

Table 3-1. Total detected PFAS Data Summary with Mass Removal Calculations

	Analytical Method	Cleaning Step		Step A Fluoro Fighter Application	Post-Step A Water Rinse	Step B Fluoro Fighter Application	Post-Step B water rinse	Step C Fluoro Fighter application	Post-Step C water rinse
		Residual Rinse	Pre-Step A Water Rinse						
Analytical Data (ng/L)	**USEPA Method 537 Modified**	7,606,700	127,649	748,640	6,568	16,995	1,542	5,387	1,443
	After TOP assay	787,670,000	12,372,900	27,140,000	463,170	*672,700*[1]	57,200	234,800	30,386
Individual Step Removal[2] (%)	**USEPA Method 537 Modified**		98.3%		94.9%		76.5%		6.4%
	After TOP assay		98.4%		96.3%		87.7%		46.9%
Cumulative Removal[3] (%)	**USEPA Method 537 Modified**		NC		94.9%		98.8%		98.9%
	After TOP assay		NC		96.3%		99.5%		99.8%

Notes:

1. The laboratory erroneously reported that all post-TOP PFAS were non-detect (due to matrix interference). The value in this table was calculated based on the ratio of precursors reported pre-TOP and post-TOP for the Step A and Step C Fluoro Fighter™ Application data.
2. Individual step removal percentage was calculated as follows: $((PFAS_{previous\ step} - PFAS_{current\ step}) / PFAS_{previous\ step})$.
3. Cumulative removal percentage was calculated as follows: $((PFAS_{initial} - PFAS_{current\ step}) / PFAS_{initial})$.

The initial residual rinse step was performed upon discovery of gross residuals of AFFF still remaining in the trailer. In order to maintain consistency in cleaning data, the residual rinse step was added to clear the system of latent foam concentrate so subsequent data would be comparable between systems. To promote clarity in figures, the initial rinse step is not included in cleaning system performance analysis.

The performance metrics for confirmation samples for water rinses and cleaning agent applications are different. In the water rinse samples, success is identified in the progressive reduction of PFAS concentrations in the aqueous rinse. In the cleaning agent application samples, success is identified in two ways. One way is via the amount of PFAS being desorbed and captured by the cleaning agent (i.e., the more PFAS present in the cleaning agent, the more was removed from the system). A second way is through the progressive reduction in the amount of PFAS being captured by the cleaning agent. Since each cleaning agent application step is identical, the progressive reduction in the amount of PFAS captured by the cleaning agent suggests a reduction of PFAS in the system after each application step.

This project does not have direct performance criteria to achieve as neither Connecticut nor the USEPA have set performance criteria for PFAS cleaning of AFFF-related infrastructure. As such, the primary goal of cleaning is to reduce the amount of PFAS mass in the AFT prior to filling with Fluorine Free Foam (F3), reducing future liability in the event of a foam spill or application.

Currently, the Connecticut Department of Public Health (DPH) has set a Drinking Water Action Level (DWAL) for five PFAS identified below:

1. perfluorohexanesulfonic acid (PFHxS)
2. perfluoroheptanoic acid (PFHpA)
3. perfluorooctanoic acid (PFOA)
4. perfluorooctanesulfonic acid (PFOS)
5. perfluorononanoic acid (PFNA)

CTDEEP has not set action levels for surface water; however, CTDEEP has set Additional Polluting Substance criteria (APS) for soil and groundwater. The APS for these five PFAS was set to less than 70 ng/L as a sum of all detections for the five identified PFAS. Subsequently in this document, these five PFAS are referenced as the “CT5”. While the APS is not relevant as a performance metric criterion for PFAS removal from the AFT, the APS is voluntarily provided here as a performance metric for considering the PFAS content of the final water rinse. Table 3-2 provides trailer demonstration performance for each of the CT5. Water rinse data from the Winsted trailer cleaning show that after the second and third cleaning agent applications, the CT5 concentrations were below the 70 ng/L limit as a sum of all five PFAS, with an incremental decrease from the second to third application (42 to 21 ng/L, respectively). However, it is noted that CTDEEP's Water Permitting and Enforcement Division is requiring treatment of wastewater from a known PFAS source to non-detect for Method 537M (with method detection limits below at least 10 ng/L) prior to authorizing discharge to surface water or a POTW.

Figure 3-1 and Figure 3-2 show the before and after TOP assay data for each cleaning step during the Winsted trailer cleaning for total detected PFAS, respectively. Figure 3-3 and Figure 3-4 show the before and after TOP assay data for each cleaning step during the Winsted trailer cleaning for CT5 PFAS, respectively. The data presented in these graphs (and in Table 3-1) indicate that the majority of PFAS was removed during the first and second cleaning agent applications (96.3% and 99.5%, respectively), with only an incremental increase in removal for the third cleaning step (0.3% from 99.5% to 99.8%). This data suggests that there may be limited value in conducting a third cleaning step.

Table 3-2. Concentrations of the Five PFAS included in CTDEEP's Additional Polluting Substance (APS) Groundwater Protection Criterion for the Sum of 5 PFAS as Measured during the Cleaning Process

Concentration (ng/L)

PFAS	Residual Rinse		Pre-Step A Water Rinse		Step A Fluoro Fighter™ Application		Post-Step A Water Rinse	
	Pre-TOP Assay	Post-TOP Assay	Pre-TOP Assay	Post-TOP Assay	Pre-TOP Assay	Post-TOP Assay	Pre-TOP Assay	Post-TOP Assay
PFHxS	1,500	39,000	ND	ND	220	ND	4.2	ND
PFHpA	140,000	150,000,000	580	1,700,000	1,300	4,100,000	22	63,000
PFOA	1,500,000	52,000,000	4,800	700,000	12,000	1,600,000	200	28,000
PFOS	7,900	ND	84	ND	220	ND	5.6	ND
PFNA	81,000	37,000,000	320	780,000	760	1,100,000	13	23,000
Total	***1,730,400***	***239,039,000***	***5,784***	***3,180,000***	***14,500***	***6,800,000***	***245***	***114,000***
PFAS	**Step B Fluoro Fighter™ Application**		**Post-Step B Water Rinse**		**Step C Fluoro Fighter™ Application**		**Post-Step C Water Rinse**	
	Pre-TOP Assay	**Post-TOP Assay[1]**	**Pre-TOP Assay**	**Post-TOP Assay**	**Pre-TOP Assay**	**Post-TOP Assay**	**Pre-TOP Assay**	**Post-TOP Assay**
PFHxS	ND	ND	5.5	ND	2.3	ND	0.9	ND
PFHpA	ND	ND	4.1	6,500	10	29,000	2.0	3,300
PFOA	220	ND	27	3,100	87	14,000	14	1,100
PFOS	150	ND	3.2	ND	4.4	ND	2.4	ND
PFNA	ND	ND	2.1	2,600	6.6	11,000	1.5	370
Total	***370***		***42***	***12,200***	***110***	***54,000***	***21***	***4,770***

Notes:

1. Step B Fluoro Fighter™ application post-TOP assay data was reported as non-detect due to an increased reporting limit caused by matrix interference during lab analysis. Based on pre-TOP assay data, concentrations of PFAS in the post-TOP assay data are not expected to be non-detect. Unlike the calculation performed in Table 3-1, there is not a consistent ratio of pre-TOP to post-TOP data for individual PFAS, which makes a similar calculation infeasible.

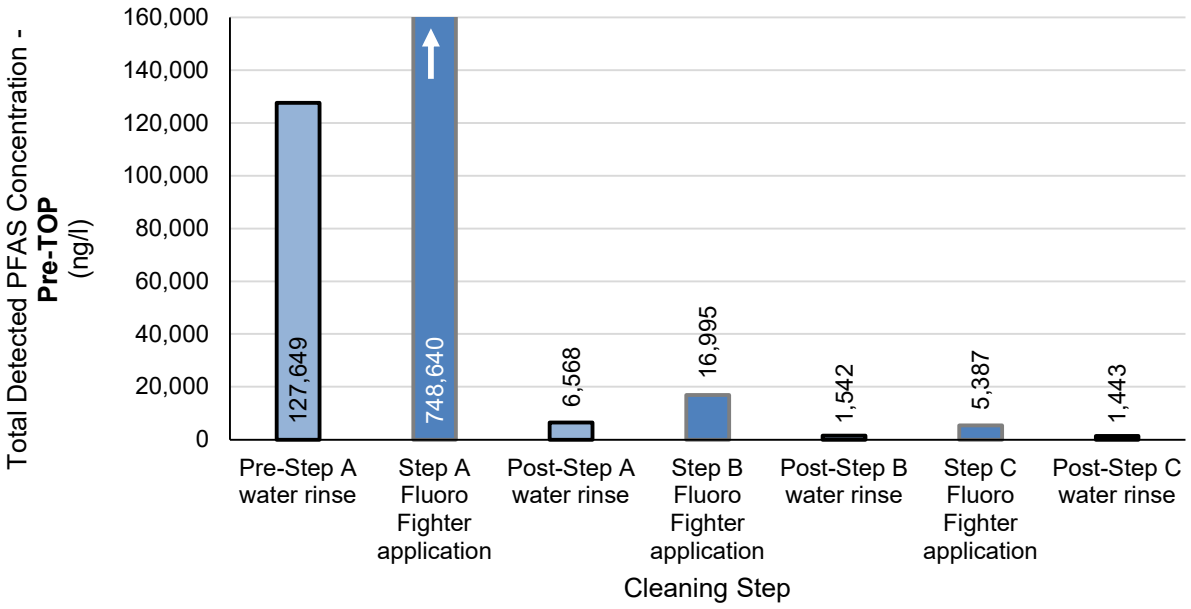

Figure 3-1. Total Detected PFAS Concentrations by Cleaning Step for Pre-TOP Analysis

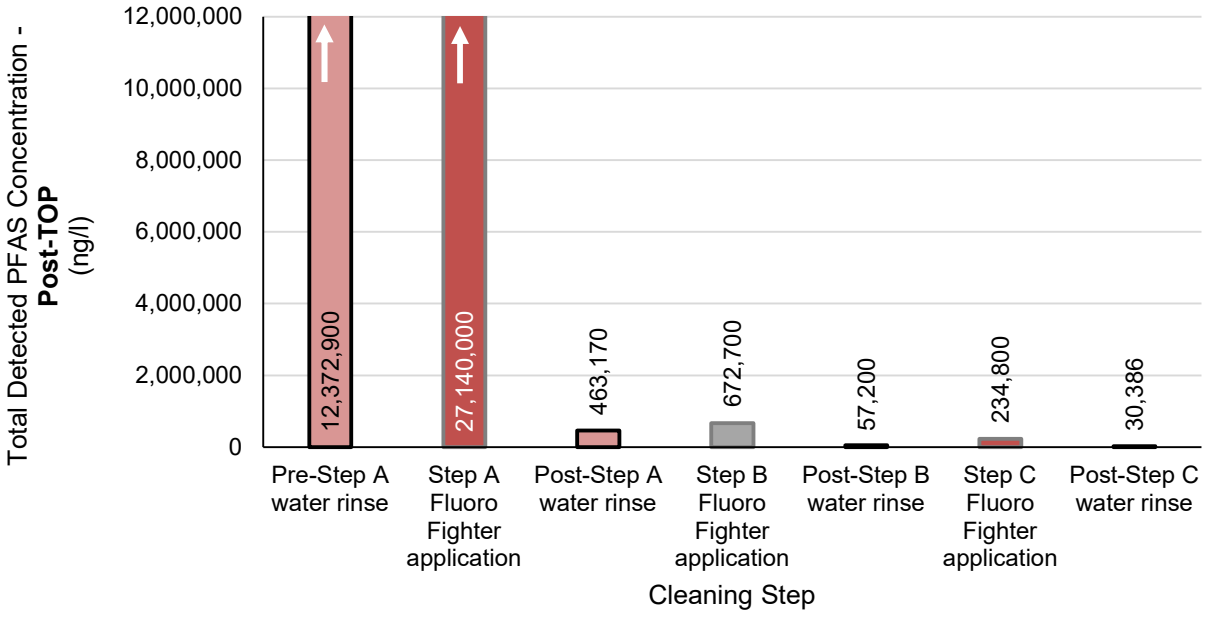

Figure 3-2. Total Detected PFAS Concentrations by Cleaning Step for Post-TOP Analysis

Note: the gray bar is a calculated value because of analytical lab matrix interference as described in the text.

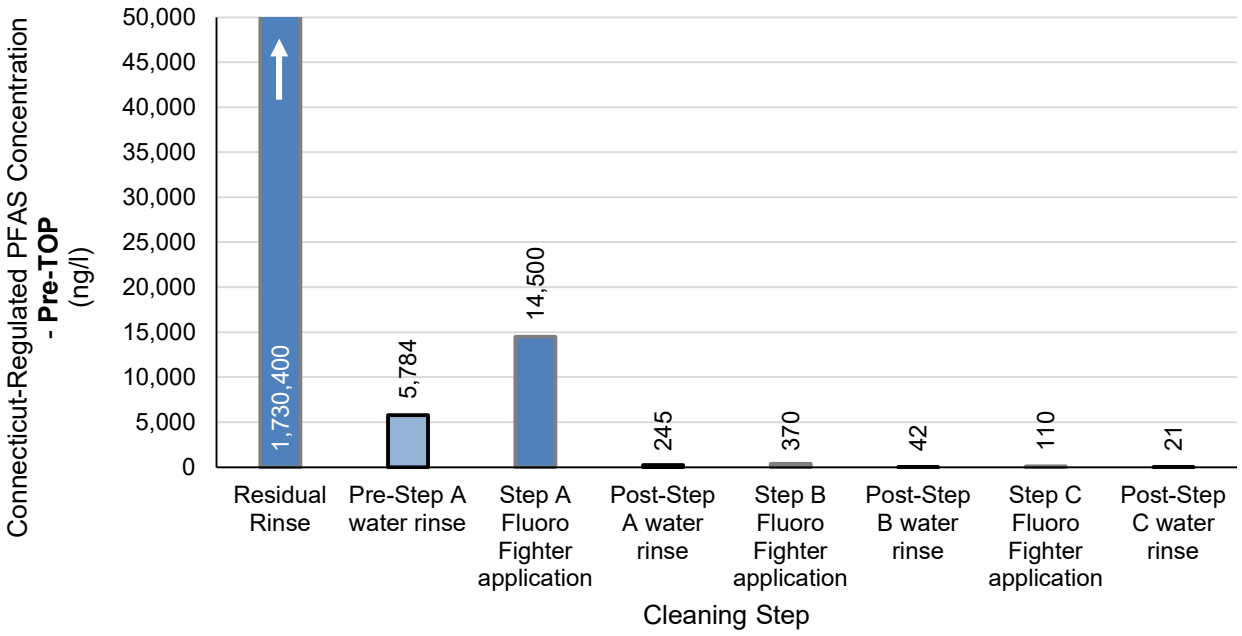

Figure 3-3. CT5 PFAS Concentrations by Cleaning Step for Both USEPA Method 537 Modified and Analysis Pre-TOP Assay

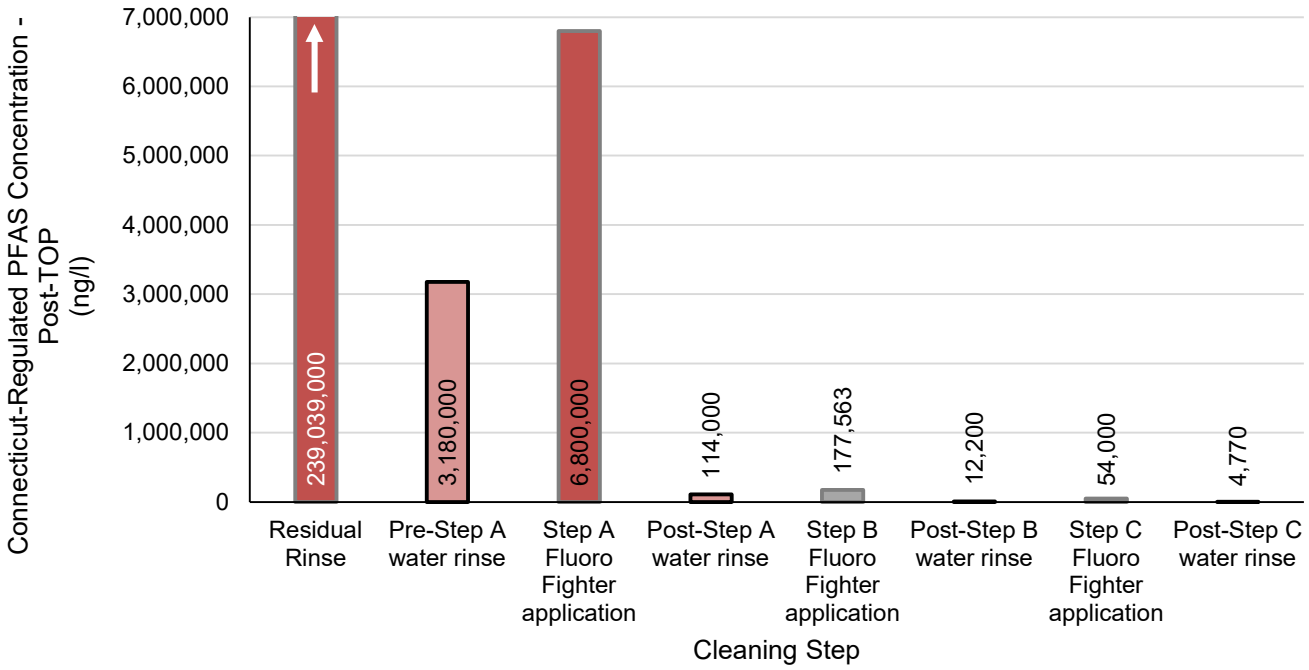

Figure 3-4. CT5 PFAS Concentrations by Cleaning Step for Both USEPA Method 537 Modified and Analysis Pre-TOP Assay

Figures displaying confirmation sampling for individual PFAS during the trailer cleaning are provided in **Appendix C**. There are four figures showing pre-TOP analysis, which subdivide the PFAS into several categories:

1. sulfonates and carboxylates
2. chain length, and
3. PFAS identified in Connecticut DPH DWALs.

Individual PFAS charts show concentrations that are consistent with the general trends seen in the total PFAS and the CT5 PFAS data. Water from the residual rinse contained the residual AFFF that was present in the trailer prior to cleaning. Because of this, any PFAS that are present in the residual rinse analysis are expected to be present in the AFFF. All terminal PFAAs that were detected in the residual rinse water were also present in subsequent confirmation samples. Two compounds were only detected in the confirmation samples following the residual rinse: perfluorobutanesulfonic acid (PFBS) and perfluorononanesulfonic acid (PFNS). Results of the confirmation samples for PFBS and PFNS are presented in Figure 3-5.

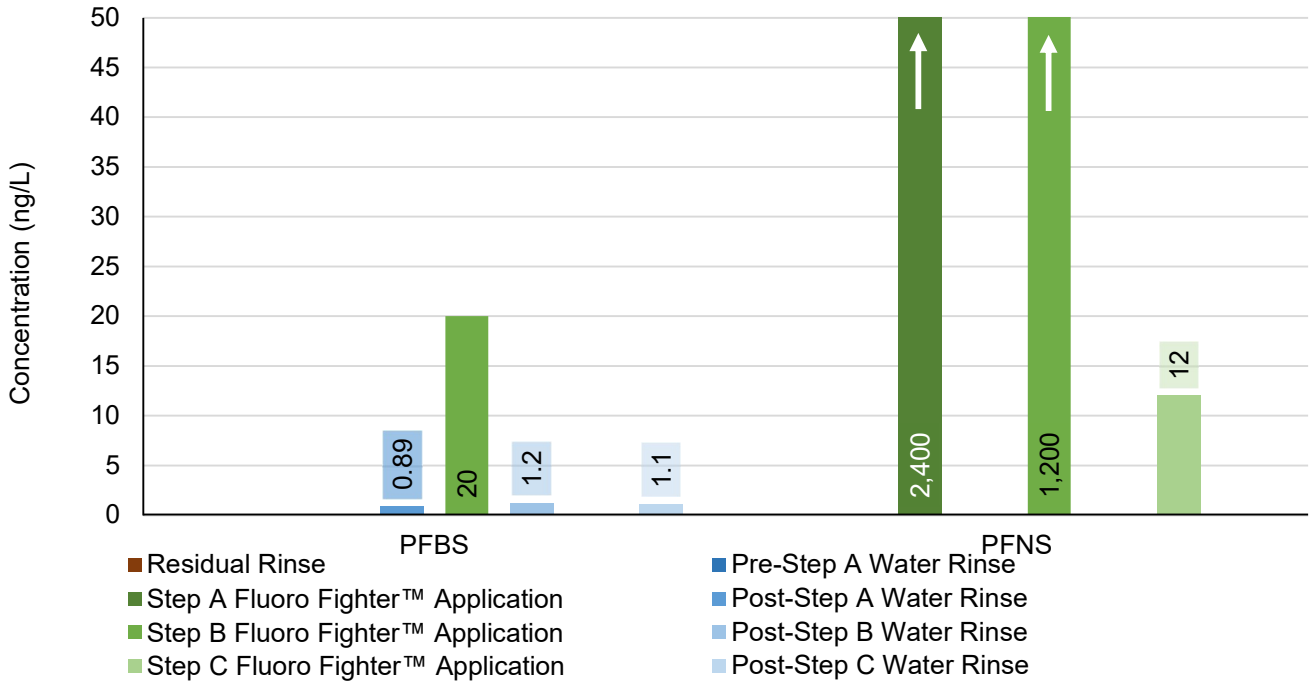

Figure 3-5. Confirmation Sampling Data for PFBS and PFNS

PFBS was present in three water rinses (Post-Step A, Post-Step B, and Post-Step C) and one Fluoro Fighter™ application (Step B). PFBS is a short-chain PFAS that is more soluble in water than longer-chain compounds. Table 3-3 shows the concentrations of PFBS and PFNS relative to method reporting limits. Reporting limits for the residual rinse and Pre-Step A Water Rinse were elevated compared to later water rinse reporting limits. This may indicate the presence of PFBS or PFNS at levels near or below the reporting limit. PFBS was not present in the Residual Rinse or in the Pre-Step A water rinse, which indicates that PFBS was not likely available for removal prior to the application of Fluoro Fighter™ in Step A. PFBS may have been available for removal subsequent to the Step A Fluoro Fighter™ application due to the removal of surface PFAS layers by the cleaning agent.

Table 3-3. Pre-TOP Assay Concentrations of PFNS and PFBS as Measured during the Cleaning Process.

Concentration (ng/L)

PFAS	Residual Rinse	Pre-Step A Water Rinse	Step A Fluoro Fighter ™ Application	Post-Step A Water Rinse	Step B Fluoro Fighter ™ Application	Post-Step B Water Rinse	Step C Fluoro Fighter ™ Application	Post-Step C Water Rinse
PFBS	< 2000	< 20	< 200	0.89 J	20	1.2 J	< 1.7	1.1 J
PFNS	< 2000	< 20	2400	< 1.7	1200	< 1.8	12	< 1.8

Notes:
1. < indicates analytes that were detected at or below laboratory reporting limits.
2. J indicates an estimated value.

PFNS was not present in the residual rinse, nor any of the water rinses. This indicates that PFNS is not readily soluble in water and would not be removed using only a water rinse. However, PFNS was removed during each of the cleaning agent applications. That PFNS was not likely present in the residual rinse indicates that this PFAS was likely present in an AFFF that was previously stored in the Winsted trailer. The data suggests that use of Fluoro Fighter™ disrupted PFAS layers on the impacted surfaces of the foam system making available PFAS that may have been present due to storage of a previous AFFF.

4 Waste Cleaning Fluid Treatment

At CTDEEP's request, Arcadis implemented GAC treatment of the waste cleaning fluids. Three 250-pound Disposorb® drums containing Calgon Carbon Corporation (Calgon) Filtrasorb 400 (F400) were acquired. Arcadis set up two treatment trains, one to treat water rinses and one to treat spent Fluoro Fighter™. The water rinse system consisted of two Disposorb® drums plumbed in series. Water rinse was passed through this system twice prior to storage ahead of disposal. Each pass through the GAC represented 10 minutes of empty bed contact time (EBCT). Approximately 2,300 gallons of rinse water were passed through the water rinse carbon. The spent cleaning agent system consisted of one Disposorb® drum and spent cleaning agent was passed through this system five times prior to storage ahead of disposal. Each pass of the cleaning agent through the GAC represented 5 minutes of EBCT. Approximately 1,650 gallons of spent Fluoro Fighter™ were passed through the cleaning agent GAC system. In typical flow through applications, a minimum of 15 minutes of EBCT is recommended for PFAS removal. Two passes through the water rinse carbon approximated 20 minutes of EBCT. Five passes through the cleaning agent GAC approximated 15 minutes of EBCT. However, since the water was stored in a tote between passes, the actual EBCT for portions of the treated water may be less.

For water rinses and spent cleaning agent, confirmation samples were collected during the final transfer of the treated effluent to the waste storage vessels staged for disposal. CTDEEP requested that waste cleaning fluids be treated to non-detect for total PFAS, as measured by USEPA Method 537 Modified.

Charts of confirmation data for GAC treatment of PFAS between C4 (four carbons in the fluorinated tail) and C9 (nine carbons in the fluorinated tail) are provided in **Appendix D**. Table 4-1 includes treated water PFAS concentrations for waste fluids from the various cleaning steps, which show that GAC treatment did not reduce PFAS levels to non-detect for any of the waste fluids.

Percent removal data provided in **Appendix D** shows that GAC treatment universally reduced PFAS levels in the Pre-Step A and Post-Step A water rinses and the Step A Fluoro Fighter™ waste. For the remaining waste fluids, the concentration of at least one C4 to C9 PFAS increased during GAC treatment, while concentrations of other PFAS were reduced.

Increases in some PFAS concentrations and the associated negative removal calculation after GAC treatment are related to the relative affinity of different PFAS to GAC. Generally, PFAS affinity to GAC is related to molecular characteristics like chain length, head functional group, and substitution of the fluorinated tail (e.g., partially- or full-substituted with fluorine atoms). Longer chain terminal PFAAs have a higher affinity to GAC via adsorption than shorter chain terminal PFAAs and sulfonates have higher affinity than carboxylates with the same length fluorinated tail (Appleman, Higgins et al. 2014, McCleaf, Englund et al. 2017). Similarly, partially fluorinated precursors like fluorotelomer sulfonates (i.e., 4:2 FTS, 6:2 FTS and 8:2 FTS) have a lower affinity to GAC when compared to longer chain PFAAs (Rodowa, Knappe et al. 2020). Because of these relative affinities, some PFAS in highly concentrated PFAS waste may be displaced during treatment by other PFAS with higher affinity. This phenomenon is present in the cleaning fluid waste streams treated. The GAC treatment data shows that after Step A, shorter chain carboxylates (i.e., PFBA, PFPeA, and less consistently, PFHxA, and PFHpA) had increases in concentration after treatment, while longer chain sulfonates (i.e., PFHxS, PFOS and PFNS) were more readily adsorbed. Longer chain PFAAs (not charted) generally followed the same trend, except for Step B Fluoro Fighter™ data, which showed an unexpectedly high perfluorodecanesulfonic acid concentration after GAC treatment, which is inconsistent with other Fluoro Fighter™ data.

Notably, there are large increases in the concentrations of certain PFAS during GAC treatment of the Post-Step C rinse water. This indicates that the GAC being used to treat the rinse water was nearing saturation by the third treatment step. This demonstrates that a larger GAC system would be needed in future applications to adequately remove PFAS at the concentrations seen in this rinse water.

The GAC treatment data demonstrates varying degrees of removal. The highest GAC removal rates occurred when treating waste fluids from the water rinses. This is expected, as the rinse water contains lower PFAS concentrations and a less complex sample matrix. Conversely, PFAS removal rates by GAC were lower when treating Fluoro Fighter™ waste streams; most likely due to the higher PFAS concentrations and more complex sample matrix. Nonetheless, GAC treatment of the Step A Fluoro Fighter™ waste achieved removal rates of up to 70% for certain PFAS, suggesting that with a system of greater capacity, GAC may be able to achieve adequate removal of PFAS from Fluoro Fighter™.

Table 4-1. PFAS concentrations in GAC-treated waste fluids.

PFAS	Pre-Step A Water Rinse	Step A Fluoro Fighter™ Application	Post-Step A Water Rinse	Step B Fluoro Fighter™ Application	Post-Step B Water Rinse	Step C Fluoro Fighter™ Application	Post-Step C Water Rinse
PFBA	ND	2,100	93	ND	170	32	600
4:2 FTS	ND	790	1.8	ND	4.7	3.0	63
PFBS	ND	ND	ND	35	ND	ND	ND
PFPeA	2.7	810	8.5	84	17	10	120
PFPeS	ND	ND	ND	ND	ND	0.9	ND
PFHxA	10	12,000	18	520	40	140	520
6:2 FTS	270	390,000	20	23,000	39	8,000	3,100
PFHxS	ND	190	ND	ND	ND	1.0	ND
PFHpA	1.9	820	ND	49	ND	11	16
PFOA	7.0	8,500	0.8	440	0.8	96	38
8:2 FTS	1,900	160,000	37	3,800	25	25,000	130
PFOS	1.2	220	ND	69	ND	5.4	ND
PFNA	1.3	520	ND	34	ND	6.3	0.5
PFNS	ND	640	ND	ND	ND	ND	ND
PFDeA	21	3,000	0.4	ND	ND	ND	1.3
PFDeS	ND	3,700	ND	1,100	ND	1.5	ND
PFUnA	15	220	ND	ND	ND	3.1	ND
PFDoA	140	1,500	5.8	80	1.0	22	2.4
PFTriA	7.2	ND	1.4	ND	ND	ND	ND
PFTeA	72	890	21	49	3.7	17	3.1
Total CT5 PFAS:	**11.4**	**10,250.0**	**0.8**	**592.0**	**0.8**	**119.7**	**54.5**
Total Detected PFAS:	**2,449**	**585,900**	**208**	**29,260**	**301**	**33,349**	**4,594**

5 Conclusions and Recommendations

Arcadis successfully executed the cleaning of the Winsted AFT provided by DESPP. Confirmation sampling indicated removal of 99.0% and 99.8% of all detected PFAS, pre- and post-TOP, respectively. Data analyzed post-TOP was approximately 20 to 100 times greater than the pre-TOP data. CT5 PFAS were removed to below a sum of 70 ng/L after the Step B and Step C cleaning agent applications (42 and 21 ng/L, respectively). Arcadis identified two PFAS that were not likely present in the AFFF stored in the trailer immediately prior to cleaning, but that did appear in the Fluoro Fighter™ waste streams, indicating that the cleaning agent was able to disrupt the historical layers of PFAS from the impacted foam system surfaces.

Confirmation sampling data showed limited PFAS during Step C of the cleaning process, suggesting that three applications of previously unused Fluoro Fighter™ is not significantly more effective than two applications. Arcadis recommends that future cleaning activities be limited to two applications of Fluoro Fighter™ cleaning agent. However, although Arcadis doesn't recommend a third application of previously unused cleaning agent, the low PFAS concentrations in the cleaning agent following the second application (only 2.4% of PFAS level in the cleaning agent following Step A) suggest that Fluoro Fighter™ could be used again to remove additional PFAS. A second application of the Fluoro Fighter™ used in Step B could allow for additional PFAS removal while avoiding the cost of a third application of fresh cleaning agent. Additionally, the Fluoro Fighter™ volume used in the second application could be used as first application cleaning agent in a subsequent cleaning, further reducing the required cleaning agent volume per piece of equipment.

The GAC treatment data from this project suggests that GAC could be an effective treatment for waste rinse water produced during future cleaning events. However, a larger system than was used in this project would be needed to avoid PFAS desorption as the GAC becomes saturated. Also, it is recommended that a flow-through system be used, rather than a system involving recirculation. Due to high PFAS concentrations and a complex sample matrix, used Fluoro Fighter™ is not highly amenable to GAC treatment. However, it may be possible for a flow-through GAC system with an adequate empty-bed contact time (e.g., 20 minutes or more) to reliably remove PFAS from cleaning agent waste fluids; and this could be explored during future cleaning events.

Arcadis recommends further exploration of the pre-treatment of foam transition waste. First, Arcadis recommends the execution of bench-scale testing with waste generated during cleaning of the Winsted trailer to inexpensively determine the potential for GAC to effectively remove PFAS from spent cleaning agent. Rapid small-scale column testing using spent Step A Fluoro Fighter™ at several EBCT (e.g., 20, 40 and 60 minutes) could better define its ability to be used to pre-treat spent cleaning agent.

Second, Arcadis recommends the bench-scale testing of spent Step A Fluoro Fighter™ for the applicability of foam fractionation. Arcadis has a pilot-scale foam fractionation system that could be used during the next phase of treatment (state-wide fire apparatus foam transition) to further reduce waste cost by dramatically reducing waste volumes (up to 99.5% volume reduction).

6 References

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Appleman, T. D., C. P. Higgins, O. Quinones, B. J. Vanderford, C. Kolstad, J. C. Zeigler-Holady and E. R. Dickenson (2014). "Treatment of poly- and perfluoroalkyl substances in U.S. full-scale water treatment systems." Water Res **51**: 246-255.

Houtz, E. F. and D. L. Sedlak (2012). "Oxidative conversion as a means of detecting precursors to perfluoroalkyl acids in urban runoff." Environ Sci Technol **46**(17): 9342-9349.

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Rodowa, A. E., D. R. Knappe, S.-Y. D. Chiang, D. Pohlmann, C. Varley, A. Bodour and J. A. Field (2020). "Pilot scale removal of per-and polyfluoroalkyl substances and precursors from AFFF-impacted groundwater by granular activated carbon." Environmental Science: Water Research & Technology **6**(4): 1083-1094.

Appendix A

Photo Log

Photograph Log

Connecticut Department of Energy and Environmental Protection
Trailer Demonstration
30084571

Photograph: 1

Description:
The Winsted attack foam trailer (AFT) staged at Connecticut Department of Energy and Environmental Protection's (CTDEEP) Old Saybrook garage.

Location:
Old Saybrook, CT

Photograph taken by:
Agnes Link-Harrington

Date: 9/7/2021

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Photograph: 2

Description:
The Winsted AFT staged in secondary containment at the CTDEEP Old Saybrook garage.

Location:
Old Saybrook, CT

Photograph taken by:
Agnes Link-Harrington

Date: 9/9/2021

Photograph Log

Connecticut Department of Energy and Environmental Protection
Trailer Demonstration
30084571

Photograph: 3

Description:
Clean Harbors personnel draining ~385 gallons of AFFF from the Winsted AFT's foam cell.

Location:
Old Saybrook, CT

Photograph taken by:
Agnes Link-Harrington

Date: 9/14/2021

Photograph: 4

Description:
50 gallons of AFFF drained from the Winsted AFT by Clean Harbors during removal of AFFF from the foam cell.

Location:
Old Saybrook, CT

Photograph taken by:
Agnes Link-Harrington

Date: 9/9/2021

Photograph Log

Connecticut Department of Energy and Environmental Protection
Trailer Demonstration
30084571

Photograph: 5

Description:
Waste (AFFF, PPE) produced during AFFF removal containerized in 55-gallon drums.

Location:
Old Saybrook, CT

Photograph taken by:
Agnes Link-Harrington

Date: 9/14/2021

Photograph: 6

Description:
Construction of Arcadis PFAS cleaning agent conveyance and application system. View of pumps, hoses, piping, and segregated 275-gallon totes for storage of interim cleaning process waste.

Location:
Old Saybrook, CT

Photograph taken by:
Keith McConnell

Date: 9/21/2021

Photograph Log

Connecticut Department of Energy and Environmental Protection
Trailer Demonstration
30084571

Photograph: 7

Description: Arcadis PFAS cleaning agent conveyance and application system. Front view of the AFT, including the AFT's four (4) foam proportioners.

Location:
Old Saybrook, CT

Photograph taken by:
Keith McConnell

Date: 9/21/2021

Photograph: 8

Description: Arcadis PFAS cleaning agent conveyance and application system. Front view of the AFT, including granular activated carbon (GAC) drums.

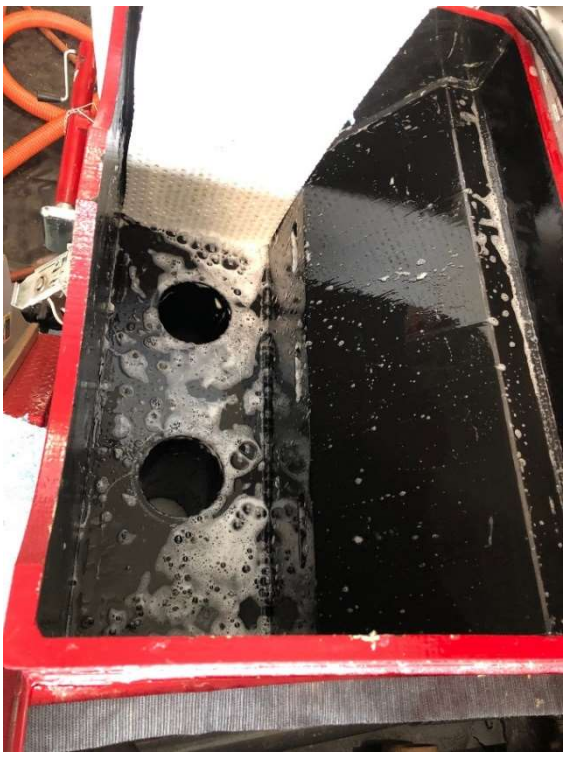
Location:
Old Saybrook, CT

Photograph taken by:
Keith McConnell

Date: 9/21/2021

Photograph Log

Connecticut Department of Energy and Environmental Protection
Trailer Demonstration
30084571



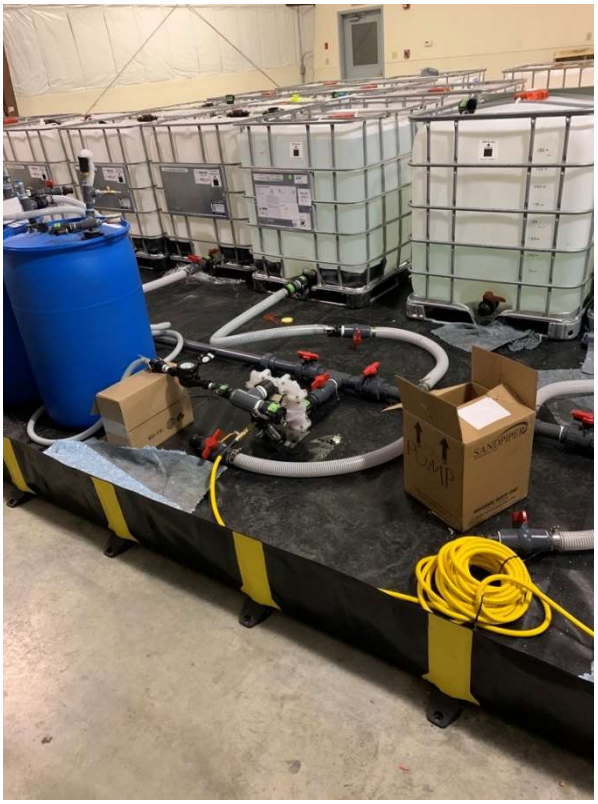
Photograph: 9

Description:
View of the Winsted AFT's two-can fill tower during the residual rinse step.

Location:
Old Saybrook, CT

Photograph taken by:
Agnes Link-Harrington

Date: 9/24/2021



Photograph: 10

Description: Two (2) 275-gallon totes of Fluoro Fighter™ connected to the conveyance and application system during the Step A Fluoro Fighter™ application.

Location:
Old Saybrook, CT

Photograph taken by:
Keith McConnell

Date: 9/25/2021

Photograph Log

Connecticut Department of Energy and Environmental Protection
Trailer Demonstration
30084571

Photograph: 11

Description: View of waste totes stored in segregated secondary containment berm.

Location:
Old Saybrook, CT

Photograph taken by:
Agnes Link-Harrington

Date: 9/29/2021

Appendix B

Field Notes

Friday 9/24/01

0800 onsite
0816 Chemical arrived
Added 100 gal of FF and 100 gal of water to trailer. Recirculate for 1 hour and drain
1059 starting residual/ rinse fill
1346 finished residual Rinse
1400 shannon onsite
1405 started Proportioner Rinse.
5 Gallons of FF through proportioners the Two 2" and the one on the left side of trailer. The 3" proportioner only took about 2.5 gallons. I Dont think we have enough pressure for the 3" Line.
1815 filled trailer with 1720 and started Recirculation
1915 drained Recirculation water to GAC spent rinse totes
1942 Questions on sampling
1923 figured out sampling
2100 Loaded 500 Gallons OF FF into trailer
2200 offsite

saturday 9/25
0815 onsite. Reading Action Plan
0910 conference call
0930 call ended
0935 set up valving for FF recirculation
0954 Recirculation begins
1057 Recirculation ends
1104 Drained FF
1130 Finish drain
1132 Fill ②
1145 sample Winsted - AFT - Pre-A-Rinse
1200 Drain ②
1237 Fill ②
1305 Drain ③
1340 Fill
1400 Finish 1ST recirculation of spent rinse water
Sample GAC-water-Mid
1402 Drain

1519 Fill
1520 Set up 2nd containment and some totes
1700 Collect sample
1706 Begin last drain to Gac recirc system used original FF totes. Moved to Gac treatment and Filled by Manifold
1716 30 Minute conference call
1740 FF from step A fully drained to original totes
1750 Loading 5'00 gal of H2O into trailer
1816 Recirculating H2O in trailer
1910 Compressor runs out of fuel
2018 System back up
2018 Draining rinse water
2033 trailer empty

Sat 9/25 ⑨

2040 Filling tracker with FF
2109 trailer full

Sunday 9/26

0815 FF recirculation
0920 stop recirculation
0922 started 2st drain
0949 Fill Done 1019
1022 Drain Done 1047
1049 Fill Done 1115
1121 Drain Done 1147
1150 Fill Done 1214
1216 Drain Done 1240
1245 Fill Done 1316
1348 trailer drained
1352 Added H2O to trailer
1420 started recirculation
1520 Recirculation stopped.
1500 conference call with Colin regarding tote shortage. He suggested pumping the rinse water from trailer through manifold to 2 totes at the end. I tried to suggest moving the totes to the end with forklift. Didnt want to discuss
1513 system down due to no storage
1540 transferring rinse water via hose to end of line to 2 new totes
1602 Totes empty
1622 set up rinse totes for Gac recirculation
1627 started recirculation
1657 Moving rinse totes A out of berm and replacing with 2 new totes. As per Joha
1715 Draining trailer to 2 new totes

GAC Rinse water Pre A ①

Saturday ①

Time	Totalizer	PSI	GPM @
1200	168	4.75	3.5
1241	475	4.75	3.5
1250ish	Arranged 2nd containment and added totes		
1351	Transfer to clean tote		
1351	475	5	3.5
1433	1st Rinse tote empty		

GAC Rinse water Pre A ②

1445	727	5.75	3.5
1530	1017	5.75	3.5
1615	To clean tote 1253	5.75	3.5
1700	Treated contaminated fresh H20 tote		
1745	Passed to clean totes		
1745	1544	5.75	3.5

Both Rinse totes complete Pre A

Flood treatment Tote 1

1756	1544	5 PSI	~ 3.25
1825	1727	5 PSI	~ 3.25
1846	1828	6 PSI	~ 3.25
1910	Ran out of fuel		
2019	2009	6 PSI	3.5
2053	2233	6 PSI	3.5
2115	2382	6 PSI	3.5

Sunday

0815	2393	6.5 PSI	3.5
0928	To clean tote 2635	6.5 PSI	3.5

Sunday (2)

1012 1st tote of ff processed to clear tote

	Time	Totalizer	PSI	GPM @ 30sec
1	1012	3086	6.0	-3.5
2	1040	3086	6.0	-3.5
2	1115	3336	6.0	-3.5
2	1213	3671	6.0	-3.5
2	1312	4056	6.0	-3.5
2	1411	4380	6.0	-3.5
2	1456	4645	6.0	-3.5

Switched to 3 hours for ff recirculation
Conference call with Colin for 30 minutes
Transfered totes using main manifold to rear of treatment as per Colin.

1602 Totes drained
1622 Flushed Lines
1622 Set up rinse totes
A/1 1627 3 4713 5.5 -3.25
A/1 1651 4855 5.5 -3.25
1657 Moving rinse tote A's out of berm and replacing with new totes as per John
A/1 1725 Transfer to storage
A/1 1725 5093 5.5 -3.25
A/2 1745 5093 5.75 -3.25
A/2 1759 5292 5.75 -3.25
A/2 over ran 5311
1806 - 1901 conference call with John in regards to not enough totes
1910 - Filled trailer with ff.

1920 - 2000 Tote inventory

Time	Totalizer	PSI	GPM @ 30 sec
Transfer tote to 2nd containment			
2/2 2007			
2/2 2007	5439	5.5	3.25
2/2 2020	5549	5.5	3.25
2/1 2110	5705	5.5	3.5
2130	Setup New set of Pince totes		
2/1 2145	sent to 2nd containment		
2/1 2145	5975	5.5	3.5
2/1	sent to 2nd containment		
2/1 2300	6243	5.75	3.5
2/1 2320	6353	5.75	3.5
2/2 2345	6493	5.75	3.5
B1 2350	6493		
B1 2430	6732	6.10	3.5
B1 2434	6756	6	3.5
B1	To containment		
120 AM	OFFsite		

Monday	FF Tote recirculate		
0901	7200	5	3.5
0951	7551	5	3.5
1042	7911	5	3.5
1114	8125	5	3.5
1144	8341	5	3.5
1214	8391	Started transfer to 2nd containment	
1239	8562	4.75	3.5
1324	8702	5	3.5
1410	8997	5	3.5
1444	9211	5	3.5
1606	9759	5	3.5
1715	McConnell	offsite	

1750 Filled trailer with FF
1754 rouference call regarding not enough totes
1800's callended
1910 out of fuel.
1945 started FF recirculation
2048 Recirculation finished
2050 set up rinse totes for Gac recirculation
2110 Rinse totes running through Gac's
2115 Need to have samples of treated totes for courier tomorrow. Concentrating on treating totes we have.
2213 Ran recirculation on trailer again
2434 last tote going to containment
0130 shut down trailer recirculation

Monday 9/27
0855 Draining trailer of FF.
0928 Fill Done 0944
0957 Drain Done 0954
1025 Fill Done 1055
1057 Drain Done 1122
1125 Fill Done 1151
1154 Drain Done 1219
1200 Setting up totes for Gac recirculation
1337 Filling trailer with rinse water
1441 started recirculation of rinse water
1540 stopped recirculation of Rinse
1607 set up drain of rinse water to totes
1620 stopped operation, the totes that the final rinse was going to were at the end of the line where John suggested they be put. After staring at this I realized the final rinse was going through the entire manifold risking contamination.

Spoke with John. Emptied totes. I was more full than the other so I used the less full one after draining and moved it to the front of the line to be filled.

1715 Gathered tools and left site

September 28th, 2021

08:44: pump on for treating STEP C FF
Rate: ~~35~~ 8 gpm, 5 PSI
Flow Meter.
(97 x 100) + (9 x 10) + (1 x 9) + (0.1 x 0.5) + (6.8 x 0.01)
9,700 + 90 + 9 + 0.05 + 0.068
Total gallons: 9,799.12 gallons

09:20: 8 gpm, 3.8 PSI
(101 x 100) + (6.5 x 10) + (1 x 7) + (0.1 x 3) + (6.5 x 0.01)
10,100 + 65 + 7 + 0.3 + 0.065
Total gallons: 10,172.365

10:07: 7 gpm, 3 PSI
(~~10~~ x 104) + (1 x 10) + (1 x 0) + (3 x 0.1) + (7 x 0.01)
10,400 + 10 + 0 + 0.3 + 0.07
TG: 10,410.37

10:4~~8~~4: 7 gpm, 3 PSI
(107 x 100) + (5 x 10) + (1 x 1) + (5 x 0.1) + (0 x 0.01)
10,700 + 50 + 1 + 0.5
Total gallons: 10,751.5 gallons

11:01: 7 gpm, 3.2 PSI
(107 x 100) + (7 x 10) + (1 x 7) + (0.1 x 5) + (6 x 0.01)
10,700 + 70 + 7 + 0.5 + 0.06
TG: 10,777.56

September 28, 2021

4:35 pump on to treat first tote of Step C rinse water (flush out in FF GAC)

4:45 Transfer to rinse water GAC
5.5 gpm, 5.6 PSI
(111 x 100) + (1 x 10) + (6 x 1) + (0.1 x 8) + (5 x 0.01)
11,100 + 10 + 6 + 0.8 + 0.05
Total gallons: 11,116.85 gallons

5:22 6 gpm, 5.5 PSI
(113 x 100) + (1 x 10) + (7 x 1) + (0.1 x 8) + (9 x 0.01)
11,300 + 10 + 7 + 0.8 + 0.09
Total gallons: 11,317.89 gallons

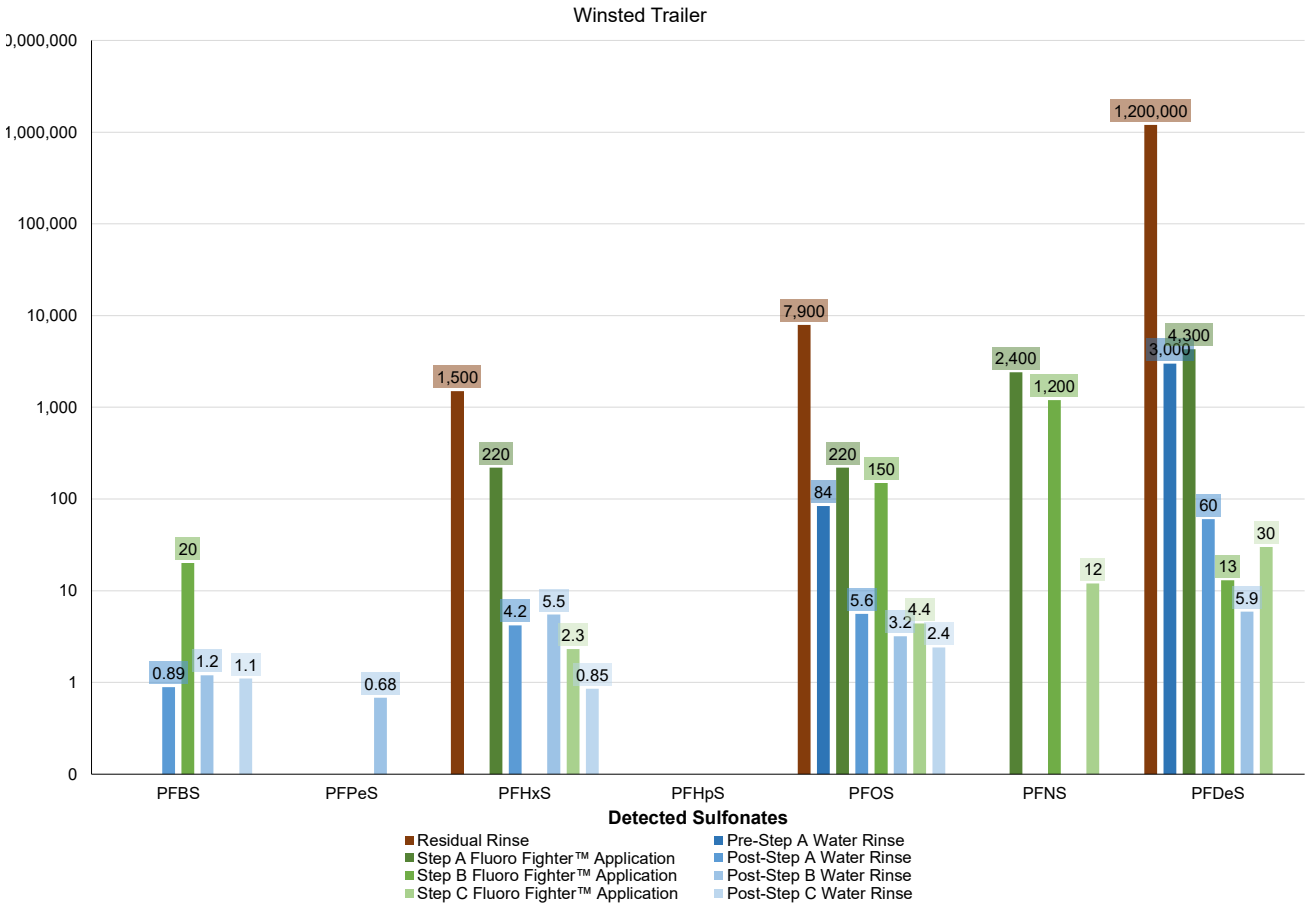
5:44 6.5 gpm, 5.8 PSI
(114 x 100) + (1 x 10) + (7 x 1) + (0.1 x 4) + (7.5 x 0.01)
11,400 + 10 + 7 + 0.4 + 0.075
Total gallons: 11,417.475 gallons ← 1 pass GAC DONE

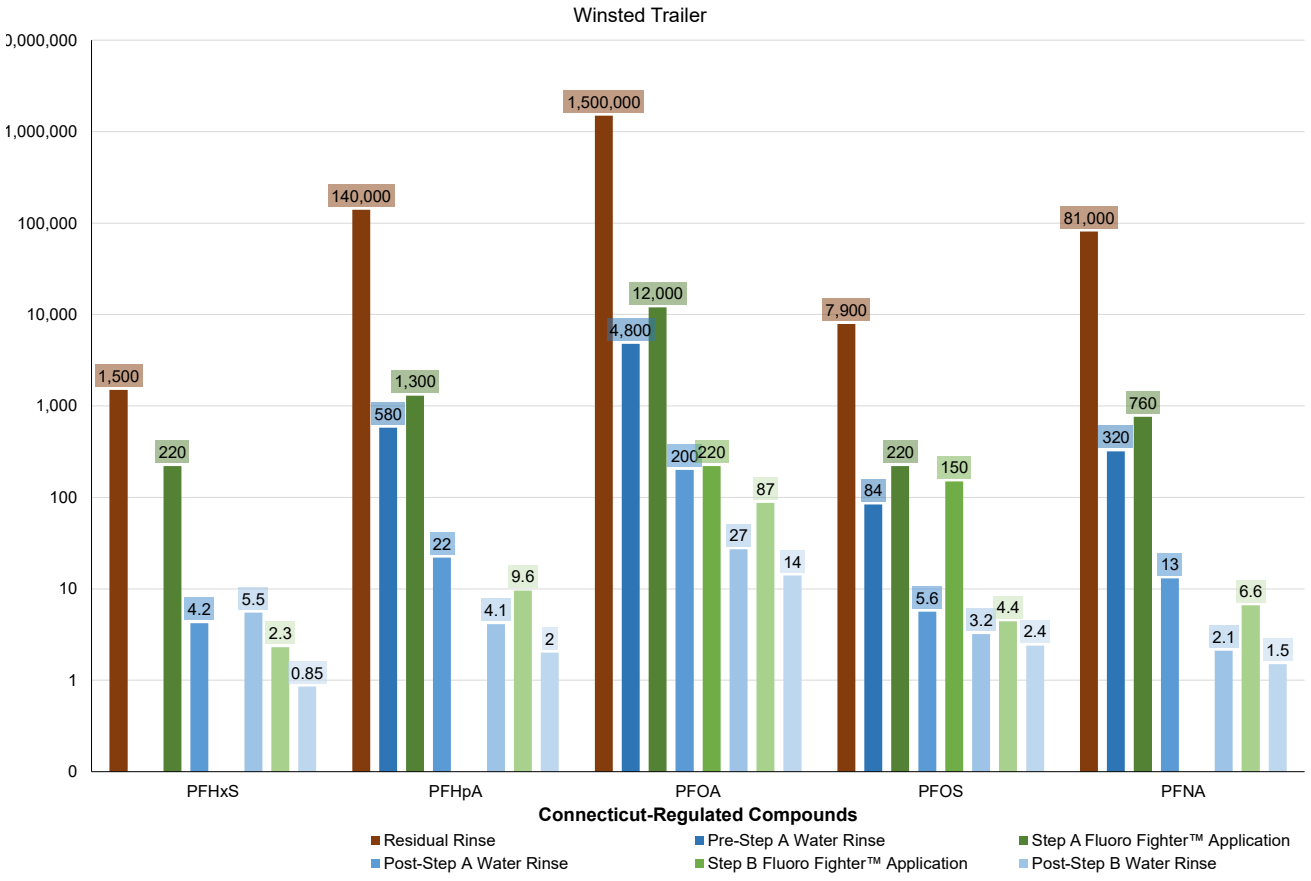
6:24 6.5 gpm, 5.8 PSI
(116 x 100) + (10 x 9) + (1 x 7) + (0.1 x 6) + (5 x 0.01)
11,600 + 90 + 7 + 0.6 + 0.05
Total gallons: 11,698.1 ← 2 passes through GAC DONE

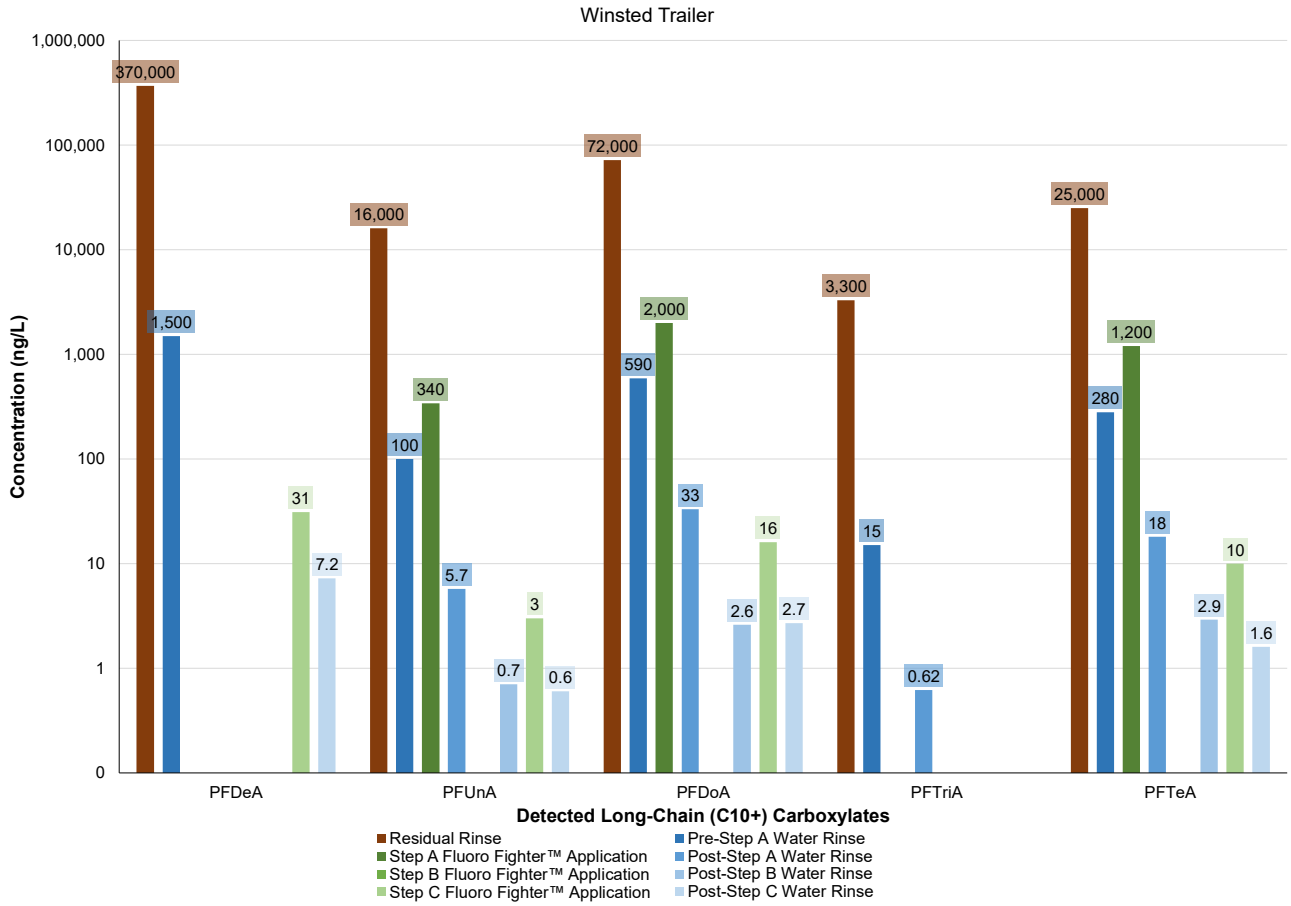
6:45 Start final pass
6.5 gpm, 5 PSI
(117 x 100) + (10 x 6) + (1 x 8) + (0.1 x 5) + (0.01 x 7)
11,700 + 60 + 8 + 0.5 + 0.07
Total gallons: 11,768.57 gallons

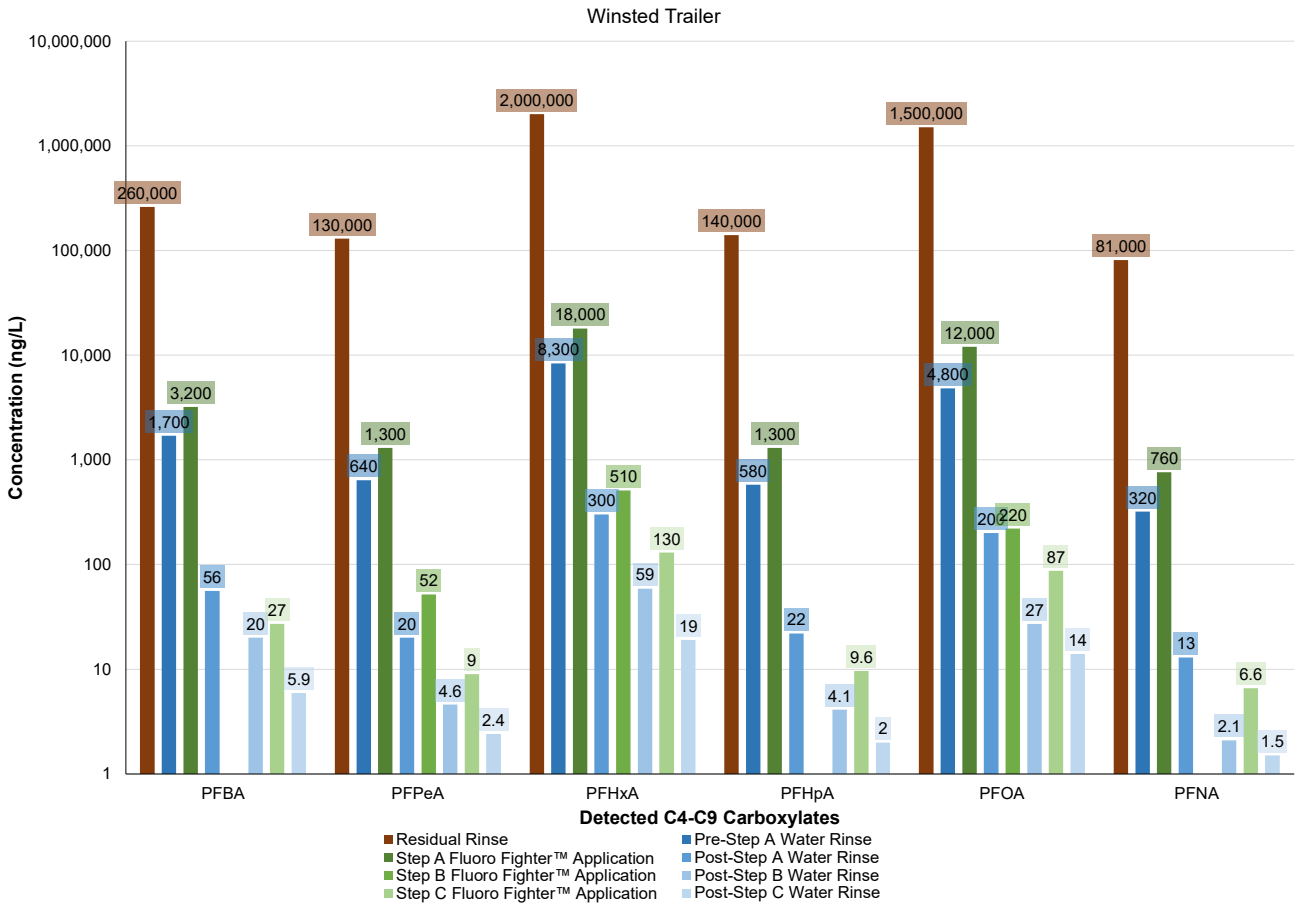
Appendix C

Individual PFAS Charts


Winsted Trailer
1,000,000
100,000
10,000
1,000
100
10
1
0
0.89
20
1.2
1.1
0.68
1,500
220
4.2
5.5
2.3
0.85
7,900
84
220
150
5.6
3.2
4.4
2.4
2,400
1,200
12
1,200,000
3,000
4,300
60
13
5.9
30
PFBS
PFPeS
PFHxS
PFHpS
PFOS
PFNS
PFDeS
Detected Sulfonates
Residual Rinse
Step A Fluoro Fighter™ Application
Step B Fluoro Fighter™ Application
Step C Fluoro Fighter™ Application
Pre-Step A Water Rinse
Post-Step A Water Rinse
Post-Step B Water Rinse
Post-Step C Water Rinse


Winsted Trailer
1,000,000
100,000
10,000
1,000
100
10
1
0
1,500
220
4.2
5.5
2.3
0.85
140,000
580
1,300
22
4.1
9.6
2
1,500,000
4,800
12,000
200
220
27
87
14
7,900
84
220
5.6
150
3.2
4.4
2.4
81,000
320
760
13
2.1
6.6
1.5
PFHxS
PFHpA
PFOA
PFOS
PFNA
Connecticut-Regulated Compounds
Residual Rinse
Pre-Step A Water Rinse
Step A Fluoro Fighter™ Application
Post-Step A Water Rinse
Step B Fluoro Fighter™ Application
Post-Step B Water Rinse

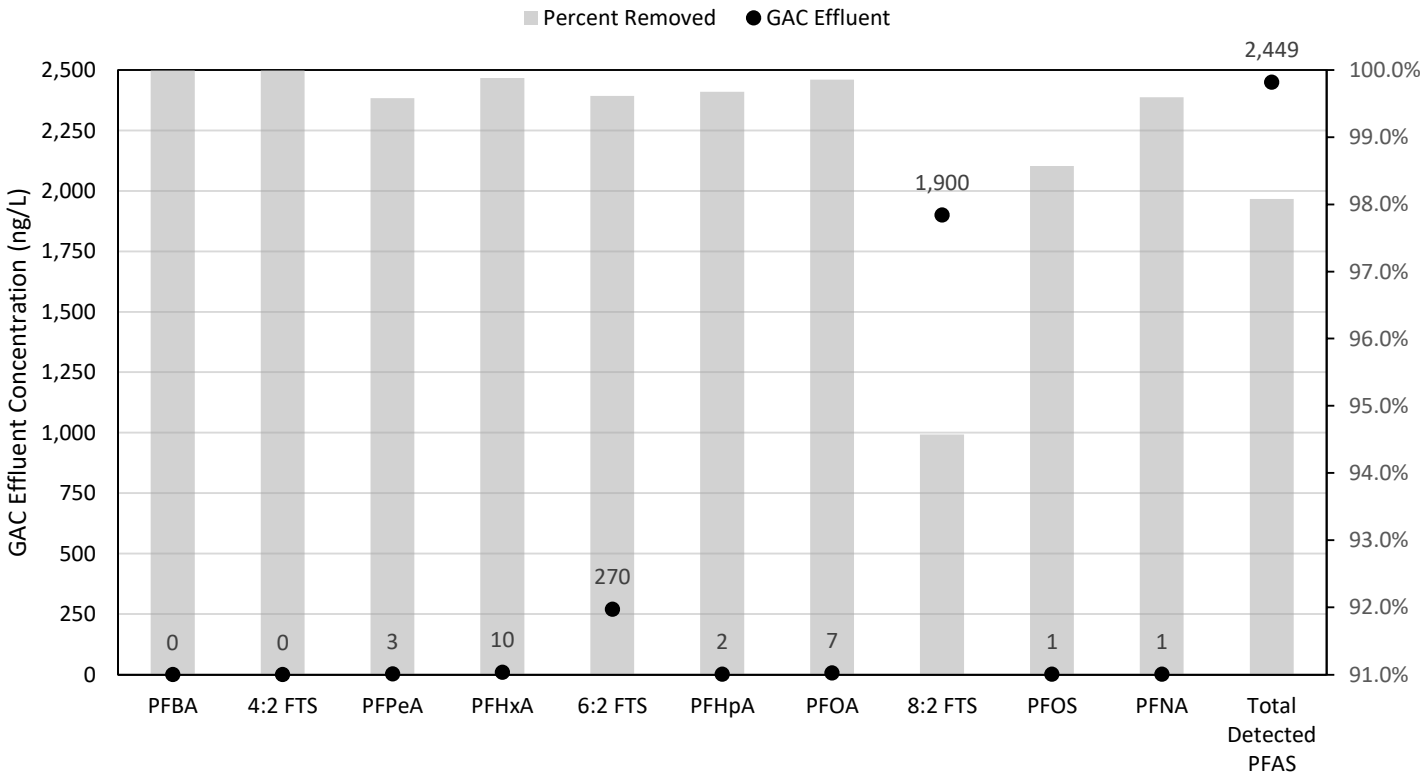

Winsted Trailer
Concentration (ng/L)
1,000,000
100,000
10,000
1,000
100
10
1
0
370,000
1,500
31
7.2
16,000
100
340
5.7
0.7
3
0.6
72,000
590
2,000
33
2.6
16
2.7
3,300
15
0.62
25,000
280
1,200
18
2.9
10
1.6
PFDeA
PFUnA
PFDoA
PFTriA
PFTeA
Detected Long-Chain (C10+) Carboxylates
Residual Rinse
Pre-Step A Water Rinse
Step A Fluoro Fighter™ Application
Post-Step A Water Rinse
Step B Fluoro Fighter™ Application
Post-Step B Water Rinse
Step C Fluoro Fighter™ Application
Post-Step C Water Rinse


Winsted Trailer
Concentration (ng/L)
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
260,000
1,700
3,200
56
20
27
5.9
130,000
640
1,300
20
52
4.6
9
2.4
2,000,000
8,300
18,000
300
510
59
130
19
140,000
580
1,300
22
4.1
9.6
2
1,500,000
4,800
12,000
200
220
27
87
14
81,000
320
760
13
2.1
6.6
1.5
PFBA
PFPeA
PFHxA
PFHpA
PFOA
PFNA
Detected C4-C9 Carboxylates
Residual Rinse
Pre-Step A Water Rinse
Step A Fluoro Fighter™ Application
Post-Step A Water Rinse
Step B Fluoro Fighter™ Application
Post-Step B Water Rinse
Step C Fluoro Fighter™ Application
Post-Step C Water Rinse

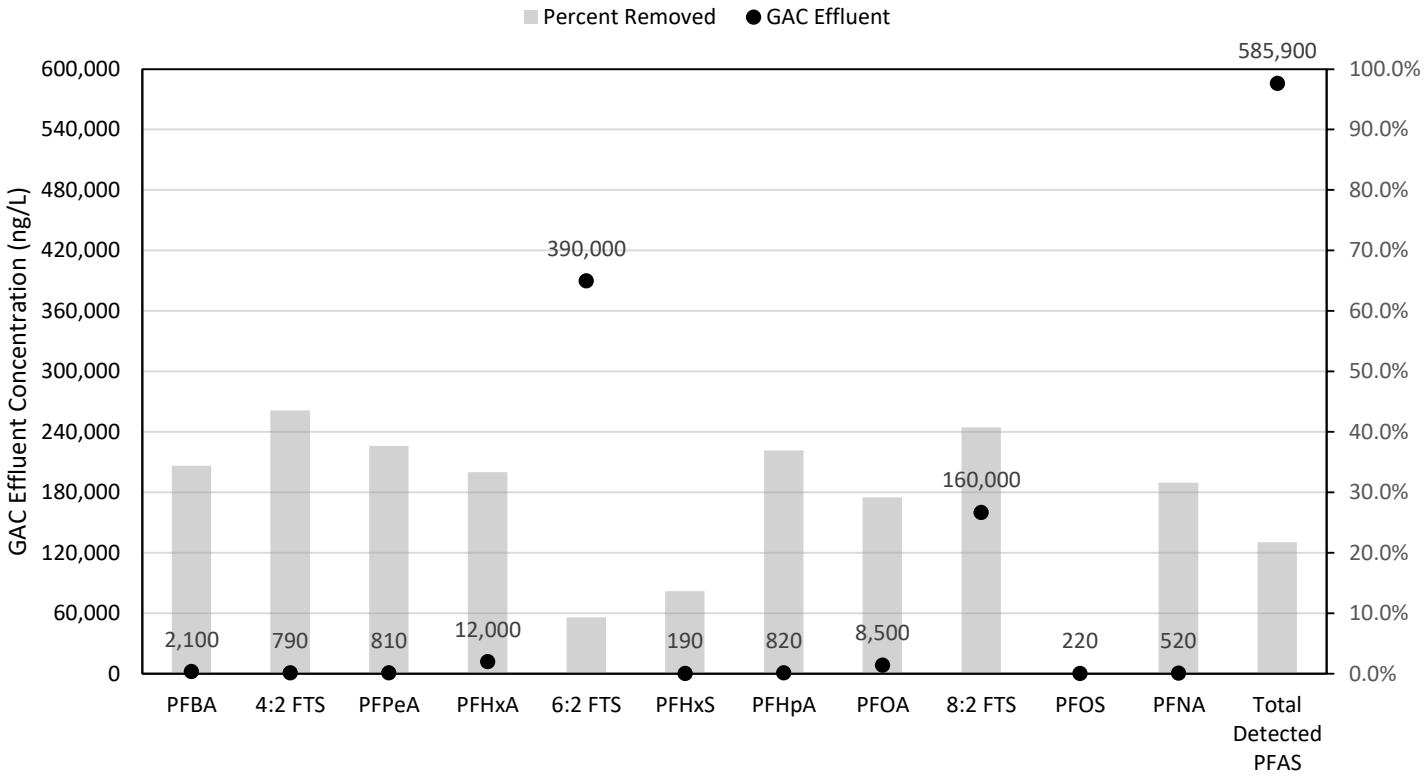
Appendix D

GAC Treatment Data

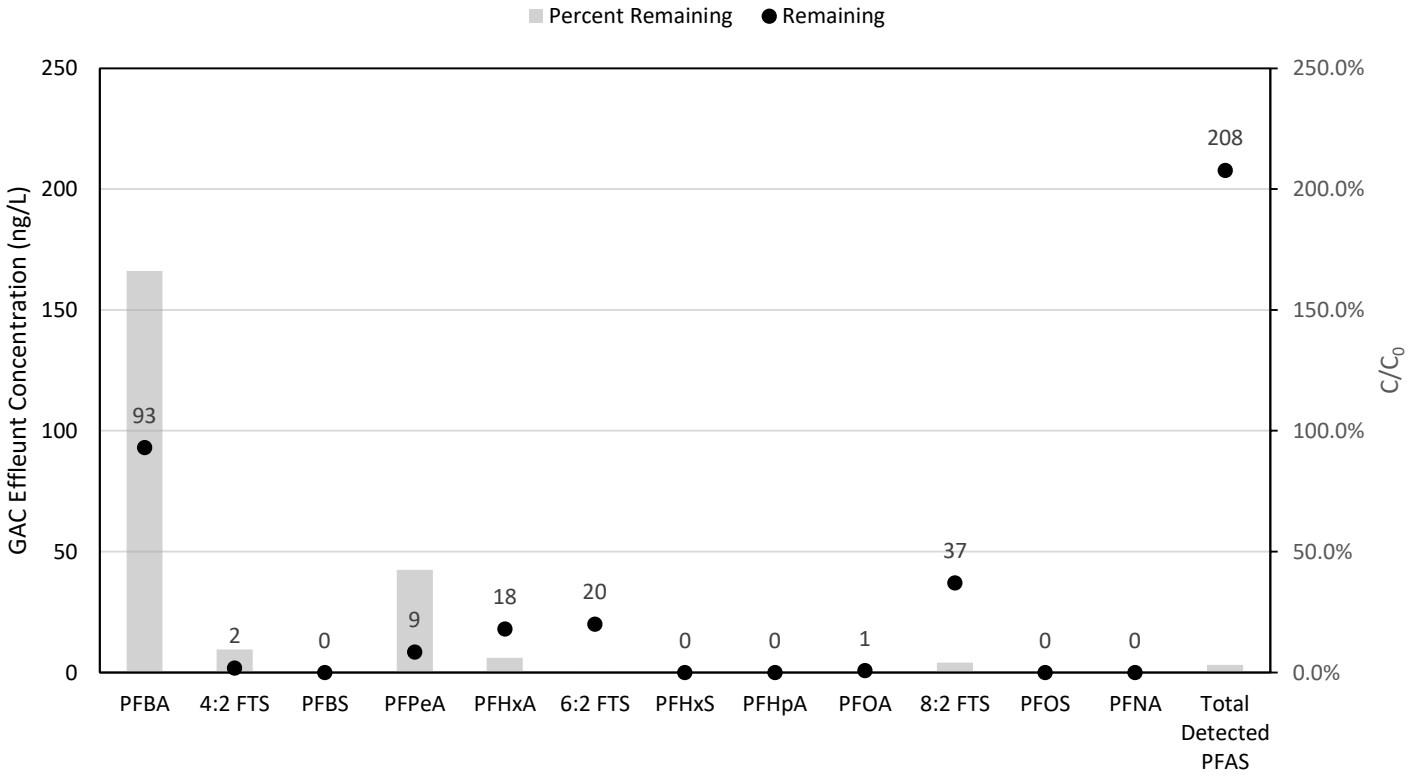
Water Rinse Before Step A GAC Treatment



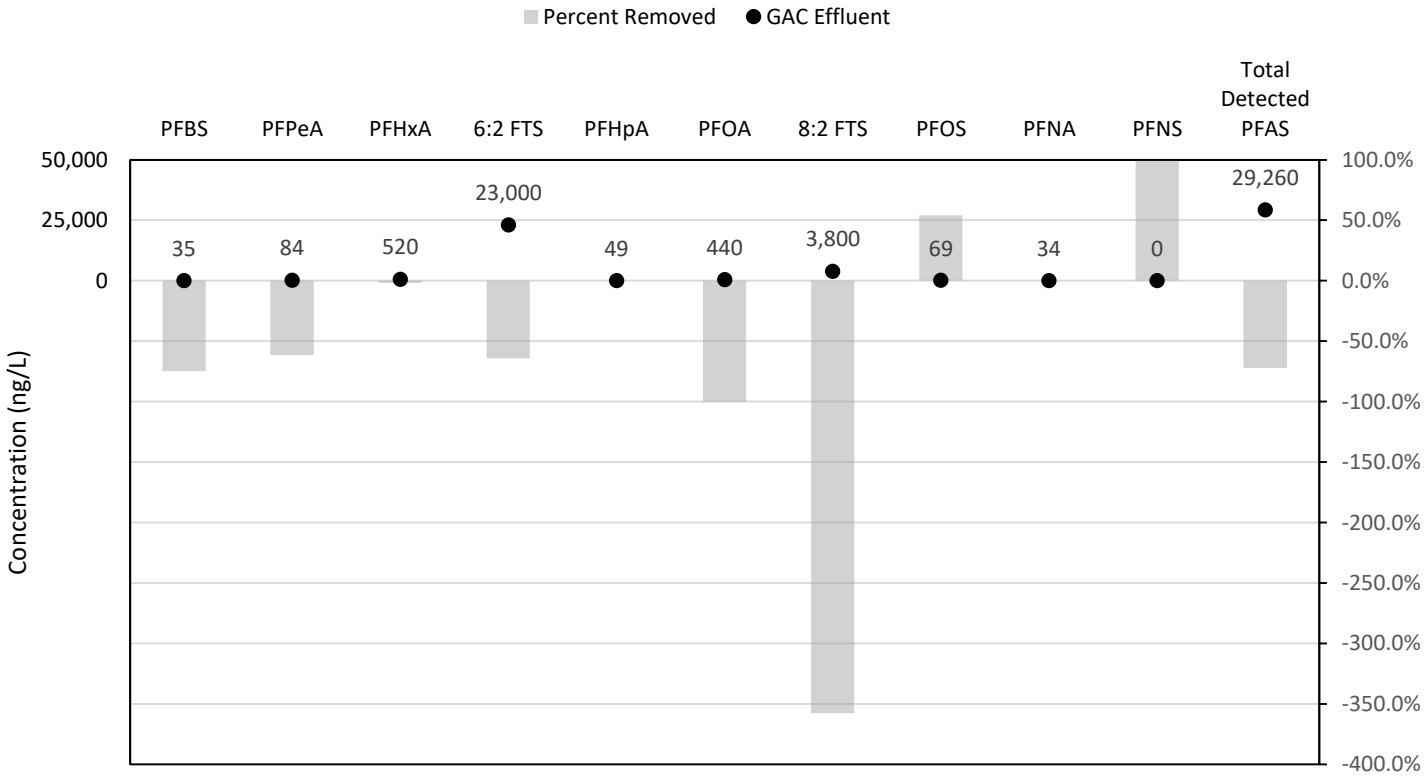
Fluoro Fighter Step A GAC Treatment



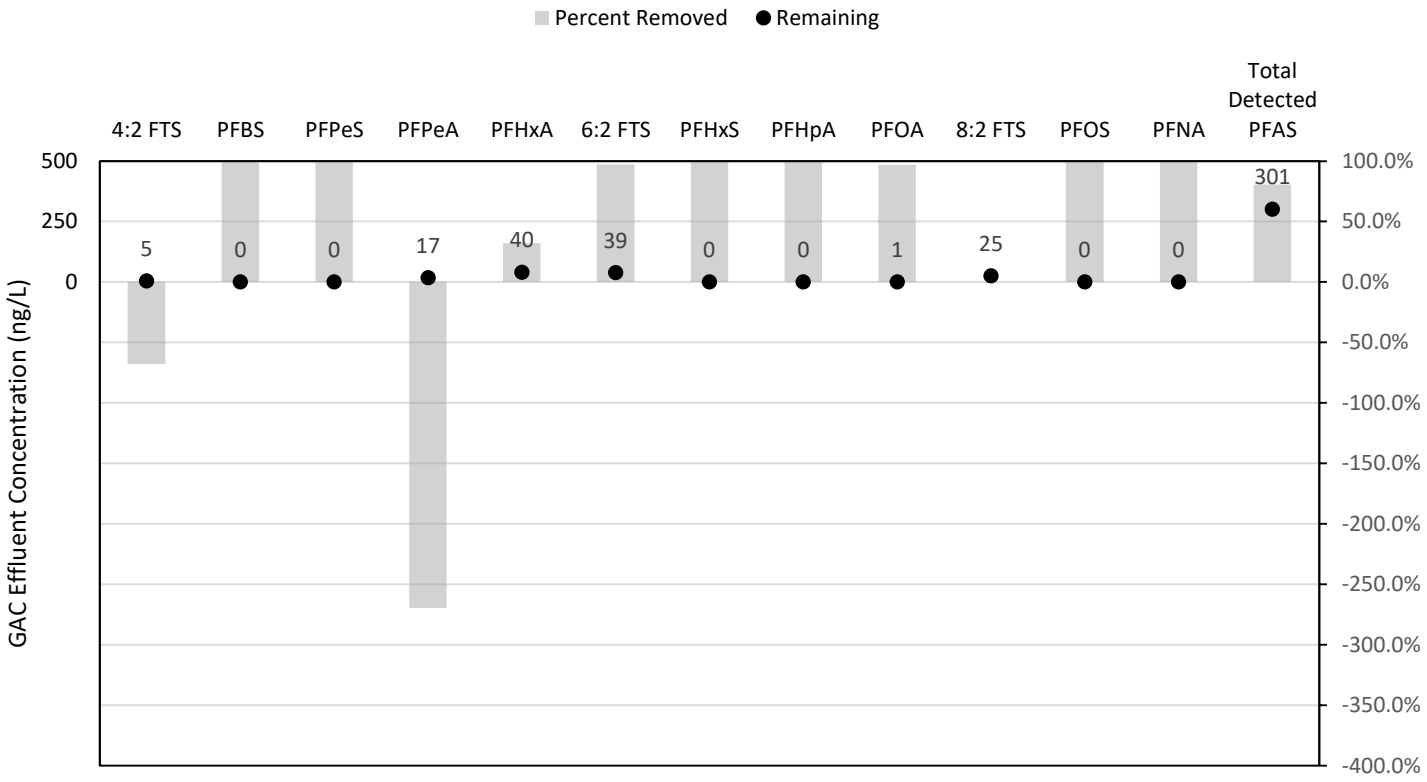
Water Rinse After Step A GAC Treatment



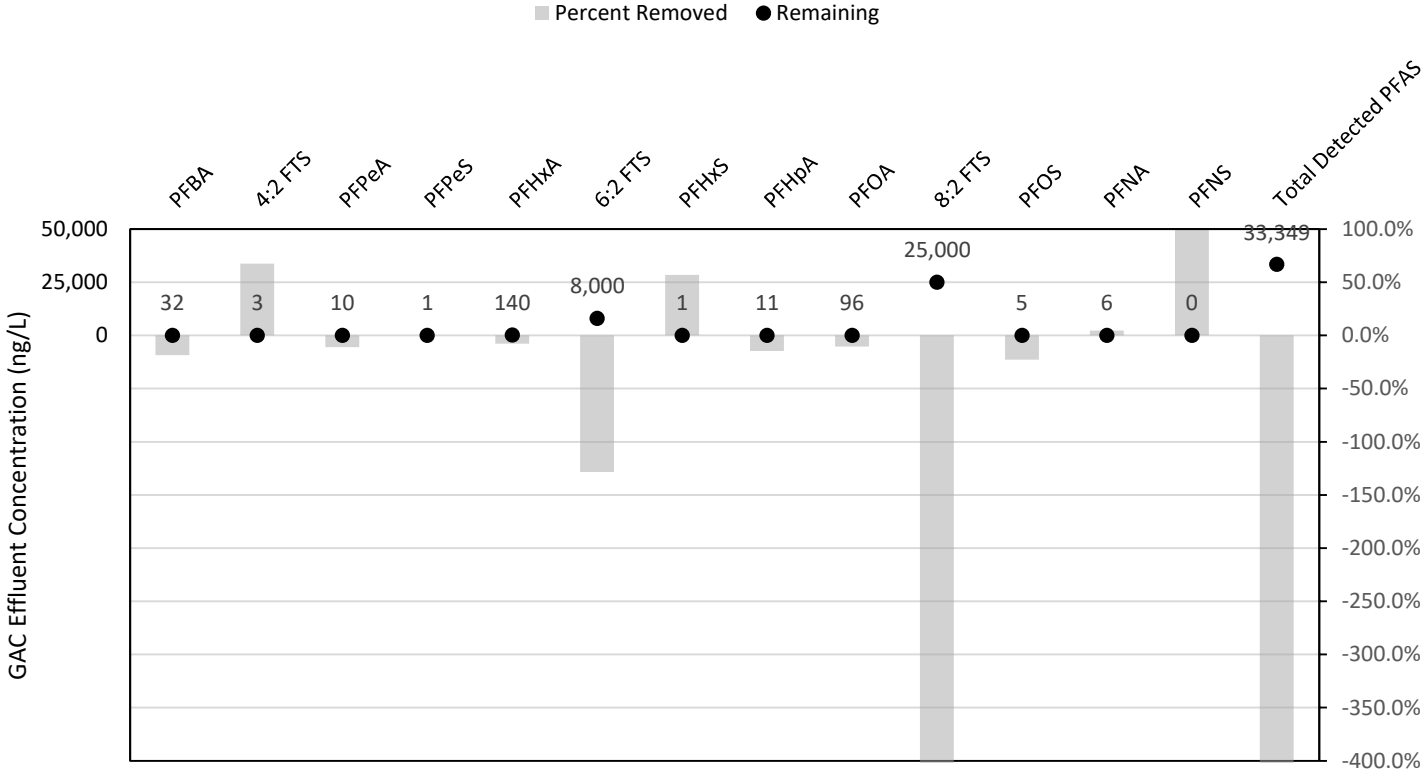
Fluoro Fighter Step B GAC Treatment

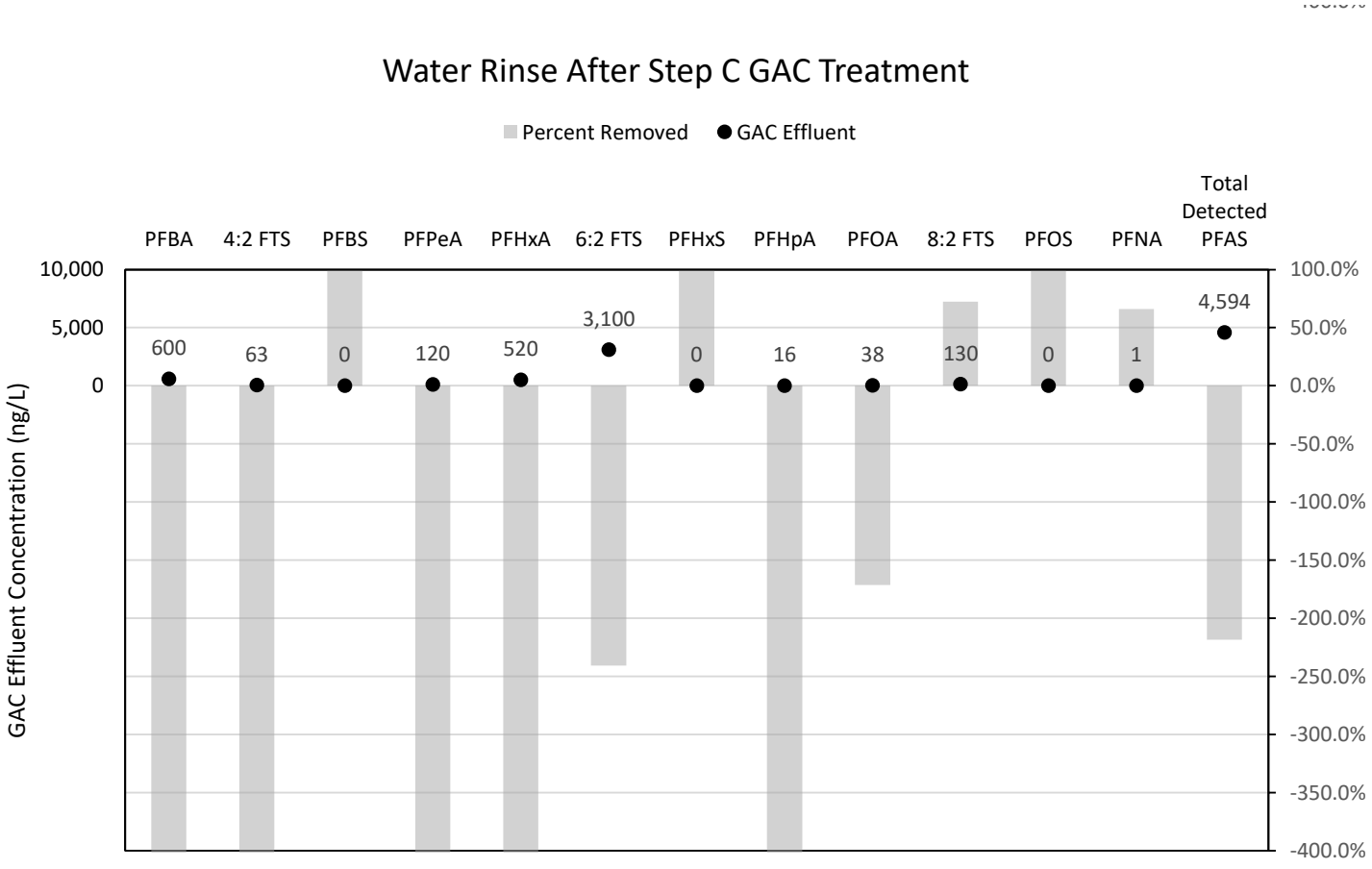


Water Rinse After Step B GAC Treatment



Fluoro Fighter Step C GAC Treatment




Water Rinse After Step C GAC Treatment
Percent Removed
GAC Effluent
PFBA
4:2 FTS
PFBS
PFPeA
PFHxA
6:2 FTS
PFHxS
PFHpA
PFOA
8:2 FTS
PFOS
PFNA
Total Detected PFAS
10,000
5,000
0
GAC Effluent Concentration (ng/L)
600
63
0
120
520
3,100
0
16
38
130
0
1
4,594
100.0%
50.0%
0.0%
-50.0%
-100.0%
-150.0%
-200.0%
-250.0%
-300.0%
-350.0%
-400.0%

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